COFSEP

Analysis of Cooperation Opportunities for Europe in Future Space Exploration Programmes

Euroconsult for the European Commission

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METHODOLOGY NOTE

1. Definition of Exploration

For the purpose of the present study, Exploration includes three different types of missions:

- **Capability-driven exploration**: Missions designed to develop industrial and technological capabilities for the exploration (human and robotic) of celestial bodies, including planets and near-earth asteroids.
- **Science-driven exploration**: Planetary science missions design to acquire scientific knowledge of a given celestial body
- **Human spaceflight**: including all manned spaceflight missions

Astrophysical scientific missions, not dedicated to the exploration or knowledge acquisition of one specific planet or asteroid **are not included** in the context of this study.

This definition allows taking into account scientific missions that are not financed through pure Exploration budget (such as Mars Express for ESA, Dawn for NASA and the Venus Climate Orbiter for JAXA), but which should nevertheless be taken into account as the capabilities developed for such missions may be reused for pure exploration programs.

2. Methodology for country profiles

Country profiles for the countries the most involved in Space Exploration have been established based on Euroconsult in-house reports, publicly available information and interviews of the major space exploration stakeholders, including space agencies and industrial players.

The profiles are divided into 4 main sections:

- **Institutional Framework for Space Exploration initiatives**: Presentation of the public agencies in charge of Space exploration activities, policy objectives and budgetary aspects

- **National Space Exploration activities**: Detailed review of existing and future exploration programs. The content of this section varies from one country to the other due to strong differences in the organization and in the number of space exploration activities, notably whether or not the country conducts space exploration initiatives both at national and at ESA level.

  A detailed table of space exploration missions has been included at the end of this section for all the countries with significant activities in space exploration. This table lists all the space missions to which the country participates, including the missions led by the country but also the mission to which he provides scientific or industrial contributions. For each mission, the name of the national stakeholders involved in the mission as well as its contributions to the program has been included.

  While the number of missions in the tables is exhaustive, this is obviously not the case of the names of the stakeholders involved in the missions, since the detailed breakdown of the industrial activities is, in most of the case, not publicly available. Euroconsult used its best efforts to provide the maximum of details regarding the activities of the participants.

Regarding scientific contributions, Euroconsult included contributors at Principal Investigator (PI) level. Co-investigators are therefore not listed in the table.

- **National capabilities in Space Exploration:** This section presents the industrial and scientific capabilities of each country. This includes a review of the main industrial stakeholders involved in space exploration as well their level of capabilities in thirteen capability areas, which cover all the technologies and capabilities required for exploration missions.
- **International cooperation for Space Exploration:** Qualitative information regarding the level of cooperation of each country with the other countries studied. This section focuses on institutional cooperation and does not include industrial procurement since this does not result from a political will to cooperate.

  A pie-chart breaking down by country the cooperation activities led by the profiled country has been included. This pie-chart relates to the number of mission led conducted in cooperation and does not take into account the significance of the contribution. For example, if one country provides a scientific instrument to another for a space exploration mission, it will be included in the chart exactly as if the country had provided a key contribution to the mission, such as the spacecraft platform. This pie chart includes past missions and missions that are currently in development.

  Finally, a table summarizing the most relevant international agreements was established. This table is not exhaustive since the information required is not always publicly available and it takes into account the most recent relevant agreements.

BRAZIL

1. Institutional framework for Space Exploration initiatives

Brazilian national and international space activities are coordinated by the Brazilian Space Agency (AEB), which is also in charge of the implementation of the Brazilian Space Policy. The AEB reports the Ministry of Science and Technology. The Brazilian Space Research Institute (INPE) is responsible for the design of the Brazilian satellite subsystems and the industry procurement process.

The Brazilian Space program is currently focused on applicative areas and launchers, so that Space exploration is not a key priority of the Brazilian Space policy.

Brazil does not have any space exploration item in its national budget.

2. Brazilian space exploration programs

Scientific organizations in Brazil are currently planning a deep space Asteroid mission, **ASTER**. The ASTER mission would be launched in 2015 and reach its target in 2018 using solar electric propulsion. Several scientific instruments would be fitted on the spacecraft, including an Imaging Camera, a Laser Rangefinder, an Infrared Spectrometer, a Synthetic Aperture Radar and a Mass Spectrometer. Brazil intends to develop the technologies required and the payload elements on its own but Russia will provide technical and scientific support.

Several options are currently considered for the launch of the spacecraft. Brazil could piggyback on a larger launch or set up a dedicated launch with a Russian ICBM.

As of March 2012, ASTER still hasn’t received government support for the $40 million required to develop the mission.

Regarding Human Spaceflight, Brazil signed a bilateral agreement in 1997 with NASA providing for the development, operation and use of Brazilian developed flight equipment and payloads for the International Space Station. Under this agreement, Brazil was to provide six elements in exchange for access to NASA ISS facilities on orbit and a flight opportunity for one Brazilian astronaut. The planned investment of Brazil in the ISS amounted to US $120 million. However, budgetary issues on Brazil side led to several delays in the provision of the committed elements, followed by a total cancellation.

Brazil does not have future plans for human space exploration.

3. Brazilian industrial capabilities

The Brazilian space industry seems very little developed despite the attempts made in the 80s and 90s to indigenously develop launcher technologies and satellite technologies, largely because the national budgets devoted to space activities have been too limited. Space exploration has not been yet on the space agenda of Brazilian authorities. The most notable facts are the cooperation with China to develop Earth resources monitoring satellites (CBERS) and occasional co-operation plans (mostly regarding launcher development) with Russia, Ukraine, Europe and the US, very few of which have really come to fruition.

The main player for space system development is the public National Institute for Space Research (INPE) with more than 1000 staff, now developing a national Earth observation satellite platform (Amazonia-1). Equatorial Sistemas (20-30 people) is a space-dedicated company, now partly owned by Astrium, which develops satellite equipment (supplied the wide field instrument on CBERS, and a humidity sounder for one of NASA satellites). Other actors of the Brazilian aerospace industry may contribute on an occasional basis or as subcontractors to INPE (Embraer, Aeroeletrifica, Cenic, Digicon).

CANADA

1. Institutional framework for Space Exploration initiatives

General framework for space activities

The Canadian Space Agency (CSA) is responsible for coordinating all federal civil space-related policies and programs pertaining to science and technology research, industrial development and international cooperation. The CSA reports to Industry Canada, a government department in charge of regional economic development, investment, and innovation.

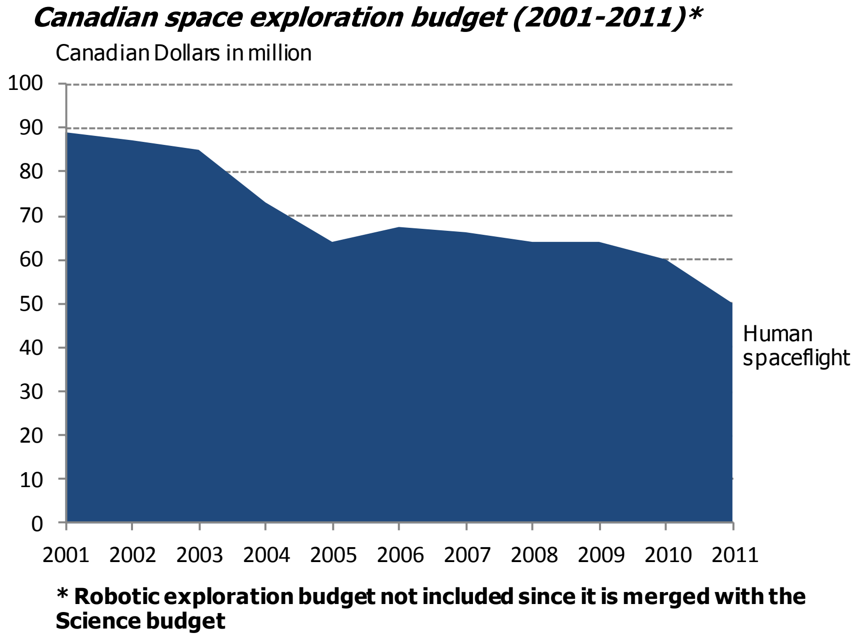
In 2011, CSA's Program Activity Architecture (PPA) was reorganized in four main pillars. Space Exploration is one of them, with three distinct sub-programs :

1) International Space Station
2) Exploration missions and technology
3) Human Space mission and support

The objective of this programmatic pillar is to remain key partner in international initiatives involving exploration of the solar system and the conducting of science in space. Through the development of Exploration programs, the CSA wishes to stimulate innovation and application development to improve quality of life, strengthen Canada reputation as a knowledge-intensive and innovation driven nation and reinforce its global position as a reliable broker and partner.

Budget dedicated to Space and Exploration activities

The total space budget of Canada amounts to CAD 580 million (US$ 593 million) in 2011, split between national civil activities (68%), participation to ESA (5%) and defense programs (27%). Identifiable space exploration expenditure amounted to CAD 50 million in 2011, i.e 13% of the CSA's expenditure. However, this does only include Human space exploration activities since the development of robotic missions is included in the scientific budget.



The Human Spaceflight budget of Canada has been decreasing steadily over the past ten years, corresponding to the progressive completion of the ISS deployment. As the deployment phase is now over and the Member states focus on the ISS exploitation, this budget is expected to stabilize.

2. Canadian Space Exploration Programs

Robotic exploration activities

The contribution of Canada to robotic space explorations until now is essentially focused on the provision of scientific instruments to international missions. CSA has provided a Thermal Plasma Analyzer to JAXA for the Planet-B mission, a Meteorological Station to NASA for Phoenix and an Alpha Particle X-ray Spectrometer to NASA for the Mars Science Laboratory.

The next scientific instruments to be provided include the MATMOS (Mars Atmospheric Molecular Occultation Spectrometer) instrument, which be provided by the CSA to ESA for the Exomars Trace Gas Orbiter. The CSA has developed this instrument in partnership with the NASA JPL and the Caltech University. The status of the instrument as of March 2012 is unclear since NASA announced its withdrawal from the mission. All US instruments and contributions will be withdrawn from the mission, which could include the MATMOS instrument, since it was a joint US-Canadian contribution.

Canada also intended to contribute to the 2018 Exomars rover, potentially by providing a robotic arm for the mission. However, this contribution was directly linked to the US elements and has therefore been cancelled following the US withdrawal from the mission.

Finally, the CSA will provide a LIDAR instrument for the NASA OSIRIS-Rex mission, which is scheduled for 2016.

In the long term, Canada is interested in participating to all the main international exploration missions, including the Mars Sample Return mission and the ESA Lunar Lander. CSA intends to capitalize on its robotic capabilities acquired through its ISS participation for future Lunar and Mars missions. Areas of interest include Space Robotic Servicing (development of the next generation of Canadarm), Surface Mobility (development of light rovers) and robotic subsystems and ISRU technologies such as vision, manipulators and drilling. These technology developments are partially funded by a stimulus package granted by the Canadian government to the CSA in 2009.

Manned exploration activities

Canada is one of the international participants to the International Space Station. Its contribution has essentially consisted in the provision of the **MSS (Mobile Servicing System)**, a space robotics system used by astronauts to assemble and maintain the International Space Station. The MSS is made of three elements:

- A mobile base
- The 17.6m long Canadarm2
- The two-armed 3.5m long dexterous manipulator Dextre

Beyond the ISS, Canada is interested in participating in further Human Space exploration missions. Its contribution will essentially consist in the development of robotic capabilities to prepare for international Human exploration missions.

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Exploration missions						
2001	Launched	**Canadarm2**	CSA	Key element of the Canadian MSS, which moves equipment and supplies around the station, supports astronauts working in space, and services instruments and other payloads attached to the ISS	MD Robotics	Prime Contractor
					MacDonald Detwiller	Development of the Operation and Control Software
					EMS Technologies	Design of space flight hardware
					IPM Group	Design, development and fabrication of external electrical wire harnesses
					SED Systems Inc	Design of ground-based system
					CAE Electronics Ltd	MSS Operations and Training System (MOTS)
					FRE Composites	Design, fabrication, assembly testing of all ten feet long segments, which make up Canadarm2
2002	Launched	**MBS (Mobile Base System)**	CSA	Moveable work platform and storage facility for astronauts during space walks	MD Robotics	Prime contractor
					EBCO Aerospace	Subcontractor
					EMS Technologies	Subcontractor
					FELLFAB Limited	Subcontractor
					Héroux Devtek Inc.	Subcontractor
					MBM Tool & Machine Co. Limited	Subcontractor
					Rostar Precision Inc	Subcontractor
					Wardrop Engineering Inc	Subcontractor
					xwave	Subcontractor
2008	Launched	**Dextre (Special Purpose Dexterous Manipulator)**	CSA	A two armed robot part of the Canadian MSS	MDA Space Missions	Prime Contractor

Robotic Exploration missions						
1998	Failed to enter Mars orbit	**Planet-B (Nozomi)**	JAXA	Mars orbiter to study the upper atmosphere	University of Calgary	TPA (Thermal Plasma Analyzer)
2007	Launched	**Phoenix**	NASA	Mars Lander to examine the water-ice-rich northern polar region	CSA	MET, a meteorological station daily weather of the martian northern plains using temperature and pressure sensors LIDAR instrument (light detection and ranging)
2011	Launched	**Mars Science Laboratory**	NASA	Mars Rover	CSA	APXS (Alpha Particle X-ray Spectrometer)
2016	In development	**OSIRIS-REX**	NASA	Asteroid Sample return	CSA	Responsible for the Canadian contribution
					MDA Corporation	Prime contractor for the LIDAR (Light Detection and Ranging)
					Optech	Contribution to the LIDAR

* At PI level only for scientific instruments

3. Canadian industrial capabilities

The Canadian space capacities relative to space exploration are for the most part addressing robotics and more recently planetary surface mobility. The key actor of those capacities is MDA, and particularly MD Robotics, which has developed the Canadian robotic arms since the mid 1980's (Canadarm1 & 2 and Dextre) now used on the ISS to assist in cargo vehicle berthing (for those needing it), in the Shuttle operation (now no longer needed), in the ISS in-orbit assembly tasks and in the EVA operations of astronauts. MD Robotics is today leader with respect to large robotic in-orbit experience, an experience which is in the process of being transferred to satellite in-orbit servicing missions. MD Robotics is also developing rover and associated technologies and has contributed several equipment in NASA (Lidar sensor for Phoenix Mars lander and asteroid sample return Osirix-Rex mission) and ESA (spectrometer for Exomars) rovers.

Other Canadian companies contribute to the Canadian space exploration capacities, in general as subcontractors to MDA for hardware and software components (see table above for details of the past mission contributions).

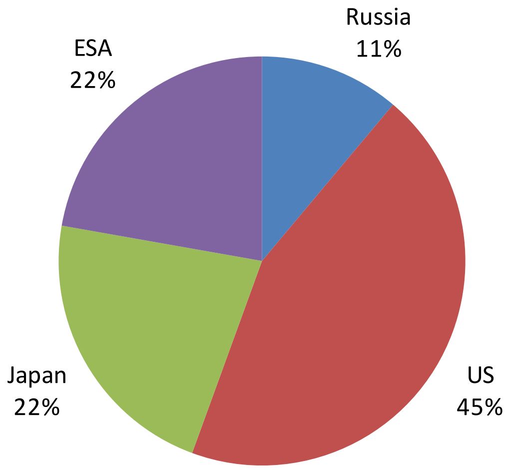
General overview of industrial capabilities in Canada for space exploration

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	🟩 Flight system experience 🟨 Breadboard or ground system experience ▨ Significant partial experience **Comments**
MDA (MD Robotics)						🟩				🟨		🟩			ISS Canadarm 1 and 2, DEXTRE, Orbital Express Arm Lidar sensors for Phoenix Mars lander and Osiris-Rex asteroid sample return missions Exomars, Lunar and Mars mobility platforms prototypes

4. International cooperation

Canada does not have the financial capacity to develop exploration mission on its own. Its entire space exploration program therefore relies on international cooperation.

Breakdown of Canadian space exploration activities by cooperating country (from 1997 to future approved missions)



The main partner of Canada is the US, to which the CSA has supplied several scientific instruments for exploration missions (Phoenix, MSL and the planned Osiris-REX). However, Canada also provides instruments for missions of other countries, notably Japan, and ESA.

Canada is a member of the ISECG, the IMEWG and the iMARS forum, which are considered a essential for determining the direction of its future space exploration program.

Canada is currently in negotiation for a space cooperation treaty with Russia to facilitate access of Canadian companies to the Russian market. Canada has also reportedly begun talks about a similar treaty with China.

Most recent agreements relevant for space exploration between Canada and other space nations

Partner	Date	Type	Description
ESA	Renewed on December 15th, 2010	Framework agreement	Canada and ESA renewed in 2010 their cooperation agreement for a period of ten years
Multilateral	January 29th, 1998	Program-related agreement	Intergovernmental Agreement on Space Station Cooperation
Russia	Currently in negotiation	Framework agreement	The CSA recently got cabinet approval to negotiate a treaty with Russia to be signed shortly for space cooperation, notably for facilitating access of the Canadian Industry to the Russian Market.
USA	1997	Memorandum of Understanding	General cooperation agreement between NASA and the CSA concerning cooperation on the ISS
USA	January 29th, 1998	Memorandum of Understanding	MoU between NASA and CSA concerning cooperation on the civil international space station
USA	September 9th, 2009	Framework agreement	Framework agreement for cooperation in the exploration and use of outer space for peaceful purposes., including space exploration.

CHINA

1. Institutional framework for Space Exploration initiatives

General framework for space activities

The Chinese space activities are coordinated by the CNSA (China National Space Administration), which is in charge of defining the civil space policy and programs and managing international cooperation. The CNSA is supervised by the SASTIND (State Administration for Science, Technology, and Industry for National Defense), which reports to the Ministry of Industry and Information Technology (MIIT).

The Chinese space activities are governed by the five years plans of the People's Republic of China, a series of social and economic development initiatives in all sectors. The 12th Five year plan sets a series of guidelines for space activities for the 2011-2015 period. This plan is accompanied by a White Paper on China Space Activities, released in 2011, which defines the space strategy of China until 2020. In addition, a 2009 roadmap, named « Space Science & Technology in China: A Roadmap to 2050", determines objectives in twenty-two science and technology applications areas, including Space science and Exploration.

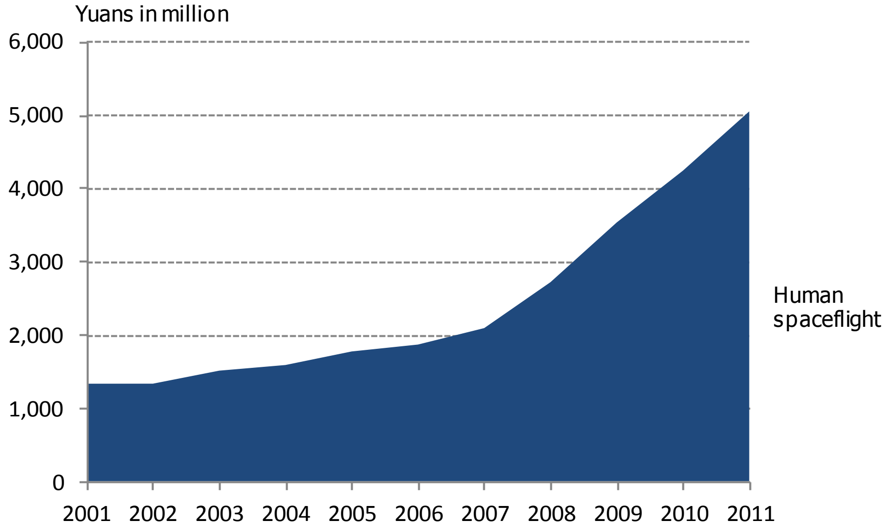
The Chinese government has also direct control over the development of space systems and technologies, since the two largest industrial conglomerates report directly to the central government:

- China Aerospace Science and Technology Corp. (CASC), which is the main contractor for the Chinese space program, with more than 150,000 employees. CASC is a conglomerate of around 200 companies and factories including China's principal satellite manufacturer, the Chinese Academy of Space Technology (CAST) and its two launch vehicle manufacturers, the Chinese Academy of Launch Technology (CALT) and China Great Wall Industry Corp (CGWIC)
- China Aerospace Science and Industry Corp. (CASIC), which focuses on the defense program

Budget dedicated to Space and Exploration activities

The total budget for Chinese space activities was estimated by Euroconsult at CNY 19.8 billion (US$ 3 billion in 2011), excluding classified military programs. 25% of this budget (US$ 776 million) is estimated to be dedicated to the Human Spaceflight program. The robotic exploration program however, is unknown, as it is merged with space science activities

Chinese space exploration budget (2001-2011)*



*** Robotic exploration budget not included since it is merged with the Science budget**

The budget dedicated to manned space flight activities has been multiplied by four over the past decade due to the acceleration of the Shenzhou program and is further expected to be multiplied by three before 2020 to finance the deployment of the Chinese Space Station Tiangong. The robotic exploration program will also require a sustained investment for the Chinese government in order to support the Chinese Lunar Exploration program.

2. CNSA Space Exploration Programs

Robotic Exploration programs

The robotic exploration activities of China are essentially oriented towards Lunar exploration, through the CLEP (Chinese Lunar Exploration Program). However, China also developed a small Mars orbiter, Yinghuo-1, which was launched in 2011 as a piggyback on the Russian Phobos-Grunt spacecraft.

Lunar Exploration

The objectives of the CLEP are to boost technological development, start lunar scientific research and application study and become involved in exploration, development and utilization of lunar resources for the future.

The CLEP has designed a three stage approach for lunar exploration, namely:

1) Circumlunar exploration, through lunar orbiters between 2002 and 2007
2) Lunar surface exploration, through lunar landers and rovers between 2008 and 2014
3) Lunar sample return, between 2015 and 2020.

The first step of the program was accomplished through the development and launch of two lunar orbiters, Chang'e 1 in 2007 and Chang'e 2 in 2010.

The main objective of **Chang'e 1** was to obtain a three-dimensional mapping of the lunar surface, including areas near the north and south poles not covered by previous missions. The probe was designed to remain on orbit for one year around the Moon but is mission was later extended and it remained in lunar orbit until March 2009.

Chang'e 2 was similar in design toe Chang'e 1 but its main purpose was to conduct research from a 100-kilometer-high lunar orbit in preparation for the second stage of the program, the 2013 soft landing by Chang'e 3. Chang'e 2 reportedly outperformed and provided the highest-resolution picture of the entire Moon surface thus far. After completing its primary objective, the probe left lunar orbit for the Earth-Sun Lagrangian point, to test the Chinese tracking and control network.

The second step of the CLEP will start in 2013 with the planned launch of **Chang'e 3**, which entered the manufacturing phase in 2012. Chang'e 3 is a lunar lander, fitted with a 100-kilogram rover, developed by the Shanghai Aerospace System Engineering Institute, and scientific instruments in order to conduct territory survey, living conditions assessment and space observations.

A second landing and roving mission, **Chang'e 4** is being developed as a backup to Chang'e 3 and is scheduled for launch in 2015.

The third step of the Lunar program will consist in two lunar sample return missions, currently scheduled for 2017 and 2019. A significant technology development has to be undertaken as China will have to acquire capabilities for a sample and return capsule, a lunar surface drilling machine, a sampler and a robotic arm. Moreover, Chang'e 5 and 6 will be launched by the Long March 5 launcher, which is currently under development by CALT.

Mars Exploration

The **Yinghuo-1** Mars probe had been intended to be the first Chinese spacecraft to visit Mars. Pursuant to a 2007 cooperation agreement between the director of the CNSA and the head of Roscosmos, Yinghuo-1 was designed as a piggyback on the Russian Mars Sample return mission, Fobos-Grunt.

Yinghuo-1 probe was intended to orbit Mars for around two years, studying the planet's surface, atmosphere, ionosphere and magnetic field. However, the propulsion module of Fobos-Grunt failed to ignite shortly after launch so that both spacecrafts were declared at loss and reentered the Earth Atmosphere in 2012.

No additional Mars mission was announced by the Chinese government as of March 2012 since the current efforts in space exploration are focused on the development of the Chang'e 3 spacecraft. However, the Chinese Academy of Space Technology (CAST) submitted a plan for a new Mars mission by 2015 to the central government and is currently waiting for approval.

Manned spaceflight program

The Chinese manned exploration program is also structured around three main steps:

1) Launch of manned spacecrafts : 1999-2008
2) Launch of docking stations to develop extra-vehicular activities and acquired rendezvous and docking capabilities: 2009-2016
3) Built a permanently manned space station by 2020

The first step of the program consisted in four unmanned spacecrafts (**Shenzhou-1 to 4**), which led to the successful launch of the first Chinese manned mission, **Shenzhou-5**, in 2003. A second manned mission, **Shenzhou-6**, was completed in 2005 with two astronauts on board during a 5-day flight. **Shenzhou-7** mission in 2008 included three astronauts, of which two performed extra-vehicular activities during the flight.

The second step of the program was launched in 2011 with the first unmanned laboratory module, **Tiangong-1**. An unmanned Shenzhou vehicle was launched in 2011 and docked twice successfully with Tiangong-1.

The next Shenzhou mission, **Shenzhou-9,** to be launched in 2012, will be a manned mission with three astronauts and will dock to the Tiangong-1 module. It will be followed by a second manned mission, **Shenzhou 10**, which will be the last before the deorbitation of Tiangong-1.

China then intends to launch two additional Tiangong larger modules, in 2013 and 2015, to which several manned missions will dock.

Finally, for the third step of its manned space program, China has finalized a concept of a 60-ton **space station**, which is planned to be put into orbit between 2020 and 2022. The station will support three astronauts for long-term habitation..

The station will include a Core Cabin Module (CCM), which will provide life support and living quarters for three crew members, and guidance, navigation, and orientation control for the station. This module also provides the station’s power, propulsion, and life support systems. Two Laboratory Cabin Modules (LCM) will be docked to the CCM, providing a pressurized environment for researchers to conduct science experiments in free-fall or Zero-gravity.

The station will be resupplied by a robotic spacecraft, similar in design to the Tiangong-1 module, with a capability of 13 tons.

Besides the low-earth orbit manned program, China has the objective to send manned flights to the moon to set up a lunar man-tended base by 2030 and to land on Mars by 2050.

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Exploration missions						
1999	Launched	**Shenzhou-1**	CNSA	Unmanned Spacecraft	CAST	Prime Contractor
2001	Launched	**Shenzhou-2**	CNSA	Unmanned Spacecraft carrying animals to test life support systems	CAST	Prime Contractor
2002	Launched	**Shenzhou-3**	CNSA	Unmanned Spacecraft carrying a dummy to simulate physiological signals of a human	CAST	Prime Contractor
2002	Launched	**Shenzhou-4**	CNSA	Unmanned Spacecraft carrying a dummy and several science experiments	CAST	Prime Contractor
2003	Launched	**Shenzhou-5**	CNSA	First Manned spacecraft carrying one astronaut for 21 hours	CAST	Prime Contractor
2005	Launched	**Shenzhou-6**	CNSA	Manned mission with two astronauts for five days and conduct scientific experiments	CAST	Prime Contractor
2008	Launched	**Shenzhou-7**	CNSA	Manned mission with two astronauts to test Extra vehicular activity.	CAST	Prime Contractor
2011	Launched	**Tiangong-1**	CNSA	Chinese space laboratory module to demonstrate rendezvous and docking capabilities	CAST	Prime Contractor
2011	Launched	**Shenzhou-8**	CNSA	Unmanned mission to demonstrate docking with Tiangong-1	CAST	Prime Contractor
2012	Launched	**Shenzhou-9**	CNSA	First manned mission (3 astronauts) docking to Tiangong-1	CAST	Prime Contractor
2012	In development	**Shenzhou-10**	CNSA	Manned mission with two or three astronauts docking to Tiangong-1	CAST	Prime Contractor
2013	In development	**Tiangong-2**	CNSA	Larger replacement of Tiangong-1	CAST	Prime Contractor
2015	Planned	**Tiangong-3**	CNSA	Replacement of Tiangong-2 with 40-day habitability for three astronauts	CAST	Prime Contractor
2020-2022	Planned	**Chinese Space Station**	CNSA	3 modules of 20 tons each to be assembled in space to build the first permanent Chinese space station	CAST	Prime Contractor
Robotic Exploration missions						
2007	Launched	**Chang'e-1**	CNSA	Moon orbiter to achieve a 3D mapping of the Moon surface	CAST	Prime Contractor
					Shanghai Institute of Technical Physics	Laser Altimeter
					Xi'an Institute of Optics and Precision Mechanics (XIOPM), CAS	CCD Stereo Camera

					Institute of High Energy Physics (IHEP), CAS	X-ray spectrometer
					Purple Mountain Observatory (PMO), CAS	Gamma-ray spectrometer
					Center for Space Science and Applied Research (CSSAR), CAS	Microwave radiometer
					Center for Space Science and Applied Research (CSSAR), CAS	High-energy particle detector and solar wind detectors
					Xi'an Institute of Optics and Precision Mechanics (XIOPM), CAS	Imaging spectrometer
2010	Launched	**Chang'e-2**	CNSA	Conduct research in preparation of landing mission	CAST	Prime contractor
					See Chang'e-1	Same instruments than Chang'e 1
2013	In development	**Chang'e-3**	CNSA	Lunar Lander and rover	CAST	Prime contractor
					Shanghai Aerospace System Engineering Institute	Development of the rover
2015	In development	**Chang'e-4**	CNSA	Backup to Chang'e-3	CAST	Prime contractor
2015	Not approved	**Unknown**	CNSA	Potential mission to Mars		
2015	Planned	**Chang'e-5**	CNSA	Lunar Sample return	CAST	Prime contractor
2016	Planned	**Chang'e-6**	CNSA	Lunar Sample return	CAST	Prime contractor

* At PI level only for scientific instruments

3. Chinese industrial capabilities

The Chinese space industry is concentrated in a giant organisation named CASC (China Aerospace Corporation) which employs from 150 000 to 250 000 people (according to various sources). This organisation is responsible for the research, development, production and operation of space systems. The same organisation is also in charge of Chinese defense programs for space, aeronautics and missiles. CASC comprises a very large number of entities (probably close to 200) grouped in about 20 "academies" and corporations, among which:

- CAST (China Academy of Space Technology) in Beijing, developer of the DFH satellites (in particular)
- CALT (China Academy of Launch vehicles Technology), developer of the Long March launcher family
- AALPT (Academy of Aerospace Liquid Propulsion Technology)
- AASPT (Academy of Aerospace Solid Propulsion Technology)
- SAST (Shangai Academy of Space Technology)
- CASET (China Academy of Aerospace Electronics Technology)
- CEC (China Electronics Corporation), involved in radar instruments, O/B space electronics, solar generators
- Harbin Institute of technology, the key Chinese university for aeronautics and space engineering.

Chinese space capacities have increased rapidly over the past 15 years, and are now quite close to state-of-the-art for a number of key capacities related to space access and orbital flight control, including human space access (impressive reliability track record of Long March and Shenzou capsule and human flights, automatic in-orbit rendez-vous of Shenzou-8 and the Tiangong-1 space lab module in 2011). Other capacities, such as related to robotic technologies or related to space robustness and durability of certain technologies are likely still behind international state-of-the-art. However, the massive efforts which are deployed by China in space and the resulting harvest of space flight experience and heritage which ensues will probably gradually close the gap over the next decade.

General overview of industrial capabilities in China for space exploration

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	🟩 Flight system experience 🟨 Breadboard or ground system experience ▨ Significant partial experience **Comments**
CASC	🟩	🟩			🟨		▨		🟩	🟨		🟩			Long March launch system, Shenzou-8 and Tiangong-1 successful rendez-vous, Tiangong-2 and 3 Laboratory, Change'e 1 and 2 Moon orbiters, Lunar lander and rover in Change'e-3

4. International cooperation

In the 2011 White Paper on Chinese Space Activities, China considers that international exchanges and cooperation should be strengthened to promote inclusive space development on the basis of equality and mutual benefit, peaceful utilization and common development.

China has therefore adopted a set of principles governing potential cooperation opportunities :

- Supporting activities regarding the peaceful use of outer space within the framework of the United Nations. Supporting all inter-governmental and non-governmental space organizations' activities that promote development of the space industry
- Emphasizing regional space cooperation in the Asia-Pacific area, and supporting other regional space cooperation around the world;
- Reinforcing space cooperation with developing countries, and valuing space cooperation with developed countries;
- Encouraging and endorsing the efforts of domestic scientific research institutes, industrial enterprises, institutions of higher learning, and social organizations to develop international space exchanges and cooperation in diverse forms and at various levels under the guidance of relevant state policies, laws and regulations;
- Appropriately using both domestic and foreign markets and both types of resources, and actively participating in practical international space cooperation.

However, the cooperation areas of China do not extend to Space Exploration where its only partner used to be Russia until 2011 when China turned towards Europe. Both countries have established a space Cooperation Sub-committee under the Prime Ministers' Meeting and have signed a number of cooperation agreements, notably on space science and deep-space exploration. Both countries also cooperated extensively on the development of the Chinese Shenzhou spacecraft, whose technology was transferred from Russia based on capabilities acquired through the Soyuz program.

However, in 2007, the head of TsNIIMASH-Export Company, which was responsible for the cooperation with China on Shenzhou, was sentenced to 11 years in prison for passing classified technology for China, which could be used to create missiles capable of carrying nuclear warheads.

In 2011, Germany successfully cooperated with China through the provision of a scientific experiment which was fitted on Shenzhou-8. This cooperation was considered as particularly positive by Germany, which is currently considering further potential areas of cooperation with China.

In November 2011, China invited Italy to participate to its future space station. China is particularly interested in the capabilities acquired by Italy through the development of the ISS pressurized modules. Both countries signed a general cooperation agreement covering nearly all space areas, which paves the way for more specific agreements.

Most recent agreements relevant for space exploration between China and other space nations

Partner	Date	Type	Description
Brazil	November 8th, 1994	Framework agreement	Framework agreement between Brazil and China on cooperation in the peaceful applications of outer space science and technology.
ESA	November 2005	Framework Agreement	General agreement for on space cooperation for peaceful purposes
ESA	2011	Framework Agreement	Status Quo of China-Europe Space Cooperation and the Cooperation Plan Protocol , including for space exploration
France	May 15th, 1997	Framework agreement	The agreement primarily focuses on cooperation in the scientific area
Germany	2011	Framework agreement	Framework agreement on bilateral cooperation in the field of human spaceflight, which led to the development of a German Experiment for the Shenzhou-8 spaceflight.
Italy	November 2011	Framework agreement	Cooperation agreement covering science and exploration, space transportation, Earth observation, telecommunications, satellite navigation, and education. This agreement paves the way for future specific agreements related to the participation of Italy to the Tiangong program.
Russia	March 26th, 2007	Framework agreement	Cooperative Agreement between the China National Space Administration and the Russian Space Agency on joint Chinese-Russian exploration of Mars, which allowed the piggyback of Yinghuo-1 on Fobos-Grunt
Russia	1995	Program related agreement	Under this agreement, Russia transferred to China several Soyuz-related technologies. This agreement also include training, provision of Soyuz capsules, life support systems, docking systems, and space suits
UK	2007	Establishment of a joint laboratory	Establishment of a joint laboratory on space science and technology, discussions on lunar cooperation

EUROPEAN SPACE AGENCY

1. Institutional framework for Space Exploration initiatives

General framework for space activities

ESA activities are driven by the Long Term Plan (LTP) which establishes on a 10 year time frame its strategic objectives and priorities, the resulting thematic objectives and related programmatic lines and the corresponding financial plan. The Long Term Plan is revised regularly, at each ESA Ministerial Councils which take place every three to four years.

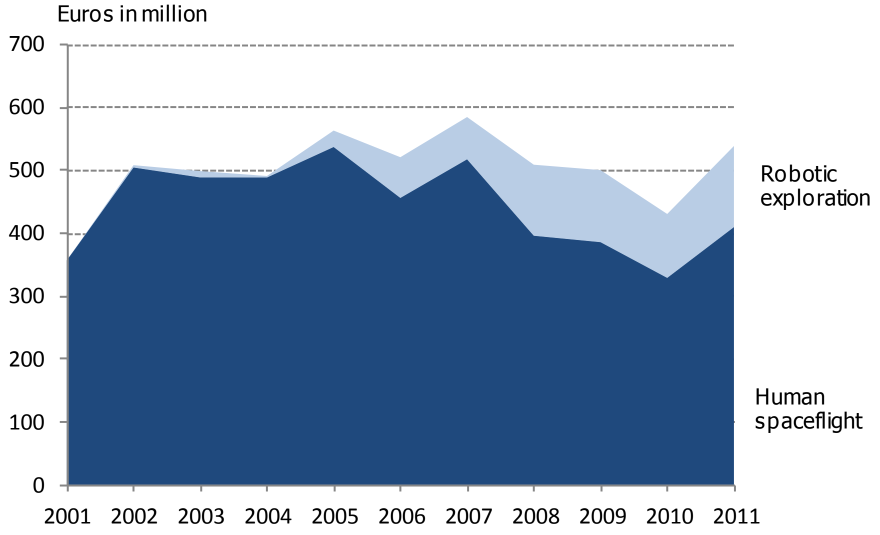
During the last Ministerial council, ESA member states agreed on a series of strategic objectives among which are listed the development of studies to support the debate for a long-term global vision on exploration, and the necessity to find an agreement for participating to ISS Exploitation programme, resulting in the lifetime extension of the ISS.

ESA programs are based on the geographic return principle, where Member States achieve an adequate return proportionally to their investments. This principle has been instrumental in motivating European member states to invest in ESA programs are they consider it as a way to improve the competitiveness of their industry, maintain and develop capabilities, and deliver services to European citizens.

Budget dedicated to Space and Exploration activities

ESA has the third largest space budget in the world, with €3.3 billion in 2011, of which 13.5% (€540 million) were dedicated to Space Exploration. However, the largest part of the robotic exploration projects are funded through ESA Scientific budget, which encompasses planetary science, astronomy and astrophysics, solar and solar-terrestrial science, plasma physics and fundamental physics. The share of the scientific budget dedicated to exploration activities is unknown.

ESA space exploration budget (2001-2011)*



*** Largest part of robotic exploration budget not included since it is merged with the Science budget**

Funding for Human Spaceflight activities is expected to decline significantly over the next few years as the deployment of the ISS is now completed and the participating states now focus on the exploitation of the station.

The funding for robotic activities through the scientific program will remain stable as the contribution from the Member states in this area are mandatory and based on their relative GDP. However, the funding for the Robotic exploration program Aurora is uncertain as of March 2012, essentially due to the latest development around Exomars and the US withdrawal from the mission. ESA concluded an agreement with Roscomos that should save the project but will required an additional €200 million from the Member states, which will add to the €150 million that remain to be financed for the mission.

The future of the exploration program will be at the heart of the 2012 ESA ministerial council, which will take place in Fall 2012.

2. ESA Space Exploration Programs

ESA activities in Space exploration are split between two directorates:

- **The Directorate of Human Spaceflight and Operations (D/HSO)**, which manages and develops the human exploration programs.
- **The Directorate of Science and Robotic Exploration (D/SRE)**, which manages the robotic exploration programs.

Robotic Exploration programs

Robotic Exploration within ESA is financed through two separate channels: The mandatory science program and the optional robotic exploration program.

ESA mission developed as part of the science program

The contribution to ESA scientific program is mandatory for all member states and calculated based on their relative GDP. The ESA scientific program covers three main areas: Planetary science, Solar terrestrial probes and Astronomy. Only missions developed as part of the planetary science area have been included in the present study,

Space Exploration missions at ESA have initially been developed as part of the Horizon 2000 program, which was adopted in 1984. Horizon 2000 distinguished between two main types of missions: Cornerstone and medium missions. Cornerstone missions were allocated the equivalent of 2 years of ESA scientific budget while Medium missions could only receive half of this budget.

In 1994, the Horizon 2000+ program succeeded to Horizon 2000. The new program added a small mission category and reviewed the budgets allocated to the different types of missions so that Cornerstone projects were only eligible to 1.5 budget year, Medium missions could receive 0.5 budget year and small missions 0.25 budget year.

ESA is currently preparing the new program called Cosmic Vision 2015-2025, with two classes of missions: M-missions, which will essentially be ESA stand-alone missions with a limited budget of €470 million, and L-missions, which will often be carried out in collaboration with other partners and whose cost for ESA cannot exceed €900 million.

The only mission currently in development at ESA as part of the scientific program is **BepiColombo,** a cornerstone mission of the Horizon 2000+ program, carried out in collaboration with Japan. The objectives of BepiColombo are to study the magnetosphere, the surface and the internal composition of Mercury.

The mission consists of two separate spacecrafts: the MPO (Mercury Planetary Orbiter) which is being developed by ESA, and the MMO (Mercury Magnetospheric Orbiter) which represents the Japanese contribution to the mission. ESA selected EADS Astrium as the prime contractor for the MPO in 2008 for €351 million.

The total cost of the mission to ESA was initially planned at 665 million Euros, including the launch and the operations up to 2020. However, the mass of the spacecraft has grown significantly since the beginning of the project so that the launcher had to be changed, resulting in a total cost for ESA nearing €970 million. The launch of the mission is now scheduled for 2015.

ESA is now in the process of selection for the third M-class mission of Cosmic Vision. The only Planetary science candidate mission is **MarcoPolo-R**, an asteroid sample mission which would help to answer key questions about the processes that occurred during planet formation. Selection of the mission should occur in the course of 2012.

ESA had also planned an L-Class planetary science mission in cooperation with NASA, **EJSM/Laplace** (Europa Jupiter System Mission – Laplace), whose objective was to perform an in-depth exploration of Jupiter's moons with a focus on Europa, Ganymede and Jupiter's magnetosphere. However, budgetary constraints in the US compromised the possibility of a joint mission so that ESA is presently considering a European-led reformulation of the mission, called **JUICE** (Jupiter Icy Moon Explorer), which is a candidate to become the first L-class mission. JAXA and Roscosmos have both expressed their interest in the JUICE mission, though no official agreement has been formalized yet.

Space exploration missions conducted as part of ESA science program since 1997

Name of the mission	Date	Class of mission	Mission cost to ESA
Cassini-Huygens	1997	Medium	€380 million
Mars Express	2003	Medium	€300 million
SMART-1	2003	Small	€110 million
Rosetta	2004	Cornerstone	€980 million
Venus Express	2005	Medium	€220 million

BepiColombo	2015	Cornerstone	€970 million

ESA mission developed as part of the robotic program

ESA Member states established in 2001 the AURORA program with the primary objectives of creating, and then implementing, a European long-term plan for exploration of the Solar System using robotic spacecraft and human spaceflight and to search for life beyond the Earth.

The AURORA program is an ESA optional program, which means that the contribution to these activities is voluntary. The budget allocated to the program is voted at each ESA Ministerial council. Aurora has received an average of €118 million annually since the last Ministerial council in 2008.

Exomars: The fist "Flagship" mission developed as part of the Aurora program is Exomars**,** which targets the development of a Mars orbiter, a descent module and a Mars rover, initially in cooperation with the US. The Exomars mission will be two-phased, with the initial launch of a Trace Gas Orbiter in 2016, followed by a 2018 Rover mission.

ESA was supposed to develop the Orbiter, which would have been launched by the US, the Entry, Descent and Landing Demonstrator Module (EDM), and to participate to the development of a rover jointly with NASA. However, NASA informed ESA at the beginning of 2012 that it would most likely not be able to contribute to the mission due to budgetary cuts and the necessity to finance the James Webb Space Telescope.

The recent withdrawal of NASA will necessarily lead to a complete restructuration of the mission during the next ESA Ministerial Council. In March 2012, ESA announced that it had found an agreement with Roscosmos to resume the development of the program. Under this agreement, Roscosmos would launch the European orbiter in 2016 and develop a lander that would release a rover built by ESA for the 2018 mission.

The 2016 EDM would still be fitted with the same payload instruments as originally planned but would see its lifetime on Mars increased as it would be equipped by a Russian Radioisotope thermoelectric generator (RTG).

The landing technologies developed by ESA for the EDM would also be used for the 2018 Russian lander as ESA would participate to its development up to 20%. The payload of the rover is expected to remain the same than initially planned.

However, this new mission configuration has a strong impact on its cost, as the Rover, which was supposed to be developed jointly with the US, is now a full European contribution. ESA estimate the cost increase at around 20%, bringing the total mission budget to €1.2 billion. Member States have subscribed for €850 million only up to now so that the remaining €350 million will have to be voted during the 2012 Ministerial council.

Mars Sample Return: The second Flagship mission, currently in planning, is Mars Sample Return, which could be launched between 2020 and 2022. Five spacecrafts will have to be developed for this mission: an Earth/Mars transfer stage, a Mars orbiter, a descent module, an ascent module and an Earth re-entry vehicle. The total cost of the mission could exceed €5 billion, which has driven ESA to turn to the International Mars Exploration Working Group (IMEWG) and to set up a dedicated Working group, iMars (International Mars Architecture for the Return of Samples) to develop a potential plan for an internationally sponsored and executed mission.

ESA also conducts a technology development program, the **MREP** (Mars Robotic Exploration Preparatory program), under which it develops critical technologies, required for future missions, and long-term enabling technologies. These capabilities notably include soft landing technologies, sample capture in orbit, RTGs and high-thrust engines.

Lunar Lander: Though Mars is the current focus of ESA robotic activities, a Lunar Lander mission will be proposed for approval by the Member States during the 2012 Ministerial Council. This mission, which is essentially supported by Germany aims at achieving a soft precision landing near the Lunar South Pole based on technologies acquired through the development of the ATV thrusters, to prepare for future Human activities. The total cost of this mission is estimated at €500 million. Its approval during the 2012 Ministerial conference is unsure since Member States will already be solicited for the Exomars mission and may not accept to engage in another large exploration mission.

Human Spaceflight programs

ESA activities in Human Spaceflight are currently focused on the International Space Station. These activities are financed through several ESA optional programs (covering fixed and variable costs), to which Germany is the main participant with a 41% share to the program, followed by France (28%) and Italy (19%).

ESA estimates its share of the total cost of the program to €8 billion from the start of the program to 2015. ESA has followed a "No exchange of Funds" approach with its international partners by concluding "barter agreements" with the US, Russia, Japan and Italy. These agreements formalize exchanges of goods and / or services between the participating parties without a corresponding financial transaction.

The main advantages of these agreements is that there is no transfer of funds from ESA to non-Member States and that they result in an increase in work for the European Industry. NASA committed for example, in the ESA / NASA Columbus Orbital Facility Launch Barter; to launch the Columbus module and its initial payload on the Shuttle for ESA in exchange for the provision by ESA to NASA of fully integrated Node-2 and -3 ISS Modules, cryogenic freezer and crew refrigerator / freezer equipment of the ISS.

Europe's current main contribution to the ISS is the **ATV (Autonomous Transfer Vehicle)**, which is an unmanned, non-reusable cargo spacecraft for delivering 7.5 tons of supplies and fuel to the International Space Station. Europe committed on the launch of 5 ATVs between 2008 and 2014. Each ATV has been reported to cost around $300 million, excluding launch and mission costs.

As the ATV barter deal with NASA expires in 2017, ESA is currently defining the nature of its future contribution to the ISS. France had proposed to develop an orbital manoeuvring vehicle that could capture "non-cooperative" targets in orbit for assembly or disassembly but NASA was not interested in this idea, preferring the ESA contribution to focus on the development of a propulsion module for NASA's Orion crew-transport capsule.

ESA contributions to the ISS

Equipment	Date	Mission
DMS-R	2000	Data Management System-Russian. Control equipment on the Russian segment of the ISS.
MSG	2001	Microgravity Science Glovebox. European glovebox installed in the US destiny module
PFS	2005	Pulmonary Function System. Medical research facility installed inside the US destiny module
MELFI	2006	Minus Eighty degree Lab for ISS. Freezer for samples installed inside the US destiny module
Harmony	2007	Node module 2
Columbus	2007	European laboratory module
ATV-1 (Jules Verne)	2008	First ATV Cargo supply spacecraft
MSL-USLab	2008	50% contribution on the Material Science Research Pack installed in Destiny
Tranquility	2010	Node module 3
Cupola	2010	Observatory module
ATV-2 (Johannes Kepler)	2011	Second ATV Cargo supply spacecraft
ATV-3 (Edoardo Amaldi)	2012	Third ATV Cargo supply spacecraft
ATV-4 (Albert Einstein)	2013	Fourth ATV Cargo supply spacecraft
ERA	2013	European Robotic Arm
ATV-5 (Georges Lemaître)	2014	Fifth ATV Cargo supply spacecraft

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Exploration missions						
2000	Launched	**Zveda**	Roscosmos	Russian module of the ISS	Astrium	Data Management System, control equipment on the Russian segment of the ISS
2001	Launched	**Destiny**	NASA	US ISS Laboratory Module	Astrium	Microgravity Science Glovebox, one of the major dedicated science facilities inside the US module Destiny
2008	Launched	**Columbus Orbital Facility**	ESA	Space laboratory module docked to the ISS	Astrium Space Transportation	Prime contractor, Environmental Control and Life Support, Software, MDPS
					Astrium Satellites	Atomic Clock Ensemble in Space , Protein Crystallization Diagnostics Facility , Fluid Science Laboratory sub-systems, DMS, BioLab, components
					Thales Alenia Space	Command Pulse Distribution Unit , Pre Integrated Columbus Assembly , Fluid Science Laboratory , European Drawer Rack , European Transport Carrier, Solar, software, Electrical Ground Support Equipment , recorders
					Draeger Aerospace	Environmental Control and Life Support sensors
					OHB System	Ground Support Equipment, electrical harness, video monitors and recorders, European Physiology Modules, BioLab model, FSL, EDR and ETC sub-systems
					EREMS	European Physiology Modules sub-systems
					Secan	Heat exchangers
					Soterem	Air conditionning
					Carlo Gavazzi Space	EuTEF, BioLab, EPM and FSL sub-systems
					Ferrari	BioLab sub-systems
					Microtecnica	Thermal control
					Officine Galileo	Cameras
					Space Software Italia	Software

					Logica	BioLab sub-systems
					Spacebel Informatique	Test software
					Verhaert	BioLab, EPM and FSL sub-systems
					Rovsing	Software, BioLab science model
					Terma	Software
					SPS-OR	Components
					Atos Origin	Software
					Bradford Engineering	Valves, BioLab, EDR and ETC sub-systems
					EADS Crisa	Software
					NTE	BioLab sub-systems
					Sener	EPF, racks, decks, BioLab and FSL sub-systems
					SAAB Ericsson Space	Components
					Hamilton Bonaduz	BioLab sub-systems
					OCI	EDR and ETC sub-systems
					Rosys	BioLab sub-systems
					Treff	BioLab sub-systems
					Syderal	CPDU subsystems
2007-2010	Launched	**Node 2 & 3**	ESA	Utility hubs of the ISS	Thales Alenia Space	Prime contractor for the two nodes
2008-2014	3 launched, 2 more approved	**ATV 1-5**	ESA	Autonomous Transfer Vehicle for delivering	Astrium Space Transportation	Prime contractor for the ATV Development

				supplies and fuel to the ISS	Thales Alenia Space	Solar Array Drive Sub-System, PCU Unit and TT&C communication equipment via TDRSS (France) Prime contractor for the Cargo carrier (Italy)
					SODERN	Star trackers and Rendezvous sensors
					SAFT	Batteries
					SNECMA	Engines
					Clemessy	Integration and test of the vehicle
					TESAT	Manages the procurement for all electronic components
					Azurspace	Solar cells
					Jena Optronik	Part of the optical sensors
					OHB/ MT Aerospace	Cabling, Tanks, and meteorite protection shield
					Rymsa	Communication antennas
					Thales Espacio	Communication equipment for the vehicle’s docking maneuvers with the ISS
					EADS CASA	Structures
					EADS Astrium CRISA	CPF and the CPD
					IBERESPACIO	Risk Testing for the mission
					Selex Galileo	Solar arrays, electrical power and RF equipments
					DATAMAT	Flight Application software and MSU software
					LABEN	GPS Receiver
					RUAG	Structure of the propulsion modules, racks for accommodating payloads in the cargo bay and Thermal insulation

					APCO Tech	Mechanical support and test equipments, as well as a Meteorite and Debris protection system
					Dutch Space	Solar Arrays
					ETS	Logistic Support
					Bradford	Thermal control and propulsion system
					EuroHeat Pipes	Pipes
					SAS	Mission support
					ROVSING	Software validation and verification
					RUAG AB	MSU
2010	Launched	**Cupola**	ESA	Pressurized observation and work area for the Space Station crew	Thales Alenia Space Italy	Prime contractor, Responsible for design verification, delivery of the Cupola and associated ground support
					EADS CASA	Cupola shutters
					APCO	Meteorite and debris protection system and mechanical ground support equipement
					Ruag Space Sweden	Harness
					Lindholmen Development	Cupola mock-up and associated ergonomics analysis
					EADS Space Transportation	Life support analysis
					Verhaert	Attachment fixtures for maneuvering the Cupola in space and change-out covers. Participation to the development of the Cupola's secondary structure.
2013	IN development	**European Robotic Arm**	ESA	Robotic arm to be attached to the Russian Segment of the ISS	Dutch Space	Prime contractor

Robotic Exploration missions						
1997	Launched	**Cassini-Huygens**	NASA (Cassini) ESA (Huygens)	Saturn orbiter and probe	Aerospatiale (now Thales Alenia Space)	Huygens Prime Contractor Huygens Front Shield
					Oerlikon Contraves (now RUAG Space)	Huygens Back Cover Huygens separations
					Martin Baker	Huygens Descent Control
					CASA (now EADS Casa)	Huygens Inner Structure Huygens Probe Harness
					DASA (now EADS)	Huygens Thermal Control & AIT
					LABEN (now Finmeccanica)	Huygens Data Management
					ETCA (now Thales Alenia Space ETCA)	Huygens Power Supply
					Alenia (now Thales Alenia Space)	Huygens RF Data Relay
					Logica	Huygens Probe Software Huygens Avionics Software
2003	Launched	**Mars Express & Beagle-2 lander**	ESA	Mars orbiter to search for sub-surface water from orbit and drop a lander on the Martian surface	EADS Astrium	Prime contractor (Astrium France) Lander's heat shield and thermal aft system (Astrium France) On-board high-resolution stereo camera (Astrium Germany) Spacecraft propulsion system (Astrium UK) Prime contractor for the Lander (Astrium UK)

					DNV	Reliability, availability, maintainability and safety tasks at system level
					Kongsberg	Supplied two SADMs
					CAPTEC	Independent Software Validation
					AEA Battery Systems	Re-chargeable lithium-ion batteries
					Qinetiq	Lander communication system
					Teldix	Wheels
					Intespace	Mechanical testing
					Alcatel Espacio	Remote Terminal Unit
					Crisa (now EADS Astrium Crisa)	Spacecraft computers and controllers
					Casa	Supply of high rigidity tubes, made in carbon fiber, that support the reflector of the orbital module
					Terma	Power Conditioning Unit
					Nexans	Electrical wire and cable
					Austrian Aerospace	Thermal protection
					Contraves	Flight Structure
2003	Launched	**SMART-1**	ESA	Lunar orbiter to test technologies	Swedish Space Corp.	Prime Contractor
					Omnisys Instruments	Power Control and Distribution Unit
					SAAB Ericsson Space (now Ruag Space Sweden)	Flight Module Assembly Integration and Testing Antennas Remote Terminal Unit

						Electromagnetic Compatibility Thermal Subsystem
					Terma	On-board Independent Software Validation
					DTU Technical University	Star Tracker
					Astrium Germany	Deep Space X/Ka Band transponders
					MPI Aeronomie	Near Infrared Spectrometer
					APCO Technologies	Structure and Mechanical Ground Support Equipment
					Contraves (now Ruag Space)	Electric propulsion mechanism
					CSEM	Asteroid-moon micro imager
					LABEN (now Finmeccanica)	Electric Propuslion Diagnostic
					RSIS	Radio Science Investigation
					Finnish Meteorological Institute	Space Plasma Electron and Dust Detection (SPEDE)
					Rutherford Appleton Laboratory	Compact imaging X-ray spectrometer (D-CIXS)
					Fokker Space (now Dutch Space)	Solar Arrays
					TNO	Sun Acquisition sensors
					Spacebel	On-board Software detailed design
					Alcatel ETCA (now Thales Alenia ETCA)	Electric propulsion power processing
					SAFT	Batteries

					Snecma	Solar Array Mechanism Electric Propulsion System (EPS)
					ATERMES	Electric propulsion pressure regulation
					Alcatel Espacio	S-Band Transponder
					CRISA (now EADS Crisa)	Battery management electronics
2004	Launched	**Rosetta**	ESA	Comet orbiter and lander	EADS Astrium	Prime contractor (Astrium Germany) Spacecraft platform (Astrium UK) Spacecraft Avionics (Astrium France)
					Thales Alenia Space Italy	Assembly, integration and verification
					DLR	Prime contractor for the Lander
2005	Launched	**Venus Express**	ESA	Venus orbiter for long term study of Venus atmospheric dynamics	See Mars Express	The objective of ESA for Venus Express was to use roughly the same industrial team than for Mars Express.
2015	In development	**BepiColombo**	ESA (MPO) JAXA (MMO)	Mercury orbiters	EADS Astrium	Prime contractor (Astrium Germany) Avionics and systems (Astrium Germany) Spacecraft ETB AIT (Astrium Germany) Central Software (Astrium France) Mechanical propulsion bus (Astrium UK)
					Thales Alenia Space	Power subsystem

					Italy	TT&C subsystem Thermal subsystem Spacecraft AIT
					Tecnologica	CPPA
2016-2018	In development	**Exomars**	ESA / Roscosmos	Mars Orbiter and Rover	Thales Alenia Space Italy	Prime contractor & system integration Prime contractor for the orbiter module Prime contractor for the EDL Demonstrator Prime contractor for the Rover Module Analytical Laboratory Drawer
					Thales Alenia Space France	Orbiter Module Bus Entry and descent subsystem for the EDL demonstrator
					OHB	Mechanical Thermal Propulsion for the Orbiter module
					RUAG	Main Separation Assembly for the Orbiter module Chassy and locomotion for the Rover Vehicle
					SENER	Surface Platform structure & separation mechanism for the EDL Demonstrator Front shield separation mechanism for the EDL Demonstrator
					Galileo Avionica	Drill subsystem for the Rover module
					ALTEC	Rover Operations control centre
					Astrium UK	Rover Vehicle
					Kaiser Threde	SPDS for the Rover module

* At PI level only for scientific instruments

3. Industrial capabilities in ESA Member States

The industrial capabilities for space exploration in Europe are in practice the cumulative capacities of ESA Member States, the most important being France, Germany, Italy and the UK. These countries are the most important in space exploration because they are the most important in space in general. Whereas intrinsic industrial capacities required for the development of space exploration systems are, for most of them, multiple across ESA member states (at least in the four above), direct and actual experience of space exploration realizations reflects individual countries' financial participation levels in the different ESA programs.

France

The French capabilities for space exploration have been mostly turned to robotic exploration systems. This has taken place in the context of several ESA and non-ESA (bi-lateral collaborations) deep space missions with an essentially scientific objective, as well as with the development of the robotic low Earth orbit space transportation system ATV designed to provide cargo transportation services in support of human space exploration at the International Space Station (part of Europe's contribution in the international deal to exploit the ISS).

A pioneer in the development of space capacities in Europe since several decades, the French space industry has soon developed a strong competence to manage the prime contractorship of complex missions, which in Europe generally incurs leading a wide consortium of industrial suppliers from all ESA Member states. In general, prime contractorship entails direct contributions to system design and specifications, on-board software development and avionics, as well as assembly, integration and testing of the full system. Thus, Astrium-France was the prime contractor of the Mars-Express and Venus-Express probes for ESA, and Thales Alenia Space took this responsibility for the development of the Huygens probe, again for ESA (and NASA, as Cassini-Huygens was a joint ESA/NASA mission). Taking the same contractor for both Mars and Venus Express allowed ESA to save on costs by re-using part of the design and of the hardware from one mission to the other. This particular synergy of means developed within Astrium was also put to bear in the Rosetta probe for which Astrium-Germany was the prime contractor. In the case of ATV, France led the development (Astrium ST Les Mureaux) and later transferred the production of the vehicles to Astrium ST in Germany (Bremen); today, the Astrium ST ATV team operates as an integrated team between France and Germany in view of evolving the capacities of ATV (introducing atmospheric re-entry and eventually making it a crewed vehicle).

When neither of the two French large system integrators is chosen as prime contractor by ESA, other actors of the French space industry can more easily find a role in ESA exploration missions and systems. The reason is that prime contractorship tends to absorb a significant share of the mission/system development budget, leaving little room for other contributions in the context of a constrained national budgetary return. France has strong industrial capacities for space batteries (with SAFT), for optical GNC sensors – such as star trackers – (with SODERN), high temperature materials (with Astrium ST Bordeaux), space avionics and on-board software (Astrium and TAS), electric in-space propulsion (Snecma).

Other smaller actors in France have contributed to ESA space exploration missions as well, for instance in the Colombus program (Erems supplying physiology modules and Soterem supplying air conditioning equipment).

In addition to purely industrial capacities toward the development of space exploration systems, France also houses a number of top-level laboratories and research organisations capable of designing and delivering on-board instruments for space probes (usually under CNES supervision and coordination). The contributions of French scientific actors over the past 10-15 years seem to have focused around six types of instruments, namely:

- **Spectrometers for remote sensing analysis**: French laboratories (LATMOS, LESIA and IAS) have developed a wide range of optical, UV and infrared spectrometers for European and international missions (Cassini – Huygens, Mars Express, Venus Express, BepiColombo...)
- **Gas Chromatographs:** French gas chromatographs are developed by two laboratories, the LATMOS and the LISA. The chromatograph columns of five missions (Cassini – Huygens, Rosetta, Mars Science Laboratory, Phobos-Grunt and Exomars) have been or will be provided by France.
- **Laser Spectroscopy:** The IRAP laboratory is developing a key capability in this area, with participation to the Mars Science Laboratory and potential contributions to ExoMars and Selene-2.
- **Hyperspectral microscopic imager for in-situ analysis:** The Institut d'Astrophysique Spatiale has gained a strong capability in this area through its participation to the ROsetta mission and has developed the MicrOmega infrared spectrometer that was fitted on the Phobos-Grunt lander and could be equipped on the Exomars rover and on the candidate landers on Hayabusa-2 and Marco Polo R.
- **Seismology**: The IPGP laboratory developed a first version of an highly sensitive seismometer for the failed Russian Mars 96' mission. After fifteen years of R&D, an improved version of the instrument was developed: the Very Broadband seismometer. This instrument could potentially be fitted on the GEMS, Selene-2, Hayabusa-2 and Marco Polo R missions, all of them pending official selection
- **Ground penetrating radars:** A ground penetrating radar to support drilling operations were already developed by the LATMOS for the Rosetta mission. Such a radar is also planned for the PASTEUR payload of the Exomars mission and could be included in the candidate lander for the Marco Polo R ESA mission.

Germany

The German space industry has most of the capabilities to develop interplanetary robotic spacecraft as well as Earth-orbital man-tended facilities, and has gained experience of such systems over the past 15 years in several high profile ESA programs (Colombus, ATV, Rosetta, BepiColombo)

The main actors of space exploration in Germany are:

- Astrium Satellites GmbH, involved as a systems integrator for several ESA robotic exploration missions (Rosetta, BepiColombo), and also leading the Lunar Lander program. With its three main sites (Friedrichshaffen, Ottobrunn and Lampoldshausen), Astrium GmbH has capacities for developing complex spacecraft systems including avionics, in-space propulsion, structures, solar generators as well as performing integration and tests.
- Astrium Space Transportation GmbH localized in Bremen is the main actor for human space exploration. This is where the Colombus ISS laboratory was developed and where the ATVs are produced.
- DLR, also the German space agency, comprises a number of R&D Institutes, some of which are involved in space exploration research (robotics and life sciences in particular). DLR is thus in a position to prime contract certain missions or mission segments, such as the Philae lander in Rosetta or the Mascot lander in Japanese mission Hayabusa-2, and to contribute specific instruments within ESA or in bilateral cooperations.

Several other German research institutes and universities are major contributors to space exploration as well, by proposing/leading scientific experiments, and by designing/building (or supervising the construction and testing) the corresponding space instruments. The Max Planck Institute is a frequent contributor for particle physics and solar system research by providing cameras and spectrometers (Rosetta, VenusExpress, BepiColombo). Universities of Cologne, Munich, Berlin, Braunschweig and Muenster have also participated in space exploration missions (see table above for details).

Other industrial actors of space exploration programs in Germany include Kayser Threde (now part of the OHB Group) which has developed life support systems and microgravity payloads for the ISS, Draeger Aerospace which supplied environment control and life support equipment for Colombus, OHB Systems which contributed a number of modules and equipment in the Colombus program, JenaOptronik (now part of Astrium GmbH) supplying optical sensors for the ATV, AzurSpace which supplies solar cells for the ATV solar generators, MT Aerospace (an OHB Group company) supplier of the ATV propellant tanks, VonHoerner&Sulger which has developed a variety of instruments (spectrometer) and mini-rovers in the context of Rosetta, Exomars and some NASA missions (Stardust, Contour). The ESA Astronaut (training) Center is also located in Germany (Cologne).

Italy

The dominating actor of space exploration in Italy is Thales Alenia Space (TAS-I).

TAS-I has been a major contributor to the ESA human space exploration programs, and has taken the lead in the European Exomars robotic mission. Over the past 10-15 years, TAS-I Turin site has gained extensive expertise in the design, development and integration of orbital pressurized modules, starting with the development of three MPLM (multi-mission pressurized launch modules) for NASA and contributing a variety of equipment to the Columbus ISS facility (fluid science lab, transport carrier, …etc – see table above). TAS-I was prime contractor for nodes 2and 3 of the ISS and for the pressurized cargo carrier of the ATV (in addition to supplying other ATV subsystems such as solar array drive, power control unit and TT&C). This expertise led TAS-I to be selected by Orbital Science Corporation to supply the pressurized modules of their Cygnus commercial ISS re-supply vehicle.

TAS-I has also developed strong capacities in the design and development of robotic space exploration systems, being co-prime of BepiColombo with Astrium GmbH (electrical power, thermal control, communication system) and which will culminate by their taking responsibility for the complete Exomars mission integration (including prime contractorship for the orbiter module, the entry/descent module and the rover module). TAS-I has experience in developing space instruments, often in collaboration with research organisations (radar Doppler altimeter on Exomars, accelerometer and ion spectrometer on BepiColombo, sub-surface sounding radar on NASA Mars Reconnaissance Orbiter mission).

Selex Galileo (including former Galileo Avionica) is another important player for space exploration in Italy. The company has capacities in small robotics (through former Tecnospazio expertise) and will provide the drilling subsystem for Exomars rover. Selex Galileo has strong capacities in optics and optoelectronics which are used to develop space instruments (spectrometer-type instruments for Rosetta, Venus Express and NASA's Dawn and Juno missions) including several instruments on Exomars.

Other industrial actors occasionally contributing in the development of space exploration hardware and software include Carlo Gavazzi Space (microgravity payloads for the ISS), Microtecnica (thermal and fluid control in Colombus), Laben (now a TAS-I site) with GPS receivers on the ATV, Space Software Italia, Datamat and Altec (now a TAS-I company) for software development in, respectively, Colombus, ATV and Exomars.

The Italian research organisations and universities participate as well with instrument designs, for examples: Rome La Sapienza with sub-surface radar in the NASA Mars Reconnaissance Orbiter mission and a radio science instrument for the Juno mission , Università di Padova (camera for Rosetta), Politecnico di Milano (solar panel subsystem on Rosetta), and especially the Interplanetary Space Physics Institute (IFSI) which has contributed to many exploration missions with specific instrument designs (spectrometers essentially), often in collaboration with either TAS-I or Selex Galileo.

UK

The main actor of Space exploration in the UK is Astrium Ltd which has taken lead roles in Rosetta (prime contractor of the Rosetta platform), in Mars Express (prime contractor of the Beagle-2 lander), in Exomars (will build the Exomars rover), and which has supplied major subsystems in ESA robotic missions (the propulsion systems for Mars Express, Venus Express and BepiColombo).

Other industrial contributors are QinetiQ (communication equipment for Beagle-2, but also developer of electric in-space propulsion technologies), AEA (now ABSL Power Solutions) which supplied the Beagle-2 batteries, Logica and SciSys who developed software for Beagle-2.

British universities are also contributors in space exploration missions. The Rutherford Appleton Laboratory has developed considerable expertise and technology development capacities in relation to space sciences (200 people working for space Science and EO projects in 2007) and has contributed various instruments in past space exploration programs (Smart1 lunar mission, Chandrayaan-1 lunar orbiter). Other contributing universities include the Open University, University College London or the University of Wales.

Other ESA Member States capacities for the development and operation of ESA space exploration systems can be found, for the most significant:

- In Sweden, with Swedish Space Corporation (now part of the OHB Group) which specializes in the development of small spacecraft and which prime-contracted for the ESA Smart-1 lunar mission. Former Saab Space (now a Ruag company) contributed to this mission (flight module, antennas, RTU, thermal subsystem)
- In Norway, with Kongsberg supplying high temperature mechanisms for BepiColombo and also for Mars and Venus Express
- In The Netherlands, with Dutch Space (now an Astrium company) prime contractor of the European Robotic Arm soon to be deployed in space and supplier of the solar arrays on the ATVs, or with Bradford Engineering (recently acquired by Moog Inc.) which supplied microgravity equipment to ESA and NASA (gloveboxes) as well as some propulsion equipment for the ATV. In addition, research institute TNO is a contributor of optical instruments and sensors (sun sensors).
- In Spain, EADS CASA (structures), EADS Astrium Crisa (electronics), former Alcatel Espacio (now TAS-Spain), Sener (microgravity payload equipment and mechanisms in Exomars) are regular component/equipment suppliers of ESA space exploration missions within their respective field of expertise.
- In Switzerland, Ruag (structures and mechanisms), CESM (microsystems) contribute to EU space exploration capacities
- In Austria, Austrian Aerospace (now a Ruag company) can provide thermal protection blankets
- In Denmark, DTU can provide startrackers, and Terma can contribute in software validation
- In Belgium, Verhaert (now a QinetiQ company) has capacities to develop microgravity equipment, whereas Spacebel can contribute in on-board software development.

General overview of industrial capabilities in Europe for space exploration

- 🟩 Flight system experience
- 🟨 Breadboard or ground system experience
- ▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	Comments
Astrium Satellites F										🟩					Mars and Venus Express primeship, on-board software and avionics (Rosetta, ..)
Astrium ST F	🟩	🟩					▨								Ariane 5, ATV - High temperature structures
TAS Cannes									🟩	🟩					Huygens probe in the Cassini-Huygens mission
SODERN		🟩													GNC in ATV
SAFT		🟩													Batteries in ATV (and many GEO satellites worldwide)
SNECMA			🟨												Flight experience of electric propulsion with GEO satellites
Astrium Satellites GmbH									🟩						Prime contractor for Rosetta and BepiColombo missions
Astrium ST GmbH	▨	🟩					🟨			🟨					Ariane 5 propulsion, ATV system integration, high temperature structures for re-usable launchers, Lunar lander studies
Kayser Threde/OHB Systems					🟩										ISS/Colombus life support equipment, microgravity payloads and other modules
JenaOpronik		🟩													GNC sensors in ATV
Draeger Aerospace					🟩										life support equipment in Colombus
Von Hoerner&Sulger										▨		▨			instruments and mini-rovers in Rosetta, Exomars, Stardust and Contour NASA missions
DLR Institutes			🟨							🟩		🟩			prime contractor for Rosetta and Hayabusa-2 landers instruments contributed to JAXA's Selene-2 mission and NASA's GEMS Mars mission
TAS Turin				🟩		🟨			🟩	🟩					developer of the MPLM pressurized modules for NASA, of nodes 2 & 3 of the ISS for ESA, of the pressurized module in the ATV and in the Orbital Science Corporation Cygnus program - Co-prime contractor for BepiColombo mission and prime contractor for Exomars ESA mission
TAS Milano (Laben)		▨													supplier of GPS sensors for ATV
Selex Galileo											🟨	🟩			drilling system for Exomars, optical and optoelectronic instruments in Rosetta, Venus express, NASA's Dawn and Juno missions, and Exomars
Carlo Gavazzi Space				▨											microgravity payloads for ISS
Astrium Satellites UK							🟩			🟩					Rosetta platform, Beagle-2 lander, Exomars rover, propulsion sub-systems for Mars Express, Venus Express and BepiColombo
Rutherford Appleton Laboratory												🟩			Smart-1 and Chandrayaan-1 lunar orbiter instruments
QinetiQ			🟩							🟩					electric propulsion, Beagle-2 communication
ABSL										▨					Batteries in Beagle-2 (and many smallsats worldwide)
Swedish Space Corp									🟩						Smart-1 lunar mission prime contractor
Dutch Space						🟩									European Robotic Arm ready for launch to the ISS
UK Academic Laboratories (Universities of Wales, Open university, University College London, ...etc)												🟩			Contributions to Huygens, Rosetta Philae, MSL,
Italian Research Laboratories (university Rome La Sapienza, university di Padova, Politecnico di Milano, IFSI)												🟩			spectrometers, cameras, sub-surface radar
German Research Laboratories (Max Planck Institute, universities of Braunschweig, Muenster, Cologne, Munich, Berlin)												🟩			Contributions to Exomars, BepiColombo, Rosetta, Mars & Venus Express, NASA's Dawn asteroid mission, ISRO's Chandrayaan-1 Moon mission and JAXA's Planet-B mission
French Research Laboratories (LATMOS, LISA, IAS, ...etc)												🟩			Contributions to Huygens, Rosetta Philae, MSL,
Other EU Research Laboratories (DTU, CSEM, TNO ...etc)												🟩			Contributions to Smart-1 and other missions

4. International cooperation

ESA cooperation activities can be divided into two main categories:

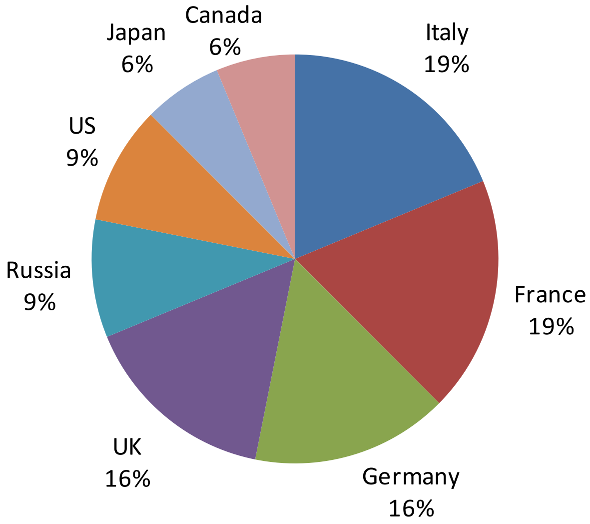
- Cooperation with its own member states: This includes essentially the provision of scientific instruments, paid for by the Member states, on ESA missions and accounts for 70% of the cooperation activities of ESA in space exploration
- Cooperation with non-member states: Though these countries may provide scientific instruments to ESA missions, the main purpose of these cooperation opportunities is to split the cost of large missions. This is notably the case of BepiColombo (with Japan) and Exomars (initially with the US, now with Russia), but also of course of the International Space Station as ESA would not have been financially capable of leading a large Human Spaceflight program without international cooperation.

The cooperation activities to which ESA participate rarely lead to technology transfer between the participants as most of the technologies Europe does not own are considered as strategic by the other parties. Cooperation is therefore generally limited to the joint launch of two separate elements that share a common exploration objective.

The main risk associated to cooperation for ESA is the political and financial agenda and difficulties experienced by the other party. These factors have notably led to the withdrawal of NASA from Exomars and EJSM/Laplace. Though ESA managed to save these two missions, these withdrawals could have led to the total cancellation of the mission, which would have a strong impact on ESA Member states since, notably in the case of Exomars, industrial stakeholders had already started to develop the programs.

To avoid these risks in the future, ESA intends to favour a 80% / 20% approach for its future space exploration cooperation activities. This means that if ESA leads the mission, the contribution of its partner would be capped at 20% so that the whole mission is not threatened in case of withdrawal of the partner. In the same way, if ESA joins a mission led by another country, it would limit its participation to 20%.

Breakdown of ESA space exploration activities by cooperating country (from 1997 to future approved missions)



Most recent agreements relevant for space exploration between ESA and other space nations

Partner	Date	Type	Description
India	June, 27th 2005	Program-related agreement	Agreement related to the provision of European instruments for Chandrayaan-1
India	Renewed in January 2007	Framework agreement	General cooperation agreement in the peaceful uses of outer space for mutual benefit. Renewed every 5 years since 1978.
Italy	April 1997	Program-related agreement	Arrangement between ESA and ASI on the Exploration of Common Features of the pressurized modules developed by the Parties
Japan	November 1997	Program-related agreement	Memorandum of Understanding between NASDA and ESA on Hardware Exchange for Utilisation of the ISS.
Multilateral	January 29th, 1998	Program-related agreement	Intergovernmental Agreement on Space Station Cooperation
Russia	February 11th, 2003	Framework agreement	Agreement between ESA and the Government of the Russian Federation on Cooperation and Partnership in the Exploration and Use of Outer Space for Peaceful Purposes
Russia	March 1996	Program-related agreement	Arrangement between ESA and the Russian Space Agency concerning Cooperation in the development and operations of the Service Module Data Management System for the Russian segment of the ISS and of the Space Vehicle Docking system
Russia	1996	Program-related agreement	Arrangement on the development and utilization of the European Robotic Arm (ERA) for the Russian ISS segment
Russia	1999	Program-related agreement	Contract on the integration of the ESA Automated Transfer vehicle (ATV) into the Russian segment of the ISS
US	January 29th, 1998	Memorandum of Understanding	Memorandum of understanding concerning cooperation on the civil international space station
US	June 28th, 2010	Program-related agreement	Agreement concerning cooperation on the robotic exploration of Mars.
US	March 1997	Program-related agreement	First Barter deal with the US. Memorandum of understanding between ESA and NASA enabling early utilization opportunities of the ISS
US	August 1997	Program-related agreement	Second Barter deal with the US. Barter contract for the ESA provision of a Supper Guppy Transport in Exchange for NASA provision of Shuttle Services
US	October 1997	Program-related agreement	Third Barter deal with the US. Arrangement between ESA and NASA regarding Shuttle Launch of Columbus Orbital Facility and its Offset by ESA Provision of Goods and Services
US	1999	Program-related agreement	Fourth Barter deal with the US. Arrangement between NASA and ESA concerning ESA's Provision of Cupola 1 and 2 in Exchange for NASA's provision of shuttle launch and return services for five external European payloads.

FRANCE

1. Institutional framework for Space Exploration initiatives

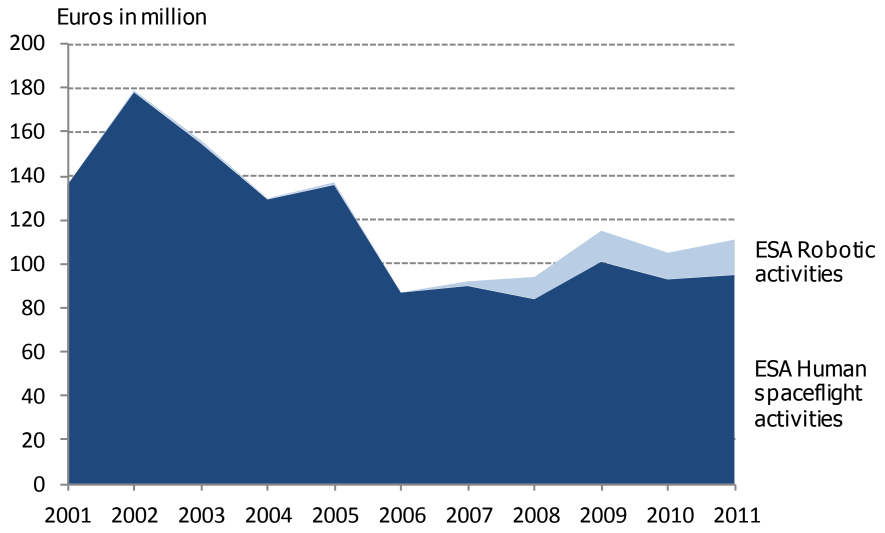
General framework for space activities

The French space activities are led by the National Center for Space Studies (CNES), which is supervised both by the Research and the Defence ministries. The CNES is responsible for shaping and implementing the French Space policy as well as managing the French contribution to ESA. The main objective of this policy, formulated in a 2008 presidential statement, is to master all aspects of space, from end to end and to drive the development of the European space sector.

Budget dedicated to Space and Exploration activities

France manages the single largest European space budget, with €2.2 billion in 2011, split between civil (84%) and military expenditures (16%). Identifiable space exploration-related expenditures amounted to €111 million the same year, i.e. 6% of the total civil budget.

French space exploration budget (2001-2011)*



*** National budget not included since budgetary line is merged with Science activities**

The French space exploration budget reached an high of €179 million in 2002, at the height of the ISS deployment. It has decreased progressively afterwards and has stabilized at an average of €100 million annually since 2006.

The budget dedicated to the ISS is expected to decrease over the next few years as the deployment of the station is now completed and the countries focus on its exploitation. France is also involved in the Robotic program Exomars but the recent development around the project could lead to its total reorganization during the next Ministerial council.

2. French Space Exploration programs

Programs conducted within ESA

Within ESA, its contribution to the Manned Spaceflight program is the second largest, after Germany, with a average annual contribution of €93 million over the past five years, equivalent to around 28% of the total ESA Human spaceflight budget.

This contribution is essentially focused in the production of the Automated Transfer Vehicle (ATV), in which several French companies (EADS Astrium, EADS Sodern, Clemessy, Thales Alenia Space, Scnema and SAFT) are involved.

In 2011, France brought its support to the extension of the International Space Station until 2020, under the condition that the formula for the calculation of the European contribution to the program be revised. France proposed a new barter deal with NASA, that would lead to the development of a an orbital manoeuvring vehicle that could capture "non-cooperative" targets in orbit for assembly or disassembly. However, this project is not supported by NASA, which would prefer that Europe develops a propulsion module for NASA's Orion crew-transport capsule.

France also participates to the ESA optional AURORA Exploration program, with an average annual contribution of €11 million between 2007 and 2011, i.e. 11% of the total program budget. At industry level, France will be strongly involved in the development of Exomars, as Thales Alenia Space France will develop the Orbiter Module Bus, the Entry & Descent system, the Reaction Control subsystem and the back cover structure for the EDL Demonstrator. And Astrium Space Transportation is responsible for the Heat Shield of the EDL Demonstrator. However, France was the only ESA member states to refuse to endorse additional spending on the program in 2011 until a detailed review of the program was led to assess the impact of the NASA withdrawal from the program.

Programs conducted at National level

At national level, CNES also leads its own Exploration program, which essentially consists in the provision of scientific instruments to international missions, through bilateral and multilateral agreements. The budget dedicated to these activities is unknown as CNES considers them as science activities and integrate them in a broad "Space Science and preparation of the future" budgetary item.

The participation of CNES to these missions is driven by a scientific bottom-up approach in which French scientists working in laboratories express their ambitions and request financial support from CNES, which is also in charge of finding flight opportunities for the scientific instruments. CNES provides funding for the development of the French instruments and coordinates the participation of all French partners that do not interact directly with foreign partners.

French industrial stakeholders are not involved in the development of these instruments, which is entirely done by public laboratories.

Review of space exploration programs conducted since 1997 in France

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
1997	Launched	Cassini-Huygens	NASA (Cassini) ESA (Huygens)	Saturn orbiter and probe	Service d'Aéronomie (now LATMOS)	ACP (Aerosol Collector Pyrolyser), an instrument collecting aerosols at different altitudes to analyze their chemical composition
					LESIA	HASI (Huygens Atmosphere Structure Instrument) Sensors for measuring the physical and electrical properties of the atmosphere and an on-board microphone that will send back sounds from Titan
2003	Launched	Mars Express	ESA	Mars orbiter and lander to search for sub-surface water	Institut d'Astrophysique Spatiale	OMEGA (Observatoire pour la Minéralogie, l'Eau les Glaces et l'Activité), an imaging spectrometer operating in the visible and near-infrared domain
					Service d'Aéronomie (now LATMOS)	SPICAM (Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars), a set of two spectrometers (UV and infrared)
2004	Launched	Rosetta	ESA for the orbiter, DLR for the lander	Comet orbiter and lander to study the nucleus of the comet	CNES	Subsystem which ensures the communication between the orbiter and the lander. Batteries for the lander. Global architecture of the lander ground segment, Centre managing scientific and navigation operations
					IPAG	CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission), a ground penetrating radar
					Institut d'Astrophysique Spatiale	CIVA (Comet Infrared and Visible Analyzer), a visible microscope and an IR spectrometer
2005	Launched	Venus Express	ESA	Venus orbiter to study atmosphere in great detail	LESIA	VIRTIS (Visible and InfraRed Thermal Imaging Spectrometer), a Spectro-imager inherited from Rosetta
					Service d'Aéronomie (now LATMOS)	SPICAV (Spectroscopy for the Investigation of the Characteristics of the Atmosphere of Venus), a set of three spectrometers derived from Mars

						Express
2011	Launched	Mars Science Laboratory	NASA	Mars rover carrying more advanced and elaborate scientific instruments than any other mission to Mars	IRAP	Mast Unit of the CHEMCAM (Chemistry Camera), which consists of a laser, a telescope and of a Remote Micro Imager (RMI).
2011	Launch Failure	Phobos-Grunt	Roscosmos	Phobos Lander to collect soil samples from Phobos and bring them the samples back to Earth	GMSA	TDLAS, a laser spectrometer for the GAP (Gas Analytic Package)
					LATMOS	Gas Chromatograph for the GAP
					Institut d'Astrophysique Spatiale	Two panoramic cameras and a pair of stereoscopic cameras. A visible and IR microscope (MicrOmega)
2013	Approved	MAVEN	NASA	Mars orbiter to measure atmospheric loss	Centre d'Etude Spatiale des Rayonnements	SWEA (Solar Wind Electron Analyser), except the digital part linked to the DPU (Digital Processing Unit)
2014	Approved	BepiColombo	ESA / JAXA	Mercury orbiter to study planet formation	LATMOS	PHEBUS (Probing Hermean Exosphere by Ultraviolet Spectroscopy), a UV Spectrometer for the MPO (developed by ESA)
2014	Mascot Not approved	Hayabusa-2 / Mascot	JAXA (Hayabusa-2) DLR (Mascot)	Asteroid sample return with a possible Asteroid lander (MASCOT)	Institut d'Astrophysique Spatiale	MicrOmega, an IR microscope
2015	Not approved	Selene-2	JAXA	Moon lander to study the Moon sub-surface	IPGP	VBB (Very BroadBand) seismometer
2016	In discussions. Payload selected	Exomars	ESA / Roscosmos	Mars orbiter and rover to check for signs of past life and demonstrate a number of essential flight and in-situ enabling technologies that are necessary for future exploration mission	LATMOS	WISDOM (Water Ice and Subsurface Deposit Observation on Mars), a ground penetrating UHF radar
					Institut d'Astrophysique Spatiale	MicrOmega-IR (an infrared and visible microscope for the study of Martian samples)
2016	Selection in 2012	GEMS (Geophysical Monitoring Station)	NASA	Mars lander to study Mars inner composition	IPGP	VBB (Very BroadBand) seismometer

2021	Not approved	MarcoPolo R / Mascot	ESA (Marco Polo R) DLR (Mascot)	Asteroid Sample return with a possible Asteroid lander (MASCOT)	Institut d'Astrophysique Spatiale	MicrOmega, an IR microscope
					IPGP	VBB (Very BroadBand) seismometer
					To be decided	Tomographer radar

* At PI level only for scientific instruments

3. French industrial capabilities

See part on French industrial capabilities within ESA budget for more information.

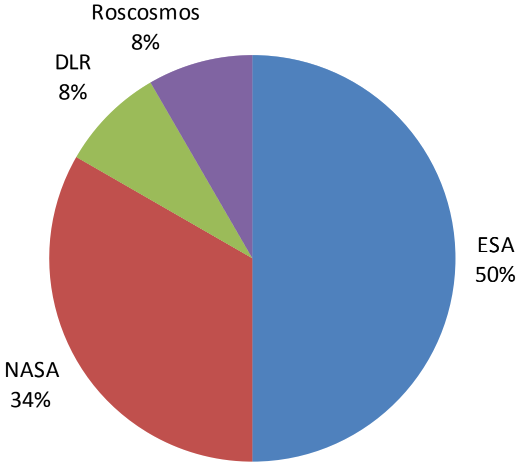
General overview of industrial capabilities in France for space exploration

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	Comments
Astrium Satellites F										🟩					Mars and Venus Express primeship, on-board software and avionics (Rosetta, ..)
Astrium ST F	🟩	🟩					▨								Ariane 5, ATV - High temperature structures
TAS Cannes									🟩	🟩					Huygens probe in the Cassini-Huygens mission
SODERN		🟩													GNC in ATV
SAFT		🟩													Batteries in ATV (and many GEO satellites worldwide)
SNECMA			🟨												Flight experience of electric propulsion with GEO satellites
Research Laboratories (LATMOS, LISA, IAS, …etc)												🟩			Contributions to Huygens, Rosetta Philae, MSL,

🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

4. International cooperation

Breakdown of French space exploration missions by cooperating country (from 1997 to future approved missions)



ESA provides French laboratories with the highest potential for cooperation as it will essentially include scientific instruments developed by its member states for its own space exploration missions. However, France has also a long history of cooperation with the United States in this area. France has cooperated extensively with Russia over the past twenty years, notably for the Mars ’96 and Phobos Grunt. However, both these missions have failed to reach their initial objective.

Japan seems to be considered by CNES as a potentially strong partner. France has proposed, jointly with Germany to add a Lander, called Mascot, to the future Japanese asteroid mission Hayabusa-2 and has also offered to include a seismometer to the future moon mission Selene-2.

Cooperation with China had been considered by France for the Chinese mission Chang’e but both parties did not manage to find an agreement on the level of technology transfer involved with the French participation.

List of agreements relevant for space exploration between France and other space nations

Partner	Date	Type	Description
China	May 15th, 1997	Intergovernmental Framework agreement	The agreement primarily focuses on cooperation in the scientific area
India	September 30th, 2008	Framework agreement	Framework Agreement on cooperation in the field of exploration and use of outer space for peaceful purposes such as joint research and development activities, instrumentation for satellites, development of small satellites, study of weather and climate change using earth observation satellites and the development of ground infrastructure for satellite programmes
Italy	February 6th, 2007	Intergovernmental Cooperation agreement	The Agreement defines the areas of cooperation within the framework of the European Space Agency (launchers, Earth observation, space exploration), the European Union and at the multilateral and bilateral levels
Japan	n.a.	Establishment of five working group	Establishment of five working groups, notably in the fields of exploration, components and use of the International Space Station
Russia	November 26th, 1996	Intergovernmental Framework agreement	The agreement covers a broad spectrum of areas, including space exploration.
US	Renewed on January 23rd 2007	Intergovernmental Framework agreement	The agreement covers a broad spectrum of areas, including space exploration.

GERMANY

1. Institutional framework for Space Exploration initiatives

General framework for space activities

The National Space program of Germany is managed by the German Aerospace Centre (DLR), which is responsible for drawing up German aerospace projects for the federal government and carrying out aerospace programs. The DLR reports to the Federal Ministry of Economics and Technology.

The German government considers space as a strategic activity to affirm national leadership in the field of innovation and high technologies. Exploration is at the heart of the 2010 Space Strategy, whose main objectives include:

- Expanding the strategic space expertise by developing selected key technologies and a domestic know-how in selected key areas, including robotics.
- Reinforcing its position in space research, through ESA, national and bilateral space missions
- Improving the German positioning in Space Exploration, with a priority given to the ISS for human exploration and a focus on robotical exploration otherwise. Establish the "made in Germany" robotic as a global reference.

The main objective of Germany for its participation to space exploration programs is to develop capabilities and technologies which provide a long term benefit, including on Earth. Scientific return and knowledge improvement are also key objectives of the German exploration program.

Germany follows a stepwise approach in its exploration strategy. Its participation to the ISS and its cooperation with other participants has led to the completion of several preparatory activities, such as space medicine, which will be used for future programs. The next steps are the Moon, Mars and beyond Mars. The Mars 500 experiment, to which the DLR participated, is considered as a significant preparatory activity for future manned missions and is part of this stepwise approach.

The German space program is clearly oriented towards international cooperation, both through ESA and through bilateral programs. Its national program focuses essentially on R&D and not on the development of operational missions.

Besides of the contribution of the DLR, acting as a space agency, to exploration programs, scientific laboratories linked to the DLR, such as the Institute of Space systems and the Institute of Robotics and Mechatronics participate on their own to space missions, by providing instruments and components.

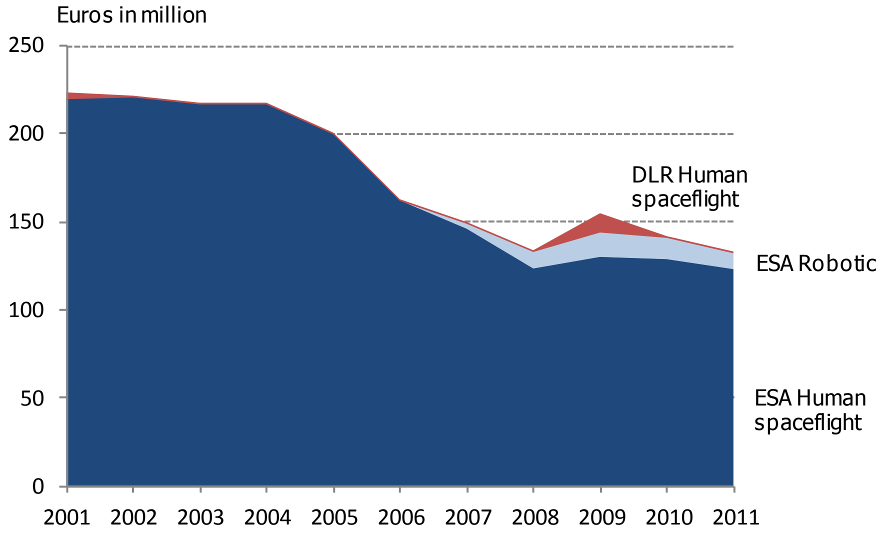
Budget dedicated to Space and Exploration activities

Germany had a total budget of €1.4 billion in 2011, of which €536 million are dedicated to national civil activities, €714 million to ESA and an estimated €120 million for national military programs. Identifiable expenditure for human and robotic accounted for 9.5% (€132 million) in 2011. However, this figure does not include national robotic activities, since these activities are financed on the DLR R&D budget, which is the largest DLR budget item, and therefore not identifiable as such.

The German Human spaceflight budget has been decreasing steadily over the past decade due to the progressive completion of the ISS deployment. This trend is expected to continue over the next decade as the member states will focus on the exploitation of the station.

The future perspective for the German contribution in ESA robotic activities is rather uncertain as of March 2012. Germany should remain committed to the Exomars program, in which it is the fourth largest contributor but the contribution could grow considerably if the ESA Member states decide to go on with the development of the Lunar Lander in which Germany was the main country involved, with a 70% share in the Phase A.

Germany's space exploration budget (2001-2011)*



*** National robotic budget not included since budgetary line is merged with R&D activities**

2. German Space Exploration programs

Programs conducted within ESA

Germany is the main contributor to ESA Manned Spaceflight program, with a 41% share in the development of the European infrastructure and to the scientific use of the space station. Germany notably contributed to the development of the Columbus Orbital Facility, for which Astrium Germany was the prime contractor, and of the ATV.

Germany also contributed to the planning and execution of the operations/logistics programme, including how the astronauts are used, to the operation of the Columbus Control Centre, the data management for the Russian module Zarya and to the robotic arm (ERA) for the Russian part of the ISS.

Germany now intends to Germany intends to make full use of the ISS potential, for scientific research opportunities within Colombus especially/ German scientific institutes participate to several research activities especially in biology, biotechnologies, physiology, materials, fluid mechanics and combustion.

Germany is the fourth contributor to the Exomars mission, with a 14% share, to which several German laboratories are participating. German companies are also involved in the Exomars industrial team, notably OHB for the Mechanical Thermal Propulsion subsystem of the Orbiter, and Kaiser Threde for the Sample Preparation and Distribution System.

However, Germany's main topic of interest in robotic mission is the Lunar Lander, which could be launched by the end of the decade. Germany initially tried to push such a lunar mission at national level but the program failed to receive federal financing. Germany therefore took a 70% share in the Phase A of the ESA Lunar Lander and hopes to convince enough member states to join the program, whose total cost is estimated around €500 million, at the next ministerial conference in 2012. The current design of the mission is carried out by Astrium Germany, under a €6.5 million contract awarded by ESA in 2010.

Programs conducted at national level

As part of its stepwise approach to Space Exploration, Germany is currently focused on the development of lunar capabilities. After failing to receive national funding for a lunar mission in 2009, the DLR is conducting several feasibility studies, with a funding in the range of several hundred thousand Euros.

The DLR is notably working on a lunar mission that would demonstrate both exploration and robotics capabilities but also satellite communication technologies. The DLR has been actively looking for partners for the development of this mission but the current lunar plans of other countries focuses on the Lunar near-side while the mission planned by Germany would take place on the far-side of the moon.

The DLR also plans to participate to the ESA Lunar Lander mission, by providing an in-kind contribution: the Mobile Payload Element, which would demonstrate robotic and mobility technologies and return data to support the design of future robotic elements.

Besides robotic and mobility capabilities, Germany also intends to develop technologies for soft landing and energy systems, as well as life support systems for future manned space exploration missions.

National universities and research institutes are strongly associated to these projects and have develop key robotical capabilities and scientific instruments as part of these missions. These research institutes include essentially DLR institutes, in Space Simulation, Planetary research and Space systems, but also the Max Planck Institutes for Particle Physics and Solar system research and several universities (Munich, Münster, Braunschweig, Cologne and Berlin). This allowed Germany to develop key scientific capabilities, notably for Framing cameras, in-situ measurements on planetary surfaces, laser altimetry, IR spectrometry and radiometry, Data Processing Units and Software.

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
1997	Launched	**Cassini-Huygens**	NASA (Cassini) ESA (Huygens)	Saturn orbiter and probe	Max Planck Institute for Particle Physics	CDA (Cosmic Dust Analyser)
						DWE (Doppler Wind Experiment)
1998	Failed to enter Mars orbit	**Planet-B (Nozomi)**	JAXA	Mars orbiter to study the upper atmosphere	University of München	MDC (Mars Dust Counter)
2003	Launched	**Mars Express**	ESA	Mars orbiter and lander to search for sub-surface water	University of Cologne	MaRS (Mars Express orbiter Radio Science)
					Freie Universität Berlin	HRSC (High Resolution Stereo Camera)
2004	Launched	**Rosetta**	ESA for the orbiter DLR for the lander	Comet orbiter and lander to study the nucleus of the comet	DLR	Prime contractor for the Philae lander.
					Institute for Planetology (IfP) of the University of Münster	MUPUS (Multi purpose Sensors for Surface and Subsurface Science)
					DLR Institute of Space Simulation	SESAME (Surface Electrical Sounding and Acoustic Monitoring Experiment)
					DLR Institute of Planetary Research	ROLIS (Rosetta Lander Imaging System)
					Max-Planck-Institute for Solar System Research	COSIMA (Cometary Secondary Ion Mass Analyser) OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System)
					Technical University of Braunschweig	MAG (Fluxate Magnetometer)
					University of Cologne	RSI (Radio Science Investigation)
2005	Launched	**Venus Express**	ESA	Venus orbiter to study atmosphere in great detail	Univ. der Bundeswehr, Munich	VeRa (Venus Radio Science Experiment)
					Max Planck Institute for Solar System Research	Venus Monitoring Camera
2007	Launched	**Dawn**	NASA	Asteroid flyby using an innovative ion drive to travel between its targets	Max Planck Institute for Solar System Research	Framing camera
2008	Launched	**Chandrayaan-1**	ISRO	Moon orbiter to achieve a 3D mapping of the Moon surface and other scientific objectives	Max Planck Institute for Solar System Research	SIR-2, a near infrared spectrometer
2014	Lander not approved	**Hayabusa-2**	JAXA	Asteroid sample return with a possible Asteroid lander (MASCOT)	DLR	Prime contractor for the MASCOT lander.

2015	Approved	**BepiColombo**	ESA / JAXA	Mercury orbiter to study planet formation	Max Planck Institute for Solar System Research	BELA (BepiColombo Laser Altimeter)
					Technical University of Braunschweig	MERMAG (Mercury Magnetometer)
					Institute for Planetology (IfP) of the University of Münster	MERTIS-TIS (Mercury Thermal Infrared Spectrometer)
2016	Candidate payload	**Selene-2**	JAXA	Lunar landing mission	DLR Institute of Space Systems	HP3 geophysical heat flow probe instrument
2016	Selection in 2012	**GEMS (Geophysical Monitoring Station)**	NASA	Mars Lander to study Mars inner composition	DLR Institute of Space Systems	HP3 geophysical heat flow probe instrument
2018	Planned	**Exomars**	ESA / Roscosmos	Mars lander and rover	DLR Institute of Space Systems	Development of the rover wheels
					Max Planck Institute for Solar System Research	MOMA (Mars Organic Molecule Analyser)
2020	Not approved	**Lunar Lander**	ESA	Lunar lander fitted with a robotic rover that will study the site in anticipation of eventual human habitation	DLR	MPE (Mobile Payload Element) to demonstrate robotic and mobility capabilities
2021	Candidate mission	**MarcoPolo R**	ESA	Asteroid sample return with a possible Asteroid lander (MASCOT)	DKR	Prime contractor for the MASCOT lander.

* At PI level only for scientific instruments

3. German industrial capabilities

See part on German industrial capabilities within the ESA profile for more information.

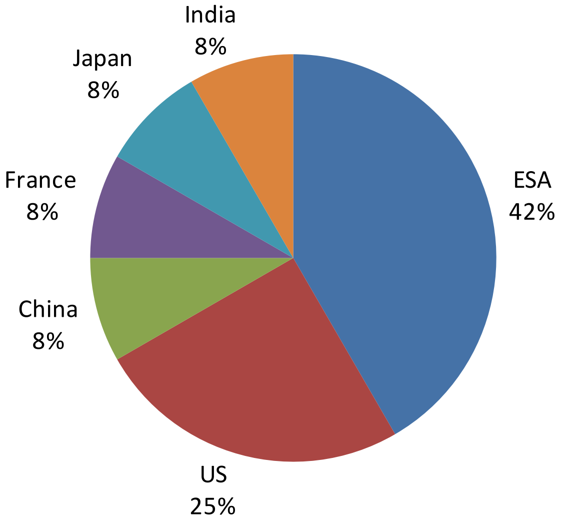
General overview of industrial capabilities in Germany for space exploration

🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	Comments
Astrium Satellites GmbH									🟩						Prime contractor for Rosetta and BepiColombo missions
Astrium ST GmbH	▨	🟩					🟨			🟨					Ariane 5 propulsion, ATV system integration, high temperature structures for re-usable launchers, Lunar lander studies
Kayser Threde/OHB Systems					🟩										ISS/Colombus life support equipment, microgravity payloads and other modules
JenaOpronik		🟩													GNC sensors in ATV
Draeger Aerospace					🟩										life support equipment in Colombus
Von Hoerner&Sulger										▨		▨			instruments and mini-rovers in Rosetta, Exomars, Stardust and Contour NASA missions
DLR Institutes			🟨							🟩		🟩			prime contractor for Rosetta and Hayabusa-2 landers instruments contributed to JAXA's Selene-2 mission and NASA's GEMS Mars mission
Research Laboratories (Max Planck Institute, universities of Braunschweig, Muenster, Cologne, Munich, Berlin)												🟩			Contributions to Exomars, BepiColombo, Rosetta, Mars & Venus Express, NASA's Dawn asteroid mission, ISRO's Chandrayaan-1 Moon mission and JAXA's Planet-B mission

4. International cooperation

Breakdown of German space exploration activities by cooperating country (from 1997 to future approved missions)



The main international partner of Germany is ESA, for which scientific laboratories and institutes have provided a large number of instruments over the years (notably for Mars Express, Venus Express, Rosetta and BepiColombo). However, Germany has also cooperated with a large number of countries for space exploration missions, including the US (Cassini-Huygens, Dawn and possibly GEMS) and India (Chandrayaan-1) and has cooperation opportunities with Japan (Hayabusa-2 and Selene-2).

The DLR started cooperating with China through the provision of a scientific experiment that was fitted on Shenzhou-8. This cooperation was considered as particularly positive by Germany, which is currently considering further potential areas of cooperation with China.

Most recent agreements relevant for space exploration between Germany and other space nations

Partner	Date	Type	Description
China	2011	Framework agreement	Framework agreement on bilateral cooperation in the field of human spaceflight, which led to the development of a German Experiment for the Shenzhou-8 spaceflight.
USA	December 13th, 2010	Framework agreement	Framework agreement on cooperation in aeronautics and the exploration and use of outer space for peaceful purposes, including space exploration

INDIA

1. Institutional framework for Space Exploration initiatives

General framework for space activities

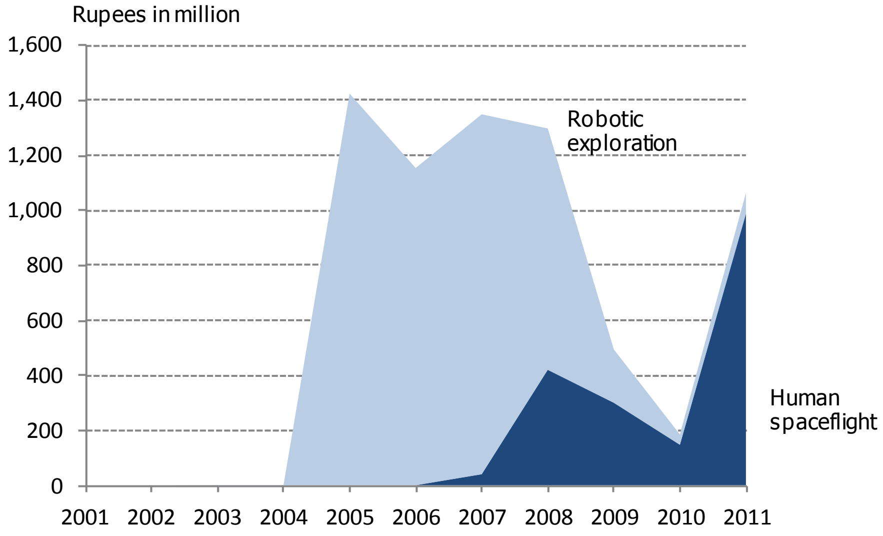
Indian space activities are managed by the Indian Space Research Organization (ISRO), which is also responsible for space technology development. The Space policy is defined by the Space Commission, which reports directly to the prime minister. The Department of Space is responsible for the implementation of the policy, under the supervision of the Space Commission.

The current space policy is governed by the 11th five-year plan that covers the 2007-2012 period. One the main objectives of this plan were to achieve global standard in space technologies and thereby increase India's international reputation. The robotic exploration program Chandrayaan is considered as a way to reach this objective.

Budget dedicated to Space and Exploration activities

India had a total space budget of US$ 1.44 billion in 2011. The high ambitions of the country in the space area have boosted the Indian space budget, which has grown at a 5-Y CAGR of 17% between 2017 and 2011. However, India has essentially focused on satellite communications and launcher development so that budget dedicated to space exploration remains relatively low, with US$ 29 million in 2011, i.e. 2% of the total space expenditure.

Indian space exploration budget (2001-2011)



ISRO Robotic Exploration activities received significant resources between 2004 and 2008, which corresponds to the development and launch for CHandrayaan-1. However funding almost stopped entirely afterwards.

The budget dedicated to robotic space exploration is expected to grow significantly over the next five years as India will have to finance the development and launch of Chandrayaan-2, whose cost was reported at US $82 million. However, no other exploration mission has been announced as of March 2012 so that the robotic exploration expenditure could experience a strong drop over the second half of the decade.

The Human spaceflight budget will also require a strong boost if India is to meet its objective of launching the first manned mission by the end of the decade. The necessary technology development for this mission cannot be funded at the current level of expenditure.

2. ISRO Space Exploration Programs

Robotic Exploration programs

The Indian robotic exploration program focuses on the Moon, with one orbiter launched in 2008 (Chandrayaan-1) and a mission in preparation, Chandrayaan-2, in cooperation with Russia.

Chandrayaan-1 was the first unmanned Indian exploration program. The mission included an orbiter and an impactor, with the objective to demonstrate Indian technologies and to conduct scientific experiment, including a 3D mapping of the moon and establishing the distribution of various minerals and elemental chemical species. The spacecraft also carried six foreign scientific payloads, from the US, ESA, the UK, Germany and Bulgaria.

The mission duration was planned for two years, but communication with the spacecraft was lost after 10 months of operation, having nonetheless completed 95% of its primary objectives. The cost of Chandrayaan-1 was reported at US$ 90 million.

The major result of the mission is the discovery of Water on the Moon by the US Moon Mineralogy Mapper (M3), which was one of the payload fitted on the spacecraft. However, India considered that the discovery of water was first made by its Lunar impactor. Several Indian scientists involved in the mission considered that India failed at taking credit for this scientific breakthrough and was marginalized on its own space mission.

The second Indian mission to the Moon, **Chandrayaan-2**, was designed to maximize the visibility of India in the world scientific community. Chandrayaan-2 is led in cooperation with Russia, which, after several changes in the mission configuration, will provide the lander which will release an Indian-built rover. India will also provide a lunar orbiter

The objective of the mission is to deploy a lunar rover to pick up soil and rock samples for on-site chemical analysis and send the results back to Earth through the orbiter. No foreign payload will be fitted on the mission due to weight restrictions.

The mission cost was reported at US$ 90 million, the same amount as Chandrayaan-1. The launch of the spacecraft was initially scheduled for 2013 but will need to be rescheduled to 2016 due to the recent failure of the Russian mars sample return mission Fobos-Grunt. Russia recently announced that the lunar lander for Chandrayaan-2 incorporated technologies that had failed on Fobos-Grunt so that a deep review of the mission was required. Moreover, Chandrayaan-2 is supposed to be launched with GSLV, which has experienced several failures at launch, thus delaying furthermore the launch of the mission.

India had not made any back-up arrangement for the lander so that it will have to reschedule the whole mission according to the Russian calendar, since India will not be able to develop its own lunar lander before 2013.

In its 2012 budget, ISRO received US$24 million for the development of a **Mars Orbiter**, which would carry 25 kg of scientific payload to Mars orbit by end-2013.

Human space exploration programs

ISRO started its human spaceflight program in 2006, though with very limited funding. The objective of the program is to launch the first Indian manned mission carrying two astronauts to 400km for a 7-days mission by the end if the decade.

India has successfully demonstrated a Space capsule recovery experiment in 2007 with the launch of **SRE-1** that orbited the Earth during 12 days before re-entering the Earth Atmosphere and being recovered by the Indian Navy. A second experiment, **SRE-2**, is planned in 2012 as a follow-on.

ISRO has reused the design of the SRE for its **Orbital Vehicle**, currently in development. The current design has a capability of three astronauts and is fitted with life and environment control systems as well as with an emergency mission abort and escape system.

India concluded a ten-year cooperation agreement with Russia in 2009, under which Roscosmos will help ISRO to build its orbital vehicle based on Soyuz technology. The first demonstration of the Orbital vehicle is planned for 2016.

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Exploration missions						
2007	Launched	**SRE-1**	ISRO	Demonstration of re-entry capsule	ISRO	Prime Contractor
2012	Planned	**SRE-2**	ISRO	Demonstration of re-entry capsule	ISRO	Prime Contractor
2016	Planned	**Orbital Vehicle**	ISRO	First unmanned demonstration of ISRO orbital vehicle	ISRO	Prime Contractor
Robotic Exploration missions						
2008	Launched	**Chandrayaan-1**	ISRO	Moon orbiter to achieve a 3D mapping of the Moon surface and other scientific objectives	ISRO	Prime Contractor TMC (Terrain Mapping Camera) HySy (Hyperspectral Imager) LLRI (Lunar Laser Ranging Instrument) HEX (High Energy aj/gamma x-ray spectrometer) MIP (Moon Impact Probe)
2013	In development	**Mars orbiter**	ISRO	Mars orbiter carrying a payload of 25kg for scientific purposes	ISRO	Prime Contractor
2016	In development	**Chandrayaan-2**	ISRO	Moon orbiter and Rover to conduct soil and rock analysis	ISRO	Prime Contractor CLASS (Large Area Soft X-ray Spectrometer) L and S band Synthetic Aperture Radar IIRS (Imaging IR Spectrometer) TMC2 (Terrain Mapping Camera2)
					Physical Research Laboratory	XSM (Solar X-ray Monitor) APIXS (Alpha Particle Induced X ray Spectroscope)
					Space Physics Laboratory	ChACE2 (Neutral Mass Spectrometer)
					Laboratory for Electro Optic Systems	LIBS (Laser Induced Breakdown Spectroscope) for the Rover

* At PI level only for scientific instruments

3. Indian industrial capabilities

The development of space technologies and systems is still largely done by the governmental space organisation ISRO, with its nearly 20 establishments and 17 000 staff throughout the country. The ISRO sites most relevant to space exploration systems are:

- LEOS (Laboratory for electro-optics systems) for sensors and cameras
- ISAC (Space applications center) which develops satellite payloads (mostly for communication, meteorology and EO applications) and covers all technologies required in satellites
- ISRAD (Radar development unit) specialised in space radars
- SCL (Semi-conductor lab) developing VLSI circuits for space and telecom applications
- ISDN (Indian deep space network) which operates 2 large antenna stations (18 and 32 m)
- LPSC (Liquid propulsion center) in charge of developing and producing spacecraft and launcher propulsion solutions
- Physical research laboratory, the most important space research (including physics, astronomy, astrophysics, planetology) actor in India

The space flight equipment and components required by Indian missions are designed, developed and produced in those establishments, from the high power LOX/LH2 engines of the Indian launchers to the VLSI circuits needed in payloads. There is some level of outsourcing in the Indian aerospace and telecom industries for the less sophisticated components and lower-end processes (it has been estimated that 20% of the value in satellite manufacturing is thus outsourced today). This situation is gradually changing with the expansion of the Indian space programs which will see a number of industrial actors increase their participation and move up the value chain to provide complete subsystems. For example:

- Godrej, a company involved in liquid propulsion
- Larsen & Toubro, a company involved in advanced manufacturing processes for composite structures and products
- Taneja Aerospace & Aviation which will provide avionics sub-systems for space applications
- Wipro, a company which is involved in space robotics and which has plans to develop a Moon rover

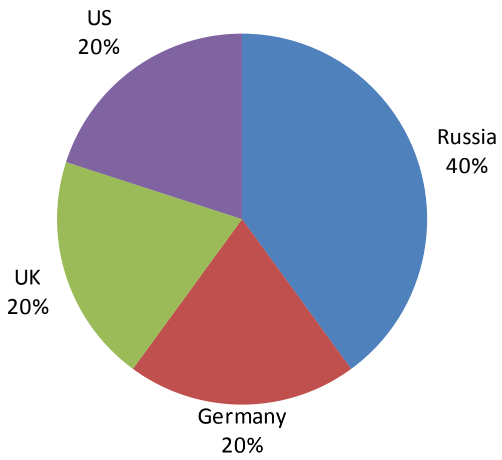
General overview of industrial capabilities in India for space exploration

🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	Comments
ISRO							🟨		🟩			🟩			Chandrayaan 1 and 2, demonstration of re-entry capsules, space instruments (imagers, spectrometers, SAR and other sensors)

4. International cooperation

Breakdown of ISRO's space exploration activities by cooperating country (from 1997 to future approved missions)



India's most significant partner for space exploration activities is Russia. Both countries cooperate since the 80's and the first Indian astronaut flew on the Soviet Salyut space station. India and Russia are also collaborating on the development of Chandrayaan-2 and have reached an agreement regarding ISRO's orbital vehicle that will benefit from a Russian technology transfer, whose extent is unknown as of March 2012.

However, India has also collaborated with other countries, notably the US and European countries, by incorporating foreign scientific payload into its first lunar spacecraft, Chandrayaan-1.

Most recent agreements relevant for space exploration between India and other space nations

Partner	Date	Type	Description
Brazil	January, 25th 2004	Framework agreement	General agreement for cooperation in the field of outer space
ESA	June, 27th 2005	Program-related agreement	Agreement related to the provision of European instruments for Chandrayaan-1
ESA	Renewed in January 2007	Framework agreement	General cooperation agreement in the peaceful uses of outer space for mutual benefit. Renewed every 5 years since 1978.
France	September 30th, 2008	Framework agreement	Framework Agreement on cooperation in the field of exploration and use of outer space for peaceful purposes such as joint research and development activities, instrumentation for satellites, development of small satellites, study of weather and climate change using earth observation satellites and the development of ground infrastructure for satellite programmes
Italy	February 14th, 2005	Framework agreement	Cooperation in Space Science, Technology and Applications
Japan	November 2008	Framework agreement	Agreement to increase co-operation between their respective space programmes
Korea	January 2010	Framework agreement	MoU for cooperation in the peaceful uses of outer space
Russia	November 12th, 2007	Framework agreement	Agreement on joint projects in lunar exploration
Russia	April, 1st, 2010	Program-related agreement	Protocol N°1 to the 2007 agreement to establish the cooperation framework for the Chandrayaan-2 mission
USA	February 1st, 2008	Framework agreement	Agreement for future cooperation between the two agencies in the exploration and use of outer space for peaceful purposes.
USA	May 9th, 2006	Program-related Agreement	Agreement between NASA and ISRO to two NASA scientific instruments on India's Chandrayaan mission.

ITALY

1. Institutional framework for Space Exploration initiatives

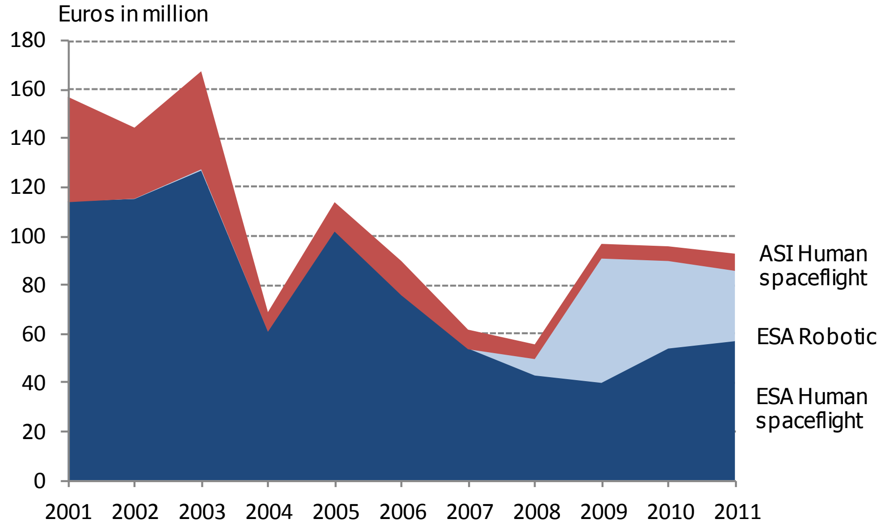
General framework for space activities

The Agenzia Spaziale Italiana (ASI) promotes, coordinates and implements the Italian Space Policy under the supervision of the Ministry of Education, Universities and Research (MIUR). Pursuant to the Strategic Vision 2010-2020, the main objectives of the Italian space activities are to develop the awareness of the space sector within the Italian society and respond to the goals and needs expressed by the citizens. One of the method laid out by the Strategic vision to reach these objectives is to drive Exploration through use of the International Space Station, ISS (for human exploration), and via the ExoMars missions (for robotic exploration).

Budget dedicated to Space and Exploration activities

Italy had a total space budget of €804 million in 2011, split between civil activities (87%) and military projects (13%).About €290 million (41% of the civil expenditure) was dedicated to national activities while the remaining €410 million went to ESA and Eumetsat activities. In total, space exploration activities received €93 million in 2011, i.e. 13% of the civil space budget.

Italian space exploration budget (2001-2011)*



*** National robotic budget not included since budgetary line is merged with Science activities**

The total Italian space exploration budget culminated between 2001 and 2003, at an average of €156 million annually, when the deployment of the ISS required a significant effort from the ESA Member states. At the same time, Italy was also involved in the ISS at national level with the delivery of the MPLMs. The total budget dropped then progressively to €56 million in 2008, before rebounding due to the start of the ESA Exomars program, in which Italy is the main contributor.

The Human spaceflight budget is expected to decrease progressively over the next decade, as the deployment of the International Space Station is now over and the countries focus on the exploitation of the station. The Exomars mission will require a significant commitment from Italy as at least €350 million will be required from the ESA Member States during the next ministerial conference.

2. Italian Space Exploration programs

Programs conducted within ESA

Within ESA, Italy is the third contributor to the Human Spaceflight program, with an average contribution of €50 million annually (15% of the total program budget). Italy was significantly involved in the development of the Columbus Orbital Facility (COF) with a 19% share in the program. Italian companies Thales Alenia Space (TAS) Italy, Elsag Datamat, Dataspazio, Selex Galileo and Avio also participate to the development of the ATV. Moreover, TAS Italy was the prime contractor for the ESA-built observatory module of the ISS, the Cupola.

Italy now intends to make full use of the ISS research potential, it is especially interested in bio-medicine research and bio-technologies in microgravity, as well as on the impact of long duration flights on the human body.

Italy is particularly involved in the ESA exploration program Aurora, in which it took a 40% share and has dedicated an average of €25 million annually over the past five years. Italy has also taken a 33% share in the development of the first Aurora flagship mission Exomars, in which TAS Italy is the prime contractor and in charge of the development of the Orbiter Module, the EDM and the Rover Module. Italy also contributes significantly to the development of the BepiColombo Mercury orbiter, which is financed through ESA mandatory scientific program. TAS Italy is co-prime contractor for the development of the MPO’s electrical power, thermal control, and communications systems and for the integration and test activities.

The current uncertainties around the financing of Exomars are a threat to the Italian space strategy as it is still unknown if ESA will be able to resume the development of the program despite the withdrawal of the US. The recent agreement between ESA and Roscosmos should normally allow to save the project but will probably require a strong additional commitment from Italy.

Programs conducted at national level

Besides its participation to the ISS through ESA, Italy also concluded a partnership with NASA at national level, under which it has supplied to NASA three MPLM (Multi-Purpose Logistics Module) flight units called Leonardo, Raffaello and Donatello between 1998 and 2001 in exchange for use rights equivalent to 0.85% of NASA's quota and six flight opportunities for Italian astronauts (three short-term ones as members of the space shuttle and three long-term ones as members of the Station's crew).

Italian scientists and industrial stakeholders are also involved in international robotic missions. Contrary to the situation in France, Italian Research Laboratories and Universities tend to partner with industrial stakeholders in order to develop scientific instruments. In these cases, the scientific institutes design the instruments, which are then built by the industrial partner.

3. Italian industrial capabilities

See part on Italian industrial capabilities within ESA profile for more information.

General overview of industrial capabilities in Italy for space exploration

🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	**Comments**
TAS Turin				🟩		🟨			🟩	🟩					developer of the MPLM pressurized modules for NASA, of nodes 2 & 3 of the ISS for ESA, of the pressurized module in the ATV and in the Orbital Science Corporation Cygnus program - Co-prime contractor for BepiColombo mission and prime contractor for Exomars ESA mission
TAS Milano (Laben)		▨													supplier of GPS sensors for ATV
Selex Galileo											🟨	🟩			drilling system for Exomars, optical and optoelectronic instruments in Rosetta, Venus express, NASA's Dawn and Juno missions, and Exomars
Carlo Gavazzi Space				▨											microgravity payloads for ISS
Research Laboratories (university Rome La Sapienza, university di Padova, Politecnico di Milano, IFSI)												🟩			spectrometers, cameras, sub-surface radar

Review of exploration programs conducted since 1997 by Italy

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
1998-2001	Launched	3 MPLM Units for the ISS (Leonardo,Raffaello and Donatello)	ASI / NASA	3 pressurized modules for transporting equipment, supplies and experimental devices on board the ISS	ASI / TAS Italy	As prime contractor to ASI/NASA, Thales Alenia is in charge of the design, development, qualification and integration of the three MPLM units. It also supports NASA for their utilization through ALTEC (Advanced Logistic TEchnology Centre) throughout the operational life.
1997	Launched	Cassini-Huygens	NASA (Cassini) ESA (Huygens)	Saturn orbiter and probe	ASI	High gain antenna with the incorporation of a low-gain antenna VIMS (Visual and Infrared Mapping Spectrometer) RSIS (radio-science subsystem) compact and lightweight radar HASI (Huygens Atmosphere Structure Instrument) to measure the measure the physical properties of the atmosphere and Titan's surface
2003	Launched	Mars Express	ESA	Mars orbiter and lander to search for sub-surface water	ASI	PFS (Planetary Fourier Spectrometer) for studying the atmosphere Subsurface radar MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding), realized with the contribution of NASA/JPL
2004	Launched	Rosetta	ESA	Comet orbiter and lander to study the nucleus of the comet	IFSI	VIRTIS (Visual InfraRed and Thermal Imaging Spectrometer)
					OAC	GIADA (Grain Impact Analyser and Dust Accumulator)
					Università di Padova	WAC (Wide Angle Camera)
					Galileo Avionica	Acquisition and distribution of samples system (SD2) of the Philae Lander.

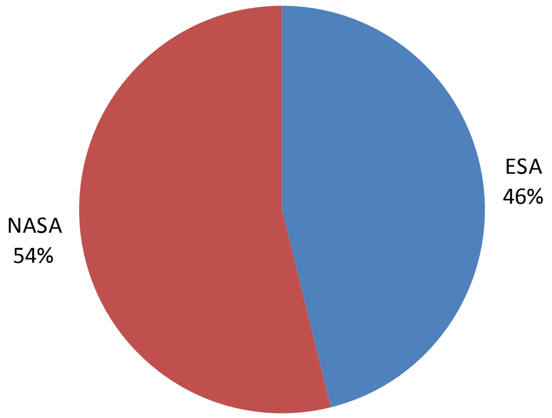
					Politecnico di Milano	Solar panel subsystem
2004	Launched	Mars Reconnaissance Orbiter	NASA	Mars orbiter to conduct reconnaissance and Exploration of Mars from orbit	TAS Italy / University La Sapienza	SHARAD (SHAllow-RADar) subsurface sounding radar to map the first kilometer below the Mars surface, provide images of subsurface scattering layers with the intent to locate water/ice/ deposits.
2005	Launched	Venus Express	ESA	Venus orbiter to study atmosphere in great detail	IASF	VIRTIS (Visible and InfraRed Thermal Imaging Spectrometer), a Spectro-imager inherited from Rosetta
					INAF	PFS (Planetary Fourier Spectrometer) for performing vertical scans of the atmosphere, twin of the instrument in flight on Mars Express
2007	Launched	Dawn	NASA	Asteroid flyby using an innovative ion drive to travel between its targets	Galileo Avionica / IFSI	VIR-MS (Visible-IR Mapping Spectrometer), an imaging spectrometer derived from the VIRTIS instrument on board the Rosetta mission
2011	Launched	Juno	NASA	Jupiter orbiter to study the planet's composition, gravity field, magnetic field, and polar magnetosphere	Selex Galileo / IFSI	JIRAM (Jovian InfraRed Auroral Mapper), an infrared image spectrometer
					TAS Italy / University La Sapienza	KaT (Ka-Band Translator), a radio science instrument which makes up the Ka band portion of the gravity experiment
2014	Approved	BepiColombo	ESA / JAXA	Mercury orbiter to study planet formation	TAS Italy	Co-prime contractor for the development of BepiColombo MPO’s electrical power, thermal control, and communications systems and for the integration and test activities
					TAS Italy / INAF	ISA (Italian Spring Accelerometer), an high sensivity accelerometer
					TAS Italy	SERENA experiment for the study of the particle environment through two analyzers of neutral particles (NPA) ELENA and STOFIO and two ion spectrometers (IS) MIPA and PICAM
2015	In development	Cygnus (COTS)	Orbital Science Corporation for NASA	New space transportation system in the COTS cooperative program to demonstrate the capability to provide logistics to the International Space	TAS Italy	TAS Italy will design, develop, produce and deliver pressurized modules for cargo transport – including equipment, spare parts, scientific experiments and other item based on previous capabilities acquired through the development of the MPLM.

				Station (ISS)		
2016-2018	In discussions. Payload selected	Exomars	ESA / Roscosmos	Mars orbiter and rover to check for signs of past life and demonstrate a number of essential flight and in-situ enabling technologies that are necessary for future exploration mission	TAS Italy	TAS Italy is the prime contractor and responsible for the system integration. It is also the prime for the Orbiter module, the EDM and the Rover Module. Moreover, it will provide the Analytical Laboratory Drawer, the Radar Doppler Altimeter and the central terminal power unit as well as the XRD (X-Ray Diffratometer) for mineral analysis
					Aero Sekur	Will provide the Parachute for the EDM
					Galileo Avionica	Will provide the Drilling subsystem for the Rover module
					ALTEC	Will provide the Rover Operations Control Centre
					Selex Galileo / IFSI	MIMA (Martian Infrared Mapper) for analyzing atmosphere and meteorological on-ground conditions MA_MISS (Mars Multispectral Imager for Subsurface Studies) spectrometer for the analysis of geological and biological evolution of the Martian subsoil
					Selex Galileo / OAC	MEDUSA (Martina Environmental Dust Systematic Analyser) detector for analyzing water vapour and atmospheric dust

* At PI level only for scientific instruments

4. International cooperation

Breakdown of Italian space exploration activities by cooperating country (from 1997 to future approved missions)



Italy is a member of the International Space Exploration Coordination Group (ISECG). Given the choice between the two scenarios established by ISECG (Asteroid-first or Moon-first), Italy would favour the first option as it includes a Deep Space habitat component in which it would be able to reuse technologies acquired during the development of the MPLMs.

At bilateral level, Italy has developed a strong relationship with the NASA since the 60's and the US agency has become the first partner of ASI, ahead of ESA. ASI and NASA reaffirmed their commitment and their willingness to cooperate, notably in space exploration, through a Declaration of Intents signed in May 2004.

ASI has also concluded generation cooperation agreements which consider space exploration as an area of interest with other nations, notably Russia and Japan. However, none of these agreements have materialized in the exploration area until now.

Most recent agreements relevant for space exploration between Italy and other space nations

Partner	Date	Type	Description
France	February 6th, 2007	Intergovernmental Cooperation agreement	The Agreement defines the areas of cooperation within the framework of the European Space Agency (launchers, Earth observation, space exploration), the European Union and at the multilateral and bilateral levels
India	February 14th, 2005	Framework agreement	Cooperation in Space Science, Technology and Applications
Japan	November 16th, 2004.	Joint Statement between ASI and JAXA	General agreement expressing intent to cooperate in the future.
Russia	September 2011	Establishment of an expert group	ASI and Roscosmos have established an expert group dedicated to cooperation. Manned spaceflight and the ISS are among the top priorities of this group.
US	May 2004	Declaration of intents	Declaration of willingness to intensify the cooperation between ASI and NASA, notably in space exploration

JAPAN

1. Institutional framework for Space Exploration initiatives

General framework for space activities

The Japan Space activities are led by the Japan Aerospace Exploration Agency (JAXA), which is in charge of all aerospace projects, from basic research to development and utilization. The JAXA reports to the Ministry of Education, Culture, Sports, Science and Technology (MEXT). However, the Space strategy of Japan is defined by the Strategic Headquarters for Space Policy (SHSP), which is also responsible for the coordination of space activities at ministerial level.

The SHSP released the Basic Plan for Space Policy in 2009 that is the latest policy framework governing space activities. Several of the objectives of the Basic Plan relates to Exploration activities, notably:

- Continue to lead Space science missions in order to achieve world-leading scientific results and strengthen the cooperation with fields other than space science.
- Continue to contribute to ISS through the Japanese Experiment Module "Kibo" and H-II Transfer Vehicle
- Examine the feasibility of a robotic Moon exploration mission around 2020

The JSPEC (JAXA Space Exploration Centre) is responsible for the development of robotic space exploration programs within JAXA, together with the ISAS (JAXA Institute of Space and Astronautical Science), which coordinates the scientific aspects of the missions. Several Japanese institutes and universities provide instruments for space exploration programs.

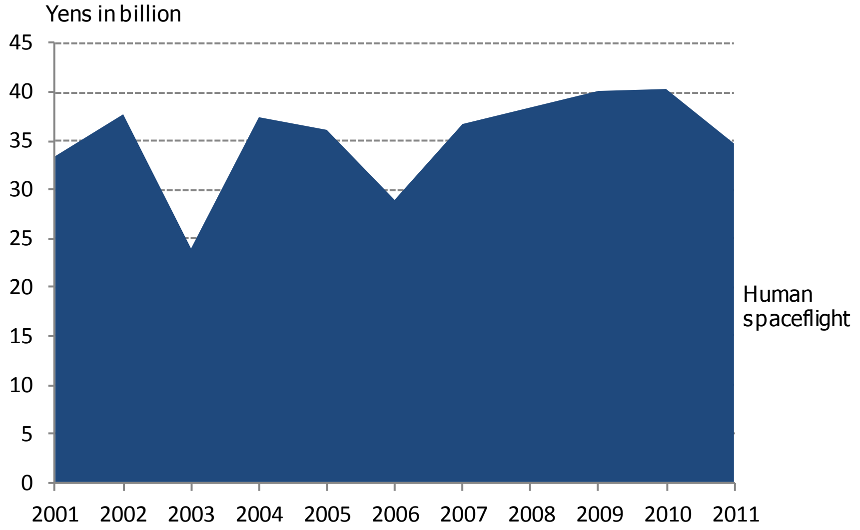
Budget dedicated to Space and Exploration activities

The total space budget of Japan amounts to ¥286 billion in 2011 (US $3.5 billion), split between civil activities (69%) and military programs (31%). Human spaceflight activities are the first budgetary item of the civil budget, accounting for 20% of the JAXA budget (¥35 billion). National robotic activities are funded through the scientific budget and can therefore not be individualized.

In August 2011, the SHSP issued a report defining priorities for the implementation of the Japanese space program, to fit in a tight budget and adapt to the difficult environment created by the economic crisis and the earthquake and tsunami disaster of March 2011.

This report considers that scientific programs, and especially planetary science missions such as Hayabusa, benefit from a strong public support and should therefore be fully funded. However, the report advises to cut expenses on the Kibo / JEM module of the ISS starting in 2016 as the experts estimate that these activities do not generate real benefits in terms of industrial competitiveness.

Japanese space exploration budget (2001-2011)*



*** Robotic exploration budget not included since it is merged with the Science budget**

2. Japanese Space Exploration Missions

Robotic exploration activities

Lunar missions

Japan has successfully launched a lunar Mission in 2007, with **Selene-1** (nicknamed Kaguya). The objectives of Selene-1 were essentially to study the origins of the Moon and its geologic evolutions and obtain information about the lunar surface environment, as well as performing radio science to measure the moon's gravity field. The US$ 138 million mission was conducted in partnership with 5 Japanese universities and institutes, who provided the 13 scientific instruments of the payload.

Japan now seeks to capitalize on this mission and has therefore develop a three-stage approach towards lunar exploration.

The first step of the Lunar Program involves the development and launch of **Selene-2**, which will demonstrate Japanese high-precision autonomous landing, obstacle avoidance and roving technologies and investigates the surface, the rocks, and the sub-surface of the moon. Selene-2 is planned for 2016.

The second step of the mission would consist in an advance lander and rover that would explore the Lunar South Pole and return samples. This mission, currently called **Selene-X**, would allow Japan to demonstrate robotic sample collecting technologies as well as a sample return spacecraft. Selene-X has not been approved by the Japanese government yet. Its launch is currently planned for 2020.

The third step of the mission would build on the previous missions by allowing Japan to participate to international manned missions to the Moon, with Japanese crew and using Japanese robotic technologies developed during previous Selene missions and through the development and operation of the ISS and the HTV.

NEA missions

Besides Lunar Exploration, Japan intends to continue to develop "Primitive Body Exploration" missions. Through the 2003 **Hayabusa** mission, Japan became the first country in the world to bring back to earth samples collected on an asteroid. This mission also allowed Japan to demonstrate rendezvous and soft-landing technologies as well as capsule recovery capabilities. However, Hayabusa carried a small rover, Minerva, which did not manage to land on the asteroid surface.

Japan now intends to launch a follow-on to the Hayabusa mission, **Hayabusa-2**, which would lead similar operations on another asteroid with improved ion engines, upgraded guidance and navigation technology, and new antennas and attitude control systems. The spacecraft would be launched by 2014, reach the asteroid in mid-2018 and depart in December 2019, with a landing on Earth expected in 2020. The total mission cost has been reported at US$ 200 million. Threatened of cancellation due to tight budget constraints, the mission was finally approved in 2012 thanks to strong scientific support. Hayabusa-2 could include a small lander, MASCOT, developed jointly by DLR and CNES, though the payload has not been officially selected as of March 2012.

Japan had made plans for a third Asteroid sample return, Hayabusa-Mk2. However, Japan finally decided to join the ESA mission **Marco Polo R**, which has similar objectives. The mission, which is still at candidate stage within ESA Scientific program, may be selected in 2012 for a launch planned in 2019 at the earliest.

Other planetary missions

JAXA developed and launched a Mars orbiter, **Planet-B** (nicknamed Nozomi), in 1998. The objectives of the mission were to study the upper Martian atmosphere and its interaction with the solar wind and to develop technologies for use in future planetary missions. However, the spacecraft was unable to reach Mars orbit due to electrical failures

The **Planet-C** mission (also called **Venus Climate Orbiter**, and nicknamed Akatsuki) was a US$ 290 million Venus orbiter launched in 2010 with the objective of studying the dynamics of the atmosphere of Venus from orbit. However, the spacecraft failed to enter orbit around Venus due to a malfunction in the propulsion system.

The current efforts of Japan regarding exploration of the solar system are focused on the development of the MMO (Mercury Magnetospheric Orbiter), which is one of the elements of the joint JAXA / ESA mission **BepiColombo**. The MMO will Mercury's magnetosphere and is slated for launch in 2015.

JAXA is currently studying the possibility of a Mars orbiter and lander, **MELOS,** which would be dedicated to the study of the evolution of the Martian atmosphere, the water, and its climate. This mission has not been approved yet and would most likely not be launched before 2020.

Human space exploration activities

The Japanese contribution to the International Space Station has consisted principally in the development of the Japanese Experimental Module (JEM), or "Kibo" and the H-II Transfer Vehicle (HTV), a cargo transportation vehicle for re-supply mission.

Kibo Laboratory Module

Kibo is the single largest ISS module. It was launched in three separate sub-modules between 2008 and 2009 and assembled in orbit. Kibo consists in a Pressurized Module, an Experiment Logistics Module, an Exposed Facility and a Remote Manipulator System.

The main purpose of Kibo is to conduct scientific experiment in microgravity in order to solve problems on Earth. It also allowed Japan to gain some key industrial and technological capabilities since it was the first Japanese-built manned space facility. The total cost of the laboratory is estimated at US $1 billion.

Japan now focuses on the exploitation of Kibo for scientific purposes. Universities and research institutes have been invited to suggest scientific experiments but Japan also intends to develop the private use of its laboratory by offering commercial companies to use Kibo for experiments in exchange for a fee.

H-II Transfer Vehicle (HTV)

Japan developed the HTV in as an expendable cargo supply vehicle for the Kibo laboratory and the ISS. It has a pressurized payload capability of 5.2 tons. Japan committed to the launch of seven HTVs before 2016. Two of them have already been launched, in 2009 and 2011. The development cost of the HTV is estimated at $680 million, with each HTV costing an additional $220 million.

JAXA is currently working on an enhanced version of the HTV, the HTV-R, which would be fitted with a return capsule capable of returning 1.6 ton from the ISS to Earth. The first HTV-R is expected to be launched in 2017.

Future developments

JAXA has developed a technology roadmap in preparation of future manned space exploration missions. Several technologies have been identified for future developments, including:

- Human re-entry and return
- ECLSS System
- Human orbital Transfer
- Extra Vehicular Activity suits
- Space Medicine
- Human landing and ascent from the moon
- Power technology for Night survival
- Human surface mobility

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Exploration missions						
2008	Launched	**JLP (Kibo Module 1)**	JAXA	Japanese Experiment Logistics Module	Mitsubishi Electric	Prime contractor
2008	Launched	**JPM (Kibo Module-2)**	JAXA	Kibo Pressurized Module	Mitsubishi Electric	Prime contractor
2009	Launched	**JEF (Kibo Module-3)**	JAXA	Kibo module exposed continuously to outer space	Mitsubishi Electric	Prime contractor
2009	Launched	**HTV-1**	JAXA	First H-II Transfer Vehicle to resupply the Kibo laboratory and the ISS	Mitsubishi Heavy Industries	Prime contractor
2011	Launched	**HTV-2**	JAXA	Cargo Supply	Mitsubishi Heavy Industries	Prime contractor
2012	Launched	**HTV-3**	JAXA	Cargo Supply	Mitsubishi Heavy Industries	Prime contractor
2013	Launched	**HTV-4**	JAXA	Cargo Supply	Mitsubishi Heavy Industries	Prime contractor
2014	Launched	**HTV-5**	JAXA	Cargo Supply	Mitsubishi Heavy Industries	Prime contractor
2015	Launched	**HTV-6**	JAXA	Cargo Supply	Mitsubishi Heavy Industries	Prime contractor
2016	Launched	**HTV-7**	JAXA	Cargo Supply	Mitsubishi Heavy Industries	Prime contractor
Robotic Exploration missions						
1998	Failed to enter Mars orbit	**Planet-B (Nozomi)**	JAXA	Mars orbiter to study the upper atmosphere	JAXA Institute of Space and Astronautical Science	Prime Contractor ISA (Ion Spectrum Analyzer) MGF (Magnetic Field Measurement) PET (Electron Temperature Probe)
					Tokoho University	UVS (Ultraviolet Imaging Spectrometer) PWS (Plasma Wave and Sounder Experiment)
					Kyoto University	ESA (Electron Spectrum Analyzer) LFA (Low Frequency Wave Analyzer)
					Waseda University	EIS (Electron Ion Spectrometer)
					Nagoya University	XUV (Extreme Ultraviolet Spectrometer)
					Kobe University	MIC (Mars Imaging Camera)

2003	Launched	**Muses-C (Hayabusa)**	JAXA	Asteroid lander and sample return	JAXA Institute of Space and Astronautical Science	Mission Management NIRS (Near Infrared Spectrometer) XRS (X Ray Spectrometer)
					NEC	System development, manufacture, testing, and operations
					Tokyo University	AMICA (Asteroid Multi-band Imaging Camera)
					Kobe University	LIDAR (Light Detection and Ranging Instrument)
					National Astronomical Observatory of Japan	Minerva Rover (failed to land on asteroid)
2007	Launched	**Selene-1 (Kaguya)**	JAXA	Lunar orbiter to study the origins of the Moon	JAXA Institute of Space and Astronautical Science	Mission Management XRS (X-Ray Spectrometer) LISM (Three high-performance optical instruments) CPS (Charged Particle Spectrometer) PACE (Plasma Energy Angle and Composition Experiment) RS (Radio Science)
					NEC	Prime contractor
					Waseda University	GRS (Gamma Ray Spectrometer)
					Tokohu University	LRS (Lunar Radar Sounder)
					National Astronomical Observatory of Japan	LALT (Laser Altimeter) VRAD (Differential VLBI Radio Source)
					Tokyo Institute of Technology	LMAG (Lunar Magnetometer)
					Tokyo University	UPI (Upper Atmosphere and Plasma Imager)
					Kyushu University	RSAT, Doppler measurements by Relay Satellite
					NHK Broadcast Engineering Department	HDTV (High Definition Television)
2010	Failed to enter orbit	**Planet-C (Akatsuki)**	JAXA	Venus orbiter to study the dynamics of the atmosphere	JAXA Institute of Space and Astronautical Science	Mission Management
					NEC	Prime contractor
2014	In development	**BepiColombo**	JAXA / ESA	Mercury orbiter to study planet formation	ISAS	Manages the development of the MMO (Mercury Magnetospheric Orbiter) MPPE (Mercury Plasma Particle Experiment)

					Tokoho University	PWI (Plasma Wave Investigation)
					Tokyo University	MSASI (Mercury Sodium Atmosphere Spectral Imager)
					Kyoto University	MDM (Mercury Dust Monitor)
2014	In development	**Hayabusa-2**	JAXA	Asteroid sample return with a possible lander developed by DLR	JSPEC	Manages the mission
					NEC	Prime contractor
2016	In development	**Selene-2**	JAXA	Moon lander and rover	JSPEC	Manages the mission
2019	At candidate stage	**Marco Polo R**	JAXA / ESA	Asteroid sample return	JSPEC	Manages the Japanese contribution
Post 2020	At candidate stage	**MELOS**	JAXA	Mars orbiter and lander to study the evolution of Mars climate	JAXA	Manages the proposal
					Physical Research Laboratory	XSM (Solar X-ray Monitor) APIXS (Alpha Particle Induced X ray Spectroscope)
					Space Physics Laboratory	ChACE2 (Neutral Mass Spectrometer)
					Laboratory for Electro Optic Systems	LIBS (Laser Induced Breakdown Spectroscope) for the Rover

* At PI level only for scientific instruments

3. Japanese industrial capabilities

There are two major industrial players for space exploration (and more generally for integration of space systems) in Japan (in addition to space agency JAXA internal capacities): the Mitsubishi Group, developer and producer of the H-2 launch vehicles and of the orbital systems linked to the ISS (HTV cargo vehicle and JEM, the Japanese ISS experiment module), and NEC, developer of Japanese satellites and robotic missions (such as Hayabusa). In addition, IHI Corporation has an extensive space activity focused on space and launcher propulsion technologies (development/manufacturing of turbo-pumps for the H-2 engines, development of a LNG launcher engine technology, development/manufacturing of solid rocket boosters and launch vehicles such as M-V and Epsilon, as well as bi-propellant thrusters for in-space propulsion – of the HTV in particular). IHI is also a contributor in space exploration missions (sample container in Hayabusa asteroid mission, or development of the penetrator in JAXA lunar exploration vehicle).

The Japanese space industry appears less diversified than in the US or Europe (or even Russia), and highly integrated within the two main system integrators. One possible explanation is the fact that the aeronautics & defence industry, which traditionally plays host to space activities in the advanced nations, is weaker in Japan for historical reasons, which may also have led Japanese space players to rely more on US technologies for their space systems (for instance Japanese propulsion technologies, such as the H-2 MB-XX engine developed in cooperation with Rocketdyne, or the NEC-Aerojet cooperation to develop low power in-space electric propulsion based on microwave discharges).

The world advanced position of Japan in robotics, communication electronics and underlying micro-nano-technologies offers promising perspectives for robotic space missions, although today the Japanese experience of space robotics, while quite successful, remains limited (NEC-developed robotic arm on the ISS Japanese module, sample return in Hayabusa mission).

Japanese research institutes and universities also have demonstrated strong capacities to develop the space instruments and sensors needed in Japan's exploration missions.

General overview of industrial capabilities in Japan for space exploration

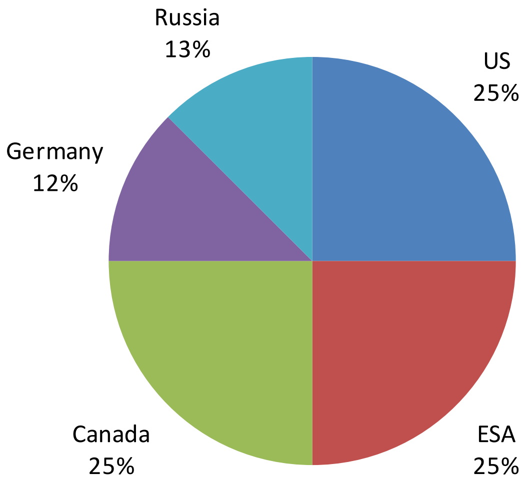
🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	**Comments**
Mitsubishi	🟩	🟩								🟩					H-2 launch vehicle, HTV orbital cargo vehicle
IHI	🟩	🟩					▨			▨					Propulsion solutions for H-2 and HTV,equipment in Hayabusa and JAXA lunar missions
NEC			🟩			🟩			🟩	🟩	▨				Electric propulsion, ISS JEM robotic arm, prime contractor for Hayabusa 1 and 2, Akatsuki, Selene-1 exploration missions
Research Laboratories (Tokyo Institute of Technology, Tokyo, Kyushu, Tokohu, Waseda, Kobe universities, ISAS)												🟩			Contributions to Hayabusa, Selene-1, BepiColombo

4. International cooperation

The development of past exploration initiatives of Japan, besides the ISS, have essentially been conducted at national level. Even robotic spacecraft included few foreign instruments. However, future missions will almost all be conducted in cooperation with other countries, essentially ESA and European countries, which allows Japan to decrease the mission costs.

Breakdown of Japanese space exploration activities by cooperating country (from 1997 to future approved missions)



Most recent agreements relevant for space exploration between Japan and other space nations

Partner	Date	Type	Description
ESA	November 1997	Program-related agreement	Memorandum of Understanding between NASDA and ESA on Hardware Exchange for Utilisation of the ISS.
France	n.a.	Establishment of five working group	Establishment of five working groups, notably in the fields of exploration, components and use of the International Space Station
India	November 2008	Framework agreement	Agreement to increase co-operation between their respective space programmes
Italy	November 16th, 2004.	Joint Statement between ASI and JAXA	General agreement expressing intent to cooperate in the future.
Multilateral	January 29, 1998	Program-related agreement	Intergovernmental Agreement on Space Station Cooperation
USA	July 31st 1969	Framework agreement	Agreement concerning cooperation in space activities for peaceful purposes.
USA	March 29th 1985	Program-related agreement	Agreement concerning the furnishing of launch and associated services for the Spacelab mission, with memorandum of understanding
USA	May 9th, 1985	Program-related agreement	Memorandum of understanding for a cooperative program concerning design (Phase B) of a permanently manned space station.
USA	January 29, 1998	Memorandum of Understanding	MoU between NASA and the government of Japan concerning cooperation on the civil international space station

RUSSIA

1. Institutional framework for Space Exploration initiatives

General framework for space activities

Russian civil Space activities are conducted by Roscosmos, which is both the policymaking and the executive body. Russian space activities are governed by the 2005 Federal Space Program, which sets out the objectives for the 2006-2015 period, including:

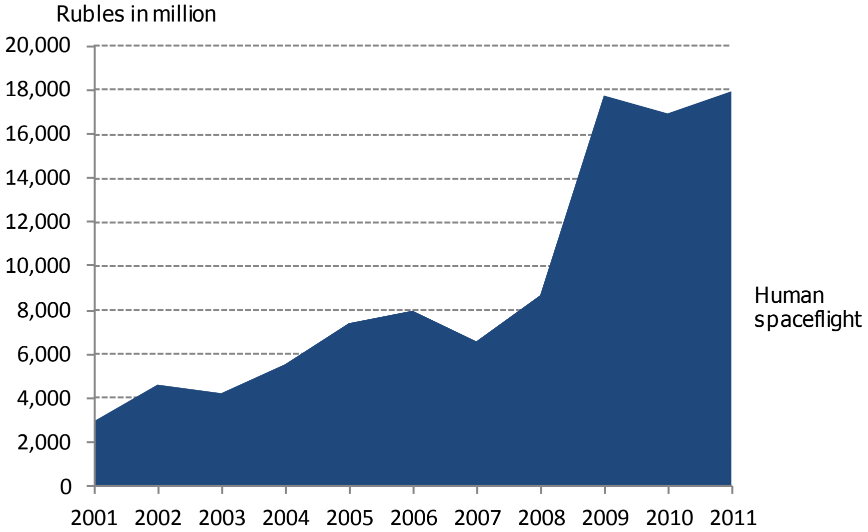
- Further development of Moon and Mars exploration initiatives at the national and international levels
- Maintenance of ISS Operations until 2020 and development, deployment and maintenance of the ISS Russian Segment (ISS-RS) elements for fundamental and applied research.

Several Russian scientific laboratories are also associated to the development of space exploration initiatives, notably the IKI (Space Research Institute), which is in charge of most scientific payload on exploration missions and the Vernadsky Institute of Geochemistry.

Budget dedicated to Space and Exploration activities

Russia manages the second largest space budget worldwide, with an estimated RUB 189 million (US$ 6.5 billion in 2011). Half of this budget is estimated to be dedicated to civil activities, with Human Spaceflight activities accounting for 19% of the total civil expenditure. The budget of robotic exploration activities is unknown since it is merged with Space science activities.

Roscosmos space exploration budget (2001-2011)*



*** Robotic exploration budget not included since it is merged with the Science budget**

Russia's Human spaceflight budget has been multiplied by six over the past decade, due to the adoption of the 2006-2015 Federal Strategy, which put the ISS at the centre of the Russian space activities. Moreover, Russia fulfills its obligations in the ISS program with the launch of four manned Soyuz and five Progress cargo vehicles per year.

The growth of the ISS budget is expected to slow down over the next decade as the deployment of the station is now completed and the participating states focus on its utilization. However, Roscosmos released a new space exploration strategy in March 2012, which calls for ambitious technology development for robotic and manned exploration of the Moon, Mars and Near Earth Objects. This document pledges for a US$ 162 billion investment between 2020 and 2050, i.e. $5.43 billion annually in order to achieve these objectives.

2. Roscosmos Space Exploration Programs

Robotic Exploration programs

Before the fall of the USSR, Russia was particularly active in robotic exploration, with 21 spacecrafts and probes launched to Venus, 58 to the Moon and 16 to Mars between 1958 and 1990. However the majority of these spacecrafts either failed at launched or during the orbital insertion, so that Russian scientists loss the political and financial support required to develop exploration programs after the collapse of the Soviet Union. The failure of the Mars 96' mission whose development had started in 1987 marked the beginning of a long hiatus in the Russian robotic exploration program, which lasted until the 2011 launch of Fobos-Grunt

Fobos Grunt

The development of the Mars Sample Return program Fobos Grunt started in 1996 but did not received substantial funding before 2007. Fobos Grunt consisted in a main cruise stage and of a return vehicle, which would release a landing capsule on the surface of Mars to collect soil samples and bring them back to earth. The spacecraft carried several scientific instruments, essentially developed by the Russian IKI laboratory but also by French scientists A cooperation agreement had been concluded with China, which had developed a small piggyback orbiter on Fobos-Grunt, Yinghuo-1, which was supposed to be released after reaching Mars orbit.

However, Fobos-Grunt failed to ignite its propulsion module after launched and remained stuck in low earth orbit. Several communication attempts were conducted both by Roscosmos and by ESA in order to fire the propulsion module but these efforts remained in vain and the spacecraft re-entered the earth atmosphere in January 2012.

An estimated US $170 million was spent by Russia on the Fobos-Grunt program.

Luna Glob

After years of discussions, first with Japan, then with China, Russia finally decided to develop the Luna Glob on its own, with a launch scheduled for 2015. The objective of Luna-Glob is to launch a Moon orbiter and release a lander on the surface on the lunar surface to carry scientific experiments for one year in order to collect information on the internal structure of the Moon and its South Pole crater.

NPO Lavochkin is the prime contractor for the program, with scientific instruments being essentially developed by IKI. The budget dedicated the mission is unknown.

Chandrayaan-2 (Lunar-Resurs)

Russia and India signed an agreement on Lunar exploration in 2007, with the objective to develop a joint mission involving a lunar orbiter, a lander and a rover. The configuration of the mission experienced significant changes over the years, finally leading to the development of an Indian orbiter and a Russian lander, which would release a small Indian rover on the surface of the Moon. Russia will also develop a robotic arm on its lander and possibly a drill. The spacecrafts will be launched by an Indian GSLV-Mk II rocket.

The mission was initially slated for launch in 2013 but was rescheduled to 2016 in the aftermath of the Fobos-Grunt failure as the technologies that experienced technical issues for Fobos-Grunt were also planned to be used for the Russian lunar lander. The mission cost is unknown.

Lunokhod Lunar Rovers

In a report released in April 2012, the Russian Academy of Sciences clarified the second step of the Russian Lunar program. Russia intends to launch two Lunokhod rovers (Lunokhod-3 and -4) to the Moon between 2020 and 2022. These rovers will be followed by the launch of a landing station in 2013 in order to test the area for a future lunar base deployment.

Venera-D

Venera-D will be the first Russian mission to Venus since the collapse of the Soviet Union. The design of the mission experienced several changes in 2011 and presently includes a main orbiter, a lander and an additional small satellite of Venus dedicated to studies of plasma environment around the planet.

IKI has launched an international call for proposals to include foreign scientific instruments on the spacecraft in addition to those developed by Russian laboratories (IKI, GEOKHI and the Schmidt United Institute of Physics of the Earth). The mission is planned to be launched in 2016.

Exomars

Russia joined the Exomars project following the withdrawal of NASA from the program due to budgetary issues. An agreement was found in March 2012, under which Russia will launch the 2016 orbiter and develop a lander for the 2018 mission, which will release the European-built rover on the Mars surface.

Russia will also provide a RTG for the 2016 European lander demonstrator, which will strongly extend the lifetime of this module.

However, the agreement is very recent and there are very few information available as to the exact details of the cooperation.

Future plans

In March 2012, Roscosmos released an exploration strategy until 2050. Though the exact details of the strategy are unknown, it calls for the launch of rovers and sample return missions to the Moon, Venus and Jupiter starting in 2020. Robotic exploration missions will also be developed for Moon and Mars in order to prepare for future manned missions.

Human Spaceflight programs

International Space Station

Russia has built a strong capability in the development of low-earth orbit manned station, first through the Salyut space station, developed between 1971 and 1986, then through Mir, the first permanent manned outpost in space, until 1998 and finally through the International Space Station.

The contribution of Russia to the **International Space Station** has been instrumental. The Zarya control module was the first ISS element to be launched, in 1999 and it was followed by four other Russian modules, namely the Zveda service module in 2000, the Docking compartment in 2001, MiM-2 research module in 2009 and the MiM-1 research module in 2010. A backup of the Zarya control module, called FGB-2 is planned for launch in 2013.

Russia provides crew and cargo supply to the ISS, with the annual launches of four manned Soyuz and five Progress cargo vehicles. With the retirement of the US Space Shuttle in 2011, Russia became the only ISS-participating nation with the capability to deliver astronauts to the ISS. NASA therefore contracted Roscosmos for US$ 1.1 billion to purchase crew transportation until 2013.

The 2012 Russian Space strategy calls for an exploitation of the ISS at least 2020 and possibly 2028. Russia also wishes the increase the duration of the astronaut stays onboard the ISS, from six months currently to nine months in the future.

Future Plans

The new Russian Space Strategy sets high ambitions for the manned space exploration program. This strategy calls for a manned mission to the Moon in 2030 and a 2025-2050 staged approach for moon exploration involving:

1) Robotic Exploration to the moon to prepare for manned missions
2) Deployment of a lunar orbital station
3) Manned missions to the lunar station and manned lunar landings
4) Deployment of a lunar base wth a capability of four astronauts
5) Development of the lunar base with additional facilities and equipment
6) Deployment of a permanently manned lunar base
7) Initial exploitation of the Moon's natural resources.

Russia also intends to standardize Moon and Mars spacecraft and equipment in order to decrease the cost of the future missions.

The Mars exploration strategy follows a similar step-by-step approach, from 2035 to 2050, starting with robotic missions to reach the deployment of industrial production facilities on Mars surface in 2050.

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Exploration missions						
1998	Launched	**Zarya FGB**	Roscosmos	Control module for the ISS	Khrunichev	Prime contractor
2000	Launched	**Zvezda**	Roscosmos	Service module for the ISS	RKK Energia	Prime contractor
2001	Launched	**Docking Compartment**	Roscosmos	Docking compartment for the Russian spacecrafts	RKK Energia	Prime contractor
2008-2014	2 launched, 3 remaining	**ATV**	ESA	Autonomous Transfer Vehicle	RKK Energia	Docking and refueling subsystems
2009	Launched	**MiM-2**	Roscosmos	Mini-Research Module providing power-supply outlets and data-transmission interfaces for two external scientific payloads	RKK Energia	Prime contractor
2010	Launched	**MiM-1**	Roscosmos	Mini-Research Module providing five to eight standard work spaces	RKK Energia	Prime contractor
2013	Launched	**FGB-2**	Roscosmos	Backup copy to Zarya	Khrunichev	Prime contractor
Robotic Exploration missions						
1999	Launched	**Mars Polar Lander**	NASA	Mars lander	IKI	LIDAR (Light Detection and Ranging)
2001	Launched	**2001 Mars Odyssey**	NASA	Mars orbiter	IKI	HEND (High-energy neutron detector)
2009	Launched	**Lunar Reconnaissance Orbiter**	NASA	Moon orbiter	IKI	LEND (Lunar Exploration Neutron Detector)

2011	Failed at launch	**Fobos-Grunt**	Roscosmos	Phobos lander and sample return	NPO Lavochkin	Prime contractor Development of the Cruise Stage Development of the Return vehicle Development of the Main propulsion unit based on Fregat upper stage
					NIIMash	Development of the propulsion unit onboard the return stage with a pressure-fed propellant supply system
					OAO Vega	DISD (Doppler Measurer of Velocity and Range)
					IKI	GAP (Gap Analytic Package) Manipulator Instruments Set Neutron Spectrometer Laser TOF Mass Spectrometer Secondary Ions Mass Spectrometer Seismometer Navigation TV system Panoramic TV camera Visible Optical Spectrometer Infrared Optical Spectrometer Solar occultation spectrometer (TIMM-2) Plasma Science Package Solar sensor Ultra Stable Oscillator
					GEOKHI	Gamma Spectrometer

						Dust counter
					IFSI	IR Spectrometer Thermal Sensor
					IRE	Long-wave penetrating Radar
2015	In development	**Luna-Glob**	Roscosmos	Lunar orbiter and lander	NPO Lavochkin	Prime contractor
					IKI	Radio beacon TV for field of operations UF Imaging Spectrometer LIS_IR for IR spectra of minerals Gas analytical complex LASMA (Laser mass-spectrometer) ADRON (Active neutron and gamma-ray analysis of nuclei composition) Radiometer-Thermometer PmL Dust counter LINA and ARIES for Measurements of plasma and neutrols
					GEOKHI	Contact Thermometer
					Institute of Physics of Earth	SEISMO (Measurements of seismic activity)
2015	In development	**BepiColombo**	ESA / JAXA	Mercury orbiters	IKI	MGNS (Mercury Gamma ray and Neutron Spectrometer)
2016	In development	**Chandrayaan-2**	ISRO	Lunar Rover	NPO Lavochkin	Development of the Lunar lander to release the Indian-built rover
					IKI	BUNI (Power distribution from power supply system, SES; data collection, storage and transmission; control of science instruments)

						Radio beacon TV camera/spectrometer LIS (Remote sensing in the infrared range of the mineral and water content in the surface layer of regolith) ANDRON-LR (Study of element composition and hydrogen component in regolith via neutron and gamma spectrometry) Chromatograph LASMA-LR (laser mass spectrometry of chemical and isotope composition of regolith) RAT (Measurements of radio brightness of regolith up to a depth of 2 meters) PML (Studies of physical characteristics of lunar dust exosphere and surface regolith) ARIES-L (Studies of solar wind interaction with lunar regolith)
					RASTR Technology	TV-RPM (TV sensor on remote robotic arm for imaging of working area)
					IPhZ	SEISMO-LR (Seismic studies)
2016	In development	**Venera-D**	Roscosmos	Venus orbiter and lander, with an additional small satellite dedicated to studies of plasma environment around the planet	NPO Lavochkin	Prime contractor
					Keldysh Applied Mathematics Institute	Mission Planning
					IKI	Science program
					GEOKhI	Science program
					Shmidt Earth Physics Institute	Science program
2016-2018	Planned	**Exomars**	ESA / Roscosmos	Mars orbiter and rover to check for signs of past life and demonstrate a number of essential flight and in-	Roscosmos	Manages the Russian participation to the program

				situ enabling technologies that are necessary for future exploration mission		
2020	Planned	**Lunokhod-3**	Roscosmos	Lunar rover	Roscosmos	Program management
2022	Planned	**Lunokhod-4**	Roscosmos	Lunar rover	Roscosmos	Program management
2022	Planned	**Lunar landing station**	Roscosmos	Lunar rover	Roscosmos	Program management

* At PI level only for scientific instruments

3. Russian industrial capabilities

The two main players of the Russian space industry today are Energia and Krunichev, both heirs to the impressive soviet space systems development effort since the 1950s, and both still employing on the order of 20 000 people (includes the defense activities related to ballistic missiles). Both companies have very extensive experience in the development of launchers, crewed vehicles and satellites. Energia, builder of the Soyouz launcher and Soyouz TMA manned spacecraft, of the Progress M robotic spacecraft, of the N1 and Energia heavy lift launchers (100 tons in LEO) – the former developed for the Soviet Lunar program and the latter used for the Buran shuttle also developed by Energia, of ISS Russian components (associated to Krunichev), and of the USC satellite platform used in the Yamal 100 and Yamal 200 satellite missions. Energia has plans to modernize both the Soyouz vehicle and the Progress cargo carrier (Tarom space tug). Krunichev is the developer and manufacturer of the Proton launcher, of the Salyut and MIR space stations.

Two other major players are NPO Energomash, the world specialist of high power kerosene/oxygen rocket engines employing 5500 people, which has developed most of Russian launcher engines (in particular the RD 170, most powerful engine in the world to date, and the RD 180 which license was bought by Pratt & Whitney in view of supplying the Atlas 5 vehicle), and NPO Lavochkin (4500 people) which is specialised in robotic interplanetary missions, starting with the Luna program (and Lunokhod rovers landed on the Moon in the early 70s) and then the Venera program (Venus orbiter and lander missions), the Vega program (comet rendez-vous), and more recently Mars-96 and Phobos-Grunt which both failed, the latter due to design issues associated with the central and GNC computer.

Most of these actors appear today as vertically integrated industries following successive re-organisations of the various "design and production bureau" after the Soviet era.

Other space industrial actors which may, for some of them, be involved in space exploration with the supply of equipment are:

- NII Mash, a manufacturer of low thrust liquid propellant engines for spacecraft, used on Soyuz and Progress vehicles, in particular.
- Fakel, which developed and pioneered the use of electric ion engines in space since 30 years ago (and which sold to European and American commercial communication satellite integrators).
- ISS Reshetnev (7000 people), main satellite manufacturer in Russia today, including for telecommunication satellites for which a partnership was established with ThalesAleniaSpace.
- Polyus, a manufacturer of momentum wheels
- Geofizika-Cosmos, a manufacturer of sun sensors and star trackers
- Saturn, a manufacturer of space batteries (NiH2) and now developing Li-ion
- NPP Kant, a manufacturer of GaAs solar cells.

Russian research institutes are also contributors to space exploration missions with space instruments and sensors. Among them, IKI, the Space Research Institute of the Russian Academy of Sciences (various neutron detectors, LIDARs, imaging cameras, spectrometers, seismometers), GEOKHI, an institute of Geochemistry (gamma spectrometer, dust counter, thermometer) and IRE, Institute of Radio-Engineering and Electronics of the Russian Academy of Sciences (radars) are most notable in the latest missions (Fobos-Grunt) or under preparation (Luna-Glob, Venera-D, Russian participations in BepiColombo and Chandrayaan-2).

General overview of industrial capacities in Russia for space exploration

🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	**Comments**
RKK Energia	🟩	🟩			🟩		🟩								Soyuz launcher and space vehicle, Progress M cargo vehicle, Energia rocket, Buran shuttle, ISS Russian modules (Zvesda, Docking compartment for Soyouz and Progress M, MiM-1 and 2 research modules)
Krunichev	🟩	🟩		🟩	🟩										Proton launcher, Salyut and MIR space stations, ISS Russian module Zarya
NPO Energomash	🟩														High power launcher liquid propulsion engines
NPO Lavochkin							🟩		🟩	🟩	🟩	🟩	🟩	🟩	Soviet heritage of Moon, Venus and Mars exploration missions - prime contractor for Phobos-Grunt and Luna-Glob
Fakel			🟩												Pioneer of in-space electrical propulsion
OKB Mars									▨						Supplier of O/B mission computers
NII Mash									▨	▨					Supplier of in-space liquid propulsion systems
Research Laboratories (IKI, GEOKHI, IRE)												🟩			Suppliers of a large array of in-situ remote sensing instruments with IKI (the Space Research Institute of the Russian Academy of Science) being the main actor (Lidars, gamma ray and neutron detectors & spectrometers,ion and mass spectrometers, IR and UV imagers, dust counters, …etc)

4. International cooperation

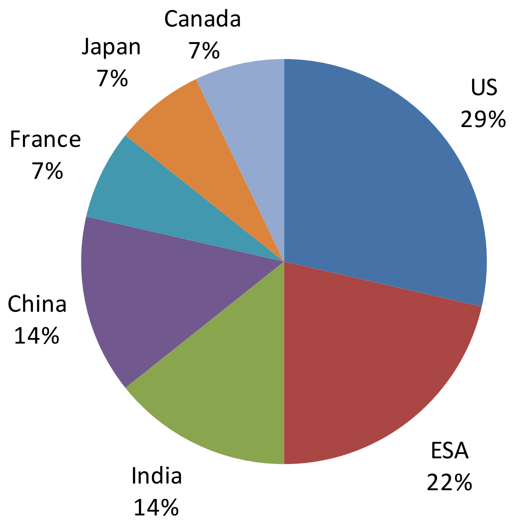
International cooperation is considered by Roscosmos as one of its most valuable functions.

Russian scientific laboratories have provided several scientific instruments to US and European missions and have fitted foreign instruments on the Russian Fobos-Grunt spacecraft. However, Russia has also cooperated extensively to transfer human spaceflight technologies to China (for the Shenzhou vehicle) and India (for the future ISRO manned vehicle).

However, these technology transfers are relatively risky for Russia and for the people involved in the agreement. In 2007, the head of TsNIIMASH-Export Company, which was responsible for the cooperation with China on Shenzhou, was sentenced to 11 years in prison for passing classified technology for China, which could be used to create missiles capable of carrying nuclear warheads. The details of the case are unknown but illustrate the difficulty of technology transfer in strategically sensitive areas such as launchers and critical satellite technologies.

More recently, Roscosmos became a key contributor to international missions, notably for Exomars, for which Russia found an agreement with ESA to replace NASA on the program, and for Chandrayaan-2 for which Russia will provide the Moon lander. Roscosmos used to develop its space explorations missions on its own but the failures of Mars 96' and Fobos-Grunt may have lead to a change in the international strategy of the agency.

Breakdown of Roscosmos space exploration activities by cooperating country (from 1997 to future approved missions)



Most recent agreements relevant for space exploration between Russia and other space nations

Partner	Date	Type	Description
China	March 26th, 2007	Framework agreement	Cooperative Agreement between the China National Space Administration and the Russian Space Agency on joint Chinese-Russian exploration of Mars, which allowed the piggyback of Yinghuo-1 on Fobos-Grunt
China	1995	Program related agreement	Under this agreement, Russia transferred to China several Soyuz-related technologies. This agreement also include training, provision of Soyuz capsules, life support systems, docking systems, and space suits
ESA	February 11th, 2003	Framework agreement	Agreement between ESA and the Government of the Russian Federation on Cooperation and Partnership in the Exploration and Use of Outer Space for Peaceful Purposes
ESA	March 1996	Program-related agreement	Arrangement between ESA and the Russian Space Agency concerning Cooperation in the development and operations of the Service Module Data Management System for the Russian segment of the ISS and of the Space Vehicle Docking system
ESA	1996	Program-related agreement	Arrangement on the development and utilization of the European Robotic Arm (ERA) for the Russian ISS segment
ESA	1999	Program-related agreement	Contract on the integration of the ESA Automated Transfer vehicle (ATV) into the Russian segment of the ISS
India	November 12th, 2007	Framework agreement	Agreement on joint projects in lunar exploration
India	April, 1st, 2010	Program-related agreement	Protocol N°1 to the 2007 agreement to establish the cooperation framework for the Chandrayaan-2 mission
Multilateral	January 29, 1998	Program-related agreement	Intergovernmental Agreement on Space Station Cooperation
UK	July 21st, 2010	Framework agreement	Memorandum of Understanding for cooperation in civil space activities.
USA	June 17th, 1992, extended in 2008	Framework agreement	Agreement concerning cooperation in the exploration and use of outer space for peaceful purposes
USA	December 16th, 1993	Framework agreement	Protocol to the implementing agreement of October 5, 1992 on human space flight cooperation.
USA	January 29, 1998	Memorandum of Understanding	MoU between NASA and the RSA concerning cooperation on the civil space station
USA	April 6th, 2001	Program-related agreement	Implementing agreement on the flight of the Russian High Energy Neutron Detector (HEND) on the United States 2001 Mars Odyssey Orbiter Mission.

SOUTH KOREA

1. Institutional framework for Space Exploration initiatives

The Space activities of Korea are led by the Korea Aerospace Research Institute (KARI), which is also responsible for the R&D in satellites, launchers & aircrafts and advises the government in policy-making. The National Space Committee is the Chief Policy Decision body for the planning and coordination of national space activities and the long term space strategy.

One of the key objectives of the Korean National space plan is the development of domestic industrial capabilities for satellites and launch vehicles. South Korea aims to be recognized as a space power at regional and worldwide levels. In 2007, the Korean government presented a lunar exploration plan with the objective of launching a lunar orbiter in 2020 and a lunar lander by 2025.

However, these ambitions have not received the necessary funding as of 2012. Korea manages a strong space budget, with KRW 231 billion (US$ 208 million) in 2011 but 92% of the expenditure goes to the development of the KSLV launcher and the related launch complex and to the Earth Observation Kompsat program. Exploration activities fail at receiving the requested funding year after year, so that the Korean Advanced Institute of Science and Technology (KAIST) announced a 5-years public fund raising campaign in 2009 to gather the KRW 50 billion required to kickoff the lunar exploration program.

2. Korean Space Exploration programs

Initials plans for the Korean exploration program pledged for an autonomous development of the required technologies. However, considering the financial hurdles encountered by the KARI, the institution finally agreed to join the US on a **Lunar Impactor program**.

The program aims at measure the Moon's magnetic field by dropping a Cubesat impactor on the Lunar Surface. KARI considers the mission as an opportunity to demonstrate its commitment to lunar exploration to the world. The total combined cost of the mission was reported at US$ 50 million. However, it is still unknown whether the mission will piggyback on a larger NASA mission or be launch independently.

Due to the lack of financial commitments, South Korea will probably not be able to respect the schedule of its Lunar Exploration plan, especially since the missions were planned to be launched with KSLV, whose development has also suffered strong schedule delays.

Korea's activities in Human spaceflight are limited to the training of two astronauts through a $28 million agreement with Russia. One of the Korean astronauts spent ten days in the ISS in 2008.

3. Korean Industrial Capabilities

The development of space technologies is relatively recent in South Korea, where US political pressure has long discouraged indigenous research in space technologies and particularly launcher technologies. An approximate 1700 people were involved in space industrial activities in 2009. The main players are the state-owned KARI (Korean Aerospace Research Institute) developers of the Naro-1 launcher system (former KSLV) with the help of Russia (Krunichev supplying the first LOX/kerosene stage) – and particularly the solid-propellant second stage – and of the Korean EO satellite programs.

KAI (Korean Aerospace Industry), a 3000 staff company spun out from Daewoo Heavy Industries, Hyundai Space & Aircraft Company and Samsung Aerospace, involved in civil & military aircraft development as well as in satellite development, is the other main space actor. KAI was a participant in the Korean Multipurpose Satellites (KOMPSAT) program, in co-operation with Astrium.

South Korea is starting to make plans for future space exploration missions but does not have any experience yet. Space biosystems engineering (human life support) is mentioned as one possible focus area of future efforts in space exploration programs.

4. International cooperation

Korea initially intended to lead its space exploration technology development on its own, in order to acquire and demonstrate capabilities before contributing to international missions, notably through its participation to the ISECG.

However, lack of government support has forced Korea to consider alternatives, and notably the possibility to contribution to small bilateral missions in order to acquire capabilities.

UNITED KINGDOM

1. Institutional framework for Space Exploration initiatives

Since April 2010, the British space activities, which were formerly led by the British National Space Centre (BNSC), are now conducted by the UK Space Agency (UKSA). The UKSA is responsible for overseeing civil space activities and coordinate the UK Space Policy and the UK efforts within ESA. The UKSA is an executive agency of the Department for Business Innovation and Skills (BIS), reporting to the Minister of State for Universities and Science.

The UK published a National Space Technology Strategy (NSTS) in 2011, whose main objective is the development of the UK space sector to fulfil scientific priorities and government / societal strategic needs. The NSTS is broken down into 5 roadmaps linked to the main space application areas, with Robotics & Exploration as one of them.

The UK considers that Exploration and Robotics activities are technologically driven and have an excellent potential for spin-in and spin-out of other sectors. The UKSA has mapped out 70 individual technologies, which were then grouped into several themes of interest for the UK:

- Autonomous Vehicles (autonomous mission management, navigation, science autonomy, robotic control, localization without GPS, data fusion and multi-agent autonomy)
- Robotic Manipulators (teleoperation, sampling devices, sample transfer and manipulation, rendezvous and docking)
- Penetrators (modeling of de-orbit, entry and descent, flight control of high velocity objects, sensors, novel power / heating, highly rugged electronics)
- Novel Locomotion Technologies (nuclear power / heating sources, autonomous mission management, very low power systems, energy scavenging)
- Robotic Support of Manned Exploration (human factors, multi-agent collaboration, in-situ resource utilization)

The UK does not have a budget line for space exploration in its annual expenditure as robotic spending are either integrated with Science or with Technology. Within ESA, the contribution of the UK to the optional exploration program is relatively recent, with €19 million dedicated to the program in 2011. The UK does not contribute to Human Spaceflight activities, either at national level or at ESA level.

2. British space exploration programs

The UK has not participated to any of the international manned space exploration missions of the past 25 years. Prime Minister Margaret Thatcher decided in 1986 to withdraw UK from all the human spaceflight initiatives conducted within ESA and Britain has sustained this position since then. The British government recently decided to train British astronauts for international missions. However, no spending in this area has been reported as of 2012.

The UK has participated to several international missions over the past ten years. Its contribution included provision of scientific instruments (SMART-1, Rosetta, Chandrayaan-1 notably), but it also allowed the British industry to gain significant capabilities.

The development of the **Beagle-2** rover for the Mars Express mission, which was managed by the University of Leicester, has provided the UK with key robotic capabilities, on which the UK intends to capitalize for future missions.

The UKSA had made plans in 2007 for a standalone UK Lunar mission, which would consist of a Lunar orbiter and four penetrator in order to demonstrate communications and navigation technologies aimed at supporting future exploration missions and investigate the seismic environment and deep structure of the Moon. The spacecraft would be developed by SSTL. However, only pre-phase A studies have been funded as of 2012 and no progress on the mission has been made for several years now, indicating that the project may have temporarily stalled.

In 2009, ESA opened its first UK base at the Harwell Science & Innovation Campus (HSIC) that will notably focus on the development of novel power sources and innovation robotic technologies to explore space.

Future national initiatives are expected to focus on technology development pursuant to the National Exploration Roadmap.

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Robotic Exploration missions						
1997	Launched	**Cassini Huygens**	NASA (Cassini) ESA (Huygens)	Saturn orbiter and probe	Open University	SSP (Surface Science Package), a set of nine independent sensor
2003	Mars Express	**Mars Express**	ESA	Mars orbiter to search for sub-surface water from orbit and drop a lander on the Martian surface	Open University	Consortium leader for Beagle-2 & Scientific Experiments
					University of Leicester	Beagle-2 Project management, Mission management, Flight Operations Team, instrument management, and scientific experiments
					Astrium UK	Main industrial partner for Beagle-2
					Martin-Baker	Beagle-2 Entry, descent and landing system
					Logica	Beagle-2 Cruise, entry, descent and landing software
					SciSys	Beagle-2 Ground segment and lander software
					University of Wales, Aberystwyth	Beagle-2 Robotic Arm
2003	Launched	**SMART-1**	ESA	Lunar orbiter to test technologies	STFC Rutherford Appleton Laboratory	D-CIXS (Demonstration of a Compact Imaging X-ray Spectrometer)
2004	Launched	**Rosetta**	ESA	Comet orbiter and Lander	AEA Technology	Development of MIDAS (Micro-Imaging Dust Analysis System)
					Open University	Ptolemy instrument, an evolved gas analyzer designed to study the chemical composition of the outer layer of the comet nucleus
2008	Launched	**Chandrayaan-1**	ISRO	Lunar orbiter	STFC Rutherford Appleton Laboratory	C1XS (Chandrayaan-1 Imaging X-ray Spectrometer)
2018	Planned	**Exomars**	ESA	Lander and Rover	University College London's Mullard Space Science Laboratory	PanCam (Panoramic Camera)

* At PI level only for scientific instruments

3. British industrial capabilities

See part on British industrial capabilities within ESA profile for more information.

General overview of industrial capabilities in the UK for space exploration

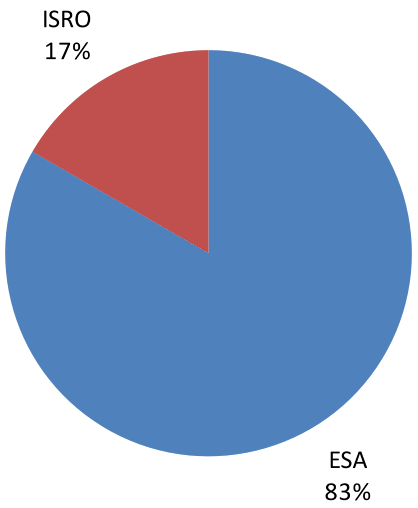
🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	Comments
Astrium Satellites UK							🟩			🟩					Rosetta platform, Beagle-2 lander, Exomars rover, propulsion sub-systems for Mars Express, Venus Express and BepiColombo
Rutherford Appleton Laboratory												🟩			Smart-1 and Chandrayaan-1 lunar orbiter instruments
QinetiQ			🟩							🟩					electric propulsion, Beagle-2 communication
ABSL										▨					Batteries in Beagle-2 (and many smallsats worldwide)
Academic Laboratories (Universities of Wales, Open university, University College London, ...etc)												🟩			Contributions to Huygens, Rosetta Philae, MSL,

4. International cooperation

The UK essentially cooperates with ESA, which provides the easiest access to international missions of British scientists. However, UK also concluded a bilateral agreement with India for the Chandrayaan-1 mission regarding the inclusion of a British spectrometer on the spacecraft.

Breakdown of UKSA space exploration activities by cooperating country (from 1997 to future approved missions)



Most recent agreements relevant for space exploration between the UK and other space nations

Partner	Date	Type	Description
Russia	July 21st, 2010	Framework agreement	Memorandum of Understanding for cooperation in civil space activities
USA	July 21st, 2010	Framework agreement	Statement of intent for potential cooperation in civil space activities. The agreement mentions Earth and space science, life sciences, and space exploration, in addition to other areas of mutual interest.

USA

1. Institutional framework for Space Exploration initiatives

General framework for space activities

The US Space Exploration program is conducted by the National Aeronautics and Space Administration (NASA), which is responsible to pioneer the future in space exploration, scientific discovery and aeronautics research.

The US 2010 Space policy[1] sets several objectives for the US Space exploration program, notably to:

- Begin crewed missions beyond the moon by 2025, including sending humans to an asteroid and send humans to orbit Mars and return them safely by the mid-2030s.
- Continue the operation of the ISS, in cooperation with international partners, to 2020 or beyond
- Partner with the commercial sector to develop safe reliable and cost-effective spaceflight capabilities and services for the transport of crew and cargo to and from the ISS
- Implement a new space technology development and test program, together with industry, academia and international partners to build, fly, and test several key technologies that can increase the capabilities, decrease the costs, and expand the opportunities for future space activities
- Maintain a sustained robotic presence in the solar system

This space policy also stresses the importance of International cooperation, notably in space exploration and human spaceflight activities, but also for the development of nuclear space power for exploration missions.

Several NASA centres are involved in Space exploration activities, though at different levels:

Name of the centre	Space Exploration activities
Ames Research Center (ARC)	As a centre involved in Space Science and Astrophysics research, the ARC provides occasionally space science instruments for exploration missions. It is the prime contractor for the Lunar LADEE mission.
Glenn Research Center (GRC)	The GRC is responsible for aeronautics research, advanced technology and spaceflight hardware development. It is notably in charge of the service module for the future Crew Exploration Vehicle.
Goddard Space Flight Centre (GFSC)	The GFSC is involved in Astrophysics programs and provides instruments for robotic exploration missions. It was also the prime contractor for the Lunar Reconnaissance Orbiter.
Jet Propulsion Lab (JPL)	The JPL leads and / or participates to nearly all Mars Exploration and Planetary science projects. It is the prime contractor for several of the largest NASA Exploration missions, such

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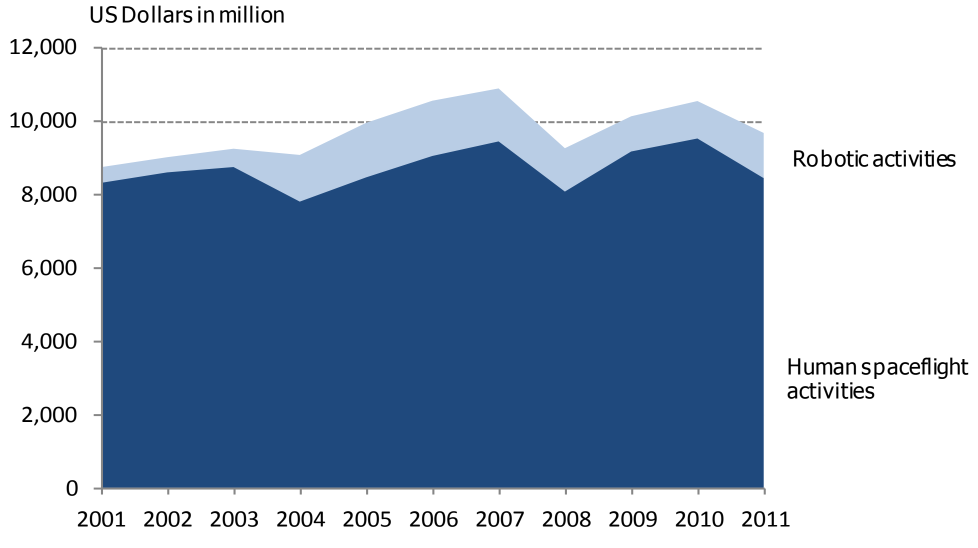
[1] National Space Policy of the United States of America, June 28th 2010

	as the Spirit and Opportunity rovers and the Mars Science Laboratory. It also provides scientific instruments for exploration missions. The JPL operates the Deep Space Communication network, the world-wide network of large antennas and communication facilities that supports interplanetary spacecraft missions
Johnson Space Centre (JSC)	The JSC is the center for human spaceflight training, research and flight control. It is notably responsible for the operation of the iSS
Kennedy Space Centre (KSC)	The KSC is essentially responsible for the launch of the Human Spaceflight missions
Marshall Space Flight Centre (MSFC)	The MSFC is involved in the development of the Discovery / New Frontiers program as well as for the future Lunar Lander.

Budget dedicated to Space and Exploration activities

The US manages the largest budget in the world, with nearly $48 billion in 2011, far ahead of Russia, the second largest, with $7.3 billion. This budget is essentially split between NASA ($18.4 billion), the NOAA ($2.2 billion) and the DoD ($26 billion). Space exploration activities amounted to $9.7 billion in 2011, i.e. 45% of the civil expenditure.

US space exploration budget (2001-2011)



The Space exploration budget has been overall stable over the past decade, growing from $8.8 billion in 2001 to $9.7 billion in 2011 (10-Y CAGR of 1%), essentially due to the increase in the cost of robotic missions.

Funding for Human Spaceflight activities is expected to decrease slightly over the next few years, at around $7 billion annually, primarily due to the 2011 retirement of the Space Shuttle. However, the extension of the ISS lifetime until 2020 and the development of the Multi Purpose Crew Vehicle, the Space

Launch Systems and the Commercial Spaceflight (Cargo and Crew) will require a sustained investment from NASA.

However, the robotic exploration budget is expected to fall over 2012-2016 due both by the end of the development cycle for key programmatic missions (Grail, MSL and LADEE) and to strong budgetary cuts, impacting essentially the Exomars mission from which NASA has withdrawn entirely.

2. NASA Space Exploration Programs

NASA activities in Space explorations are split between two directorates:

- **The Science Mission Directorate** (SMD), which conducts all robotic exploration missions
- **The Human Exploration And Operations Missions Directorate** (HEOMD), which manages and develops the human exploration programs.

Robotic Exploration programs

As part of the Planetary Science theme, the Science Mission Directorate is responsible for exploring the nature and origins of the Earth's solar system, galaxies, and the universe, as well as for exploring the characteristics of the universe more generally. Seven exploration programs are conducted in this theme.

Research Program

The Planetary Science Research Program is responsible for ensuring that the data retrieved from missions is combined with observations in ground-based laboratories to improve understanding of the content, origin, and evolution of the earth's solar system and planetary systems.

Lunar Quest Program (LQP)

The objective of the LQP is to develop flight missions and instruments for lunar missions as well as for lunar analysis.

The current focus of this program is the development of **LADEE (Lunar Atmosphere and Dust Environment Explorer),** a robotic spacecraft which will orbit the moon the measure the atmosphere and lunar dust environment. LADEE is expected to be launched in 2013. The mission should last 160 days, including 30 days for travel, 30 days for checkout and 100 days for science operations. LADEE will be the first spacecraft to test the new "Modular Common Bus", which is being developed by NASA as a flexible, low cost, rapid turnaround spacecraft for both orbiting and landing on the Moon and other deep space targets.

LADEE is managed by the Ames Research Centre, at a total cost estimated at $247 million. It was originally planned to be launched as a secondary payload with NASA's GRAIL mission, but was later transferred to a dedicated Minotaur-5 launch vehicle.

Another current key activity of the LQP is the development of a new generation of small, smart, versatile robotic landers as part of the **Robotic Lunar Lander** program. Though this Lander will be developed as part of the Lunar Program, one the objectives of the program is to reuse it for other airless celestial bodies, including near-Earth asteroids. R&D activities for this project are essentially conducted by NASA's Marshall Space Flight Center and the Johns Hopkins University Applied Physics Laboratory. This lander will be fitted with a new propulsion system designed for airless environments where parachutes and airbrakes cannot be used. To this aim, the Lander uses a series of jets carefully arrayed to achieve the right balance of thrust and control.

Discovery Program

Discovery missions are designed to advance solar system science with small-size, low-cost spacecrafts (under $450 million in 2010) developed in a short time. The objective of the program is to launch a mission every two year.

The most recent spacecraft developed as part of the Discovery Program is **GRAIL (Gravity Recovery and Interior Laboratory)**, launched in September 2011. The objectives of GRAIL are to launch twin spacecrafts in tandem orbits to map the Moon’s gravity field and in order to determine its interior structure. The mission has a duration of 270 days.

GRAIL is managed by the Marshall Space Flight Centre, though the daily supervision of the project was assigned to the Jet Propulsion Laboratory. Its total cost is estimated at $513 million.

As part of the Discovery program, NASA also develops “Opportunity missions”, which can be of two sorts:

1) Development of a scientific instrument for an international mission, such as the M3 instrument for the Indian Chandrayaan lunar mission or the STROFIO instrument for the future ESA-JAXA BepiColombo mercury orbiter

2) Reuse of an existing NASA spacecraft for a new science investigation, such as the re-direction the Deep Impact spacecraft to search for planets around other stars and observe another comet, or the new assignment given to the Stardust spacecraft that revisited the Tempel-1 comet.

Space exploration missions conducted as part of the Discovery Program since 1997

Name of the mission	Date	Type of mission	Mission cost
Lunar prospector	1998	Full mission	$63 million
Stardust	1999	Full mission	$212 million
Contour	2002	Full mission	$159 million
Aspera-3 (fitted in Mars Express)	2003	Opportunity mission	n.a.
Messenger	2004	Full mission	$286 million
Deep Impact	2005	Full mission	$267 million
Dawn	2007	Full mission	$446 million
EPOXI (extension of Deep Impact)	2007	Opportunity mission	n.a.
STARDUST-Next (extension of Stardust)	2007	Opportunity mission	n.a.
M3 (fitted in Chandrayaan-1)	2008	Opportunity mission	n.a
Grail	2011	Full mission	$513 million
Strofio (fitted in BepiColombo)	2013	Opportunity mission	n.a.

The next Discovery mission (Discovery-12) has not been selected as of early 2012. 3 candidate missions are in competition for selection in 2012, namely:

- **GEMS** (Geophysical Monitoring Station), which would perform for the first time an in-situ investigation of the interior of Mars
- **TiME** (Titan Mare Explorer), which would determine the composition and depth of the seas of Titan
- **Chopper** (Comet Hopper), which would study in detail a comet over its full revolution around the sun

New Frontiers Program

The New Frontiers program focuses on scientific solar system exploration, with the objective of launching mission every 36 months. The purpose of the program is to develop medium-class missions that cannot be accomplished within the cost and time constraints of Discovery.

The latest mission developed as part of the program is **Juno (Jupiter Near-polar Orbiter),** whose main objective is to study the origins and evolution of Jupiter. Juno was launched in 2011 and will travel for five years before entering Jupiter orbit and perform science operations for one year.

Juno is managed by the Marshall Space Flight Centre, though the daily supervision of the project was assigned to the Jet Propulsion Laboratory. Its total budget is $1.1 billion.

The New Frontiers-3 mission was selected in May 2011, for a launch scheduled in 2016: The **OSIRIS-Rex (Origins Spectral Interpretation Resource Identification Security Regolith Explorer),** which will return sample collected on the 1999 RQ36 Asteroid. Its total budget should amount to around $1 billion.

Space exploration missions conducted as part of the New Frontiers Program since 1997

Name of the mission	Date	Mission cost
New Horizons	2006	$650 million
Juno	2011	$1.1 billion
OSIRIS-REX	2016	$1 billion

Mars Exploration program (MEP)

The objective of the program is to manage the discovery-driven exploration programmatic missions to Mars and to analyze the planet's physical, dynamic and geological characteristics. The MEP has adopted a "Follow the Water" strategy to understand if ancient Mars once held a vast ocean in the northern hemisphere and how Mars may have transitioned from a more watery environment to the dry climate it has today.

The latest mission launched as part of the MEP is the **MSL (Mars Science Laboratory)** in 2011, with the objective of landing and operating a rover on the surface of Mars. The Curiosity rover should launch an Mars in August 2012 and record measurements of the planet's composition in order to analyse the formation, structure, and chemical composition of the planet, as well as determining if it was ever capable of supporting life.

The mission management and development is ensured by the JPL. Its total cost is estimated to $2.6 billion. Several international cost sharing partners have joined the mission, including ESA, the CSA, Roscosmos, CNES and the INTA in Spain.

The next mission, scheduled for launch in 2013, is **MAVEN (Mars Atmosphere and Volatile EvolutioN),** which is conducted as part of the Mars Scout program, an initiative for smaller, low-cost missions. The main objective of MAVEN is to explore the upper atmosphere and ionosphere of Mars and their interaction with the sun and solar wind.

Lockheed Martin is the prime contractor of the project, under supervision from the GSFC. Its total budget is estimated at $670 million.

NASA future plans for Mars Exploration initially consisted in the two-phase **Exomars mission**, led jointly with ESA. NASA was supposed to supply the launch vehicle, four science instruments, and a communications system for the 2016 Trace Gas Orbiter. It was also supposed to develop a rover for the 2018 Rover mission, in order to collect and cache samples of interest for a potential return to Earth by a future mission. However, NASA informed ESA at the beginning of 2012 that it would not be able to contribute to the mission due to budgetary cuts pursuant to concerns from the US Congress regarding NASA's Mars budget.

In April 2012, NASA therefore invited solicited scientists to provide ideas for future missions to Mars. The objective of the future mission, which is currently referred to as "Mars Next Generation" is to contribute to the scientific top objective of one day returning a martian soil sample to Earth. The future mission could be an orbiter or a rover and should be launched between 2018 and 2020. Its total budget is expected to be in the range of $700 million.

Space exploration missions conducted as part of the MEP since 1997

Name of the mission	Type of mission	Date	Mission cost
Mars Climate Orbiter	Orbiter	1998	$655 million
Mars Polar Lander	Lander	1998	$165 million
2001 Mars Odyssey	Orbiter	2001	$297 million
Spirit & Opportunity	Rovers	2003	$820 million
Mars Reconnaissance Orbiter	Orbiter	2005	$720 million
Phoenix	Lander	2007	$386 million
Mars Science Laboratory	Rover	2011	$2.6 billion
MAVEN	Orbiter	2013	$485 million

Outer Planets Program

The objective of the Outer Planets Program is to identify scientific priorities for exploration in the outer solar system. This program includes three elements:

1) One operating mission to Saturn: Cassini
2) Supporting Research and Technology
3) Pre-formulation study effort for a future outer planets mission

Technology

The Technology program focuses on the development of planetary science technology required for future missions, including the In-Space Propulsion (ISP), Radioisotope Power Systems (RPS), and Advanced Multi-Mission Operations System (AMMOS) projects.

Human Exploration programs

Human exploration programs are managed by the Human Exploration and Operations Missions Directorate (HEOMD), which results from the merger of the former Space Operations Mission Directorate (SOMD) and the Explorations Systems Mission Directorate (ESMD).

The HEOMD manages International Space Station operations and human exploration beyond low Earth orbit, as well as commercial crew and cargo developmental programs, construction of the Orion Multi-Purpose Crew Vehicle and development of a new heavy lift rocket, known as the Space Launch System.

International Space Station

The International Space Station (ISS) is a microgravity research laboratory in low Earth orbit, built and maintained by the United States and participating international partners (Russia, Japan, Canada and ESA).

NASA, and its prime contractor Boeing, have provided several key elements for the ISS, including the Unity connecting module and passageway, the integrated truss structure (the backbone of the station) and the Destiny scientific laboratory. Until 2011, the US also provided the Space Shuttle, which transported astronauts to the Station. However, the Shuttle was retired in 2011 due to high operating costs and to free up funds for a new generation of spacecraft that can fly farther from Earth. To bridge the gap between the ISS retirement and the development of a new transportation system, NASA contracted Roscosmos for $1.1 billion to purchase crew transportation until 2013.

The 2006-2016 US contribution to the space station is estimated at $26 billion, i.e. nearly $2.4 billion annually. The Station was completed in 2011 so that NASA now aims at utilizing the ISS for scientific and technological purposes, including testing technologies for future exploration missions, such as spacecrafts components, support systems and mission operation scenarios. The international partners of NASA have agreed to extend the lifetime of the ISS until at least 2020.

Orion Multi-Purpose Crew Vehicle (MPCV)

The development of the MPCV began in 2005 as part of the now-cancelled Constellation program. The objective of the program is to develop a vehicle for delivering astronauts to destinations beyond low-Earth orbit, such as asteroids or Mars.

NASA announced in 2006 that it had selected Lockheed Martin as the prime contractor for the development of the MPCV, over a proposal made jointly by Northrop Grumman and Boeing. The total contract value was reported at $8.15 billion.

The MPCV will hold four to six astronauts and will be capable of performing a variety of in-space activities, such as rendezvousing and docking with other craft, including habitation module in space. It will also be able to deliver cargo and crew to the ISS, though it is not its main purpose and will only be used as a backup solution. The MPCV will be fitted with a launch abort system, which will separate the Crew Module from the launch vehicle using a solid rocket-powered launch abort motor.

NASA and Lockheed Martin aim for a 2014 test of the MPCV in order to determine how heat shields on the spacecraft perform, and whether the craft can survive reentry into the Earth's atmosphere ahead of any manned missions. The first Human spaceflight aboard the MPCV is expected for 2021.

Commercial Spaceflight Theme

Since the retirement of the Space Shuttle in 2011, the US has lost their independent access to the ISS. The Commercial Crew & Cargo Program Office (C3PO) of NASA therefore launched two parallel initiatives to stimulate development of privately operated cargo and crew vehicles to low Earth orbit: The COTS (Commercial Orbital Transportation Services) program for commercial cargo transportation, and the CCDev (Commercial Crew Development) program for crew transportation.

The **COTS program** was announced in 2006. NASA has already invested $800 million in the program since then and selected two industrial consortiums that have both initiated the development of a cargo vehicle.

Prime contractor	Project Name	Description
Orbital	**Cygnus**	Advanced manoeuvring spacecraft, with a pressurized cargo module based on the MPLM developed by TAS Italy for NASA. Total Capacity of 2,000 kg in its standard version and 2,700 kg in its enhanced version. Will be launched by the Antares Launcher, also developed by Orbital.
SpaceX	**Dragon**	Free-flying, reusable spacecraft made up of a pressurized capsule and an unpressurized trunk. Dragon can deliver up to 6,000 kg to the ISS and bring 3,000 kg back to Earth. The Dragon spacecraft will be launched by the Falcon-9 launched, also developed by SpaceX.

The **CCDev program** was created in 2008 with the objective to stimulate efforts within the private sector to develop and demonstrate human spaceflight capabilities. Four US companies were selected at the end of the second phase of the program and awarded a total of $270 million to continue the development of their concepts. The program is now in its third phase, called Commercial Crew integrated Capability (CCiCap), for which NASA wants proposals to be a complete end-to-end design, including spacecraft, launch vehicles, launch services, ground and mission operations and recovery.

Projects selected as part of the second phase of the CCDev program

Prime contractor	Project Name	Funding Awarded	Description
Blue Origin	**Blue Origin**	$22 million	Biconic nose cone design orbital vehicle, including launch abort systems and restartable hydrolox (liquid hydrogen / liquid oxygen) engine
Sierra Nevada	**Dream Chaser**	$80 million	Reusable composite spacecraft designed to carry from two to seven people to the ISS. Will be fitted with a built-in launch escape system. The Dream Chaser will have an autonomous fly capability.
SpaceX	**Dragon**	$75 million	SpaceX proposed to equip the Dragon spacecraft, which is being developed as part of the COTS program, with an integrated launch abort system design.
Boeing	**CTS-100**	$92 million	Reusable crew capsule capable of lifting 7 astronauts to the ISS. Designed to be able to remain on-orbit for up to seven months and for reusability for up to ten missions

Review of exploration programs conducted since 1997 in the USA

Date	Status	Name	Management	Description	Organization involved*	Contribution to the mission
Human Spaceflight missions						
1998	Launched	**Unity (Node 1)**	NASA	ISS six-sided connecting module and passageway	Boeing	Prime contractor
					NASA Marshall Space Center	Program Management
2000-2009	Launched	**Integrated Truss Structure**	NASA	Backbone of the ISS, with mountings for logistics carriers, solar arrays, and other equipment	Boeing	Prime contractor
					Lockheed Martin	8 Solar arrays Solar alpha rotary joint, to allow the solar arrays to track the sun
2001	Launched	**Destiny**	NASA	US Space station laboratory module	Boeing	Prime Contractor
					Lockheed Martin	TCCS (Trace Contaminant Control System), an advanced air processing and filtering system
2008	Launched	**Columbus Orbital Facility**	ESA	European space station laboratory module	McDonnell Douglas Aerospace (now part of Boeing)	Master Alarm Light Panel ISS Common Items
					Security Control Integration	BCS (ICS)
					US Suppliers	Valves
2014	In development	**Orion Crew Exploration Vehicle**	NASA	Successor of the Space Shuttle in transporting humans to and from the International Space Station, the Moon and, eventually, Mars	Lockheed Martin	Prime contractor
					Orbital Science Corporation	LAS (launch abort system) design, production, integration and testing
					Aerojet	Jettison Motor

						Main engine Cluster of maneuvering engines for the service module Rocket for soft landing
					ATK	Abort Motor Attitude Control Motor UltraFlex solar array
					Honeywell	Avionics for onboard control of abort sequencing and inertial navigation
					Hamilton Sundstrand	Life support and power system
Commercial Orbital Transportation						
2012	In development	**Dragon**	NASA	Free-flying, reusable spacecraft developed as part of the COTS program	SpaceX	Prime Contractor
2012	In development	**Cygnus**	NASA	Advanced maneuvering spacecraft developed as part of the COTS program	Orbital	Prime contractor Engineering and development Cygnus service module, mission and cargo operations
					Thales Alenia Space Italy	Pressurized cargo module
					Mitsubishi Electric Corporation	Proximity location system
					Draper Laboratory	Guidance, navigation and fault tolerant computer support
					Odyssey Space Research	Visiting vehicle requirements support
					JAMSS America, Inc.	Operations Support

					Vivace	Systems engineering support
					United Space Alliance	Cargo operations support
Robotic Exploration missions						
1997	Launched	**Cassini-Huygens**	NASA (Cassini) ESA (Huygens)	Saturn orbiter and probe	NASA Jet Propulsion Laboratory	Prime Contractor, responsible for the integration of the spacecraft Cassini Radar RSS (Radio Science Subsystem)
					Southwest Research Institute	CAPS (Cassini Plasma Spectrometer) INMS (Ion and Neutral Mass Spectrometer)
					NASA Goddard Space Flight Center	CIRS (Composite Infrared Spectrometer) GCMS (Gas Chromatograph Mass Spectrometer)
					Space Science Institute	ISS (Imaging Science Subsystem)
					John Hopkins University	MIMI (Magnetospheric Imaging Instrument)
					University of Iowa	RPWS (Radio and Plasma Wave Spectrometer)
					University of Colorado	UVIS (Ultraviolet Imaging Spectrograph)
					University of Arizona	VIMS (Visible and Infrared Mapping Spectrometer) DISR (Descent Imager and Spectral Radiometer)
					Lockheed Martin	Power and Propulsion for the spacecraft, including the 3 Radioisotope Thermoelectric Generators (RTGs)
1998	Failed to enter Mars orbit	**Planet-B (Nozomi)**	JAXA	Mars orbiter to study the upper atmosphere	Johns Hopkins University Applied Physics Laboratory	NMS (Neutral Mass Spectrometer)
1998	Launched	**Deep Space-1**	NASA	Asteroid & Comet Flyby Probe to test new	Spectrum Astro (now General Dynamics)	Prime contractor, Spacecraft structure

				technologies	NASA Jet Propulsion Laboratory	Telecom, reaction control, ion propulsion, software, advanced technologies, integration, and test Autonav, a system that takes images of known bright asteroids to triangulate to position of the spacecraft Beacon Monitor, a new method for reducing DSN burdens SDST (Small Deep Space Transponder) PEPE (Plasma Experiment for Planetary Exploration), a particle spectrometer
					ABLE Engineering	SCARLET (Solar Concentrator Array with Refractive Linear Element Technology) which uses linear Fresnel lenses made of silicone to concentrate sunlight onto solar cells
					NASA Glenn Research Centre / Boeing Electron Dynamic Devices	NSTAR ion engine
					NASA JPL / NASA Ames	Remote Agent (remote intelligent self-repair software) to demonstrate the ability to plan onboard activities and correctly diagnose and respond to simulated faults in spacecraft components
1998	Launched	**Lunar Prospector**	NASA	Low polar orbit investigation of the Moon	Lockheed Martin	Prime contractor, spacecraft design and construction
					Los Alamos National Laboratory	GRS (Gamma Ray Spectrometer) NS (Neutron Spectrometer) APS (Alpha Particle Spectrometer)
					NASA Goddard Space Flight Center	Magnetometer
					University of California, Berkeley	Electron Reflectometer
					NASA Jet	(DGE) Doppler Gravity Experiment

					Propulsion Laboratory	
1998	Failed during Mars orbit insertion	**Mars Climate Orbiter**	NASA	Orbiter to study the Martian weather, climate, and water and carbon dioxide	NASA Jet Propulsion Laboratory	Management of the mission PMIRR (Pressure Modulated Infrared Radiometer)
					Lockheed Martin	Prime contractor
					Malin Space Science Systems	MARCI (Mars Color Imager)
1998	Failed during Mars orbit insertion	**Mars Polar Lander**	NASA	Robotic spacecraft lander to study the soil and climate of Mars polar region	Lockheed Martin	Prime contractor for the orbiter and lander flight system
					Malin Space Science Systems	MARDI (Mars Descent Imager)
					UCLA	SSI (Stereo Surface Imager) Robotic Arm RAC (Robotic Arm Camera) MET (Meteorological Package), several instruments related to sensing and recording weather patterns TEGA (Thermal and Evolved Gas Analyzer), intended to measure abundances of water, water ice, adsorbed carbon dioxide, oxygen, and volatile-bearing minerals in surface and subsurface soil samples collected and transferred by the Robotic Arm
1999	Launched	**Stardust**	NASA	Comet sample return	Lockheed Martin	Prime contractor, responsible for designing, building and operation
					NASA Jet Propulsion Laboratory	Mission Management Navigation Camera Dynamic Science Experiment
					University of Chicago	DFMI (Dust Flux Monitor Instrument)
					University of Washington	SSC (Stardust Sample Collection)

2001	Launched	**2001 Mars Odyssey**	NASA	Mars orbiter to gather data to help determine whether the environment on Mars was ever conducive to life	NASA Jet Propulsion Laboratory	Mission Management
					Lockheed Martin	Prime contractor
					Raytheon	THEMIS (Thermal Emission Imaging System), images Mars in the visible and infrared parts of the electromagnetic spectrum
					University of Arizona	Gamma Ray Spectrometer
					NASA's Johnson Space Center	MARIE (Martian Radiation Experiment)
2002	Failure during injection	**CONTOUR (Discovery 6)**	NASA	Multiple comet flybys with a number of earth swing-bys	Johns Hopkins University Applied Physics Laboratory	Project Management, Spacecraft Development and Mission Operations CRISP (CONTOUR Remote Imager and Spectrograph) CFI (CONTOUR Forward Imager)
					NASA Goddard Space Flight Center	NGIMS (Neutral Gas and Ion Mass Spectrometer)
2003	Launched	**Mars Exploration Rovers Spirit and Opportunity**	NASA	Two identical Mars rovers	NASA Jet Propulsion Laboratory	Designed, built, and operates the rovers
					Ball Aerospace & Technologies	Avionics that control the power aboard Spirit for maneuvers High-gain antenna system
					Lockheed Martin	Aeroshell of the rovers
2003	Launched	**SMART-1**	ESA	Lunar orbiter to test technologies	General Dynamics	Hydrazine Propulsion System
					Ithaco Space Systems	Reaction Wheels
					L3 Communications	Electrical Ground Support Equipment
					TECSTAR	Solar Celles
2004	Launched	**Messenger**	NASA	Orbiter to study the characteristics and	Johns Hopkins University Applied Physics	Designed and built the spacecraft

				environment of Mercury	Laboratory	MDIS (Mercury Dual Imaging System) GNRS (Gamma-Ray and Neutron Spectrometer) XRS (X-Ray Spectrometer) EPPS (Energetic Particle and Plasma Spectrometer)
					NASA Goddard Space Flight Center	Magnetometer MLA (Mercury Laser Altimeter)
					University of Colorado	MASCS (Mercury Atmospheric and Surface Composition Spectrometer)
2005	Launched	**Deep Impact**	NASA	Comet Rendez vous and launching of a projectile into the nucleus	Ball Aerospace & Technologies	Prime contractor, with the responsibility of the Impactor spacecraft and Flyby spacecraft 3 high resolution cameras Algorithm development Environmental testing
2005	Launched	**Mars Reconnaissance Orbiter**	NASA	Mars Orbiter to make high-resolution measurements of the surface	Lockheed Martin	Prime contractor, design of the spacecraft and integration
					Ball Aerospace & Technologies	HiRISE (High Resolution Imaging Science Experiment)
					Malin Space Science Systems	CTX (Context Camera), provides context maps for the targeted observations of HiRISE and CRISM MARCI (Mars Color Imager)
					Johns Hopkins University Applied Physics Laboratory	CRISM (Compact Reconnaissance Imaging Spectrometer for Mars), a visible and near infrared spectrometer
					NASA Jet Propulsion Laboratory	(MCS) Mars Climate Sounder, a near infrared and far infrared spectrometer

2006	Launched	**New Horizons**	NASA	Pluto Flyby	Johns Hopkins University Applied Physics Laboratory	Project Management, Spacecraft Development and Mission Operations Provision of all the scientific instruments
					U.S. Department of Energy	RTG (Radioisotope Thermoelectric Generator)
					Boeing	STAR 48 solid-propellant kick motor
					University of Colorado	VBSDC (Venetia Burney Student Dust Counter) for dust measurements
2007	Launched	**Dawn**	NASA	Multiple asteroid orbiter	Orbital Sciences Corporation	Spacecraft design, integration and test, and launch operations
					NASA Jet Propulsion Laboratory	Project management, system engineering, ion propulsion subsystem, science operations and spacecraft flight operations
					Los Alamos National Laboratory	GRAND (Gamma Ray and Neutron Detector)
2007	Launched	**Phoenix**	NASA	Mars Lander to examine the water-ice-rich northern polar region	Lockheed Martin	Prime contractor, builds and tests the spacecraft
					NASA Jet Propulsion Laboratory	Project management and mission design. MECA (Microscopy, electrochemistry, and conductivity analyzer)
					University of Arizona	SSI (Surface stereo imager) TEGA (Thermal and Evolved Gas Analyzer)
					Malin Space Science Systems	MARDI (Mars Descent Imager)
2008	Launched	**Chandrayaan-1**	ISRO	Lunar orbiter dedicated to high-resolution remote sensing of the lunar surface	NASA Jet Propulsion Laboratory	M3 (Moon Mineralogy Mapper)
					Johns Hopkins University Applied Physics Laboratory	miniSAR, an active Synthetic Aperture Radar system to search for lunar polar ice

2008-2015	2 Launched, 3 remaining	**ATV**	ESA	Autonomous Transfer Vehicle to supply cargo and fuel to the ISS	Perkin Elmer	Electronics
					Aerojet	Involved in the spacecraft propulsion
					Vacco	Provides valves
2009	Launched	**Lunar Reconnaissance Orbiter**	NASA	Lunar orbiter to prepare for future manned missions to the Moon	NASA Goddard Space Flight Center	Prime contractor, designs the spacecraft bus LOLA (Lunar Orbiter Laser Altimeter)
					University of New Hampshire	CRATER (Cosmic Ray Telescope for the Effects of Radiation)
					UCLA	DLRE (Diviner Lunar Radiometer Experiment)
					Southwest Research Institute	LAMP (Lyman Alpha Mapping Project)
					Arizona State University	LROC (Lunar Reconnaissance Orbiter Camera)
					Johns Hopkins University Applied Physics Laboratory	Mini-RF (Miniature Radio-Frequency instrument), a a synthetic aperture radar
2011	Launched	**Juno**	NASA	Jupiter orbiter to unlock secrets of solar system formation	Lockheed Martin	Responsible for spacecraft development and construction
					NASA Jet Propulsion Laboratory	Mission management MWR (Microwave radiometer) Gravity Science Investigation
					NASA Goddard Space Flight Center	Magnetometer
					Southwest Research Institute	JADE (Jovian Auroral Distribution Experiment) UVS (Ultraviolet Imaging Spectrograph)

					Johns Hopkins University Applied Physics Laboratory	JEDI (Jovian Energetic Particle Detector Instrument)
					University of Iowa	Waves (Radio and Plasma Wave Sensor)
					Malin Space Science Systems	JunoCam, a visible light camera/telescope
2011	Launched	**Grail**	NASA	Lunar gravity field mapping	Lockheed Martin	Responsible for spacecraft development and construction
					NASA Jet Propulsion Laboratory	Mission management LGRS (Lunar Gravity Ranging System) RSB (Radio science beacon)
2011	Launched	**Mars Science Laboratory**	NASA	Mars Rover	NASA Jet Propulsion Laboratory	Prime contractor Project management
					Boeing	Multi-Mission Radioisotope Thermoelectric Generator (RTG)
					Lockheed Martin	Aeroshell
					Los Alamos National Laboratory	CHEMCAM (CHEMistry CAMera), to analyse by spectrometry the plasma light emitted after a laser shot
					NASA Ames Research Center	CHEMIN (Chemistry and Mineralogy) to identify and quantify the abundance of the minerals on Mars
					Malin Space Science Systems	MAHLI (MArs HandLens Imager) MARDI (MARs Descent Imager) MASTCAM (MAST CAMera)
					Southwest research institute	RAD (Radiation Assessment Detector)

					NASA Goddard Space Flight Center	SAM (Sample Analysis at Mars) instrument suite will perform mineralogic and atmospheric analyses
2013	In Development	**LADEE**	NASA	Orbiter to explore and characterize the moon atmosphere	NASA Ames Research Center	Mission Management. Builds the spacecraft and performs mission operations UVS (UV-Vis Spectrometer)
					NASA Goddard Space Flight Center	Environmental testing and launch vehicle integration NMS (Neutral Mass Spectrometer)
					Space Systems/Loral	Design and construction of the propulsion system, based on electrical propulsion technologies developed for GEO satellites, integration of the system into LADEE
					EMCORE	Solar Panel Manufacturing
					University of Colorado	LDEX (Lunar Dust Experiment)
					MIT Lincoln Laboratory	LLCD (Lunar Laser Com Demo)
2013	In Development	**MAVEN**	NASA	Mars orbiter to study the atmosphere	Lockheed Martin	Construction and test of the spacecraft
					NASA Goddard Space Flight Center	Project management
					University of Berkeley	SWEA (Solar Wind Electron Analyzer), SWIA (Solar Wind Ion Analyzer) STATIC (Suprathermal and Thermal Ion Composition) SEP (Solar Energetic Particle)
					University of Colorado	LPW (Langmuir Probe and Waves) IUVS (Imaging Ultraviolet Spectrometer)
					NASA Goddard Space Flight Center	Magnetometer NGIMS (Neutral Gas and Ion Mass Spectrometer)

2014	In development	**BepiColombo**	ESA / JAXA	Mercury orbiter to study the surface and internal composition of the planet	Southwest Research Institute	STROFIO, a Neutral Particle Analyzer
2016	In development	**OSIRIS-REX**	NASA	Asteroid sample return	Lockheed Martin	Prime contractor
					NASA Goddard Space Flight Center	Management of the mission OVIRS (OSIRIS REx Visible-Infrared Spectrometer)
					University of Arizona	OCAMS (OSIRIS-REx Camera Suite) OTES (OSIRIS-REx Thermal Emission Spectrometer)

* At PI level only for scientific instruments

3. US industrial capabilities

NASA and the US space industry are undoubtedly the most advanced and experienced community regarding space exploration, be it with manned or with robotic missions. This is largely the result of considerable government investment in space and defence programs and technologies over the past fifty years. Many programs have been conducted since the 1960s to the Moon, asteroids/comets, Mars, Venus, Jupiter and Saturn systems, including of course leading the development of the ISS. With the Pioneer and Voyager probes, the US have built and launched the first "interstellar" vehicles (even if it will take them many thousands of years to reach the next stellar system on their course) , launched 30 years ago and now close to one light-day away from us and still (partially) operating and communicating.

As a result of such an extensive activity, many organisations have contributed over this period, which also saw many mergers and take-overs with, as it seems, a tendency to consolidation and fewer actors today. In general, space systems & equipment industrial suppliers are most often actors specialised in the Aerospace & Defence markets (aero-platforms, missiles, defence electronics), whereas component and basic technology suppliers may sometimes be positioned on a wider approach to markets (including medical, automotive or other mission-critical applications). Until recently, the US space exploration activities have been fully specified, supervised and funded by NASA Centers (with in-house development of some key technologies, such as heat shielding of the Shuttle, for instance), industry coming in as "cost plus" contractors to develop the corresponding hardware & software and integrate the final systems. A more commercial approach to space exploration (mostly ISS-servicing-type of activities so far) has emerged over the past decade, in which NASA or other national agencies buy services from commercial companies, the development of the corresponding means being the responsibility of the commercial operators (even if agencies may still significantly contribute to the development phase to prime-start this new approach). Such services are currently being developed for ferrying cargo and transporting astronauts to and from the ISS (and more generally to and from a near-Earth-orbiting space station), for launching payloads to LEO and for providing space habitat in orbit (see table below for more details).

Among the main industry actors of the US space exploration programs, one finds:

Boeing

With its Space Exploration Division 3000 people strong, Boeing is one of the leading actors in NASA space exploration programs. Boeing is a global supplier of re-usable and human space systems (X15, Gemini, Apollo, SkyLab, the space Shuttle vehicle – including the Shuttle main engines via Rocketdyne subsidiary now part of Pratt & Whitney/United Technologies - , the ISS US modules and truss structure, and now the CST-100 capsule meant to supply crew transport services on a commercial basis in NASA COTS program). Boeing is also slated to develop the upper stage and avionics of the future heavy lift SLS launch system.

Lockheed Martin (LM)

LM is another leading actor of space exploration in the US. LM has extensively contributed to robotic missions as system integrator of interplanetary probes and orbiters (Mars Odyssey, Juno, GRAIL, Stardust) or by providing major subsystems to robotic missions (MSL aeroshell) and to manned systems (provider of the Shuttle main tank, of the ISS solar arrays and communication systems). LM is now developing the Orion crewed space exploration vehicle. It is also part of the future heavy lift SLS launch system team, taking responsibility for the development of the core module (based on the Shuttle main tank).

Jet Propulsion Lab (JPL)

Although not an industrial actor per se (run by NASA, it is a CalTech laboratory), JPL has been the leading actor of deep space missions in the US, taking on the role of system developer and integrator, and calling on industry (or other NASA and academic labs in the case of specific instruments) to provide components and sub-systems. Among JPL's most notable achievements, the much publicized Spirit and Opportunity rovers Mars mission, and more recently the Mars Science Lab mission with rover Curiosity scheduled to land on Mars during the summer 2012.

Ball Aerospace

Ball Aerospace is a manufacturer of spacecraft, components, and instruments, lubricants, optical systems, star trackers and antennas. Ball Aerospace was prime contractor of the Deep Impact mission, with the responsibility for the Impactor spacecraft and Flyby spacecraft (3 high resolution cameras, Algorithm development and Environmental testing). Ball Aerospace also developed the HiRISE instrument (High Resolution Imaging Science Experiment) for the Mars Reconnaissance Orbiter mission and the avionics that control the power aboard Spirit for manoeuvres (also high-gain antenna system)

Honeywell

Honeywell's work in space is focused largely on subsystems such as electronics, avionics (including sensors such as IMUs and gyros), and mechanical systems for launch vehicle control (partnering on CEV Orion for the avionics sub-system). Honeywell is also vying to be the prime contractor for a future lunar base, based in particular on their extensive experience in automated systems.

Hamilton Sundstrand

Hamilton Sundstrand is a manufacturer of space suits (made the Apollo suit) and EVA systems, as well as a supplier of satellite equipment related to fluid/propellant handling and storage. The company will provide 13 key systems to the CEV Orion, including the fire detection and suppression system, carbon monoxide removal/humidity control system, pressure control system, atmospheric monitoring system, cabin air ventilation and potable/cooling water storage. Hamilton Sundstrand will also support Lockheed Martin as a systems integrator in the development of the CEV, integrating the environmental and life support systems.

Raytheon

Raytheon is a major defence electronics contractor which has been developing cutting-edge space sensor payloads, instruments, and associated mission software for more than four decades; mini TES on Mars Global Surveyor, mini-SAR for Chandrayaan 1 and Lunar Reconnaissance Orbiter, THEMIS on Mars Odyssey 2001, thermal emission spectrometer on several Mars missions.

Northrop Grumman (Aerospace Systems)

Northrop Grumman is one of the leading US Aerospace companies, supplying mostly government civil and defence programs (aircraft, missiles, satellites). The company's contribution to space exploration has been mostly in the development of probes and probe payload/instruments (LCROSS – Lunar Crater Observation and Sensing Satellite), as well as in contributions to space science missions and technologies (search for exo-planets in particular). Recently Northrop Grumman has been investigating concepts for in-space high power electric propulsion scalable up to 300 kW.

Alliant Techsystems (ATK)

ATK is a manufacturer of solid propellant motors for launchers and spacecraft. The company developed and produced the Shuttle solid boosters, and recently developed an enhanced 5-segment solid booster aimed for the future SLS heavy lift launch system. ATK will also develop and produce the abort solid motor of Orion, as well as the vehicle UltraFlex solar panels via acquired company Able Engineering (Able Engineering has a history of developing flexible space structures, such as solar concentrators developed for the Deep Space 1 mission).

Aerojet

Aerojet is a manufacturer of liquid propulsion space engines for launchers and spacecraft. The company is a regular supplier of liquid engines for interplanetary probes (all NASA Discovery missions) and will supply the main engine and other liquid propellant engines for Orion crewed exploration vehicle. It is also developing ion thrusters in the range 4.5 kW, as well as a new liquid propellant engine (NK-33) in association with Teledyne Brown which could compete with the ATK solid boosters solution in the future SLS launch system.

Orbital Science Corporation

Orbital is a spacecraft and launcher manufacturer addressing both the institutional (civil and defense) markets and the commercial market of (small) GEO comsats. Orbital has been prime contractor of interplanetary probes (such as the Dawn mission to a comet) and is partnering with Lockheed Martin in the Orion program to develop the launch abort system. Orbital is also developing Cygnus, a contender for commercial LEO cargo services, in collaboration with TAS Italy (leveraging the experience gained by TAS-I in the development of the four ISS MPLMs, multi-mission pressurized modules).

Space X

Space X has developed the Falcon 1 and 9 launch vehicles (as well as the Merlin liquid oxygen/kerosene engine to power them) to provide commercial low cost launch services. Both vehicles have been successfully tested. The Company has plans to develop a super-heavy Falcon 9 system in theory capable to compete with NASA SLS system (100 tons in LEO). Space X is also developing the Dragon orbital cargo as part of NASA COTS program. Dragon is meant to provide commercial re-supply services to the ISS, and has also been successfully tested in orbit.

Sierra Nevada Corporation

Sierra Nevada, initially an electronics company, has supplied actuators for Mars rovers and, following their acquisition of former SpaceDev have become another contender in the pursuit of commercial services for transport to LEO destinations with their DreamChaser crew transport vehicle (in NASA CCTV program). This vehicle is still at development level.

Blue Origin is a newly created company (founded by Amazon owner Jeff Bezos) also aiming to develop commercial space astronauts transport services to LEO. The company is currently developing a vehicle to compete in the CCTV NASA program.

Bigelow Aerospace

Bigelow Aerospace, another "independent" player has focused their efforts on the development of space/orbital habitat also to be commercialised as services (in-orbit storage, in-orbit laboratories, in-orbit living quarters, in-orbit "hotel" for future space tourists). Bigelow Aerospace has developed expandable technologies and has already tested them in orbit in 2006/2007 (Genesis 1 and 2).

The above is a high level overview of the most visible actors today on the US space exploration scene (not considering here the actions and capacities of the many US universities and research groups involved in specifying and conducting space research, or the many NASA centers which also have very active roles in designing and constructing space systems and instruments – see comments below). It is likely that quite a number of other industry actors are involved in the development of space exploration missions, in the lower tiers of the supply chain, or with less program visibility. The following is meant as an illustration of these other capacities.

Emcore is a manufacturer of solar cells, including advanced high efficiency solar cells which are used on most exploration missions, as well as solar panels. For example, Emcore will supply the solar panels of Lunar mission Ladee.

L3-ETI is the electron technologies division of L3-Com, acquired from Boeing some time ago, and producing travelling wave tube amplifiers for the comsat industry, as well as developing electric propulsion motors for orbital manoeuvres and in-space propulsion.

Astrobotic is a start-up company, evolved from Carnegie Mellon University and closely working with the University robotic teams, also addressing commercial space transportation markets, in their case payload transportation to the Moon (particularly in the context of the Google Lunar Prize).

Honeybee Robotics is another robotic company which has developed exploration payload mechanisms and actuators, including drilling systems, particularly in the context of Mars missions (contributed to Spirit and Opportunity rovers development, and to Phoenix lander)

Malin Space Science Systems is a small company specialized in the development of miniature space cameras used in space exploration missions, including on rovers. Malin SSS has developed equipment for most Martian missions (Mars Climate Observer, Mars Polar Lander, Mars Reconnaissance Orbiter, MSL) and recently on the Jupiter mission Juno.

Textron Defence Systems is a medium size defense contractor which has developed advanced industrial knowhow relative to re-entry material technologies (via the US ballistic missiles programs), and which contributes this expertise to the development of thermal shielding technologies (such as Carbon/Carbon 3D- and 5D-weaving) for exploration atmospheric re-entry systems (Shuttle, Orion in particular).

In addition to industrial actors, many US universities are also contributors to the US space exploration programs (John Hopkins, Iowa, Colorado, Arizona, California-Berkeley, Chicago, Washington, MIT, for the most visible and recurring ones – see mission tables above). They operate like most universities do in the advanced space-faring nations: the university PI (principal investigator) proposes some experiment or payload concepts which, if retained by NASA, is developed under the university's and NASA's joint supervision. Such development may be partially done at the university and partially sub-contracted out to the space industry. Some academic institutions have more capacities in this respect than others, for instance the John Hopkins Applied Physics Lab has complete systems integration capacities and is thus able to deliver a complete payload within its area of physical expertise. National research labs also occasionally contribute to space exploration programs, such as the Los Alamos Labs (nuclear physics payloads) or labs of the Department of Energy (supplying RTGs when needed).

Finally, NASA centers have a strong role in space exploration missions. For some centers, the role is more programmatic (Marshall for human space flight, Glenn,) whereas for others there is an active contribution to mission systems (hardware & software) development. Such is clearly the case for JPL regarding deep space exploration (as discussed above), but also for the Goddard center which takes responsibility for mission system development and integration in the case of Earth science or near-Earth science missions.

General overview of industrial capabilities in the US for space exploration

🟩 Flight system experience
🟨 Breadboard or ground system experience
▨ Significant partial experience

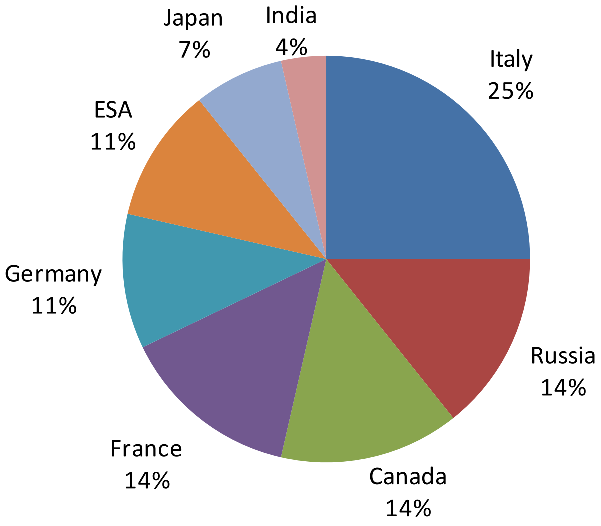
Company/Institute	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers/Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation	Comments
Boeing	🟩	🟩	🟩	🟩	🟩		🟩	🟩							Apollo, Skylab, ISS US modules and truss structure, space Shuttle, SLS upper stage, CST-100 cargo vehicle
Lockheed Martin	🟩	🟩		🟩	🟩		🟩		🟩						Mars, Jupiter and asteroid missions, Orion crew exploration vehicle, SLS mainstage
JPL							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Most of NASA's space exploration missions (Pioneer, Voyager, …), including Mars rovers, MSL
Ball Aerospace									🟩			🟩			Deep Impact comet mission prime contractor, MSL instruments, Dawn platform
Honeywell		🟩			🟩				🟩						space avionics and GNC electronics and sensors
Hamilton Sundstrand					🟩										EVA systems and other life support systems in ISS and Orion
Aerojet	🟩		🟩												liquid launcher propulsion and ion electric in-space propulsion
Raytheon												🟩			IR imaging systems, spectrometers, radars
Northrop Gruman			🟨						🟩			🟩			high power electric propulsion (300Kw)
Alliant Techsystems (ATK)	🟩			▨											SLS solid boosters, solar generators
Orbital Science Systems		🟩							🟩						prime of Dawn mission, developer of Cygnus cargo vehicle
Space X	🟩	🟨					🟨								Falcon launchers, Dragon crewed vehicle
Sierra Nevada		🟨					🟨				▨				Dream Chaser crewed vehicle, actuators in Mars missions
Blue Origin		🟨					🟨								developing a crew transport vehicle
Bigelow Aerospace				🟩											inflatable space habitat
L3-ETI			🟩												electric propulsion motors
Honeybee Robotics											🟩				drilling systems in Mars missions
Astrobotic										🟨	🟨				developing a commercial Lunar lander
Textron Defense Systems							▨								high temperature materials (Shuttle, Orion)
Malin Space Science Systems												🟩			mini-cameras for Mars orbiters and rovers
DoE laboratories													🟩		suppliers of RTG systems for US space missions
Universities (John Hopkins, Colorado, Iowa, Arizona, California-Berkeley, Chicago, Washington, MIT)												🟩			Many types of instruments (see mission table above)
NASA Goddard Space Flight Center									🟩			🟩			prime of Lunar reconnaissance orbiter, supplier of instruments
NASA Glenn Research Center			🟩												electric motors (NSTAR ion engine)

4. International cooperation

International cooperation is considered by the 2010 US Space Policy as a way to strengthen US leadership. The US government therefore encourages the US Space agencies to identify areas of mutual interest and benefit with international partners, promote appropriate cost- and risk-sharing among participating nations in international partnerships and augment U.S. capabilities by leveraging existing and planned space capabilities of allies and space partners.

Space exploration and human spaceflight are explicitly mentioned among the potential areas of cooperation.

Breakdown of US space exploration activities by cooperating country
(from 1997 to future approved missions)



The main partner of the US is Italy, which has contributed to seven NASA missions, essentially be providing scientific instruments. Russia comes second since both countries cooperated not only for the International Space Station but also on numerous occasions through the provision of scientific instruments by Russian laboratories. Altogether, European countries account for two thirds of the US cooperation in Space Exploration.

The US are very active in International Space Exploration Forums. They are a key participant to the ISECG, where their influence on the activities is considered by several countries as too strong. The US also participates to the iMARS and the IMEWG working groups.

Most recent agreements relevant for space exploration between the US and other space nations

Partner	Date	Type	Description
Brazil	October, 14th 1997	Program-related agreement	implementing arrangement providing for the design, development, operation and use of Brazilian developed flight equipment and payloads for the International Space Station
Brazil	Extended on March, 19th 2011	Framework Agreement	Framework agreement between Brazil and USA on cooperation in the peaceful uses of outer space, including space science and exploration
Canada	1997	Memorandum of Understanding	General cooperation agreement between NASA and the CSA concerning cooperation on the ISS
Canada	September 9th, 2009	Framework agreement	Framework agreement for cooperation in the exploration and use of outer space for peaceful purposes., including space exploration.
Canada	January 29th, 1998	Memorandum of Understanding	Memorandum of understanding between NASA and CSA concerning cooperation on the civil international space station
ESA	January 29th, 1998	Memorandum of Understanding	Memorandum of understanding between NASA and ESA concerning cooperation on the civil international space station
ESA	June 28th, 2010	Program-related agreement	Agreement concerning cooperation on the robotic exploration of Mars.
France	Renewed on January 23rd 2007	Intergovernmental Framework agreement	The agreement covers a broad spectrum of areas, including space exploration.
Germany	December 13th, 2010	Framework agreement	Framework agreement on cooperation in aeronautics and the exploration and use of outer space for peaceful purposes, including space exploration
India	February 1st, 2008	Framework Agreement	Agreement for future cooperation between the two agencies in the exploration and use of outer space for peaceful purposes.
India	May 9th, 2006	Program-related	Agreement between NASA and ISRO to two NASA scientific instruments on India’s Chandrayaan mission.

		Agreement	
Israel	October 2nd, 1996	Framework agreement	Agreement for cooperation in the peaceful use of space, including Space Exploration
Italy	May 2004	Declaration of intents	Declaration of willingness to intensify the cooperation between ASI and NASA, notably in space exploration
Italy	June 1st, 1991	Program-related agreement	Agreement for the design, development, operation and utilization of two mini pressurized logistics modules and a mini laboratory for Space Station Freedom, with memorandum of understanding.
Italy	January 11th, 2005	Program-related agreement	Agreement for the design, development, operation and utilization of three mini pressurized logistics modules for the International Space Station.
Italy	May 16th, 2007	Program-related agreement	Memorandum of understanding concerning the Dawn mission.
Japan	July 31st 1969	Framework agreement	Agreement concerning cooperation in space activities for peaceful purposes.
Japan	March 29th 1985	Program-related agreement	Agreement concerning the furnishing of launch and associated services for the Spacelab mission, with memorandum of understanding
Japan	May 9th, 1985	Program-related agreement	Memorandum of understanding for a cooperative program concerning design (Phase B) of a permanently manned space station.
Japan	January 29th, 1998	Memorandum of Understanding	MoU between NASA and the government of Japan concerning cooperation on the civil international space station
Japan	January 29th, 1998	Memorandum of Understanding	MoU between NASA and RSA concerning cooperation on the civil international space station
Multilateral	January 29, 1998	Program-related agreement	Intergovernmental Agreement on Space Station Cooperation
Russia	June 17th, 1992, extended in 2008	Framework agreement	Agreement concerning cooperation in the exploration and use of outer space for peaceful purposes

Russia	December 16th, 1993	Framework agreement	Protocol to the implementing agreement of October 5, 1992 on human space flight cooperation.
Russia	April 6th, 2001	Program-related agreement	Implementing agreement on the flight of the Russian High Energy Neutron Detector (HEND) on the United States 2001 Mars Odyssey Orbiter Mission.
UK	July 21st, 2010	Framework agreement	Statement of intent for potential cooperation in civil space activities. The agreement mentions Earth and space science, life sciences, and space exploration, in addition to other areas of mutual interest.

SECTION 2:

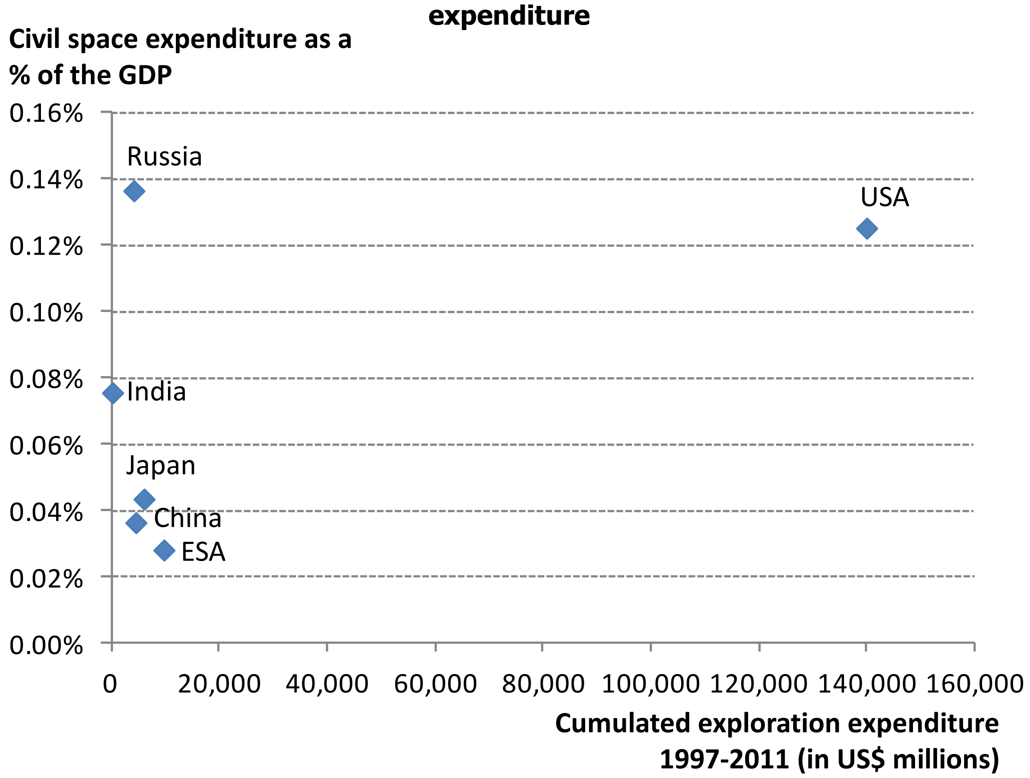
International Benchmark

INSTITUTIONAL FRAMEWORK AND FUNDING

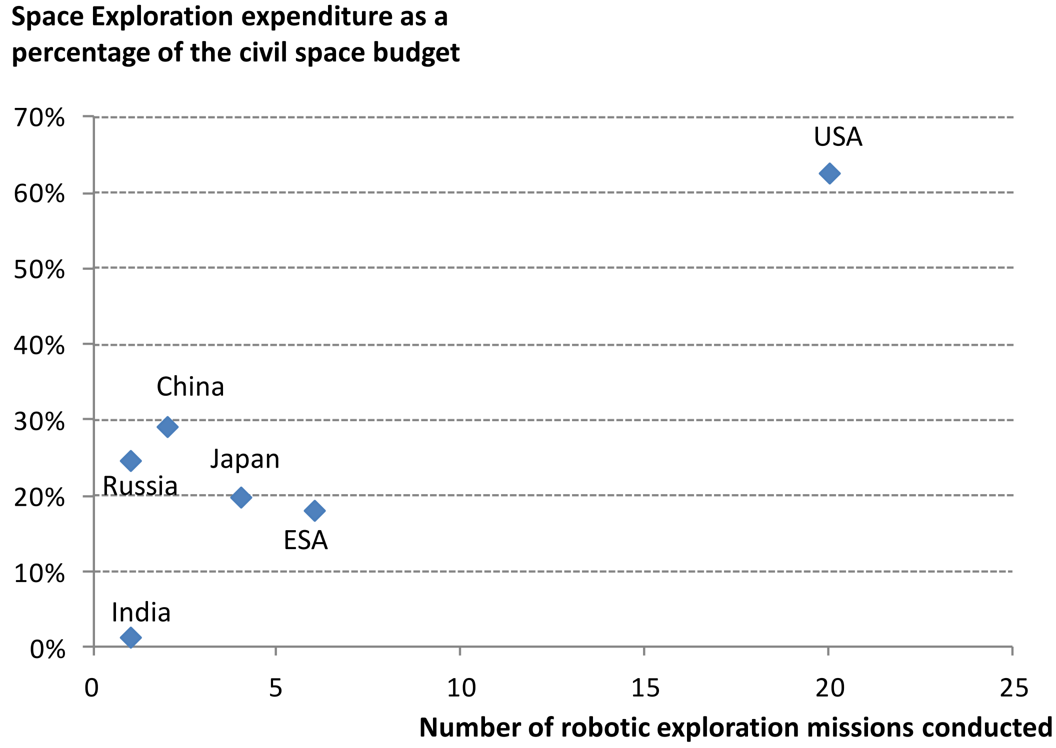
1. Benchmark of space exploration budgets

The level of funding of space exploration activities varies strongly from one country to another depending on the overall ability of the country to finance its space activities and the relative importance given to space exploration in comparison to other space applications.

1997-2011 cumulated space expenditure as a percentage of the GDP vs. exploration expenditure



Share of the civil budget dedicated to space exploration vs. number of robotic exploration missions conducted between 1997 and 2011



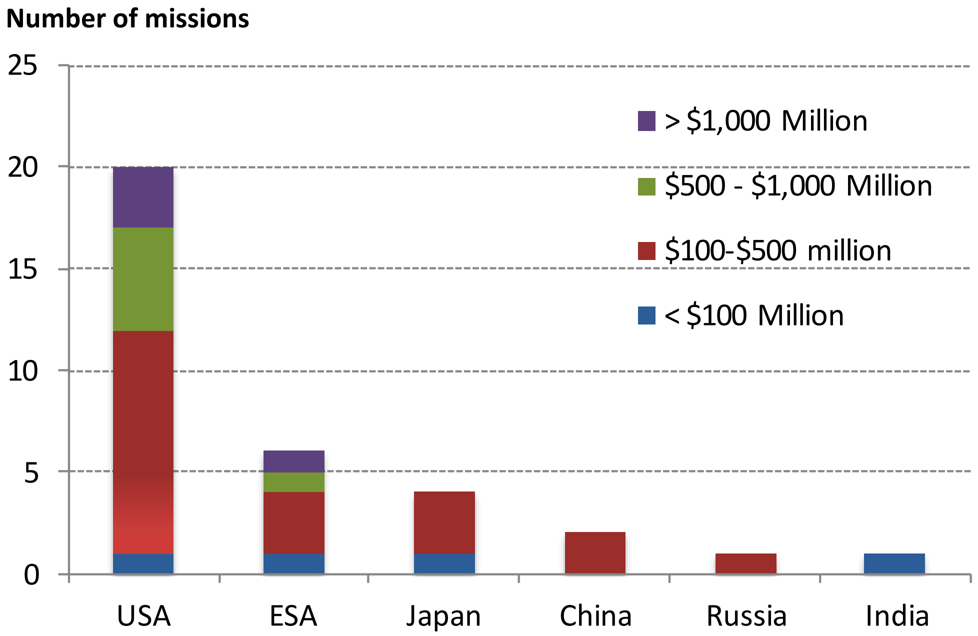
The US have by far the largest exploration budget, with an estimated $140 billion spent between 1997 and 2011, i.e. an average budget of $9.3 billion annually, which is more than five times the space exploration budget of all the other countries combined over the same period.

Russia and the US are the only countries to dedicate more than 0.10% of their GDP to civil space activities. India comes third, with nearly 0.08%, followed by Japan, China and ESA. However, the ESA figure is partially misleading as it does not include the budget dedicated to civil space activities at national level by its member states, while their respective GDPs have all been consolidated in order to calculate the percentage of space expenditure.

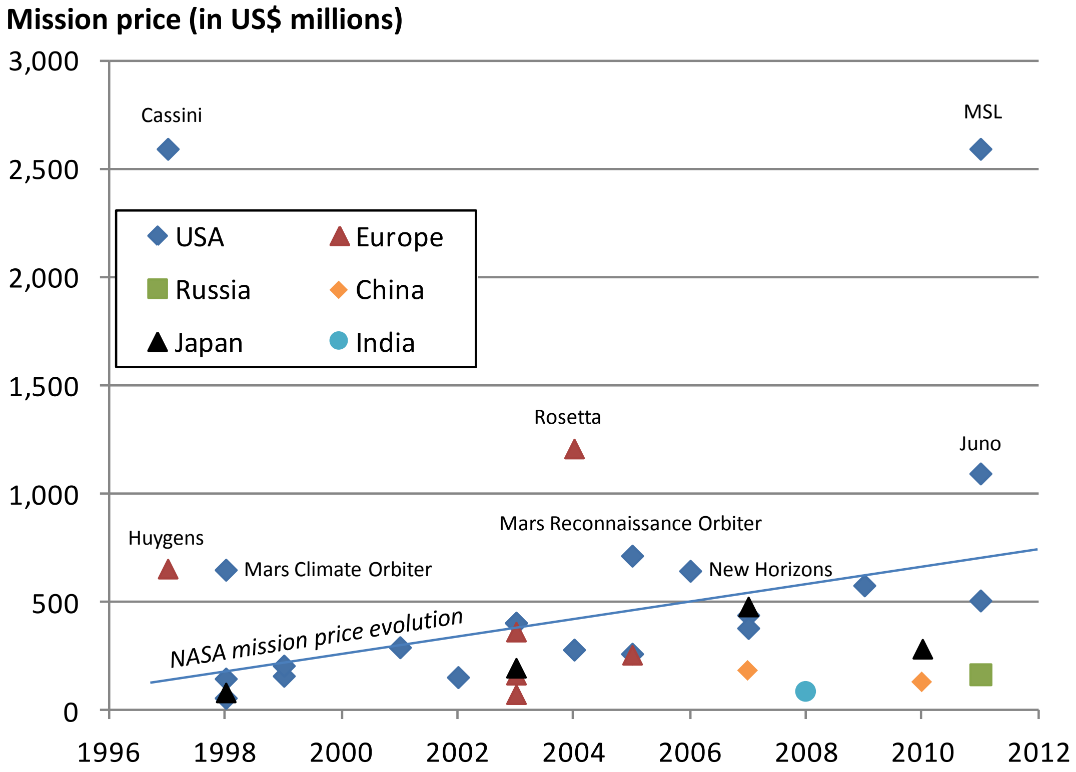
The US also clearly stand apart from the other countries regarding the priority given to space exploration activities within their total civil budget, with 63% of the 1997-2011 civil space expenditure dedicated to exploration activities. This high percentage is essentially driven by Human Spaceflight activities and especially the Shuttle program, which has received up an average of $4.1 billion yearly over the past fifteen years.

ESA, China, Russia and Japan all allocate between 18% and 30% of their budgets to space exploration activities. These countries have other programmatic areas that require a sustained funding (Launchers and EO for ESA, Japan and China; Navigation and launchers for Russia) and cannot afford to finance space exploration to the same extent than the US.

Number and budgetary range of robotic exploration missions launched between 1997 and 2011



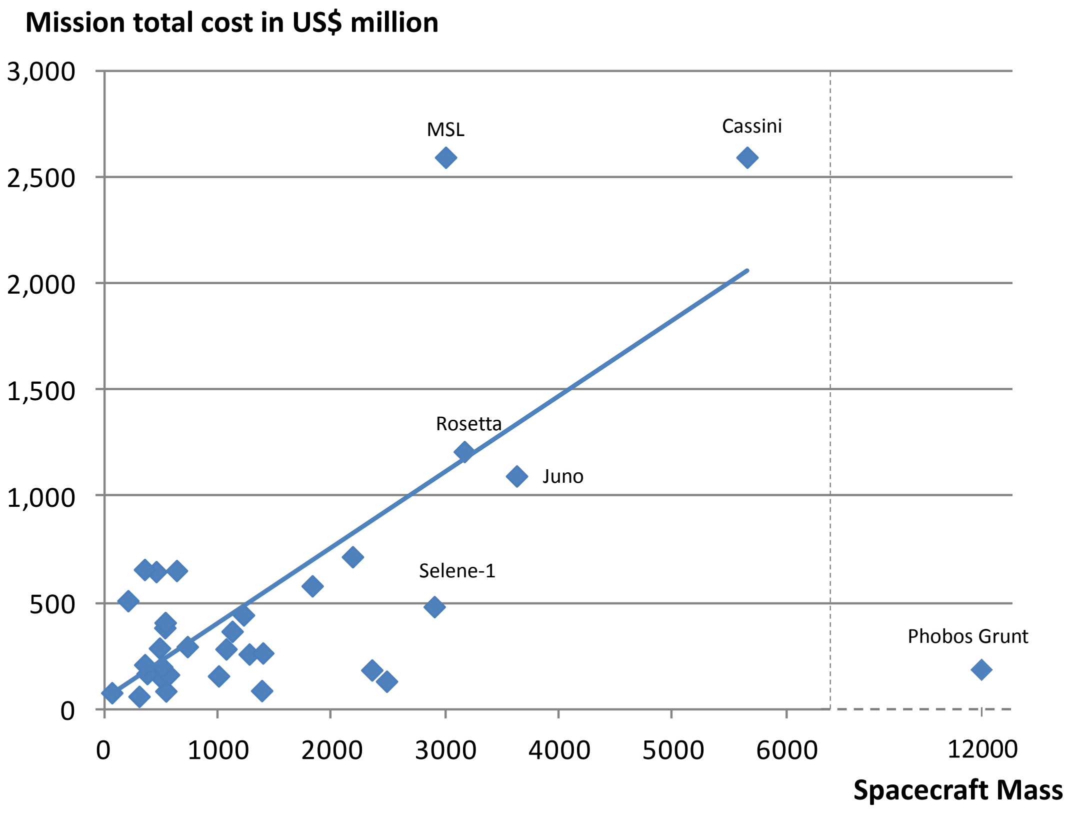
Price of robotic missions launched between 1997 and 2011



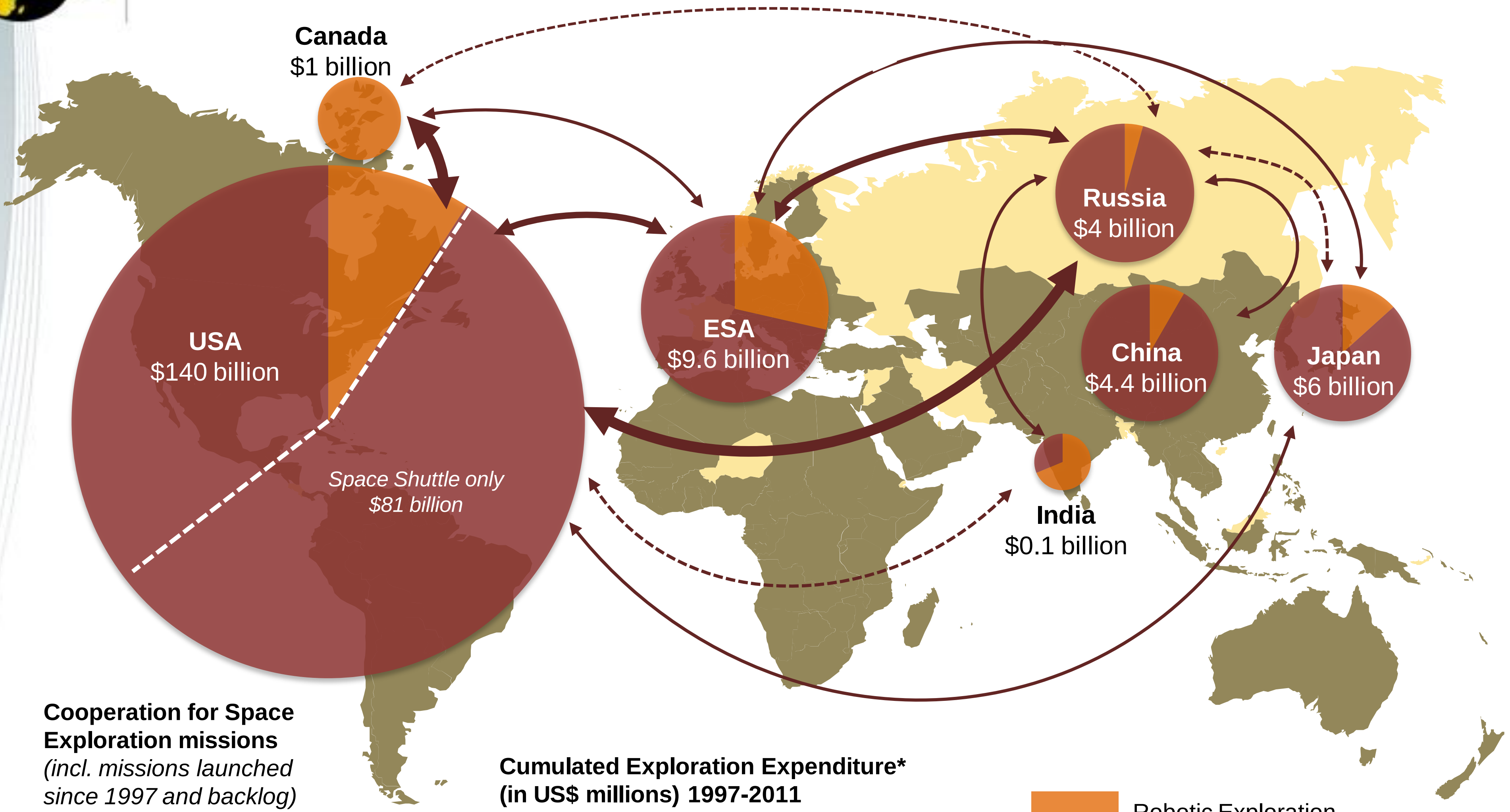
Even if the bulk of the Space exploration budget is dedicated to Human spaceflight activities, the number of robotic missions led by the agencies is directly correlated to the overall level of investment. NASA launched 20 robotic exploration missions over the past 15 years, which is more than all the other countries combined.

Only the US and ESA have launched missions with a total cost of over $500 million, and all the more, over $1 billion (Cassini, Juno and the MSL for NASA, Rosetta for ESA). These missions were also the heaviest exploration missions launched (with the notable exception of Phobos Grunt) as they were either carrying a large number of scientific instruments or required a considerable volume of fuel due to their complex trajectories. Their high price is therefore essentially attributable to their mass.

Mission price vs. Spacecraft mass at launch



World expenditure and cooperation activities for Space Exploration missions



Canada
$1 billion

USA
$140 billion

Space Shuttle only
$81 billion

ESA
$9.6 billion

Russia
$4 billion

China
$4.4 billion

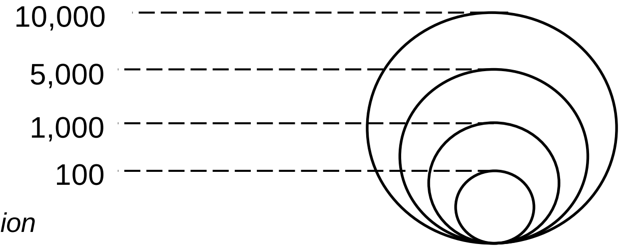
Japan
$6 billion

India
$0.1 billion

Cooperation for Space Exploration missions
(incl. missions launched since 1997 and backlog)

- Four missions
- Three missions
- Two missions
- One mission

Cumulated Exploration Expenditure*
(in US$ millions) 1997-2011



🟧 Robotic Exploration

🟥 Human Spaceflight

* Estimated from mission costs

FP7 COFSEP – Euroconsult for the European Commission

2. Influence of budgetary factors on cooperation for space exploration missions

Western countries, especially the US and Europe are currently facing strong budgetary pressure due to the economic downturn and often fail at to justifying colossal spending for space missions whose benefits on Earth are not directly tangible.

These difficulties to finance the planned missions have different impacts on the cooperation initiatives. Budgetary cuts in the NASA budget, under congressional pressure, have already led to the cancellation of the US participation in two missions supposed to be conducted in cooperation with Europe: Exomars and EJSM-Laplace. Though ESA managed to convince Russia to join the Exomars project, the reconfiguration of the mission will require an additional $200 million commitment from the ESA Member states, which will probably be reluctant to agree to this financial extension as most of them have adopted budgetary austerity measures to face the economic crisis.

These uncertainties will probably lead space agencies to rethink their future cooperation schemes, in order to minimize the impact of the withdrawal of one of the partners. ESA for example, might limit the involvement of foreign parties to 20% of the mission costs in its robotic projects, and as well cap its own participation in foreign missions to 20%.

In order to avoid total cancellation or delays of the projects, nations tend to limit the contributions of their partners on the system's "critical path"[2], i.e. the contributions that are required to complete the system, as opposed to the addition of non-critical capabilities. While, this restriction may be perceived as a lack of trust and confidence in their partners, it is the only way for the mission leader to ensure that the primary objectives of the programs will be reached.

On the contrary, financing issues may drive the countries to increasingly cooperate and mutualise space missions sharing common objectives in order to share the development and operating costs. This is partly the case of MarcoPolo-R, a joint ESA-JAXA candidate mission: Japan initially planned to conduct a similar mission at national level, Hayabusa-Mk2, but finally decided to join ESA on MarcoPolo-R.

3. Benchmark of the selection of space exploration missions

Space exploration missions worldwide are selected in two different ways, depending on the type of the mission.

Bottom-up selection process

Exploration missions driven by scientific objectives, such as planetary science missions, generally follow a bottom-up approach. Open calls for proposals are released by national space agencies, inviting the whole scientific community to propose mission concepts. The received proposals are then evaluated by a committee and go through several consecutive selection stages, such as hereafter regarding the selection of ESA Cosmic Vision M3 science mission:

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[2] See D.A. Boniatowski, G. Ryan Faith and Vincent G. Sabathier, "*The Case for Managed International Cooperation in Space Exploration"*, Center for Strategic and International Studies, Washington DC, 2006

Selection process for ESA Cosmic Vision M3 science mission

Activity	Date
Call for new M-class mission for 2022 launch (M3 slot)	July 2010
Selection of four M-class candidate missions for assessment studies	February 2011
ESA internal assessment phase of candidate missions	March 2011 - December 2011
Industrial assessment phase and parallel payload definition studies	January 2012 - December 2012
Open presentation of study results & Working Group recommendation for definition study phase	January 2013 - April 2013
SSAC down selection recommendation for missions for the competitive definition phase	May 2013
SPC decision on missions for the competitive definition phase	June 2013
Working group/SSAC evaluation and recommendation for selection of one mission	May 2015
SPC selection of one mission for implementation	July 2015
Mission launch year target	by 2024

Source: http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=42370

The exact process and the number of steps before the final selection vary from one country to the other but this approach is common to most of the scientific programs of the studied countries, notably for the Discovery and New frontiers programs within NASA, missions developed by the SRI in Russia, as well as by the ISAS in Japan.

As this selection process is generally applied to scientific programs of civil agencies, exploration missions, i.e. planetary science missions, are often in competition with other "non-exploration" scientific missions (astronomy, space physics, solar terrestrial missions etc...).

Smaller countries, which do not lead Space exploration missions on their own such as individual European countries, also follow the same bottom-up approach when they provide scientific instruments to international space missions.

As part of a bottom-up selection process, the risk for the secondary partner (i.e. not the one in which the selection process is taking place) is that the cooperation opportunity is not finally selected. The secondary partner is then left with no other choice than either redesign the whole mission at national level or cancels it entirely. However, these missions are generally selected nearly ten years before the launch, so that the secondary partner has sufficient time to consider its options.

The advantage of this type of missions is that once the selection has been made, the risk of cancellation of the primary partner is minimal since the budget allocated to scientific space programs is relatively stable and generally not the target of political changes of heart, unless the cost of the program soars suddenly.

Moreover, the withdrawal from the secondary partner(s) does generally not cause the whole project cancellation since the contributions of these partners is often limited to the provision of scientific instruments. Additional funding may nevertheless be required from the primary partner in order to complete the project.

Top-down selection process

On the contrary, Exploration missions aiming at gaining capabilities to prepare for future missions, generally follow a **top-down approach**. High-level political documents, such as the US National Space Policy expressed by President Obama in 2010, set the long-term objectives in Space Exploration (for example, send humans to orbit Mars and return them safely to Earth by the mid-2030s) and the national space agencies are then responsible for implementing these policies. To do so, they generally adopt stepped approaches with increasingly difficult objectives that provide for a progressive acquisition of the industrial and technical capabilities required to reach the final goal.

The risk of political cancellation of the mission is much higher for these programs, as they are generally developed as part of a long term strategy, which is likely to evolve with changes of administrations, austerity measures due to an economic slowdown, or change of general objectives.

A significant share of these missions led in cooperation involves the provision of key elements (launcher, orbiter, lander and rover notably) by all the parties, which explains why the consequences of a withdrawal from one of the partner has generally stronger consequences than for bottom-up missions.

In this case, the partner of the agency withdrawing from the mission is often left with no choice but cancel the whole mission, as nearly happened with Exomars when the US pulled out of the project. Missions may also be delayed due to issues with the contribution of one of the partners. This is notably the case of the Indian Chandrayaan-2 mission, which was initially planned for 2013 but was rescheduled to 2016 following the failure of Fobos-Grunt as the Russian Lander planned for Chandrayaan-2 was supposed to use the same technologies than the ill-fated Mars Lander.

SPACE EXPLORATION PROGRAMS

1. Benchmark of space exploration programs

The agencies have adopted different strategies regarding the destination of their space exploration missions. NASA, ESA and JAXA do not focus on a single destination and have future missions planned to the Moon, to Mars, to NEAs and to other planetary bodies, such as Mercury, Saturn or Jupiter. India and China on the contrary focus essentially on the Moon.

This difference can partly be explained by the fact that the programs from "newcomers" in space exploration such as China and India are essentially driven by capability acquisition purposes. Both countries have adopted staged approaches, planning for the development of Orbiters, followed by Landers, Rovers and finally Sample return capsules. The Moon is therefore the simplest, and the cheapest, way to reach these objectives.

Missions developed by NASA, ESA and JAXA on the contrary are essentially driven by their expected scientific results, which allow notably the agencies to justify the costs of the missions. The destination of their missions is therefore of utmost importance as it defines the whole mission. Industrial Capabilities are also being acquired as part of these missions but at higher cost than for Lunar missions due to a greater complexity.

Mature countries share general common objectives such as the Asteroid sample return (OSIRIS-Rex for NASA, potential MarcoPolo-R mission for ESA and JAXA, Hayabusa-2 mission for Japan) and the search of past and present life on Mars (Exomars for ESA and Russia, MSL for NASA, potential MELOS mission for Japan). Moreover, these agencies agree to prepare for future manned missions by acquiring new capabilities and extending Human presence in space, notably as part of the ISECG framework, which favours a phased capability-driven approach.

Moon programs

The Moon is the most popular destination of the space exploration programs worldwide, with 14 missions planned over the next 15 years by 6 space agencies.

The reasons for this popularity are multiple. The large number of spacecrafts launched to the Moon since 1958 makes it the best-known destination but also the most accessible destination as it is relatively close to the Earth. The lunar surface is therefore often used as a test-bed by countries willing to acquire new capabilities, such as China and India notably but also Russia.

The Moon is also considered as the most-probable next destination for manned spaceflight missions. Several of the future robotic missions, notably in Russia, therefore aim at preparing for future human exploration, by deploying the first elements of space infrastructure that will be required for a future lunar base or by conducting living conditions assessments.

Most of these capability-driven spacecrafts also carry scientific payloads, developed by national science institutes and universities. But the Moon also attracts orbiters with a purely scientific purpose, essentially developed by NASA (Grail and LADEE notably).

Mars programs

Six missions to Mars are currently planned (though only three of them have been approved as of mid-2012) over the next fifteen years. As for the Moon, the orbiters (MAVEN and Exomars 2016 notably) have primarily scientific objectives, while the future landers and rovers (Exomars 2016 Demonstration lander, Exomars 2018) will combine capability acquisition and demonstration with scientific purposes.

Mars is considered by the space agencies worldwide as the ultimate goal for human space exploration over the next thirty years. However, as current efforts in manned spaceflight focus on the first steps of human exploration (Moon and Asteroid), it is unlikely that robotic missions dedicated to the preparation of future manned missions will be launched to March over the next fifteen years. Future missions will most likely focus on rover exploration of the planet and sample return.

Near-Earth object programs

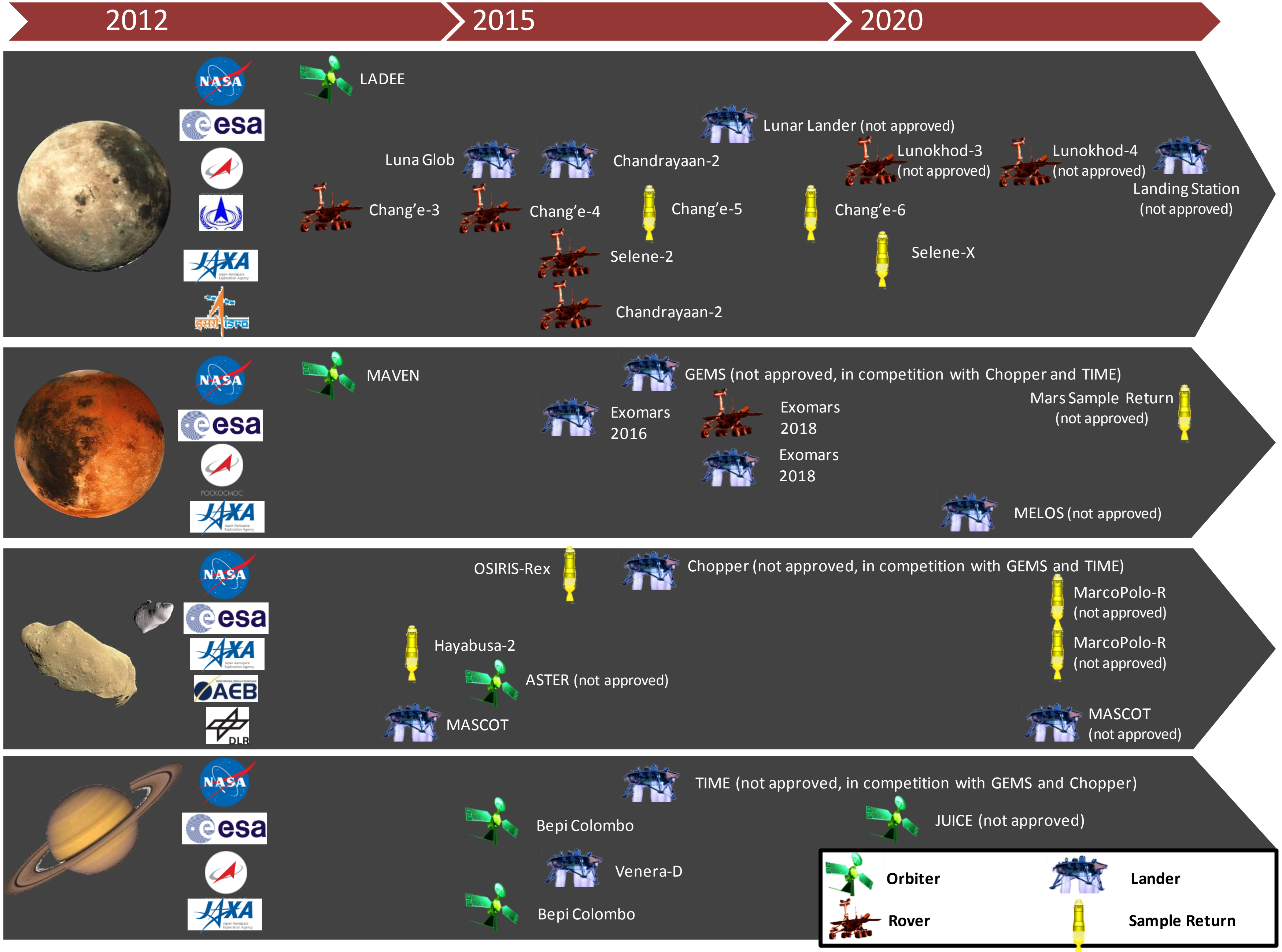
Near Earth objects are particularly attractive, with potentially five missions slated for launch over the next fifteen years (only two of them approved as of May 2012), both due to their accessibility (NEOs can be closer to the Earth than the Moon) and to the scientific return expected from these missions (NEOs contain raw material which can notably help to understand planet formation). Most of the planned missions therefore focus on Asteroid sample return, which also allows demonstrating capabilities such as rendez-vous, precision landing and atmospheric re-entry. Japan became a precursor in this area in 2010 by becoming the first country to successfully bring back asteroid sample to earth, and several agencies in turn (notably NASA and ESA) consider the development of such a mission over the coming decade.

Other planetary exploration programs

Three missions with a destination other than the Moon, Mars or Near-Earth objects could be launched over the next fifteen years. These missions are all financed on scientific budgets and have essentially scientific objectives. They are also among the most expensive (notably Cassini, at $2.6 billion and Juno, at $1.1 billion), which is essentially due to the tough environmental conditions to which the spacecrafts are exposed over their journey to their final destination and to the drastic mass and power limitations that require extensive engineering efforts.

Such missions are therefore the privilege of advanced nations, with a strong scientific base and a willingness to commit substantial resources to scientific objectives. Only NASA, ESA and Japan have led such missions over the past fifteen years.

Benchmark of future programs



2012
2015
2020

Moon

LADEE
Lunar Lander (not approved)
Luna Glob
Chandrayaan-2
Lunokhod-3
(not approved)
Lunokhod-4
(not approved)
Landing Station
(not approved)
Chang'e-3
Chang'e-4
Chang'e-5
Chang'e-6
Selene-2
Selene-X
Chandrayaan-2

Mars

MAVEN
GEMS (not approved, in competition with Chopper and TIME)
Exomars
2016
Exomars
2018
Mars Sample Return
(not approved)
Exomars
2018
MELOS (not approved)

Asteroids

OSIRIS-Rex
Chopper (not approved, in competition with GEMS and TIME)
MarcoPolo-R
(not approved)
Hayabusa-2
MarcoPolo-R
(not approved)
ASTER (not approved)
MASCOT
MASCOT
(not approved)

Others

TIME (not approved, in competition with GEMS and Chopper)
Bepi Colombo
JUICE (not approved)
Venera-D
Bepi Colombo

Orbiter
Lander
Rover
Sample Return

2. Impact of programmatic factors on future cooperation in space exploration

The main justification to engage in transnational co-operation is clearly the need to share the (usually very high) cost and risk of exploration missions, which allows a cooperating nation with a given budget to participate in a larger number of missions or in missions it could not afford alone. One aspect of this bartering is that some nations may thus elect to rely on building blocks for their mission that are already existing/developed/proven in another nation, instead of spending part of their resources to indigenously develop the required technology, even if the local industry could very well do it. This allows the "borrowing" nation to be more ambitious in their mission goals and to advance faster toward their scientific objectives.

The common objectives of nearly all agencies pave the way for future cooperation activities. Spacecrafts developed by China and India for capability acquisition purposes could notably be fitted with scientific payloads of more mature countries, which would allow both countries to reach their respective objectives and to share the mission costs. However, these spacecrafts may not be dimensioned for large scientific payloads and the primary partner may be reluctant to host a state of the art payload by fear of not being credited for the results of the mission (as was the case with India for Chandrayaan-1) and in the end being marginalized on its own mission.

Cooperation between space agencies for capability-driven programs is also an option, which is being actively considered as part of ISECG notably. However, past experience shows that critical technologies are virtually never shared as part of these missions, which means that space agencies would have to accept to specialize in specific building blocks and focus their future development in these areas only, thus becoming dependent one of another for future programs. This loss of independence may be a strong inhibitor for countries which are used to master all space exploration technology areas such as the US or for developing countries which are eager to acquire capabilities and not yet ready to specialize in one given area.

Moreover, this is not taking into account the strategic nature of space applications in general which are equally served by the building block capacities required for space exploration (access to Earth orbit, LEO and near-Earth settling and transportation, rare metal mining on Moon and asteroids, in particular).

	USA	ESA	Russia	China	Japan	India	Brazil	European individual countries
Robotic Activities								
Moon Orbiter	**LADEE, 2013**: measure the atmosphere and lunar dust environment		**Luna Glob, 2015:** Collect information on the internal structure of the Moon			**Chandrayaan-2, 2016:** Will relay to Earth the rover data		
Moon Lander		**Lunar Lander, 2018:** achieve precise soft landing near the South Pole	**Luna Glob, 2015**: Carry in-situ experiments on the moon surface **Chandrayaan-2, 2016:** Lander which will release the Indian rover. **Landing station, 2024:** develop the future Russian Lunar Base	**Chang’e-3, 2013:** conduct territory survey and living conditions assessment **Chang’e-4, 2015**: backup to Chang’e-3	**Selene-2, 2016**: demonstrate Japan high-precision autonomous landing and investigate the Lunar surface and sub-surface			
Moon Rover			**Lunokhod-3, 2020:** Form first element of future Russian Lunar base **Lunokhod-4, 2022:** Form first element of future Russian Lunar base	**Chang’e-3, 2013:** conduct territory survey and living conditions assessment **Chang’e-4, 2015**: backup to Chang’e-3	**Selene-2, 2016**: demonstrate Japan roving capabilities and investigate the Lunar surface and sub-surface	**Chandrayaan-2, 2016:** pick up samples, perform chemical analysis and send the data to the orbiter above		
Moon Sample Return				**Chang’e-5, 2017:** send back a moon rock sample to earth	**Selene-X, 2020:** Demonstrate robotic sample collecting			

	USA	ESA	Russia	China	Japan	India	Brazil	European individual countries
				Chang'e-6, 2019: backup to Chang'e-5	technologies and sample return capsule			
Mars Orbiter	**MAVEN, 2013:** explore Mars upper atmosphere and ionosphere	**Exomars, 2016:** Trace Gas Orbiter to map the sources of methane on Mars.			**MELOS, >2020:** Study the evolution of the Martian atmosphere, the water and its climate	**Mars Orbiter, 2013:** Study Mars atmosphere and especially search for Methane		
Mars Lander	**GEMS, 2017:** in-situ investigation of the interior of Mars	**Exomars, 2016:** European Demonstration Lander	**Exomars, 2018:** Development of the lander to release the European rover.		**MELOS, >2020:** Study the evolution of the Martian atmosphere, the water and its climate			
Mars Rover		**Exomars, 2018:** European Rover for exobiology and geology research						
Mars Sample return		**Mars Sample Return, >2020:** Mission should be conducted at international level						
Near-Earth Object Orbiter							**ASTER, >2015:** Exploration of three asteroids	
Near-Earth Object Lander	**Chopper, 2017:** Multiple comet landing to observe its changes and interactions with the sun							**Hayabusa-2, 2014:** Development of MASCOT Lander by Germany and France

	USA	ESA	Russia	China	Japan	India	Brazil	European individual countries
								MarcoPolo-R, >2020: Development of MASCOT Lander by Germany and France
Near-Earth Object Sample Return	**OSIRIS-Rex, 2016:** return sample collected on the 1999 RQ36 asteroid	**MarcoPolo-R, >2020:** Asteroid sample return mission			**Hayabusa-2, 2014:** return sample from a C-type asteroid **MarcoPolo-R, >2020:** Asteroid sample return mission			
Other Planetary Orbiter		**BepiColombo, 2015:** Study the magnetosphere, the surface and internal composition of Mercury **JUICE >2020:** Exploration of Jupiter's Moons	**Venera-D, 2016** : Study Venus plasma environment		**BepiColombo, 2015:** Study the magnetosphere, the surface and internal composition of Mercury			
Other Planetary Lander	**TiME, 2017:** determine the composition and depth of the seas of Titan		**Venera-D, 2016** : Study Venus plasma environment					

	USA	ESA	Russia	China	Japan	India	Brazil	European individual countries
Human Spaceflight Activities								
Space Station	**ISS:** Utilize the ISS until 2020	**ISS:** Utilize the ISS until 2020	**ISS:** Utilize the ISS until 2020	**Tiangong-2 and -3, 2013, 2015:** manned modules to perform experiments **Permanent Manned Station, >2020:** supporting three astronauts for long-term habitation	**ISS:** Utilize the ISS until 2020			
Cargo Transportation	**COTS:** Development of commercial cargo transportation spacecrafts	**ATV-4, -5, 2013-2014:** ISS Cargo supply spacecrafts	**Progress:** Five yearly resupply of cargo for the ISS		**HTV-3 to 7, <2016:** ISS Cargo supply spacecrafts			
Crew Transportation	**CCDev:** development of commercial crew transportation spacecrafts		**Soyuz-TMA:** Carries three cosmonauts every three months to the ISS and back	**Shenzhou:** Several manned missions to be launched over the next years to acquire capabilities		**Orbital Vehicle:** First demonstrations in 2016 capability of three astronauts		

SPACE EXPLORATION INDUSTRIAL CAPABILITIES

1. Benchmark of space exploration capabilities

Space exploration in general requires a number of basic enabling capacities which are needed to successfully implement the various types of missions that are pursued or envisioned today.

High capacity Earth launching

Access to space from the Earth surface is the first capacity needed to engage in space exploration. Today the capacity to perform routine launches of high mass payloads is shared by Europe, the US, Russia and China. Japan and India also have independent space access, but with more limited capacities (mass-wise and also from an operational viewpoint). The US are the only nation committed to developing new high capacity launch systems (NASA's SLS and commercial Falcon 9 Heavy) capable of 100+ tons in LEO and which should become operational at the end of the decade. Russia has a long history (under the Soviet regime) of robust launch capacities (including for high capacity systems) but appears to still be struggling to revive and stabilize their former industrial capacities. Higher launching capacities are needed to support the more ambitious exploration scenarios envisaged today (L2 or Moon permanent station, Mars missions with order of magnitude larger capacities, either robotic or manned). In such missions, a large quantity of hardware will need to be delivered in Earth orbit in preparation for the trip to the final destination. In this respect, there is a tradeoff to work out between launching many smaller mass loads and pre-assembling them in LEO, or launching fewer but larger loads which will require less assembly work in orbit. The existence and cost efficiency performance of an "in-orbit transportation infrastructure and assembly factory" would obviously be a key factor in such a tradeoff.

In-orbit and in-space transportation

The US and Russia undoubtedly have acquired the largest experience in space transportation, for both unmanned systems (automated systems) and manned systems (US and Russian capsules, US Shuttle), and the US are now pioneering a commercial approach to space transportation . Russia is today the only nation with operational capacities for routine human transportation (excluding here China still at the demonstration level). Europe has recently been very successful with the ATV cargo transport which has demonstrated faultless autonomous RV and docking performance (demonstrating European mastery of GNC and avionics technologies). Japan has also developed an in-orbit cargo transportation capacity with the HTV (although not autonomous for docking). China has been successful as well in demonstrating in-orbit RV and docking capacity in addition to demonstrating their indigenous technology for manned capsules.

Everyone is still using conventional chemical propulsion (for which the US and Russia have the largest industrial product offer, as compared to much more limited options in Europe) for in-orbit and in-space transportation. Industrial R&D is however taking place, at seemingly moderate and preliminary level, around high power electric propulsion and nuclear-based propulsion (mostly research labs) in the US and possibly in Russia.

There should soon be an overcapacity of space transportation systems (especially for cargo), possibly making in-orbit and in-space transport more affordable in view of the extensive transportation needs arising from the various exploration scenarios which are contemplated today.

In-orbit and in-space habitats and stations

Through the ISS, several nations have acquired industrial experience in the development and assembly of in-orbit habitat and facilities. Europe (mostly Italy and Germany), Russia, Japan and the US have all contributed pressurized modules. Canada (and to a lesser extent Japan and also Europe) has developed expertise in the kind of large robotic systems that will be needed for in-orbit and in-space assembly and cargo handling. The largest, most comprehensive and advanced experience of space habitat and facilities is here again in Russia (Mir, Salyut) and especially in the US (commercial initiative with Bigelow's inflatable "space hotels, labs or storage places"). China is aiming to build its own orbital station within the coming decade.

Most space faring nations would be able to contribute to a major international project such as a L2 or Moon permanent space station.

Human life support and protection

Life support and protection technologies have been developed primarily by those nations which have invested in and achieved human space flight, which means essentially the US and Russia, and now China. The support and protection has so far addressed low exposure space flights (low radiation levels and/or short duration trips, such as in the Apollo Moon missions). The capacities are today limited to rather conventional air revitalization and cleansing technologies but include also the use of advanced materials in spacesuits and shielding.

The next steps in space exploration (L2 or Moon station, Mars trip) are much more challenging with regard to human life support and protection. They will require very high reliability self-sufficient closed cycle systems for air and water recycling, which none of the space faring nations has yet achieved. R&D at moderate level is performed in the US and in Europe to develop such systems, some of them addressing as well longer term goals of incorporating food and waste processing/recycling or oxygen/water in situ mining. The question of long term radiation protection beyond LEO still remains a fully open challenge, as it seems, for all nations involved in space exploration.

Controlled high velocity atmospheric entry

The ability to perform controlled high velocity space flight entries into dense atmospheres is a major component of both human space flight (return to Earth) and planetary exploration, including with robotic vehicles. The experience of this issue (and resulting technologies – such as for thermal protection and GNC – and associated operational processes) is again largely in the hands of Russia and the US which have mastered human spaceflight for the longest and which have taken the concept of space plane the farthest. Europe has gained some knowledge of the issue, but limited to design and experimental work (Hermes and various other programs) without full scale achievement, although the European industry can easily align top level expertise in materials and GNC/avionics. Through its manned program, China has acquired some expertise of the re-entry issues, but is presently considerably behind both the US and Russia.

Soft and precision landing in non-cooperative environments

Soft landing of spacecraft on planetary surfaces has been achieved essentially by the US (with the most extensive experience by far) and by Russia (during the Soviet era). Precision landing in a non-cooperative environment requires prior extensive mapping of the surface in order to characterize usable landmarks. Europe has not had the opportunity (mission profile) to really demonstrate this capability yet, although GNC and avionics competencies to achieve this goal are strong within the European industry.

Autonomous remote sensing and exploration robotics

The capabilities to develop space instruments and robotic systems for in-situ measurements and exploration are widely diversified and shared among many actors in basically all of the space faring nations (industry, but also research and academic labs). The effort put in developing highly integrated, low mass/low consumption autonomous solutions for those instruments is largely re-used across missions and leads to some level of specialization among actors. Remote sensing instruments provide the most common ground for transnational cooperation in space exploration missions (contribution of instruments in foreign missions).

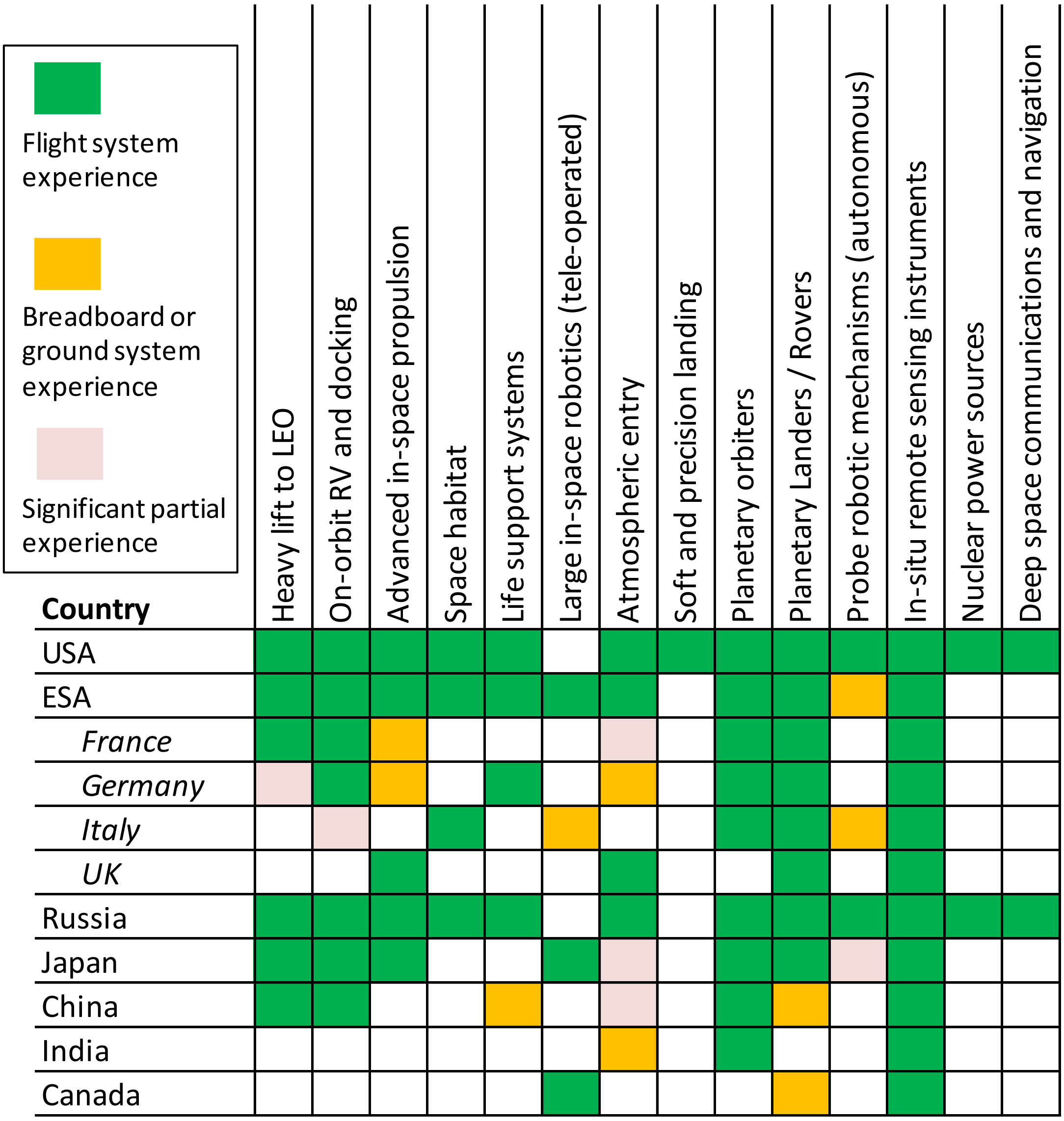
Here also, the widest experience of developing and operating autonomous remote sensing and exploration robotics (rovers in particular) is found in the US, particularly with the Jet Propulsion Laboratory. Europe has a strong experience of orbital remote sensing of most types, including in very harsh environments, but significantly more limited still regarding surface exploration of space objects. Japan has capabilities similar to that of Europe (although less diversified), and India and China have just started to get involved in space exploration remote sensing.

High power energy sources

Energy sources are one of the main limitations in space exploration today (the main source being solar power using conventional solar photovoltaic generators). Nuclear power sources are seen today as likely indispensable enablers of future exploration missions. There is experience of radioactive thermal generators in both the US and Russia (today the only two nations capable of delivering a space qualified RTG) typically at the (few) KW level. Mid/long term R&D is on-going (US, possibly also Russia) to design orders-of-magnitude more powerful generators. Europe is only starting to address this issue.

Deep space navigation and communications facilities

Deep space missions (beyond the Earth-Moon system) require an extensive system of very large antennas spread across the Earth to perform the TT&C functions. Only the US is really self-sufficient in this respect, and nations like Europe and Japan tend to rely on the US facilities (at least partly, to supplement their own TT&C network) to perform their deep space missions. The question here is more that of proper institutional investment rather than of industrial capacities, although the European industry is probably not among the most competitive for space ground equipment. The European space industry could however provide state-of-the-art, high value contributions (Galileo technologies, optical links...) in the future navigation and communications infrastructures that will likely be developed to facilitate the exploration of the Moon and Mars in the next decades.



🟩 Flight system experience

🟨 Breadboard or ground system experience

▨ Significant partial experience

Country	Heavy lift to LEO	On-orbit RV and docking	Advanced in-space propulsion	Space habitat	Life support systems	Large in-space robotics (tele-operated)	Atmospheric entry	Soft and precision landing	Planetary orbiters	Planetary Landers / Rovers	Probe robotic mechanisms (autonomous)	In-situ remote sensing instruments	Nuclear power sources	Deep space communications and navigation
USA	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
ESA	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟨	🟩		
France	🟩	🟩	🟨				▨		🟩	🟩		🟩		
Germany	▨	🟩	🟨		🟩		🟨		🟩	🟩		🟩		
Italy		▨		🟩		🟨			🟩	🟩	🟨	🟩		
UK			🟩				🟩			🟩		🟩		
Russia	🟩	🟩	🟩	🟩	🟩		🟩		🟩	🟩	🟩	🟩	🟩	🟩
Japan	🟩	🟩	🟩			🟩	▨		🟩	🟩	▨	🟩		
China	🟩	🟩			🟨		▨		🟩	🟨		🟩		
India							🟨		🟩			🟩		
Canada						🟩				🟨		🟩		

2. Impact of industrial capabilities on future cooperation in space exploration

Most of the countries studied are relatively well advanced in several technological areas, such as Heavy lift to LEO, In-orbit and in-space transportation, In space habitat and stations, and autonomous remote sensing and exploration robotics.

However, the colossal investments over the US and Russia in space exploration reflect naturally on the capabilities acquired by their industries. It seems therefore nearly impossible to conduct an ambitious mission without involving one of these countries as they are the only nations to master key elements such as Radioisotope thermoelectric generators, controlled high velocity atmospheric re-entry, advanced human life support and protection systems and to have access to the required Deep Space communications and navigation network.

SECTION 3:

Cooperation scenarios and benefit analysis

BENEFITS OF COOPERATION IN SPACE EXPLORATION

Cooperation between two space faring nations can only be successful if each nation has an inventive to cooperate, deriving benefits from the cooperation activity. The benefits associated to international cooperation are multiple and consists essentially in economic benefits, industrial benefits, scientific benefits and political benefits. This present section does not present the benefits of space exploration in itself but the benefits of cooperation in space exploration.

1. Economic benefits

As Space Exploration is a particularly expensive enterprise, the first motivation for international cooperation is to save money by splitting the financial burden of the missions among all the partners. The benefits of Space exploration are often difficult to understand for uninformed citizens and Members of Parliament, since these benefits are less conspicuous than for other, less costly, space applications such as Satellite communications, navigation or earth observation. Space exploration activities of all member states are therefore often facing strong budgetary pressures, which is a strong driver for international cooperation.

The most obvious way to derive economic benefits from cooperation in space exploration is to share the development cost of missions with a common objective by merging these missions into a single endeavour. The economic benefits derived from the cooperation will naturally depend on the size of the partner contribution, the more the partner will be involved in the critical aspects of the mission, the largest its financial contribution will be.

The possibilities in this area are multiple and range from the joint development of a whole mission, with several partners providing critical elements, such as in the case of the ISS, to the provision by one country to the other of a scientific instrument. In the latter case, the relative economic benefits for the partner providing the instruments are huge as it may save him the development of a dedicated mission while getting the same scientific results.

A country procuring in a another country a product or a capability that his domestic industry does not possess is also a form of cooperation deriving economic benefits as it will save him the R&D costs required to develop the capability.

Economic benefits may also be derived by one country by procuring a capability that he owns domestically, at a lower cost in another country. The incorporation of Russian RD-180 rocket engines into US Delta-3 and -4 launchers was partly justified by economic purposes, in addition to a political will to cooperate. However, this kind of cooperation is generally not well perceived by local industry players and by Members of Parliaments as this leads to capital flights and may destroy employment within the country.

2. Political benefits

As a general rule, international cooperation generates diplomatic influence as, more than most other areas, space exploration is a significant instrument of soft power. The political and strategic nature of space exploration activities, which was exacerbated during the Moon race, makes it particularly important for space powers to cooperate and communicate on their capabilities.

Cooperation in space exploration improves the institutional and industrial relationship of the participants and serves as a symbol for wider cooperation between states. If China or India for example were to cooperate with the US, Russia and Europe for the successor of the International Space Station, it would send a message to the international community that would not be limited to the space sector but increase the diplomatic credit of all participants.

Another political benefit from space cooperation, notably raised by the US Center for Strategic and International Studies[3], is that cooperation in Space exploration creates political sustainability, in the sense that programs led in cooperation are safer from cancellation to the extent that administrations are not willing to break international agreements.

While this may have been true for large cooperation programs such as the International Space Station, the recent budgetary pressures on the space exploration budgets proved that even missions led in cooperation can be cancelled, even when their development has already started. A unilateral withdrawal from a space exploration program causes diplomatic damages to the nation’s reputation and credibility, and may prohibit future cooperation, but is sometimes considered as the price to pay to save more operational missions.

3. Industrial benefits

Industrial benefits may be derived through several ways from cooperation in space exploration. The most direct of them, though very rare in Space Exploration, is when the industry of one country acquires capabilities as part of the cooperation, through technology transfer from another space faring nation. This type of cooperation is essentially pursued by developing countries in the space exploration area as it allows them to acquire capabilities in a straightforward manner and save them several years of R&D.

Industrial benefits also occur when a cooperation project leads to industrial developments of whole systems, subsystems or even just components, which would not have been undertaken without the cooperation. These industrial developments generate revenues for the domestic industries and help to maintain, or even, create jobs.

4. Scientific benefits

Research institutes and academia from most space faring countries develop scientific instruments that they wish to include into future space exploration missions. However, the number of slots for scientific instruments, especially those developed by universities, is often limited and may not satisfy all the stakeholders involved in the conception of these instruments.

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[3] See D.A. Boniatowski, G. Ryan Faith and Vincent G. Sabathier, "*The Case for Managed International Cooperation in Space Exploration",* Center for Strategic and International Studies, Washington DC, 2006

Cooperation in Space Exploration provides for more flight opportunities for scientists as they may be able to fit the instruments developed domestically into missions led by foreign countries.

The sharing of scientific results from a mission is also a scientific benefit that can occur as part of international cooperation.

ENABLERS FOR SPACE EXPLORATION COOPERATION

The first enabler for cooperation is that the participants share the same goal, or that their respective goals can all be achieved through a cooperative scheme.

Regarding space exploration, this approach is facilitated through the international foras to which the countries participate, where they try to reach consensus on future destinations. However, this is not the case of scientific programs, for which the missions are generally defined by the scientific community.

A communality of objectives naturally paves the way for future cooperation but objectives may also be complementary. To illustrate, if the objective of one country is to study the Martian magnetic field, it may be fulfilled through a mission led by another country whose main objective is to send an orbiter to Mars to demonstrate industrial capability.

1. Mutual synergies

If the objectives of the participants are complementary, and not common, the breakdown of the respective tasks and responsibilities is facilitated since each participant will most likely be responsible for the development of the elements allowing the fulfillment of its own objectives.

However, when countries share the exact same objectives, the breakdown of the mission development may be more difficult. Incentives for cooperation (economic, political, industrial or scientific, see previous section) have to be expected to be derived from the program. Cooperation will be made easier if the participants complete each other, notably at industrial level, though budgetary factors may be enough to drive the cooperation and break down the work accordingly to the contribution of each of the partners.

2. Accessibility and export control rules

Even if potential partners have common objectives and complement each other, the cooperation will not be possible if the respective countries are not accessible one to each other.

The accessibility of a country for another one may be appraised in the light of political and commercial factors. National export control regulations may prohibit one country to cooperate with another. In the US for example, the ITAR regulations prohibit any cooperation, for space-related activities, between entities subject to the US jurisdiction and Chinese nationals. Even for pure scientific space exploration missions, US scientists would not be authorized to cooperate with their Chinese counterparts.

From a commercial standpoint, the access of industrial players from one country to the institutional and commercial markets of another country can be threatened by protectionist measures, requiring notably the domestic stakeholders to prefer domestic-made products and services in their procurements, such as the Buy-American Act in the US. Even if there is no formal legal act in this area, internal policies and practices may limit the international competition and therefore prevent certain forms of cooperation.

METHOD FOR EVALUATION OF BENEFITS

1. Methodology change

Euroconsult initially intended to base the benefit analysis on the outcome of the gap analysis that was to be performed as part of the benchmark of programs and capabilities. The idea behind the gap analysis was to determine which requirements from potential partners' programs for future missions could not be fulfilled locally and match these requirements with European current and expected capabilities; and to determine which requirements from European programs would not be fulfilled by European suppliers and match these requirements with potential partners' capabilities.

However, contrary to other space application areas, when institutions worldwide take the decision to undertake a given space exploration project, they consider the current and expected state of the domestic capabilities and dimension the mission accordingly. There are therefore only very few cases where a country has planned a space exploration program whose requirements do not match current and expected local capabilities. The gap analysis that was initially planned has consequently very little interest.

Euroconsult therefore changed the approach, from a mission-based analysis to a country-based review, considering that the possible benefits of cooperation could be assessed based on the participating countries. The main advantage of this approach is that it allows to analyze benefits from cooperation beyond the programs that are currently scheduled, which would not have been the case with a mission-based approach.

2. Evaluation methodology

The potential cooperation of European stakeholders (as a whole, including EC, ESA, the EU and the industry) with other countries was analyzed for four different types of mission opportunities:

3. Type of mission	4. Opportunity
Capability-driven	Joint robotic mission to a planetary body for preparing future manned activities
Science-driven (mission)	Full joint development of a scientific mission
Science-driven (instrument)	Provision of an instrument to be fitted in a larger scientific mission
Manned spaceflight	Cooperation for future human spaceflight activities (parallel or post-ISS)

Two country abilities were also assessed as part of the benefit analysis:

- Participation to a large-scale mission developed as part of an international multilateral framework (as for the ISS for example)

- Simultaneous cooperation to several missions.

Each of the four opportunities will be evaluated based on the criteria (enablers and benefits) previously described, with the following sensitivity:

Criteria	**Mark min-max**	**Description**
		Enablers
Common or complementary objectives	0–3	0 = No common or complementary objectives (ex: no objectives for space exploration) 1= Few common objectives or little complementarity 2 = General objectives shared by partners (e.g. on the destination) or good level of complementarity 3= Objectives largely similar or totally compatible
Mutual synergies	0 – 3	0 = Domestic industrial and scientific base of one of the partner does not provide for any cooperation opportunity 1 = Cooperation is possible but at a minimal level due to lack of capabilities 2 = The industrial and scientific capabilities of each partner provide for significant opportunities 3 = Strong synergies between the capabilities of each partner, or obvious breakdown of tasks
Accessibility	0 – 3	0 = No possibility of cooperation due to not-accessible market or export control regulations 1 = Limited access to institutional market or strict export control regulations 2 = Access to the market and export control regulations are not an issue but lack of experience could notably be a source of complications 3 = Access to the market and export control regulations are clear and cooperation activities successfully conducted in the past
		Benefits
Economic	0 – 3	0 = The opportunity has no economic benefits for Europe 3 = The opportunity has very large economic benefits for Europe
Political	0 – 3	0 = The opportunity has no political benefits for Europe 3 = The opportunity has very large political benefits for Europe
Industrial	0 – 3	0 = The opportunity has no industrial benefits for Europe 3 = The opportunity has very large industrial benefits for Europe
Scientific	0 – 3	0 = The opportunity has no scientific benefits for Europe 3 = The opportunity has very large scientific benefits for Europe

The enablers are considered as vital for the cooperation so that the "0" mark for any of them disqualify entirely the cooperation opportunity. The final calculation formula for the rating of the opportunity is:

$$\sum Enablers = (Common\ objectives + Mutual\ synergies + Accessibility) \times 2$$

$$\sum Benefits = (Economic\ benefits \times 2) + \ Political\ benefits + (Industrial\ benefits\ \times 2) \\ + \ Scientific\ benefits$$

$$Final\ Mark = \frac{\sum Enablers\ \times \sum Benefits}{324\ (maximum\ grade\ equivalent\ to\ a\ perfect\ cooperation)} \times 100$$

According to their ratings, the opportunities have then been split into 5 categories:

Mark	Value of opportunity	Color code
-	Not Accessible	⬜
<40%	Limited	🟥
40-59%	Good	🟧
60-79%	Very good	🟩
>80%	Excellent	🟦

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND BRAZIL

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1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

Brazil has no budget line dedicated to space exploration, and the development of a joint mission is ruled out entirely. Even if Brazil was to grant significant resources to exploration over the next few years, it would probably not partner with Europe but rather with Russia, which already intends to provide technical and scientific support to the potential Brazilian ASTER mission.

2. Joint development of a scientific mission

Enablers for the cooperation

Cooperation for the joint development of a large scientific mission is excluded for the same reasons than for a joint robotic mission. However, Brazilian scientists could provide a European stakeholder with an instrument to be fitted on board of a European spacecraft. The benefits, essentially economic, of such a cooperation have already been discussed previously and will therefore not be detailed hereafter.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

Brazil signed a bilateral agreement with NASA in 1997 to become a partner on the ISS. However, the cooperation never materialized due to a lack of funding on the Brazilian side. If ever Brazil intended to fund Human spaceflight activities, Europe would probably not be its favoured partner since it has never led autonomous human exploration missions and has fewer capabilities than the US or Russia in this domain.

4. Multilateral cooperation for large scale projects

As the world's sixth largest economy, Brazil has the economic and political power to become a member of any large international exploration initiatives in the next decade. However, the Brazilian government will have to commit adequate financial resources in order not to repeat the failure of the ISS cooperation.

5. Cooperation for several of previously mentioned options simultaneously

Given the lack of funding for space exploration, it is dubious that Brazil will be in a position to finance several exploration initiatives simultaneously.

Cooperation Opportunities with Brazil									
Opportunity	**Cooperation Enablers**			**Cooperation Benefits**				**Rating**	
	Common objectives	**Mutual synergies**	**Accessibility**	**Economical benefits**	**Political Benefits**	**Industrial benefits**	**Scientific benefits**	**Total score**	**Opportunity value**
Joint robotic mission to a planetary body	**0** No plan for Moon or Mars	**-**	**-**	**-**	**-**	**-**	**-**	**-**	Not accessible
Joint development of a scientific mission	**2** Plan for asteroid mission	**0** No budget on Brazilian side	**-**	**-**	**-**	**-**	**-**	**-**	Not accessible
Scientific cooperation at instrument level	**1** No identified objectives yet	**1** No particular synergies	**2** Lack of experience is problematic	**1** Only small economic benefits	**2** New coop. but no media attraction	**0** No industrial benefits to this cooperation	**1** Probably low-tech instruments only	**12%**	Limited
Cooperation for Human spaceflight activities	**2** Ambitions of Human spaceflight	**0** No budget on Brazilian side	-	-	-	-	-	**-**	Not accessible

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND CANADA

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

The main objective of Canada in robotic space exploration is to remain a key partner in international initiatives involving exploration of the solar system and space science. The CSA does not have the financial capability to develop exploration missions on its own and therefore aims entirely at partnering on foreign missions.

This objective is therefore fully compatible and complementary with Europe's own objectives in space exploration as Canada could partner on European-led initiatives.

Canada has a strong capability in robotics, which could be integrated on all potential European capability-driven missions. Canada also intends to acquire expertise on roving technologies. The withdrawal of the US from Exomars has cancelled the Canadian contribution to the mission as it was supposed to be fitted on the US rover. Canada should therefore be particularly interested in any mission involving the development of a rover.

The accessibility is absolutely not an issue with Canada, which has been an ESA associate member state since 1979 and has contributed to a lot to ESA-led missions in the past. The financial mechanisms allowing the CSA to participate to ESA missions are therefore well established and the cooperation already well developed.

Economic benefit

Including a Canadian contribution in a ESA-led robotic mission would decrease the mission cost for ESA. Canada has shown in the past that it was able to contribute financially to the development of exploration mission, though essentially in partnership with NASA. However, this contribution would naturally be limited as the CSA does not have the same financial resources for exploration than its international partners

Political benefits

Europe has cooperated extensively with Canada in the past, notably within ESA for observation and science missions. However, Canada has essentially cooperated with the US until now for space exploration missions and never with ESA. Political benefits could therefore be derived from a joint robotic mission.

Industrial benefits

The cooperation of Canada would be limited to robotics and possibly roving technologies so that there are no particular industrial benefits to a joint capability-driven mission since Europe still would have to develop all other elements.

Scientific benefits

The cooperation with Canada would not derive particular scientific benefits. On the contrary, it is probable that one or several slots for scientific instruments would be reserved for Canadian scientific stakeholders in case of a Canadian participation to an ESA mission.

2. Joint development of a scientific mission

Enablers for the cooperation

Science is one of the key objectives of the Canadian space exploration program. Given the limited financial resources of the CSA, a scientific cooperation in this area would probably only involve the provision by Canada of one or several scientific instruments for an ESA-mission. The benefits for Europe of such a scientific cooperation have already been analysed for other countries and will therefore not be repeated hereafter, especially as they essentially consist in a modest financial contribution from the CSA to the European stakeholder leading the mission.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

Neither ESA nor the CSA have the financial capability to lead an autonomous manned spaceflight program. A bilateral contribution in this area is therefore implausible.

4. Multilateral cooperation for large scale projects

Canada has managed to gain a strong international position in space exploration through its participation to the ISS. The Canadarm is notably perceived by the Canadian public as one of the greatest achievement of Canada in space. Canada has acquired key capabilities in teleoperated robotic, which will be required for any future international collaboration.

5. Cooperation for several of previously mentioned options simultaneously

Canada is not focused on one specific space exploration domain and has a strong interest in both capability acquisition programs and scientific cooperation. Simultaneous contributions to several bilateral programs are limited by the financial resources of the CSA but are not to be excluded, notably for the participation to scientific missions.

Cooperation Opportunities with Canada									
Opportunity	**Cooperation Enablers**			**Cooperation Benefits**				**Rating**	
	Common objectives	**Mutual synergies**	**Accessibility**	**Economical benefits**	**Political Benefits**	**Industrial benefits**	**Scientific benefits**	**Total score**	**Opportunity value**
Joint robotic mission to a planetary body	**3** Main goal is partner with others nations	**2** Key robotic capabilities	**3** Canada is ESA associate member	**1** Limited contribution only	**1** Long-time partner of Europe	**0** No particular benefits to cooperation	**0** No particular benefits	**15%**	Limited
Joint development of a scientific mission	**3** Science key objective of Canada	**0** Not enough budget	**-**	**-**	**-**	**-**	**-**	**-**	Not accessible
Scientific cooperation at instrument level	**3** Science key objective of Canada	**1** No particular synergies	**3** Canada is ESA associate member	**1** Only small economic benefits	**1** Long-time partner of Europe	**0** No industrial benefits to this cooperation	**0** No scientific benefits for Europe	**13%**	Limited
Cooperation for Human spaceflight activities	**3** Ambitions in Human spaceflight	**0** No budget on both sides for coop.	-	-	-	-	-	**-**	Not accessible

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND CHINA

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

China is currently developing the next step of its staged program to the Moon, with the launch of a Lander and a Rover on the Lunar surface. As ESA has also planned several missions to the moon, for which the funding might not be available, both agencies certainly have common objectives.

Though the Chinese industry has progressed enormously over the past decade, the European industry still has more experience and flight heritage in several areas such as probe robotic mechanisms and in-space propulsion, which could improve the profile of a joint mission and its ambitions. However, the main purpose of the Chinese exploration program is to acquire capabilities so that it is dubious that the CNSA would let European stakeholders play a significant role in a Chinese-led mission as it would mean fewer capabilities acquired for the Chinese industries. As China does not have financial pressure on its exploration program, incentives for cooperation are relatively limited.

Moreover, a joint robotic mission would probably not be accessible for European stakeholders, since China is known for requiring considerable technology transfers before agreeing to any cooperating activity. This demand has already prohibited several cooperation in the scientific area from happening and should therefore even more preclude any mid-term cooperation for robotic missions involving strategic capabilities.

Another factor limiting the possibilities of cooperation with China is the extra-territoriality of the ITAR regulations. European-made space systems generally include US-made components, such as valves and electronic components notably, which subject the whole European system to ITAR regulations, and therefore prohibit export to China, or launch with a Chinese rocket. This limits considerably the cooperation potential with China, to non-critical, European-made elements only.

2. Joint development of a scientific mission

Enablers for the cooperation

As for capability-driven robotic missions, large cooperation activities in the scientific areas, such as the joint development of a mission are to be excluded as they would not be accessible, at reasonable conditions, for European stakeholders.

Cooperation in the scientific area is therefore limited to the provision of scientific instruments, by one party, to be fitted on a spacecraft developed by the other party.

China currently focuses on capability-driven missions and has a relatively limited science program. However, all its missions, to the Moon notably, are fitted with a scientific payload, which provides several flight opportunities for scientific instruments developed by European national space agencies, laboratories and universities.

However, such opportunities are limited to low-tech equipments as China also requires significant technology transfers for scientific instruments. This requirement already led to the abortion of cooperation opportunities for high-tech European scientific instruments such as seismic sensors.

Germany nevertheless managed to agree with China for a scientific cooperation on Shenzhou-8, which was fitted with bio-incubators developed by German scientists for life-science experiments, so that potential future cooperation in this area are not to be dismissed.

Chinese stakeholders could also provide scientific instruments to ESA.

Economic benefits

Fitting European-made instruments into Chinese spacecraft may bring economic benefits as it provides low-cost flight opportunities to European stakeholders. However, in most of the cases, a dedicated mission would not have been launched by Europe on its own so that the actual economic benefits are relatively limited.

The integration of Chinese instruments within ESA spacecraft would only derive small economic benefits for Europe as the contribution of the CNSA would be limited.

Political benefits

Cooperation with China is politically beneficial as very few missions have been conducted in cooperation by Europe and China until now. Cooperating with China for any kind of space activity sends a signal, demonstrating the feasibility such a collaboration. However, the media fallout would be modest given the scientific profile of the mission and the limited contribution of Europe.

Industrial benefits

There are no particular industrial benefits to a scientific cooperation with China. The potential flight opportunities would only be for low-tech instruments and would not allow the European industry to acquire new capabilities.

Scientific benefits

The scientific benefits that may be derived from cooperation on a scientific mission are consequential as the scientific results acquired by the European community would not have been obtained otherwise. However, it is possible that the Chinese partners require access to any scientific results derived, so that there would be no exclusivity for European scientists.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

Europe and China have substantial common objectives in the Manned spaceflight area as China intends to send manned flights to the moon to set up a lunar man-tended base by 2030 and to land on Mars by 2050.

However, as for potential robotic missions, cooperation opportunities for manned spaceflight activities would most likely not be accessible to European stakeholders, either because of the Chinese requirements of technology transfers or because of US-made components, software or technologies.

4. Multilateral cooperation for large scale projects

China, which is not a partner to the ISS, has joined the ISECG initiative from the start, sending signals that it was willing to cooperate with other space faring nations. However, given the impossibility for the US to cooperate with China, it is particularly unlikely that the CNSA will be allowed to participate to any international initiative involving the actual development of space systems in the midterm, unless the ITAR regulations are relaxed beyond what is actually being discussed in the US.

5. Cooperation for several of previously mentioned options simultaneously

Only small-sized scientific programs may be conducted in cooperation with China. The CNSA does only launch few robotic missions (one every 2-3 years), so that most of the slots for scientific instruments will probably be reserved for Chinese instruments. This does therefore not provide many opportunities for European stakeholders. However, there might be more potential for life-science and microgravity experiments onboard the Shenzhou program, which is launched on a more regular basis.

Cooperation Opportunities with China									
Opportunity	**Cooperation Enablers**			**Cooperation Benefits**				**Rating**	
	Common objectives	**Mutual synergies**	**Accessibility**	**Economical benefits**	**Political Benefits**	**Industrial benefits**	**Scientific benefits**	**Total score**	**Opportunity value**
Joint robotic mission to a planetary body	**2** Strong common objectives	**1** Potential complementarities	**0** Chinese requirements of techno. Transfers + ITAR	-	-	-	-	-	Not accessible
Joint development of a scientific mission	**1** China focuses on capability acquisition	**1** Potential complementarities	**0** Chinese requirements of techno. Transfers + ITAR	-	-	-	-	-	Not accessible
Scientific cooperation at instrument level	**1** China focuses on capability acquisition	**2** Potential European flight opportunities	**1** Only for low-tech sci. payloads	**2** Low cost flight opportunities	**2** New but low-profile missions	**0** Essentially for science stakeholders	**2** Only low-tech instruments	**20%**	Limited
Cooperation for Human spaceflight activities	**2** Strong common objectives	**1** Potential complementarities	**0** Chinese requirements of techno. Transfers + ITAR	-	-	-	-	-	Not accessible

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND INDIA

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

The objectives of ISRO after the launch of the lunar mission Chandrayaan-2 are unclear. The launch of Chandrayaan-2 was recently postponed from 2013 to 2016 both due to the necessity for Russia, who partners with India for the mission, to review its lander following the failure of Phobos-Grunt ; and to the successive failures of the Indian GSLV launcher, which needs to be successfully qualified twice before being used to launch Chandrayaan-2.

India therefore changed its strategy and now aims at developing a Mars orbiter, which recently obtained funding from the Indian parliament, and which could be launched by PSLV-XL. The objectives of ISRO are therefore entirely compatible with the European ones. However, the main purpose of the Indian program is to acquire capabilities so that India is not likely to partner with Europe on a mission that would consign the India participation to a mere secondary role.

If India was to cooperate with ESA, it should therefore have the same kind of agreement that ISRO had with Russia for Chandrayaan-2: a joint capability-driven mission where each of the partners provide a key element to the mission.

The Indian capabilities in space exploration are still nascent and do not include any element that is not mastered by Europe. However, Europe could support the Indian efforts at earning capabilities in key areas (cryogenic rocket engines, surface mobility and in-situ remote sensing instruments notably).

European stakeholders however, are expected to be particularly reluctant to help India acquire capabilities, especially in the launcher area, since they are not keen on supporting the emergence of a new low-cost launch service provider on the commercial market. Potential technology transfers from Europe to India would therefore only apply to less critical technologies.

Economic benefits

The economic benefits of a joint-robotic mission, for which both ISRO and ESA provide key components are obvious since it would divide the costs of the missions for both partners. However, the contribution of India is expected to be limited since the country focuses its financial efforts in the space area on the development of GSLV and has only few resources available for robotic exploration.

Political benefits

A cooperation between ISRO and ESA for the development of a robotic mission would particularly improve the relationship of both partners. India is considered to be resenting the lack of support of other space faring nations for the development of GSLV, which might be partly offset by a collaboration in the space exploration area. Moreover, there has been relatively little collaboration between both agencies in the past so that the potential political benefits of a large-scale project are still to be earned.

Industrial benefits

While India is eager to master basic exploration capabilities, such as in-space propulsion, Europe is seeking to acquire very targeted capabilities. In case of a joint large mission, the industrial benefits for Europe could be particularly significant since Europe could let India develop the capabilities and elements already mastered by European stakeholders and focus on elements that it wishes to acquire, such as soft landing technologies or electric propulsion. This complementarity of industrial objectives provides for a good basis for cooperation.

India could require a technology transfer from Europe, which might be an issue for European industrial stakeholders. Without handing over critical technologies, Europe could support the R&D efforts in India by supervising the development of the Indian contribution, which would also improve the reliability and the safety of the mission.

Scientific benefits

There are only few scientific benefits to be derived from such a cooperation as this would not be the main focus of the mission. The spacecraft would certainly be fitted with a scientific payload but it would be shared by European and Indian scientists so that the scientific benefits would not be higher than for a smaller mission solely conducted by Europe.

2. Joint development of a scientific mission

Enablers for the cooperation

Science is currently not the focus of the Indian space program, which is more oriented towards capability acquisition. The potential joint development of a large scientific mission is therefore to be dismissed.

Moreover, following the Chandrayaan-1 experience, where Indian scientists felt that they did not receive the credit they derserved due to the US strong abilty to communicate on the scientific results of its instruments, it is unlikely that India will accept high-tech foreign payloads onboard its future spacecraft.

The only remaining option in the scientific area is therefore the inclusion of an Indian payload onboard a European-built spacecraft. However, this cooperation would only derive small economic benefits for Europe and has been detailed extensively previously in the present study for other countries so that the potential benefits of such a cooperation will not be detailed hereafter.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

India has strong ambitions in the manned spaceflight area but lacks the funding to support these ambitions. Current efforts are currently oriented towards the development of the ISRO Orbital Vehicle, in cooperation with Russia.

Given Europe's lack of autonomous experience in the manned spaceflight area and the current financial context, the perspective of collaboration between Europe and India in the Manned spaceflight area is basically inexistent.

4. Multilateral cooperation for large scale projects

Over the past decade, India has essentially developed its relationship with Russia in the space exploration area. Though India was invited in 2011 to join the ISS, cooperation in this area has not materialized due to lack of financial resources on ISRO's side. However, the participation of India to future international initiatives is to be seriously considered. India will have more resources available once the development of GSLV is completed and could use this new budget to join a large multilateral cooperation.

5. Cooperation for several of previously mentioned options simultaneously

Currently, only the development of a joint capability-driven mission seems to be accessible for a cooperation between India and Europe. The limited financial resources of ISRO do not allow the simultaneous development of several exploration missions.

Cooperation Opportunities with India									
Opportunity	**Cooperation Enablers**			**Cooperation Benefits**				**Rating**	
	Common objectives	**Mutual synergies**	**Accessibility**	**Economical benefits**	**Political Benefits**	**Industrial benefits**	**Scientific benefits**	**Total score**	**Opportunity value**
Joint robotic mission to a planetary body	**2** Common objectives but unclear strategy	**1** Indian capabilities only nascent	**2** No experience for large missions	**2** Indian contribution should be limited	**3** New cooperation for large project	**3** Breakdown of tasks could be favorable	**1** Only small benefits to cooperation	**43%**	Good
Joint development of a scientific mission	**0** Focus on capability-driven missions	**-**	**-**	**-**	**-**	**-**	**-**	**-**	Not accessible
Scientific cooperation at instrument level	**1** Not key focus of India	**1** No particular synergies	**3** Not expected to be an issue	**2** Low cost flight opportunities	**2** New but low-profile missions	**0** Essentially for science stakeholders	**2** Limited to low-tech payloads	**25%**	Limited
Cooperation for Human spaceflight activities	**2** Strong common objectives	**0** No budget available	**-**	**-**	**-**	**-**	**-**	**-**	Not accessible

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND JAPAN

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

Japan is engaged in a three-stage Lunar program with the development of the Selene-2 rover, a sample return mission (Selene-X) and finally the participation to international manned missions to the moon, with Japanese crew and Japanese robotic technologies. Japan is also involved in the ISECG initiative. These objectives present strong complementarities with ESA programs.

Both Japan and Europe have earned strong industrial capabilities in the robotic area due to their recent missions. The capabilities acquired by NEC notably, in the electric propulsion and electronics areas could complement European capabilities. Synergies also exist at budgetary level since both agencies are facing strong financial constraints due to the financial and debt crisis. However, these pressures make the mission particularly subject to cancellation risks, which can be triggered by each of the partners.

Accessibility of the cooperation opportunity should not be an issue as JAXA is currently developing missions with ESA, notably BepiColombo. However, lack of experience could cause minor difficulties.

Economic benefits

The budgetary pressures on JAXA and ESA are a strong inhibitor for reaching the respective objectives of the agencies in the exploration area. Cost- and risk-sharing is therefore of utmost importance for both parties and would allow them to reach their objectives in spite of their financial difficulties.

Political benefits

Japan is a long-time partner of Europe so that the political benefits to be derived from a robotic cooperation are relatively limited. However, cooperation for a large-sized robotic mission to the Moon would necessarily bring political benefits and improve the relationship between Europe and Japan.

Industrial benefits

There would probably be no technology transfer involved in a joint robotic mission between Europe and Japan. However, the industries of both parties would develop capabilities as part of their contribution to the mission and therefore acquire new competences, which would not have been acquired without the cooperation as Europe would have had to develop the entire system on its own.

Scientific benefits

The developed spacecraft would be fitted with scientific instruments and therefore derive strong scientific results, that would not have been obtained without the cooperation.

2. Joint development of a scientific mission

Enablers for the cooperation

One of the main objectives of the Japanese Basic Plan for Space Policy is to continue to lead space science missions in order to achieve world-leading scientific results. Japan should therefore be particularly interested in cooperation in the scientific area. ESA and JAXA have also common scientific objectives, they notably proposed to partner for the MarcoPolo-R mission, an asteroid sample return mission. Synergies for a joint scientific mission are essentially budgetary, since both agencies have been facing strong economic constraints. As mentioned earlier, accessibility should not be an issue for a joint mission as both agencies have already cooperated in the past.

ESA and JAXA could also decide to cooperate through the provision of scientific instruments by one country to be fitted on a spacecraft developed by another agency, in order to have more flight opportunities for their respective scientific stakeholders.

Economic benefits

ESA scientific budget is not particularly at risk as it is based on the mandatory contributions of its member states. Cooperation with Japan would allow to increase the objectives of the mission with the same budget, or to conduct a mission that could not have been done within the budgetary limits of each ESA scientific mission category. ESA could notably likely not conduct an ambitious asteroid sample return mission on its own as part of the M-class mission category (which can receive up to €470 million), without partnering with another space agency as it did with Japan for MarcoPolo-R.

The provision by JAXA of scientific instruments for an ESA mission would derive small economic benefits as JAXA would only contribute at a small level to the mission.

Political benefits

As mentioned previously, the political benefits to be derived from such a cooperation would be limited as both countries have already cooperated extensively in the past.

Industrial benefits

If the cooperation involves the joint development of a large scientific mission, the industrial benefits could be significant since both agencies have the capabilities to develop all the critical elements of the mission and could therefore focus their contributions on elements they do not master to acquire specific capabilities. The breakdown of tasks between the partners would be critical in this regard. However, this would not lead to any additional revenues for the European space industry since the ESA budget would have been spent for space exploration even without the cooperation.

If cooperation is limited to the provision of scientific instruments, the industrial benefits would be nonexistent.

Scientific benefits

The scientific benefits of a large cooperation would be considerable as it would allow ESA to obtain scientific results it could not have obtained with the same budget, since the financial and in-kind contribution of Japan would help reaching objectives that would have been out of reach otherwise.

The provision by European scientific stakeholders of scientific instruments to be fitted onboard JAXA missions would derive significant scientific benefits at a relatively low cost, and increase the number of flight opportunities offered to the scientific community.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

Neither Japan nor ESA has led an autonomous human spaceflight program on its own in the past. As Europe, Japan was kept out of the ISS critical path so that none of the agencies have all the capabilities required for Human Spaceflight activities. A potential bilateral cooperation in this area is therefore to be ruled out.

4. Multilateral cooperation for large scale projects

Japan was one of the partners for the International Space Station and has developed key elements of the ISS infrastructure. It has also cooperated with all the space faring nations, excepting China and India, on a bilateral basis so that it should remain involved in any large multilateral cooperation in the future.

5. Cooperation for several of previously mentioned options simultaneously

Japan used to develop nearly all its space missions on its own. However, budgetary constraints have driven the country to turn increasingly towards international partners to reach its objectives in spite of the adverse economic context. Simultaneous cooperation for capability-driven and scientific missions is therefore not to be excluded.

Cooperation Opportunities with Japan									
Opportunity	**Cooperation Enablers**			**Cooperation Benefits**				**Rating**	
	Common objectives	**Mutual synergies**	**Accessibility**	**Economical benefits**	**Political Benefits**	**Industrial benefits**	**Scientific benefits**	**Total score**	**Opportunity value**
Joint robotic mission to a planetary body	**3** Similar objectives Moon / Mars	**2** Complementarities at different levels	**2** Lack of experience is problematic	**3** Both agencies have strong pressures	**1** Cooperation already developed	**3** Potential acquisition of significant capabilities	**3** Not attainable on own	**69%**	Very good
Joint development of a scientific mission	**3** Key objective of both agencies	**2** Complementarities at different levels	**2** Lack of experience is problematic	**3** Allows development of ambitious mission	**1** Cooperation already developed	**2** No new flow of money for EU industry	**3** Not attainable on own	**60%**	Very good
Scientific cooperation at instrument level	**3** Key objective of both agencies	**1** No particular synergies	**2** Lack of experience is problematic	**2** Low cost science missions	**1** Coop. developed; no media interest	**0** No industrial benefits to this cooperation	**3** Low cost flight opportunities	**30%**	Limited
Cooperation for Human spaceflight activities	**3** Key objective of both agencies	**0** No agency has enough capability	-	-	-	-	-	**-**	Not accessible

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND RUSSIA

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

Following years without any launch of robotic exploration spacecrafts, Russia is currently redesigning its strategy with a strong focus on Lunar exploration, through a staged approach to acquire new capabilities and prepare for future manned mission. Moreover, Roscomos is also involved within ISECG and therefore considers Mars as the ultimate destination. Given that ESA has also several planned missions for the Moon, the objectives of both agencies are entirely compatible.

The synergies between the Russian and the European industries for robotic exploration missions are multiple, but also difficult to estimate. Russia used to have strong capabilities for the development of robotic exploration spacecrafts but there are doubts regarding whether these capabilities have not be lost and may be used again for new missions. In any case, Russia has capabilities that Europe has not, such as RHUs and RTGs which are required for any long-duration exploration mission.

Regarding accessibility, Russia is the country that cooperates with the most countries in the Space exploration area, so that it is assumed that there are no regulation imposing impossible requirements. Moreover, Russia and Europe already found an agreement for the joint development of the Exomars. This agreement was found promptly right after the US withdrawal from the project and involved critical elements such as a RTG. A cooperation with Russia is therefore considered as easily accessible.

Past failures of Russian mission, and notably the Mars 96' spacecraft, to which Europe was associated, have led to a slight loss of confidence of European stakeholders in the reliability of Russian exploration missions. However, the considerable financial resources planned to be invested by Russia in robotic exploration should reassure Europe regarding the seriousness of the program.

Economical benefits

Contrary to Europe, the Russian space exploration budget is expected to experience a strong growth over the next years. Space exploration is at the front of the new Russian space policy and ambitious initiatives, also very expensive, have been planned by Roscosmos.

It is therefore in Europe's best interest to become associated to the development of these programs, especially as they might help Europe to reach its own objectives despite of the current budgetary constraints. Moreover, the risk of a unilateral withdrawal from Russia from a cooperation is more limited than with any other western country since Roscosmos exploration budget is not particularly at risk.

Political benefits

The relationship between Europe and Russia, in general terms, is far less developed that the relationship between Europe and the US for example, and their geopolitical relationship is relatively tensed on several topics. Besides the ISS, both agencies have never cooperated for large exploration projects, so that a large-scale cooperation for a joint robotic exploration mission would send a strong signal and potentially improve the relationship of the governments.

Industrial benefits

Russia has a strong industrial base, with a large heritage in space exploration. However, since the collapse of the USSR, very few exploration spacecrafts have been launched so that there are strong uncertainties regarding the current state of Russia's industrial capabilities.

However, Russia is currently oriented towards capability-driven programs, so that ESA could partner on such missions to also earn capabilities as part of these missions, similar to the current design of the Exomars mission, which allows both countries to gain new capabilities. Moreover, until the European R&D efforts succeed, ESA is dependent on either the US or Russia for all missions involving a long-duration stay of a lander or a rover on a planetary surface, as only RTGs provide sufficient power for this kind of missions. Given the current budgetary pressures on NASA space exploration expenditure, Russia may be a more reliable partner for future missions in this area.

Finally, Russia is the only country that has recently transferred, or agreed to transfer, space exploration technologies, notably to India and China. Though it is dubious that Europe could benefit from such a transfer, the possibility should not be dismissed beforehand.

Scientific benefits

As for a cooperation with the US, the main scientific benefit from a joint robotic mission would be to reach destinations that could not have been reached by Europe on its own.

2. Joint development of a scientific mission

Enablers for the cooperation

The respective objectives of ESA and Roscosmos differ significantly in this area since the majority of the missions developed by ESA are driven by scientific purposes while Russian past and future missions are more capability-oriented. The Russian space research institute (IKI) has participated to several international planetary space science missions over the past fifteen years but has not lead any mission on its own, besides the failed Fobos-Grunt. Only one planetary science mission is planned until 2020, Venera-D.

Synergies between Russian and European stakeholders are the same than for the joint development of a robotic mission. Russia has strong capabilities due to the heritage in space exploration but some of them might have been lost over the past decade.

The accessibility of a joint scientific mission is not considered as an issue. Russia has provided a significant number of scientific instruments in the past to other space powers, including Europe, so that cooperation is already well established.

Economical benefits

The Planetary Science budget of Europe is expected to remain stable over the next fifteen years, so that cooperation may be less vital for these missions than it is for capability driven exploration missions. Cooperation with Russia for a joint large scientific mission would nevertheless allow reaching a more ambitious objective than with the single resources of Europe. However, such a large cooperation is relatively unlikely in the near future since Russia is currently involved is a substantial capability-driven programs, which may not leave enough financial resources for planetary science missions.

The provision by Europe of one scientific instrument to Russia is an option that may be excluded since Russia has only one planetary science mission planned over the next fifteen years and European stakeholders are not associated to its development.

However, Russian scientists, which are plausibly eager to find mission opportunities, are in a position to provide instruments to European missions, as is the case for BepiColombo, in exchange for a small financial participation.

Political benefits

The political benefits of a scientific cooperation would be less important than for a capability-driven mission, especially if the Russian contribution is limited to the provision of one scientific instrument. However, such as cooperation would strengthen the relationship of both scientific communities.

Industrial benefits

Any contribution of Russia for a scientific mission (joint development or single instrument), would be developed by its own industry, so that the benefits for Europe, in terms of revenues are inexistent. As for a joint robotic mission, real industrial benefits would be derived from a favourable breakdown of tasks for Europe, which would allow the European industry to acquire new capabilities.

Scientific benefits

Considering that the only plausible option for scientific cooperation with Russia is the provision by Russia of a scientific instrument to be fitted on a European mission, the scientific benefits for Europe would be extremely limited.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

The objectives of Russia and Europe are being particularly similar in this area since both agencies view Mars as the ultimate destination and the Moon as the first step of this enterprise. Russia has an ambitious manned lunar program, involving the development of a lunar base, to which Europe could potentially become associated

Synergies in Human Spaceflight area result from the experience acquired through the ISS. Russia is among the most advanced nation in this field and is capable of providing all required elements and capabilities. Europe has gained strong competences through its participation to the Space station, though most of them are also mastered by Russia.

Economical benefits

Europe on its own would not be in a position to finance any large human spaceflight initiative. Cooperation is therefore of essence for Europe. The Russian planned program is expected to be particularly costly so that Russia might welcome a European financial contribution to the program.

However, Europe would probably have to become associated to Russia at the start of the program, whose first elements are scheduled for launch in 2020. This means that early developments would need to be financed in parallel to the ISS, which may be complicated for ESA, which is already struggling to decrease its ISS Expenditure.

Political benefits

The participation of Europe to a lunar human exploration program, with a permanent lunar settlement, would draw significant benefits. The public interest for such a mission would probably be much higher than for the International Space Station and the close cooperation with Russia would be a new elements from which additional political benefits could be derived.

Such a bilateral cooperation with Russia for a colossal project would certainly draw strong criticism from third-party nations, as the positions of Europe and Russia differ on significant issues, such as Human rights, military interventions in countries led by authoritarian regimes and other foreign policy elements. The US notably may not entirely approve of a bilateral Europe-Russia lunar exploration program, but these criticisms seem surmountable, especially as Europe would not be financially involved to the same extent than Russia on this program.

Industrial benefits

As the US, Russia has kept Europe out of the critical path of the ISS cooperation until now, ensuring that none of its contributions were vital for the station and making sure that full redundancy was guaranteed.

If Europe was to cooperate with Russia on its future Lunar program, the breakdown of the tasks could be entirely different and allow Europe to acquire capabilities that it currently lacks, such as soft and precision landing.

Scientific benefits

As Europe would not be able to lead a large Human Spaceflight program on its own, a cooperation with Russia would certainly have significant scientific benefits. No scientific results would actually be derived without such a cooperation.

4. Multilateral cooperation for large scale projects

Russia was the second largest partner for the International Space Station. It was the only country, with the US, which provided the vital modules of the station. Russia notably provided the Zarya and Zvezda module, which respectively provided electrical power, storage, propulsion, and guidance to the ISS during the initial stage of assembly; and provide all the station life support system.

Russia is therefore a key partner of any large international cooperation, if only due to its large industrial capabilities and heritage of exploration missions.

Moreover, Russia is the country that cooperates with the largest number of countries, including notably China and India and may therefore manage to federate all the space faring nations into a single endeavour.

5. Cooperation for several of previously mentioned options simultaneously

Russia has developed an extensive lunar program, involving robotic missions to prepare for future manned exploration and to set up the first infrastructure elements required for any human presence. This program will probably mobilize the bulk of the Space exploration resources available in the next decades, it is therefore dubious that Russia will join Europe on a large scientific program.

Cooperation Opportunities with Russia									
Opportunity	**Cooperation Enablers**			**Cooperation Benefits**				**Rating**	
	Common objectives	**Mutual synergies**	**Accessibility**	**Economical benefits**	**Political Benefits**	**Industrial benefits**	**Scientific benefits**	**Total score**	**Opportunity value**
Joint robotic mission to a planetary body	**3** Similar objectives Moon / Mars	**2** Strong synergies between partners	**3** Coop. worked well in the past	**3** Russian exploration budget booming	**2** Cooperation not very developed	**3** Potential acquisition of significant capabilities	**3** Not attainable on its own by Europe	**84%**	Excellent
Joint development of a scientific mission	**1** Russia focuses on capabilities	**2** Significant synergies	**3** Coop. worked well in the past	**1** Resources limited since not a priority	**2** Cooperation not very developed	**2** No new flow of money for EU industry	**2** Potentially more ambitious missions	**37%**	Limited
Scientific cooperation at instrument level	**1** Science not key objective of Russia	**2** Russian labs seek flight opportunities	**3** Coop. worked well in the past	**1** Small contribution for Europe	**1** Cooperation very limited	**0** Essentially for science stakeholders	**1** Instrument from Russia to Europe only	**15%**	Limited
Cooperation for Human spaceflight activities	**3** Similar objectives Moon / Mars	**3** Strong synergies between partners	**3** Coop. worked well in the past	**3** Cooperation is essential in this area	**3** Public interest may be very strong	**2** Europe generally kept out of critical path	**3** Cooperation is essential	**89%**	Excellent

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND SOUTH KOREA

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

The ambitious Korean objectives in space exploration have been handicapped by the lack of financial support from the Korean government. As India, Korea is funding a launcher development program that is mobilizing nearly all resources available (up to 92% of KARI budget).

KARI initially intended to develop a Lunar orbiter by 2020 and a Lunar lander by 2025. These objectives have been downsized to focus on a Korean contribution to bilateral missions in order to acquire capabilities.

These objectives are entirely compatible with ESA intent to launch one or several Lunar missions next decade. Synergies are almost inexistent as of today since Korea does not have any experience in space exploration yet. The contribution of Korea to a European-led mission would therefore necessarily remain modest. However, Korea has proven in other application areas, and especially in Earth Observation through the development of the Kompsat program, that it had the industrial and scientific resources to acquire key capabilities if the government is pushing forward the programs.

Korea has never cooperated with ESA for any missions in the past. Its main partners until now have been Russia, which has supported the development of the KSLV launcher, and the US, with which KARI intend to develop a Lunar Impactor program. However, KARI has successfully cooperated with European prime integrator Astrium for the development of the Kompsat-2 satellite and with Thales for the SAR payload of Kompsat-5 so that a cooperation between ESA and KARI seems feasible.

Economic benefits

Given the financial burden of the KSLV launcher development, KARI does not have significant resources to commit to space exploration activities. A contribution to an ESA mission will therefore only derive small economic benefits for Europe.

Economical benefits could be more important if Europe was to participate to a technology-transfer program with Korea, supporting its R&D efforts to acquire capabilities in space exploration.

Political benefits

Cooperation between Europe and Korea in space exploration could derive significant political benefits for Europe, especially if European stakeholders are supporting the acquisition by Korea of capabilities in this area. However, these benefits would be limited by the modest size of the Korean contribution.

Industrial benefits

European industrial stakeholders would not benefit much from a participation of Korea to an ESA mission. Since Korea does not master any key capabilities, Europe would have to develop almost all the mission on its own and could therefore not acquire more capabilities than if it had conducted the mission on its own.

Scientific benefits

The benefits of such a cooperation for scientific stakeholders would be nonexistent.

2. Joint development of a scientific mission

Enablers for the cooperation:

Korea is currently more interested in acquiring capabilities than in developing missions for scientific purposes. Collaboration between ESA and KARI could imply the provision of one Korean-made scientific instrument to a European space agency but the benefits for Europe of such a scientific cooperation have already been analysed for other countries and will therefore not be repeated hereafter, especially as they essentially consist in a modest financial contribution from KARI to the European stakeholder leading the mission.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation:

Cooperation between ESA and KARI in the manned spaceflight area is not to be considered as none of the agencies has the resources to conduct a large program on its own. Moreover, the Korean manned spaceflight, which essentially consists in the training of two astronauts, is conducted in cooperation with Russia.

4. Multilateral cooperation for large scale projects

Korea has demonstrated its ambition to join international initiatives in space exploration by joining the ISECG forum. Though it does not possess any capability in space exploration yet, a Korean participation to an international program could be envisaged and could be a valuable solution for it to acquire competences in this area.

5. Cooperation for several of previously mentioned options simultaneously

Given the modest resources of Korea dedicated to space exploration and its ambition to acquire capabilities, it is expected that Korea will initially focus on one single cooperative program in order to maximise the benefits it can derive from the cooperation.

Cooperation Opportunities with South Korea

Opportunity	Cooperation Enablers			Cooperation Benefits				Rating	
	Common objectives	Mutual synergies	Accessibility	Economical benefits	Political Benefits	Industrial benefits	Scientific benefits	Total score	Opportunity Value
Joint robotic mission to a planetary body	**2** Objective of Lunar missions	**1** No capabilities but industrial potential	**1** No past experience	**1** Only small financial contribution for coop	**3** Strong benefits if ESA supports R&D	**0** No industrial benefits for Europe	**0** No scientific benefits	**12%**	Limited
Joint development of a scientific mission	**0** Korea focuses on capability acquisition	**-**	**-**	**-**	**-**	**-**	**-**	**-**	Not accessible
Scientific cooperation at instrument level	**1** Science not key objective of Korea	**1** Limited synergies and budgets	**1** No past experience	**1** Small contribution for Europe	**1** Cooperation very limited	**0** Essentially for science stakeholders	**1** Only if Europe has access to results	**7%**	Limited
Cooperation for Human spaceflight activities	**2** Common objectives exist	**0** No agency has enough budget	**-**	-	-	-	-	**-**	Not Accessible

COOPERATION OPPORTUNITIES BETWEEN EUROPE AND THE US

1. Joint robotic mission to a planetary body to prepare for future manned activities

Enablers for the cooperation

NASA, ESA, CNES, ASI, DLR and UKSA share the same goal of preparing future human activities by developing robotic technologies and capabilities. As part of the ISECG forum, all agencies agree that Mars is the ultimate goal for human exploration. However the US leans in favour of asteroid missions, which match the objectives of its 2010 Space policy, while ESA currently focuses more on Moon missions.

Regarding synergies, it seems clear that the European contribution to a cooperation of this extent would only be led by ESA and not by national space agencies, which do not have the resources to conduct such large technological programs. Incentives for cooperation between ESA and NASA are multiple as both agencies suffer from strong budgetary limitations. Both agencies have a strong domestic industrial base, covering most of the technology areas required for such a mission. However the US industry has unique capabilities that could be required for such a mission that Europe does not possess such as soft and precision landing and nuclear power sources.

Finally, regarding accessibility, interviews with European stakeholders have shown that ITAR export control regulations could be an issue for any cooperation with the US but that workarounds to these regulations could be found if the US were really committed to the mission.

Moreover, both agencies already cooperated in the past, and were initially supposed to cooperate for a Mars mission until the US withdrew for budgetary reasons, so that the accessibility of the opportunity may be considered as satisfactory.

The application of ITAR to space product and technologies may be soon reformed deeply as US Senate Bill 3211, currently being debated in the US, would allow the President to declassify satellites and related items from the ITAR regulations, thus facilitating export and cooperation. China however, would remain barred from any cooperation, even scientific cooperation, with the US.

Economical benefits

The economical benefits of a cooperation for a capability-driven joint robotic mission between ESA and NASA are particularly obvious. Both agencies suffer from the current economic environment so that budgetary cuts are anticipated for both agencies in the near-term. Capability-driven robotic exploration should be particularly impacted by these cuts as the agencies have difficulties to convince their financial backers of the interest of such missions over more operational programs.

Given the high costs of these missions (Exomars is expected to cost ESA at least €1.2 billion), both agencies are eager to find partners to share the development costs. However, as the US recently pulled out of two robotic missions, ESA will probably want to limit its involvement to 20% of the mission if the mission is led by NASA or remain in control of at least 80% of the mission if it leads the mission.

Political benefits

The political benefits of such a mission are limited. ESA and NASA already planned a joint robotic mission with Exomars, so that the diplomatic credit gained by this type of mission was already acquired at this time. NASA's unilateral decision to withdraw from the program may have damaged its own credibility but the reputation of Europe should not have been damaged.

Moreover, the experience with the US have proved that cooperation does not necessarily create sustainability and that cooperative programs were not safer from cancellation that others.

Regardless, NASA's strong ability to communicate and interest the public may also benefit to ESA as European medias may be more inclined to cover the mission than if it were conducted in cooperation with another country. The media coverage of MSL in Europe for example was far more important than for similar European missions, even though the European contribution was minor and did not involve ESA.

Industrial benefits

The industrial benefits that Europe could derive from a joint capability-driven robotic mission depend on the breakdown of tasks between the partners. In any case, Europe will derive industrial revenues benefiting in the end to the industry. But additional benefits, in terms of capabilities, could be derived if the partners split the mission's building blocks so that ESA can acquire new capabilities. In the initial design of Exomars, Europe was responsible for developing a demonstration Lander, which is a capability currently not mastered by Europe.

The industrial benefit derived from such a cooperation scheme is particularly high. If Europe was to lead a large mission on its own, the development of the spacecraft' basic elements would engulf the entire mission budget and leave few resources for the acquisition of "new" capabilities.

As the US is the most advanced nation regarding space exploration capabilities, the potential industrial benefits from Europe are potentially consequential as Europe is not forced to develop a specific element that its partner could not develop on its own.

Scientific benefits

A cooperation in this area has potentially high scientific returns as it allows Europe to send a scientific payload to a destination where it may not have been able to go if the mission had been led solely by Europe. The conditions under which the payload will perform its role, for example onboard of a Mars Rover, would also probably not be attainable through a unilateral mission.

2. Joint development of a scientific mission

Enablers for the cooperation

US and European agencies all have scientific exploration programs, based on a bottom-up selection process. The development of a large scientific mission would probably be coordinated by ESA on the European side, as was the case for the cancelled mission ESJM-Laplace. However, ESA Member States could also cooperate directly with NASA for the provision of scientific instruments to be fitted onboard US scientific missions.

Synergies between the countries are particularly high depending on their specific scientific skills. France for example, has a key capability in seismometers and chromatographs, while Italy already provided spectrometers for US scientific missions.

The question of accessibility is the same than for a joint robotic mission, where even for the simple provision of an instrument, ITAR complicates the discussions and negotiations. But it can be facilitated if the US are really committed to the cooperation. National space agencies in Europe have provided instruments for US scientific missions repeatedly in the past and established a good relationship with NASA JPL. A reform of ITAR would considerably facilitate cooperation.

Economical benefits

Though ESA science budget should not be particularly impacted by potential budgetary cuts since it is financed through the mandatory program, a large scientific cooperation between the US and ESA would naturally allow sharing the mission costs, which can be very high for scientific mission (BepiColombo costs nearly €1 billion to ESA alone) and therefore design missions with a more ambitious scientific objective.

The provision by one European country to the US of a scientific instrument may also provide economical benefits if the country would have ended up developing a mission on its own to launch this instrument if it had not cooperated.

Conversely, the provision by a US laboratory or academia of a scientific instrument to be fitted on an ESA spacecraft would slightly reduce the cost of the whole mission for Europe.

Political benefits

Political benefits derived from scientific missions are less important than for capability-driven missions as the media coverage is generally less significant. Moreover, given the large number of transatlantic cooperation activities already led in the past, the diplomatic credit that could derived from scientific cooperation has already been acquired.

Industrial benefits

In terms of revenues and workforce, the industrial benefits derived from a scientific cooperation with the US are relatively limited since the scientific expenditure of ESA is stable and would not increase in case of cooperation. As for a joint robotic mission, real industrial benefits would be derived from a favourable breakdown of tasks for Europe, which would allow the European industry to acquire new capabilities.

Scientific benefits

The scientific benefits derived from a scientific cooperation with the US could potentially be particularly high. The US have a large scientific budget, which, coupled with ESA science expenditure, allows the development of very ambitious missions. In this regard, the US are probably the best partner that ESA could find as other nations are generally more driven by capabilities (Russia, China, India...) or have lesser science budgets.

The scientific return of the provision by a European country of a scientific instrument to be fitted on a US spacecraft is very high since it provides a flight opportunity for a laboratory at a relatively small cost. Conversely, the inclusion of a US instrument on a European spacecraft has a negative scientific effect since it reduces the number of slots available for European scientists.

3. Cooperation for Human Spaceflight activities

Enablers for the cooperation

The cooperation enablers are about the same than for the joint development of a capability-driven robotic mission. The US and Europe share the same general goal of a manned mission to Mars but may differ on the preliminary steps to be accomplished. However, synergies in Human Spaceflight are higher than in the robotic area as both nations have specialized in specific areas for the ISS partnership.

Economical benefits

Cooperation for Human Spaceflight activities is essential given the colossal costs of such activities. Europe would not be in a position to finance any independent initiative in this area so that cost-sharing is a requirement for any European project.

Political benefits

The public interest in Europe for the ISS has relatively faded over the past decade. A new project, with a planetary focus for example could rekindle the public enthusiasm. However, as for all cooperation activities with the US, the political credit earned through the cooperation would be lower than with a emerging country for example, since both agencies have already cooperated extensively in the past.

Industrial benefits

The industrial benefits derived from cooperation in Human Spaceflight are particularly consequential. The ATV for example, was entirely developed as part of the ISS cooperation and allowed the European industry to gain key capabilities in several technology areas such as rendez-vous and docking.

The problem with past cooperation with the US in this area is that they kept Europe out of the "critical path" of the cooperation, meaning for example that without European modules, the ISS would still be functioning, contrary to the US and Russian contributions. Moreover, the redundancy required for human exploration decrease the value of the European contribution: most nations involved in the ISS have also developed, or are currently developing, a cargo resupply vehicle. This slightly decreases the value of the cooperation as Europe will only be able to acquire annex capabilities and not be integrated as a vital partner.

Scientific benefits

The scientific benefits of a joint program in human spaceflight are very large since they can only be attained through cooperation due to the colossal costs of Human space infrastructure. The US has the capability to provide the service modules that are required for any scientific laboratory, as it is the case for the European Columbus laboratory on the ISS.

4. Multilateral cooperation for large scale projects

The US is an essential partner for any large-scale multilateral cooperation, if only due its unequalled financing capability. The US participates actively to all international fora on space exploration, to the point where several other nations feel that the US tends to impose its own objectives as part of these organizations.

However, the ITAR regulations are particularly restrictive when cooperating with some of the other largest space nations. Adding China to the multilateral cooperation for example can prove almost impossible since the US cannot cooperate, even for scientific missions, with any Chinese organizations. China called for a relaxing of the ITAR rules for Human spaceflight in 2011 but to no avail. China is also a member of ISECG and was initially eager to cooperate but this will not happen before the US revise their export control policy.

5. Cooperation for several of previously mentioned options simultaneously

The US is the country with the largest space exploration budget, far ahead any other nations. Its ability to participate to simultaneous missions in cooperation with Europe is therefore not questioned. Current budgetary pressures could be a driver for future cooperation, but the recent withdrawal from the Exomars and EJSM-Laplace missions may have damaged the US credibility.

Cooperation Opportunities with the US

Opportunity	Cooperation Enablers			Cooperation Benefits				Rating	
	Common objectives	Mutual synergies	Accessibility	Economical benefits	Political Benefits	Industrial benefits	Scientific benefits	Total score	Opportunity Value
Joint robotic mission to a planetary body	**2** General objectives shared	**2** Strong synergies between partners	**3** If ITAR is modified for space techno.	**3** Budgetary pressures in both countries	**1** Cooperation already developed	**3** Potential acquisition of significant capabilities	**3** Not attainable on its own by Europe	**69%**	Very good
Joint development of a scientific mission	**3** Science key focus of both agencies	**2** Strong synergies at payload level	**3** If ITAR is modified for space techno	**3** Allows development of ambitious missions	**1** Cooperation already developed	**2** No new flow of money for EU industry	**3** Much more ambitious missions	**69%**	Very good
Scientific cooperation at instrument level	**3** Easy to find lab. or univ. for cooperation	**3** Strong past experience	**3** If ITAR is modified for space techno	**2** Low cost science mission	**1** Cooperation already developed	**0** Essentially for science stakeholders	**3** Provides low cost flight opportunity	**44%**	Good
Cooperation for Human spaceflight activities	**2** General objectives shared	**3** Strong past experience	**3** If ITAR is modified for space techno	**3** Cooperation is essential in this area	**2** New coop. could rekindle interest	**2** Europe generally kept out of critical path	**3** Cooperation is essential	**83%**	Excellent

Section 5:

Conclusions

OPPORTUNITIES FOR EUROPE BY TYPE OF MISSION

1. Introduction

As part of the benefit analysis performed in Section 4, cooperation opportunities between Europe and its potential partners were assessed for the following four types of missions.

Type of mission	Opportunity
Capability-driven	Joint robotic mission to a planetary body for preparing future manned activities
Science-driven	Joint development of a scientific mission
Science-driven	Provision of a instrument to be fitted in a larger scientific mission
Manned Spaceflight	Cooperation for future Human spaceflight activities (parallel or post-ISS)

The benefits of these cooperation opportunities were evaluated based on the methodology described on page.

In the present section, the cooperation opportunities are summarized by type of missions and ranked by country. This ranking will allow identifying the opportunities with the strongest potential benefits for Europe. This analysis, completed by a SWOT of the European space exploration program, will lead to the identification of the top five cooperation opportunities, which implementation model will be detailed afterwards.

2. Joint robotic mission to a planetary body to acquire capabilities and prepare for human spaceflight

Country	Result	Comments
Russia	**84%**	Best opportunity for this type of mission due to the huge investment of Russia in robotic programs and potentially similar objectives of Roscosmos and ESA
Japan	**69%**	Strong opportunity slightly limited by the lack of experience with Japan
USA	**69%**	Strong opportunity limited by current US policy aiming at asteroid exploration while ESA seems to lean in favour of Lunar exploration
India	**43%**	Opportunity limited by the small potential size of the Indian contribution and the lack of capabilities of Indian industrial stakeholders
Canada	**15%**	Limited contribution from Canada decreases the value of the opportunity
South Korea	**12%**	Lack of capabilities and cooperation experience limit strongly the cooperation potential
Brazil	**-**	No common objectives
China	**-**	Not accessible due to Chinese technology transfer requirements and ITAR regulations

Capability-oriented robotic missions interest a significant number of countries, wishing to acquire new competences for their local industrial and technological stakeholders. This provides for numerous cooperation opportunities with established but also emerging countries. The best opportunity for this type of mission is cooperation with Russia, due to a lower chance of unilateral withdrawal than with Japan and the US, who are suffering from strong budgetary pressures on their exploration budgets.

3. Joint development of an entire scientific exploration mission

Country	Result	Comments
USA	**69%**	Strong opportunity slightly limited by the fact that cooperation would not bring new flow of money to industry as the same amount would have been spent as part of ESA scientific program
Japan	**60%**	Strong opportunity limited by the lack of experience with Japan
Russia	**37%**	Russia does not focus on this type of mission, its resources in this area are therefore particularly limited
Brazil	**-**	Brazil has no budget for scientific exploration mission
Canada	**-**	Canada does not have sufficient budgetary resources for such missions
China	**-**	Not accessible due to Chinese technology transfer requirements and ITAR regulations
India	**-**	India focuses on capability-driven missions and not on science
South Korea	**-**	Korea focuses on capability-driven missions and not on science

Scientific exploration remains the privilege of a few nations and space agencies. Emerging space countries tend to focus on capability acquisition and demonstration and therefore favour the development of orbiter, landers and rovers for Moon and Mars missions. Only the US and Japan have the same scientific objectives than ESA in the science area, with bottom-up selection processes. They are therefore partners of choice for the joint development of large scientific missions.

4. Provision of a scientific instrument as part of an exploration mission

Country	Result	Comments
USA	**44%**	Established relationship between NASA and ESA create strong cooperation opportunities
Japan	**30%**	JAXA and ESA have strong scientific programs, that offer numerous cooperation opportunities
India	**25%**	Cooperation is limited to the provision by ESA of low-tech instruments to India (in order not to outshine the results of the mission) or to the provision by ISRO of an instrument to ESA
China	**20%**	Limited by Chinese technology transfer requirements and ITAR regulations
Canada	**15%**	Limited to the provision by Canada of a scientific instrument to ESA, which derives no industrial and scientific benefits
Russia	**15%**	Russia does not focuses on scientific exploration missions, cooperation is therefore limited to the provision by Russia of an instrument to ESA
Brazil	**12%**	Strongly limited by lack of objectives, synergies and budgets of the country
South Korea	**7%**	Limited to the provision by Korea of a scientific instrument to ESA, which derives no industrial and scientific benefits

The benefits of cooperation at instrumentation level are relatively limited since, in most the cases, ESA will be the country hosting the instrument thus deriving small economic benefits. There are a few opportunities for European scientific stakeholders to provide instruments for foreign scientific missions, but they are limited to the countries that develop their own scientific missions, Japan and the US essentially.

The final marks of all cooperation opportunities remain low as cooperation at instrumentation level is intrinsically unbalanced. One of the partners finances 95% of the mission, while the other partner will only provide 5%. If Europe is providing the 95%, the impact of the contribution of its partner remains limited and will only derive small economic benefits for Europe. Conversely, if Europe provides the 5% contribution, the small value of this cooperation will not allow to derive large industrial and scientific benefits.

5. Cooperation for Human spaceflight activities

Country	Result	Comments
Russia	**89%**	Past experience and the need of cooperation for such activities create a strong potential
USA	**83%**	Past experience and the need of cooperation for such activities create a strong potential
Brazil	**-**	Lack of budget and capabilities on both sides inhibits cooperation
Canada	**-**	Lack of budget and capabilities on both sides inhibits cooperation
China	**-**	Limited by Chinese technology transfer requirements and ITAR regulations
India	**-**	Lack of budget and capabilities on both sides inhibits cooperation
Japan	**-**	Lack of budget and capabilities on both sides inhibits cooperation
South Korea	**-**	Lack of budget and capabilities on both sides inhibits cooperation

Cooperation for Human spaceflight activities is limited to the two countries with an autonomous capability in this area. With the potential exception of China, with whom such a cooperation would be impossible anyway due to ITAR and the technology transfer issues, only the US and Russia have the financial and technological capacity to associate ESA to manned spaceflight activities.

The marks of the cooperation opportunities with Russia and the US are particularly high since Europe cannot conduct any human spaceflight activities on its own as it does not have the financial and technological capability. Cooperation is therefore essential in this area. Russia has a higher mark than the US since its objectives seem potentially more in line with ESA objectives than those of the US.

SWOT OF THE EUROPEAN SPACE EXPLORATION PROGRAM

<table>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td colspan="2">Institutional level</td></tr>
<tr><td>• Scientific missions are protected from budgetary cuts within ESA, which is a strong guaranty for international partners
• Diversity of destinations provides for numerous cooperation opportunities and serves the interest of the scientific community</td><td>• Lack of regularity in launch of missions in Europe (no robotic mission launched since 2005) may lead to loss of capabilities
• The governance of current space activities in Europe lacks a political dimension which is required for a long-term vision</td></tr>
<tr><td colspan="2">Industrial level</td></tr>
<tr><td>• The participation of Europe to the ISS allowed it to acquire strong capabilities through cooperating, notably for propulsion and service modules that may be used for NASA MPCV
• European capabilities spread between ESA Top-4 contributing member states, ensuring support from at least these member states for future initiatives</td><td>• Europe lacks the technologies required for independence (RTG for robotic missions, life support and protection for human spaceflight)
• Europe did not manage to develop critical elements of the ISS, thus being restricted to the development of redundant systems</td></tr>
<tr><th>Opportunities</th><th>Threats</th></tr>
<tr><td colspan="2">Institutional level</td></tr>
<tr><td>• EC-led initiatives could add the political dimension required for Exploration missions and long-term programs
• Additional funding for Horizon 2020 (especially compared with FP7 where 85% of the resources were earmarked for GMES) could create boost for R&D in space exploration
• Bottom-up selection processes of scientific missions from ESA, NASA and JAXA could benefit from a slight alignment to facilitate international cooperation</td><td>• No political leadership at European level (either by the EC or by ESA) could slowdown the development of European space initiatives
• Lack of budget for future missions due to austerity measures and political failure of justifying cost of exploration
• Europe could agree to funding of exploration missions (Exomars, Lunar Lander) but not invest sufficiently in R&D programs, thus missing the opportunity to reach technological non-dependence</td></tr>
<tr><td colspan="2">Industrial level</td></tr>
<tr><td>• Develop partnerships with emerging countries could create significant opportunities
• Participation in another large cooperation should will allow Europe to acquire new capabilities</td><td>• Widening technological gap with the US, Russia and China if funding level remains constant
• Limited acquisition of capabilities due to decrease or even cancellation of Europe’s participation to new international initiative due to lack of budget.</td></tr>
</table>

IMPLEMENTATION MODELS FOR FUTURE COOPERATION OPPORTUNITIES

Five cooperation opportunities presenting potential strong benefits for Europe have been identified through the benefit analysis and the SWOT of the European space exploration program.

These top-five opportunities do not necessarily match the best-ranked opportunities of the benefit analysis since they consider not only the current and expected in the near term state of objectives and capabilities of the countries but also possible long-term prospects.

Each of the following five cooperation opportunities will be detailed afterwards:

1. Cooperate with Russia on its Lunar Exploration program
2. Continue to cooperate with the US and Japan for scientific missions
3. Support the technological development of India
4. Manage to become involved in the development of critical elements of future multilateral large infrastructure programs
5. Strengthen ties with Korea and Brazil

Their rationale and potential obstacles will be presented, together with a list of actions to support the objectives of the opportunities. Finally, a SWOT of each opportunity will be conducted.

Opportunity 1 : Cooperate with Russia on its Lunar Exploration program	
Rationale	• Russia is currently refocusing its national space program with Lunar exploration as a key focus, through a stepped program which has been granted considerable funding. The objective is to develop the Lunar infrastructure in order to prepare future manned mission and set up a permanent Lunar Base • Europe does not have the financial and technological capabilities required to conduct an equivalent program. International cooperation is therefore a necessity. • Cooperation with Russia would derive significant economic, political, industrial and scientific benefits and may be considered as accessible. However, Europe should be associated to the Russian program from the start in order to ensure it is given a significant role. • Participation to this program may allow Europe to acquire technological capabilities in several key areas in line with Europe's objectives notably: Inflatable structure (for soft landing, entry heat shell, surface habitat modules), Electric propulsion, Cargo transportation and Rover technologies • The European Union decision to potentially conduct space exploration activities was supported by the political aspect of such programs. This cooperation opportunity entrusts the EU with strong financial and political responsibilities
Issues	• ESA budgetary situation and ISS-related expenditure prevent any short and mid-term large investment in Human spaceflight and exploration. • Russia will keep European contribution out of critical elements as it is a national initiative with Russia as sole leader of the initiative
Actions	Actions suggested as part of this opportunity include the following: • **Short term**: Tap into Horizon 2020 resources to support the R&D efforts in previously mentioned technological areas, while ESA is still engaged in ISS • **Short term:** Facilitate access of Russia to FP space programs and raise maximum funding of EU per project in order to encourage joint R&D efforts between European and Russia stakeholders • **Mid-term:** Include development of Lunar infrastructure elements (such as a rover and a habitat module) in FP9 to demonstrate technologies and interoperate with Russian base • **Mid-term:** Capitalize on experience acquired through ATV and Lunar lander to develop a Cargo Lunar Lander which would resupply the Lunar base. • **Long-term:** Partner with Russia for flight opportunities for European astronauts • **Long-term:** Develop autonomous capabilities in Human space exploration by developing capabilities in Human life support and protection
SWOT of opportunity for Europe	• **Strengths**: Financing of most infrastructure and mission critical elements is done by Russia; Europe is in a position to choose what capabilities it wishes to develop. Potential acquisition of key capabilities. • **Weaknesses:** Europe kept out of critical path; Lack of control on the program; Strong financial requirements on EC side. • **Opportunities:** Build strong relationship and complementarities with Russia, which could lead to additional future cooperation, notably for Mars Exploration. • **Threats:** Potential changes of plans or failure of Russia; Contribution of Europe too small so that Russia does not burden with cooperation for future plans.

Opportunity 2 : Continue to cooperate with the US and Japan for scientific missions	
Rationale	• ESA, JAXA and NASA have all implemented bottom-up processes for the selection of their scientific missions, thus allowing their respective scientific communities to coordinate and possibly make plans for user-driven scientific cooperation • The current financial context and the natural enhancement of the scientific objectives is a strong driver for cooperation. • ESA, JAXA and NASA already cooperate extensively on a bilateral basis (notably BepiColombo and the potential MarcoPolo-R with JAXA, and Cassini-Huygens with NASA), but cooperation may be optimized to derive more benefits for Europe.
Issues	• The timing of the selection processes of each agency are not aligned even for missions where both parties have planned to cooperate right at the beginning of the scientific call for proposals • The financial issues of NASA have led to the unilateral withdrawal of the US agency from the ESJM-Laplace, illustrating the risk of mission cancellation even for scientific missions
Actions	Actions suggested as part of this opportunity include the following: • **Short term**: ESA should limit is participation to 20-25% for foreign missions of agencies where the scientific budget is not guaranteed (as for ESA itself through the mandatory program) • **Short term:** International consultation between scientific stakeholders should be facilitated to align general objectives and easing the identification of potential cooperation area • **Mid-term:** The timing of the selection processes in each agency could be aligned in order to avoid that one of the partners allocate funding to a mission that will be cancelled afterwards due to the mission being not selected by the other partner. • **Long-term:** Establish a joint selection process for large missions (L-Class for ESA), gathering scientific communities from Europe, US and Japan
SWOT of opportunity for Europe	• **Strengths**: Europe is a partner of choice for international cooperation as its scientific budget is stable and its missions selected well in advance of launch; Strong scientific capabilities in Europe at instrument level. • **Weaknesses:** Logistical and political factors limit the potential for a truly joint mission. Most of the time, cooperation is limited to provision of instruments or development of independent elements. • **Opportunities:** Enhanced coordination between countries could lead to the development of more ambitious missions benefiting pre-eminently to the scientific community • **Threats:** Change of objectives of NASA and JAXA towards more operational or capability-driven missions; Potential additional budgetary cuts.

Opportunity 3: Support the technological development of India	
Rationale	• India has a strong budget, which is poised to increase together with Indian economic development. Space exploration will receive a more prominent share of the space expenditure once the development of GSLV is complete. • One of the key objectives of India is to achieve global standard in space technologies. Significant capabilities will need to be acquired. The main partner of India, for robotic and human exploration technology development until now has been Russia. • However, current issues around Chandrayaan-2 and the refocus of Russia on its national exploration program could lead to opportunities for Europe • Cooperation present significant technology transfer opportunities from Europe to India, in an application area which is far less critical than Satcom or Earth Observation since the commercial market is very limited. If Europe does not provide its technologies to India, ISRO will either get it from another space faring nation or develop it entirely domestically. • Indian organizations already participate to over 90 FP7 projects and to large infrastructure programs such as ITER.
Issues	• India may require a more significant technology transfer than what European stakeholders were expecting or ready to agree to • Europe may face pressures from its other international partners to ensure that no critical technologies are being transferred as part of the cooperation.
Actions	Actions suggested as part of this opportunity include the following: • **Short term**: Invite India to participate to Lunar Lander / Lunar Polar Sample Return mission possibly through the development of an additional element such as a mini rover, which was planned for Chandrayaan-2. • **Short term:** Develop participation of Indian stakeholders in FP programs. India contributed to 90 FP7 programs but not a single one of them in the Space area. • **Mid-term:** Try to contribute to ISRO Mars Orbiter mission, preferably at system level, in order to develop links between Indian and European industrial stakeholders. • **Mid-term:** Develop Lunar activities with India, on capability-driven programs • **Long-term:** Partner with India for the development of capabilities that none of the agencies own. • **Long-term:** Become involved in Indian Human Spaceflight program
SWOT of opportunity for Europe	• **Strengths**: Europe owns numerous capabilities that India is trying to acquire; India has a potential strong future space budget • **Weaknesses:** Space cooperation between Europe and India is not well developed. India currently partnering with Russia. • **Opportunities:** Contribute to the dissemination of European technologies and standards; Become partner of choice for India in other areas and become associated to Indian future space exploration technological developments • **Threats:** India using transferred technologies to gain market shares on foreign institutional markets at the expense of European industrial stakeholders.

Opportunity 4: Manage to become involved in the development of critical elements of future multilateral large infrastructure programs	
Rationale	• As part of the ISS cooperation, Europe was being kept out of the "critical path" of the program, since it did not develop any elements considered as vital for the station. • Russia and the US acquired key capabilities with the ISS that will be required for any future large multilateral programs. The contribution of Europe however, is entirely dispensable since the US and Russia could have developed the same systems. • In order to ensure that it will be part of any future programs, and to increase its political and technological influence, Europe needs to acquire unique capabilities, that won't be possessed by other nations
Issues	• The US and Russia are technologically much more advanced than Europe and continue to invest considerable resources into R&D programs so that the current situation may be irreversible and could even worsen significantly over the years.
Actions	Actions suggested as part of this opportunity include the following: • **Short term**: Concert with the European stakeholders to identify key technologies in which Europe might have a head-start and that could be required for future missions. Focus on technologies whose improvment could have a strong impact (in terms of mass or performance) on future missions • **Short term:** Dedicate a significant share of the Horizon 2020 budget to Space exploration technologies and more specifically to improve the identified technologies • **Mid-term:** Continue efforts at ESA level to acquire missing key technologies (RTG / RHU, soft landing with retrorockets, capsules for sample return, rovers...) • **Mid-term:** Demonstrate technologies through bilateral missions and gain flight heritage • **Long-term:** Convince international partners that Europe is a reliable partner that should be involved at critical level for demonstrated technologies. • **Long-term:** Potentially initiate a large multilateral program that does not involve the US and Russia, but rather Japan, China and India so that each partner provides critical elements.
SWOT of opportunity for Europe	• **Strengths**: Europe does not start from scratch and already owns numerous strong capabilities for exploration • **Weaknesses:** Europe has a considerably more limited Exploration budget than the US, Russia and China • **Opportunities:** Affirm the technological leadership of Europe on several capabilities, become a necessary partner for every future exploration initiative and therefore be able to influence the mission to fulfil European objectives • **Threats:** Specialize excessively. Dedicate too many resources into technologies that won't finally be required. Financially not be able to develop large cooperation.

Opportunity 5: Strengthen ties with Korea and Brazil	
Rationale	• Brazil and Korea have ambitions in space exploration but no budget nor capabilities as of today as they are engaged into other application area • Both these countries have a strong potential in space exploration since they have significant space budgets, bound to increase in the coming years. • Numerous cooperation opportunities may therefore arise in the future as Korea and Brazil will be desirous to acquire capabilities and develop their activities in Space Exploration • If Europe manages to support the development of these programs from the start, the established relationship could lead to larger cooperation benefiting to both parties in the long term.
Issues	• Current lack of budget of Brazil and Korea could delay or lead to cancellation of initiatives so that European efforts could remain fruitless.
Actions	Actions suggested as part of this opportunity include the following: • **Short term**: Provide technical and scientific support and expertise to the Brazilian and Korean agencies for their exploration preparatory programs • **Short term:** Partner with their scientific stakeholders to include one instrument into a European-led mission • **Mid-term:** Support the development of their first mission, through industrial partnerships and possibly technology transfers • **Mid-term:** Conduct a small exploration mission at ESA level including Brazilian and / or Korean built elements. For example, European scientific mission fitted with a foreign impactor or mini-rover. • **Long-term:** Ensure that European stakeholders, at ESA or national agencies level, is consistently associated to each space exploration initiative from Brazil and Korea • **Long-term:** Associate these countries through bilateral agreements to any large international initiative, as was tentatively the case for the US and Brazil for the ISS
SWOT of opportunity for Europe	• **Strengths**: Europe has successfully conducted a large number of robotic missions and has acquired capabilities that will be required by Brazil and Korea. Brazil very oriented towards cooperation (EO with China, Argentina and the US, Science with Europe, Launchers with Ukraine etc...); Korea has already cooperated with European industrial stakeholders (TAS and Astrium for KOMPSAT) • **Weaknesses:** Brazil is already considering a launch on a Russian launcher for ASTER. • **Opportunities:** Further develop political relationship between Europe and Brazil / Korea. Spread European technologies and standards; become main partner for future initiatives. • **Threats:** Not manage to accompany Korea and Brazil all the way through their programs so that they end up turning towards Russia and the US.

LIST OF ACRONYMS

AEB: Agência Espacial Brasileira (Brazilian Space Agency)

ASI: Agenzia Spaziale Italiana (Italian Space Agency)

ATV: Automated Transfer Vehicle

CAGR: Compound Annual Growth Rate

CALT: Chinese Academy of Launch Technology

CASC: China Aerospace Science and Technology Corp

CAST: Chinese Academy of Space Technology

CGWIC: China Great Wall Industry Corp

CNES: Centre National d'Etudes Spatiales (French Space Agency)

CNSA: Chinese National Space Administration

COTS: Commercial Orbital Transportation Services

CSA: Canadian Space Agency

DLR: Deutschen Zentrums für Luft- und Raumfahrt (German Aerospace Center)

EO: Earth Observation

ESA: European Space Agency

EVA: Extra-Vehicular Activity

GDP: Gross Domestic Product

ICBM: Intercontinental Ballistic Missile

iMARS: International Mars Architecture for the Return of Samples

IMEWG: International Mars Exploration Working Group

INPE: Instituto Nacional de Pesquisas Espaciais (Brazil's National Institute for Space Research)

ISAS: Japan Institute for Space and Astronautical Science

ISECG: International Space Exploration Coordination Group

ISRO: Indian Space Research Organization

ISS: International Space Station

JAXA: Japan Aerospace Exploration Agency

JPL: NASA Jet Propulsion Laboratory

KARI: Korea Aerospace Research Institute

LEO: Low-Earth Orbit

LTP: ESA Long Term Plan

MDA: MacDonald, Dettwiler and Associates

MIIT: China Ministry of Industry and Information Technology

MPCV: Orion Multi-Purpose Crew Vehicle

MPLM: Multi-mission Pressurized Launch Modules

NASA: National Aeronautics and Space Administration

NEA: Near-Earth Asteroid

NEO: Near-Earth Object

RTG: Radioisotope Thermoelectric Generator

SASTIND: China State Administration for Science, Technology, and Industry for National Defense

SRI: Russian Space Research Institute

TAS: Thales Alenia Space

TAS-I: Thales Alenia Space Italy

UKSA: United Kingdom Space Agency