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1 Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.
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4.1 Final publishable summary report

This section must be of suitable quality to enable direct publication by the Commission and should preferably not exceed 40 pages. This report should address a wide audience, including the general public.

The publishable summary has to include 5 distinct parts described below:

- An executive summary (not exceeding 1 page).
- A summary description of project context and objectives (not exceeding 4 pages).
- A description of the main S&T results/foregrounds (not exceeding 25 pages).
- The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results (not exceeding 10 pages).
- The address of the project public website, if applicable as well as relevant contact details.

Furthermore, project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc…), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

4.1.1. Executive summary

Life is considered as a planetary phenomenon, and, besides Earth, it might have evolved in other extraterrestrial bodies. The definition of the concept of Life is not straightforward but current exploration techniques are mostly related to Earth living organisms. The hypothesis currently used is based on the assumption that, under similar environmental conditions, organisms respond and adapt with similar strategies and molecular mechanisms. Therefore one of the most direct approaches to detect life is by searching for microorganisms or the molecular remains (biomarkers) they leave in the environment. The PBSA project addresses the search for molecular evidences of life by automating bio-affinity based methods, as the immunological detection or the specific recognition between complementary DNA sequences, in a direct label-free and near real-time biosensor device.

The PBSA goal is the implementation of Lab-on-a-chip (LoC) concepts for biomarker detection in space applications such as life detection missions or microbial monitoring in space installations. PBSA combines advanced terrestrial technologies in the field of biosensors for the development of a novel and integrated solution ready to be tested for the space environment. This approach employs recent advances in immunosensing technology developed for planetary exploration with two main powerful technologies, photonic integrated circuits (PICs) and microfluidics, with promising features for the space domain.

The use of PIC enables the implementation of highly integrated solutions for new LoC developments. Multiple detections can be integrated into a single photonic chip for multiple parallel analyses. This technology has shown to be very sensitive and improves protocol simplicity compared with conventional techniques that require enzymatic or fluorescent labelling steps. The PIC based solution allows direct measurement of the target molecules (analytes), savings time and complexity of the detection protocols with similar liabilities. Moreover, this feature is very suitable for remote sensing in space applications where savings in reagents are very valuable.

Partner’s skills are very well complemented in the project. The know-how in immunoassay chemistry for space applications is combined with the expertise in CMOS photonic integrated circuits and active microfluidics. Finally a specialist in space will do control electronics and integration.
Both photonic and microfluidic systems optimize critical parameters in space applications (volume and mass) enabling new opportunities. These benefits apply also to terrestrial market. The huge growth of the terrestrial biosensing field has been mainly focused to simple low cost devices. In this sense, the search of organic molecules of unambiguous biological origin is also related to ground disciplines such as biomedicine (human, animal), bioterrorism, or environmental or industrial processes monitoring. The underlying biological system and types of biomolecules is common in these fields and the same detection mechanisms can be employed.

Consequently, PBSA has generated a unique, **light (1.2 kg)** and **compact (131x131x154 mm)** prototype instrument for multiplex (up to 10 different analytes can be detected simultaneously) and label-free immunological detection. We have designed and built a unique microfluidic cartridge that contains all the reagents necessary for two consecutive analyses with a single, reusable, photonic integrated circuit and a small array with 12 micro-ring resonator probes.

### 4.1.2. Project context and objectives

#### 4.1.2.1. Scientific context

The PBSA project arises as a response to the demanding necessity of new affordable, light and “user friendly” biosensing devices in the context of space exploration. Two fields might demand PBSA: Astrobiology and human space exploration. The search for extra-terrestrial life is a hallmark in the human knowledge, and Astrobiology addresses it through the study of the origin, evolution, distribution and future of life in the universe. The interest in exploration of life on other planets or moons is not new. It started when it was discovered that comets contributed with water and organic materials to the primitive Earth. The NASA’s 1976 Viking missions to Mars were the first space missions with clear astrobiological objectives. The inconclusive results from the Vikings missions about the presence of organic material or any other life remains led to a period of scepticism and absent of planetary missions. New findings about the recalcitrant nature of microbial life, able to proliferate under extreme environmental conditions on Earth, together with the improvement in the sensitivity of the new instrumentations, prompted scientific community and, in particularly NASA, to support and provide funding to astrobiology by the middle 90s. On the other hand, the human space exploration demands new monitoring systems ether for habitat management or health checking.

**Why to search for organic matter in the space: planetary and human exploration**

The detection of organic matter from unequivocal biological origin is essential to evaluate the presence of extant or extinct life in a planetary body. Our hypothesis is based on the assumption that, under similar environmental conditions, organisms respond and adapt with similar strategies and molecular mechanisms. If we know those terrestrial analogue environments (at least in some key environmental parameters) to other identified on other planetary bodies, we characterize some of the life forms and the remains they leave in the medium, and develop systems for detecting them, then we could extrapolate this methodology for planetary exploration.

The most direct way to identify the presence of life, past or present, is through the detection of the molecules that compose it (molecular biomarkers) or the organic matter originated from large
biological polymers. In the case of modern life, the biomarkers may be different polymers types more or less complex such as proteins, nucleic acid fragments (DNA, RNA), lipids, or biogenic polysaccharides (lipopolysaccharides, teichoic acids, etc). In the case of extinct life, the most relevant biomarkers are the products generated by transformation (diagenesis) of the different biomolecules from the cell, such as humic acids, hopanes, isoprenoids, etc.

The detection of molecular biomarkers not only help to search for extraterrestrial Earth-like life, but it can also help in human exploration by habitat monitoring or checking different health parameters of the astronauts. For example, monitoring the air, surfaces or water reservoirs, or by checking different illnesses or microbial infections during long stay missions. In that sense, it is important to routinely check for potential microbial pathogen contamination in space stations or future planetary settlements. For these purposes fast and reliable sensor system are desirable.

Bioaffinity-based sensor such as the immunosensors can detect a wide range of sizes and molecular structures, from amino acids to whole cells, using relatively simple and robust protocols. The antibody microarray technology allows analyzing hundreds or even thousands of different types of molecules simultaneously.

The technology that we propose in PBSA has an important niche in the instrumentation used in the search for life, covering aspects that no other instrument has addressed so far: the ability to recognize and detect non-volatile complex molecular structures by label-free immunoasays.

### 4.1.2.2. Technological context

Up to date, the instruments devoted to organic detection in space missions have been based on the analysis of the volatile compounds released after sample heating or pyrolysis (Table 1) mainly due to the simplicity in sample preparation. This is the case for gas chromatograph-mass spectrometers (GCMS). Two classes of instrumentation have been used in the search for organics compounds and life on planetary exploration: the classical biology and chemistry instruments, e.g., labelled release (LR) and the gas chromatography / mass spectroscopy (GCMS) as it was used on Vikings landers in 1976 on Mars. The LR experiment (Principal Investigator Gilbert Levin) tested for life by applying a nutrient solution tagged with Carbon 14 to a sample of Martian soil.

### Table 1. Different methods and instrumentation for organic detection in space exploration

<table>
<thead>
<tr>
<th>Method</th>
<th>Instrumentation</th>
<th>Sample</th>
<th>Target</th>
<th>Size</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating and Pyrolysis</td>
<td>GC-MS/Viking, Cassini-Huygens, SAM</td>
<td>Volatiles</td>
<td>Elemental, gases, PAHs, aliphatic hydrocarbons, etc</td>
<td>Elemental to 535 Da</td>
<td>Novotny et al., 1975 (Viking); Niemann et al., 2005 (Cassini)</td>
</tr>
<tr>
<td></td>
<td>(MSL-Curiosity)</td>
<td></td>
<td>(Viking) 2-535 (SAM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water extraction + volatilization</td>
<td>Capillary electrophoresis /Urey</td>
<td>Volatiles</td>
<td>Aa, nucleobases, PAHs, etc.</td>
<td>Up to 500-600 Da</td>
<td>Aubrey et al., 2008</td>
</tr>
<tr>
<td>Spectrometric</td>
<td>IR, Raman Spectrometers</td>
<td>Solid surfaces</td>
<td>Chemical bonds, pigments, etc</td>
<td>Any</td>
<td>Edwards et al., 2003</td>
</tr>
</tbody>
</table>
While best known for detecting water ice near the Northern Polar Cap, Phoenix also detected perchlorates. A critical step with a GCMS is to heat the sample to make it outgas. Ideally this is done in an oxidant-free oven to prevent spurious heat reactions. But because perchlorates are an oxidant in the presence of organics, they form dichloromethane when heated with organics. And indeed, Curiosity’s GCMS has recently detected still more dichloromethane in 2012 in the first analysis of the SAM instrument. Only after using chemical derivatizing agents SAM have detected the most complex organic matter found so far on Mars: Benzene.

To search for more complex and polymeric non-volatile biomarkers we proposed several years ago the bioaffinity-based method of immunological detection (Parro et al., 2005; 2008, 2011). Antibodies are big (150 kDa, about 7-9 nm diameter particles) and relatively robust molecules capable to specifically discriminate between enantiomeric compounds with high sensitivity. The most reliable and sensitive methods rely on the fluorescent or enzymatic labelling of antibodies. Although highly effective, these methods need laborious preparatory processes, liquid handling and incubation times ranging from 30 to 120 min, apart of the signal detection system.

PBSA project goes a step forward by simplifying the analytical process through label-free photonic detection in a near real-time reading system. PBSA is focused on the implementation of a Lab-on-a-chip (LoC) concept where advanced terrestrial technologies in the field of biosensors (photonics, microfluidics and electronics) are combined with the last advances in biochemical functionalization of surfaces for the development of a novel solution for space applications.

The use of photonic integrated circuits (PIC) enables the implementation of highly integrated solutions for the development of new LoC. This technology has shown to be very sensitive and also has the advantage of being a label-free and near real-time detection technique. Moreover the implementation of microfluidics cartridge at the device allows a low volume consume for the reagents. Furthermore, a very important feature of the project is the possibility of a multiple detection immunoassay.
4.1.2.3. Objective
The PBSA goal is to develop a compact photonic-based biosensor prototype for the simultaneous detection of several biomarkers or microbes and to demonstrate its feasibility in the context of space exploration. Because the target analytes to be detected are of similar nature as those targets in many terrestrial fields (biomedicine, veterinary, environmental monitoring), PBSA is also relevant for these ground applications.

The particular PBSA objectives are
a. To bring nanophotonic technology to space environment.
b. Improve space sensing capabilities with photonic solutions
c. Develop a nanophotonic array of sensors capable to operate in space environment (radiation).

To achieve the objectives, we have established the next work packages:

- WP1: Conception of the system: Study of Space application requirements
- WP2: Development of the sensing probes and immunoassays
- WP3: Development of photonic transducers
- WP4: Development of microfluidic structures
- WP5: Integration and Electronics
- WP6: Validation of the functionality
- WP7: Dissemination and exploitation plan
- WP8 and 9: Project management and Technical and Scientific coordination

4.1.3. Main S&T results and foregrounds

4.1.3.1. WP1: Conception of the system: Study of Space application requirements

Objectives
- Study of space mission requirements and their impact on the device
- Definition of the target application: determination of target molecules to be sensed.
- Building block breakdown of the sensing device and main action to adapt them to the space application.
- Definition of the interrelation between building blocks.
- Draw of the main action lines in each of the main parts of the system for WP2, WP3 WP4 and WP5.
- Definition of the objectives and protocols for the validation experiments in performance and in environmental conditions for WP6.

Results
- State of the art of sensing solutions for space and terrestrial applications has been provided in order to put PBSA project into its context (Fig. 1). The search for organics and molecular biomarkers is a main goal in planetary exploration. Finding molecules of unequivocal biological origin may constitute direct evidence of the actual or extinct life in other planetary bodies. In order to search for those molecules of unequivocal biological origin, one option is to search for the most characteristic molecules of life as we know it: the biological polymers such as proteins (polymers of aminoacids), DNA and RNA (polynucleic acids), polysaccharides (sugar polymers), or unique and sophisticated molecules produced by
enzymatic reactions, such as steroid-like compounds, antibiotics, etc. (Fig. 2). In addition, it is necessary to understand how biological molecules are transformed with time and the different diagenetic processes that can operate over them. The main molecular biomarkers from polymers to more simple molecules obtained after diagenesis was reviewed in PBSA deliverable D1.1.

Figure 1. PBSA potential application and targets

- The required validation test and protocols for PBSA has been initially defined in deliverable 1.4. Therefore, they were used as the base reference for the validation test to be performed during WP6.
Figure 2. The main biological polymers constituents of life are targets for PBSA (left) and fossil molecular biomarkers (hopanes), humic acids, bacterial pigments and polycarboxylic acids from oxidized organic matter are potential targets (right).

- Architectural PBSA design (Fig. 3) has been provided, including building block decomposition and interrelation. The different electrical, fluidic and optical external and internal interfaces were defined. They were used as a base for the WP5 activities.

![Figure 3. PBSA system concept block diagram](image)

- Main block interdependencies and critical parameters were defined (e.g.: tuning range of the laser with hope mode free, size of the photonic integrated circuit, packaging, maximum size of particle in the microfluidic system and functionalization methods).
- We constructed three developmental models, proto-lab 0, 1 and 2, to demonstrate PBSA concept and to test and improve the different procedures and components.

4.1.3.2. WP2: Development of the sensing probes and immunoassays

**Objectives**

- Selection of target analytes and the biorecognition elements (bioreceptor molecules)
- Functionalization of PIC transducers: Immobilization of bioreceptor molecules to the microring resonators. This requires the design of the immobilization protocols and printing strategies.
- Multiplex label-free Immunoassay development and testing for final protocol definition.

To achieve the objectives we have done multiple tasks. In biology many activities have to be repeated multiple times because biological a biochemical reagents need to be replaced in each experiment. Therefore, we have done tasks such as fabrication of multiple PIC chips, chemical activation, functionalization with antibodies (using the printing robot), immunoassay tests and photonic measurements with the different opto-microfluidic set ups (proto-labs 0 to 2). Printing of conventional antibody microarrays onto glass slides has also been done as routine check of the antibody performance by fluorescent immunoassay.
Results

A multiplex label-free immunoassay for PBSA

Multiplex functionalization following epichlorhydrin method (Fig. 4) was applied to 12 microrings PICs (Fig. 5) to be implemented into PBSA prototype. Our strategy is to functionalize several rings with the same antibody in order to have redundancy and the appropriate controls to measure the reproducibility of the assay. For the purpose of this project, the most critical aspect is to obtain consistent measurements. From all the 300 antibodies shown in Table 8, D1.1, we have just selected a very few of them (Table 3) but highly representative of the potential applications of PBSA: antibodies to the universal bacterial protein GroEL, antibodies to spores (resistant cellular forms) from the widely distributed in nature bacterium Bacillus subtilis, or an antibody to a protein from a viral pathogen affecting cattle. In the last case, it was a part of collaboration with the RAPIDIA-FIELD FP7 project and as one of the potential application in the veterinary diagnostics, we added biomarkers for viral diseases.

Table 2. Antibodies used for multiplex functionalization of the PBSA development PIC chips

<table>
<thead>
<tr>
<th>Ab Name</th>
<th>Type</th>
<th>Antigen</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-GroEL</td>
<td>Poyclonal</td>
<td>GroEL (chaperone 60)</td>
<td>Universal bacterial protein</td>
</tr>
<tr>
<td>IVH1C1</td>
<td>Poyclonal</td>
<td>Bacillus subtilis spores</td>
<td>Example for detecting resistant bacterial cells</td>
</tr>
<tr>
<td>Anti-Cys</td>
<td>Poyclonal</td>
<td>Cysteine-BSA conjugated</td>
<td>Example of amino-acids</td>
</tr>
<tr>
<td>Anti-GlnB1492</td>
<td>Poyclonal</td>
<td>17 aa peptide of protein GlnB (L. ferrooxidans extremophile from Rio Tinto)</td>
<td>A small peptide</td>
</tr>
<tr>
<td>2C4</td>
<td>Monoclonal</td>
<td>VP7 protein from BTV Virus capsid antigen</td>
<td>Bovine pathogen (Bluetongue virus) from other FP7 project collaboration (RAPIDIA-FIELD)</td>
</tr>
</tbody>
</table>

These antibodies were printed on the final PBSA PIC chip and assayed with proto-lab 2 set up. We successfully performed multiplex label-free detection of GroEL, spores and VP7 protein by using the same chip (Fig. 6). The changes in the photonic resonance were calculated by subtracting the resonance displacement of the test ring minus the value obtained in other rings functionalized with other antibodies or just with BSA (Bovine Serum Albumin). Table 2 shows the values obtained in one of the experiments.

Figure 4. Chemical activation of the micro-rings for covalente binding of proteins and antibodies.
In order to increase the photonic signal and, consequently, the sensitivity, we applied a signal enhancement strategy by adding a secondary antibody and a nanoparticle-based system (Fig. 6, D). Because antibodies can be considered as a kind of nanoparticles (7-9 nm in diameter), after the addition of a secondary antibody the photonic signal increased considerably (Fig. 6).

Figure 5. Multiplex printing onto epoxy activated PBSA chip (big picture). It can be appreciated the liquid drop (with the corresponding Ab) covering the photonic microrings (insert). A scheme showing how the printing was done is also shown (bottom)
Figure 6. Multiplex label-free immunoassay and enhanced procedures for PBSA. Resonance displacement measurements for the detection of VP7 viral antigen (A), GroEL protein (B) and Bacillus subtilis spores (C). In (D) it is shown the interpretation of the immunoassay following the different theoretical parts of photonic assay: Running Buffer (RB), Antigen or analyte addition, RB, antibody addition for enhanced sandwich, and nanoparticle addition for further enhancement. The figures are more extensively explained in D2.4.

Table 3. Photonic measurements in multiplex label-free and enhanced protocols

<table>
<thead>
<tr>
<th>Sample injected</th>
<th>Immunoassay type</th>
<th>Photodetector minus Reference</th>
<th>Signal (pm)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP7 50 ng/ml</td>
<td>Label-free</td>
<td>PH1-PH3</td>
<td>2.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Ab 2D7</td>
<td>Sandwich</td>
<td>PH1-PH3</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>GroEL 0.5 µg/ml</td>
<td>Label-free</td>
<td>PH2-PH1</td>
<td>34.0</td>
<td>82.0</td>
</tr>
<tr>
<td>Ab Anti-GroEL biotinilated</td>
<td>Sandwich</td>
<td>PH2-PH1</td>
<td>48.0</td>
<td></td>
</tr>
<tr>
<td>GroEL 0.5 µg/ml</td>
<td>Label-free</td>
<td>PH2-PH3</td>
<td>29.0</td>
<td>67.0</td>
</tr>
<tr>
<td>Ab Anti-GroEL biotinilated</td>
<td>Sandwich</td>
<td>PH2-PH3</td>
<td>38.0</td>
<td></td>
</tr>
<tr>
<td>Spores (B.subtilis)</td>
<td>Label-free</td>
<td>PH3-PH2</td>
<td>1.1</td>
<td>14.1</td>
</tr>
<tr>
<td>Ab IVH1C1</td>
<td>Sandwich</td>
<td>PH3-PH2</td>
<td>13.0</td>
<td></td>
</tr>
<tr>
<td>Spores (B.subtilis)</td>
<td>Label-free</td>
<td>PH3-PH1</td>
<td>1.4</td>
<td>16.0</td>
</tr>
<tr>
<td>Ab IVH1C1</td>
<td>Sandwich</td>
<td>PH3-PH1</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>Spores (B.subtilis)</td>
<td>Label-free</td>
<td>PH3-PH4</td>
<td>0.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Ab IVH1C1</td>
<td>Sandwich</td>
<td>PH3-PH4</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>GroEL 0.5 µg/ml</td>
<td>Label-free</td>
<td>PH2-PH1</td>
<td>5.0</td>
<td>73.0</td>
</tr>
<tr>
<td>Ab Anti-GroEL biotinilated</td>
<td>Sandwich</td>
<td>PH2-PH1</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Stv-nanoparticles</td>
<td>Nanoparticles</td>
<td>PH2-PH1</td>
<td>60.0</td>
<td></td>
</tr>
</tbody>
</table>

Our results showed that it is feasible the multiplex immunoassay (that is simultaneous detection of several biomarkers or microbial strains) with a single chip. The enhancing procedures can be run in the same chip, and clearly increase the photonic signal (Figure 1 and Table 2).

The limit of detection of PBSA photonic immunoassay
We also determined the limit of detection for some biomarkers by label-free assay, as it was the case of GroEL protein (Figs. 7 and 8), which resulted in a value of 10 ng/ml. This limit of detection is in agreement with the one obtained by fluorescent sandwich immunoassay (2-5 ng/ml).
Figure 7. Detection limit of the PBSA PIC system for detecting GroEL protein. (blue) the result of subtracting the photonic measurement in photodetector 2 (Fd2) minus the reference photodetector 1 (Fd1), and (red) after subtracting Fd3.

Figure 8. Limit of detection of a photonic label-free immunoassay for GroEL protein

Reusability of PBSA PIC chip
We also examined the reusability of the chip by performing up to ten cycles of label-free assay + regeneration with 20 mM NaOH (Fig. 3). Although the system can be improved, after 10 cycles we still detected a similar photonic measurement as with the first cycle.
Regeneration Cycle

Figure 9. Regeneration of PBSA PIC immunoassay. Photonic label-free immunoassay for detecting GroEL protein by using a single re-generable chip. The label-free assay (blue bars) was done 8 times after regeneration with 20 mM NaOH. In some of the cycles, the sandwich-type enhanced protocol was applied (red bars). The values are the average of the measurements obtained with two different rings functionalized with Anti-GroEL antibody. Error bars correspond to the standard deviation. In cycles 2 and 9 only regeneration was applied.

The reusability of the chip is feasible and it would save time and money when performing the analysis of several samples in short periods of time. However, to do that it is necessary to re-design the microfluidic cartridge so that the pumping system can be much more accurately controlled.

**Conclusion and Perspective**

**We have developed a sensitive multiplex label-free immunoassay for PIC**

**Two procedures for enhancing the photonic signals have been demonstrated**

**PIC for PBSA will be re-generable for at least ten times**

Although there are still several parameters to be optimized, we have demonstrated the performance of PIC chips for label-free, near real-time, and simultaneous detection of several biomarkers, regardless their nature. The final performance of the measurements depends of multiple factors, such as: The quality of each pair antigen-antibody or any other bioreceptor pair molecules, the functionalization efficiency, or the photonic efficiency of the chip, among others.

**4.1.3.3. WP3: Development of photonic transducers**

**Objectives**
• Assembly PIC transducer
• Design of Light interrogation system and coupling
• Optical characterisation of PIC transducers

The fabrication of the photonic structures such as the ring resonators and waveguides involves nanofabrication processes by e-Beam lithography and photolithography. Those processes are followed by a dry etching (plasma etching) to transfer the pattern onto the silicon nitride surface.

Once the PICs are fabricated and characterized, the next step is the attachment of the input and output ports. For the input-port a Fiber-array (FVA) is attached to transmit the laser light signal into the PIC. As output-port, a set of Photodetectors (PDA) is bound to the PIC to convert the photonic signal into an electrical domain (Fig. 10).

The illumination control and monitoring system takes care about the light generation system (laser sweep needed for exciting the transducer) and the measurements of the wavelengths variations produced because of the sensing interaction.

**Results**

**Assembly of a compact ad integrated PIC transducer**

For the characterization of the PIC transducer, FVA attachment and PDA need to be tested. FVA characterization was done to assess the correct alignment. For test the performance of the FVA were used a broadband ASE source centred in 1550nm and by means of GC1 and GC3 were maximized the power coupled to ensure that the GC2 was aligned with the FVA.

**Figure 10.** PIC transducer assembly. Details of fiber optic alignment, the output ports (top left), the photodetector arrays and connections (bottom left), and the whole PIC on a PCB where the FVA, PDA, and electrical connections are clearly distinguished.
Table 4. Table Alignment losses at the GC input (using GC1, GC3) from 3 measured chips

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4:6_4</td>
<td></td>
<td>-18.4</td>
<td>1.3</td>
<td>1.4</td>
<td>-19.8</td>
</tr>
<tr>
<td>6:5_4</td>
<td></td>
<td>-16.5</td>
<td>1.2</td>
<td>1.4</td>
<td>-17.9</td>
</tr>
<tr>
<td>6:1_2</td>
<td></td>
<td>-19.6</td>
<td>1.1</td>
<td>1.2</td>
<td>-20.8</td>
</tr>
</tbody>
</table>

The losses are higher than expected for only the inter-phase of 2 GC due to the source used for this test is an ASE source and the power coupler to the fibers is a bit lower than in the case of a connectorized laser monochromatic as is the case of the laboratory test.

The last results obtained from the laboratory tests, were using the PBSA Electronic Control Unit (ECU) made by EVOLEO partner and using the tunable laser EM650. Within these tests we made an electronic sweep to the laser by controlling the temperature input to tune the wavelength and obtaining the response of the system to each wavelength. The Fig. 11 shows the obtained response, which corresponds with the resonance of the ring resonator previously measured. It can be observed the deep expressed in voltage from the TIA board, due to the PD converts the optical power from the PIC circuit into a current and then the TIA convert this current to voltages. Adjusting each amplifier to the concrete RR can do some improvements of the system. In this way, it is possible to get the best dynamic range that can provide the TIA board (max range ~0-5 V).

![VLOG vs WaveLenght](image.png)

Figure 11. Electrical response of the PD using the complete system.

Optical characterisation of PIC transducers

The main procedures for PIC characterization are physical and optical characterization.
• The physical characterization relates to the physical measurement of the fabricated structures. For that purpose, SEM (Scanning Electron Microscope) and AFM (Atomic Force microscope) images are obtained in order to check specifications in terms of fabricated dimensions with respect to the original design. Additionally, interferometric techniques are employed in the fabrication process in order to verify layer’s thickness.

• In the photonic field, there are some tricky issues as the coupling of light inside the chip, which makes necessary the use of a laboratory characterization set-up. From this set-up, the optical pathway has been employed for the characterization of the fabricated chips. It basically consists of a tuneable laser source at one end of the system, and a power meter at the other. The wavelength of the laser is shifted in time to obtain the spectral response of the device. A positioning system with 6-freedom axis has been used to achieve the most accurate alignment of the fibre, having in mind that the alignment of fibber array is necessary to measure structures in parallel. A polarization controller is used in order to maximize the power on the chips since the structures used to coupling light inside the chips are polarization dependents.

Table 5. Specs of the optical characterization of the implemented set-up

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>1500 - 1600</td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td>Abs. Wavelength Accuracy</td>
<td>±0.04 nm</td>
<td></td>
<td>After self calibration</td>
</tr>
<tr>
<td>Repeatability</td>
<td>±0.005 nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement speed</td>
<td>10 - 100 nm/s</td>
<td>nm/s</td>
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</tr>
<tr>
<td>Power Stability</td>
<td>±0.01 dB</td>
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<td></td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>&gt; 60 dB</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.2 dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel</td>
<td>4 mm</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Thermal stability</td>
<td>1 μm/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>5 nm</td>
<td>nm</td>
<td>(closed loop= piezo + strain gauge)</td>
</tr>
</tbody>
</table>

Conclusions

Fabrication processes have been developed and optimized for silicon nitride technology and the PIC transducer for PBSA has been assembled.

The implemented light interrogation and readout system is working well.

The PBSA photonic integrated chip (PIC) was optically and electrically characterized and the obtained results were well in line with the simulations.
4.1.3.4. WP4: Development of microfluidic structures

Objectives

- Design and production of PBSA fluidic cartridge.
- Developing, preparing and testing cartridge technology for implementing photonic-based sensor technology and meeting the requirements of the sensor concept.
- Design of pump control.

Results

We have designed and produced a unique microfluidic cartridge for PBSA (Fig. 12). The cartridge contains several reservoirs for chemicals and reagents sufficient for full analysis of 2 samples, including enhanced protocols with secondary antibodies and nanoparticles. For those assays were no enhancement of the signal is needed, the extra reservoirs can be filled in with other reagents and used for an extra analysis.

![Cartridge Image]

**Figure 12:** Picture of the cartridge filled with inks representing reagents and labelled essential areas.

Through the cartridge assembly process it was possible to reproducibly build up cartridge batches to be used by the project partners for system level validation and biochemical experiments (Fig. 13).
Figure 13. Picture of a batch of 20 cartridges to be send to project partners for system level validation and biochemical experiments

Pump Control Design
The liquids in the reservoirs of the microfluidic cartridge are pumped through a electrochemical pumping system that needs special control. An OEM pump control was developed based on devices of the past. This allowed a fast delivery of a board controlled by the PBSA system, which is able to drive the pumps on its own (see D4.2).

For a fully integrated system and for the space conformity, the consortium agreed to develop a software component to be integrated into the PBSA environment (Fig. 14). The pump control software component is a library (“Pump Control DLL”), which can be integrated into the software environment (“Application Control”) so far developed for PBSA. The “Application Control” transmits status data for the pump to be controlled:

- “Volume”: Status of the pump, namely volume already pumped
- “Pump”: Number of the pump to be controlled
- “Flowrate”: desired flowrate

The “Pump Control DLL” calculates a current, which is than set within the “Drive Electronics”.

The PBSA system can drive the pump to achieve different flow velocities of the reagents within the sensor chamber. A typical flow velocity variation range is within $0.01\mu l/s$ and $2\mu l/s$. The availability of high flow velocities is highly dependent on the reservoir geometry. For the PBSA specialized cartridge flow velocities up to $0.9\mu l/s$ can be controlled without any additional considerations.

**Conclusions**

A unique microfluidic cartridge with pre-loaded reagents and electrochemical pumping system has been designed, built, and tested for performing 2 immunological assays in PBSA.

4.1.3.5. WP5: Integration and Electronics

**Objectives**

- Final concept definition including thermal considerations.
- Laser control board.
- Photodetector Signal Conditioning board.
- Electronic Control System board.
- PSU and the power distribution unit.
- Final integration and verification tests of the PBSA prototype

**Results**

As a result of this WP fully final design was done for each individual component and the whole assembly was implemented. After final design of all the components, procurements, and construction of all PBSA parts, the final integration was achieved to obtain the PBSA prototype instrument (Fig. 15). We carried out the verification tests: power supply, voltage to all components, microfluidic control, laser control, photonic measurements, etc.
Figure 15. PBSA prototype. Integration of the final and operative PBSA prototype

Figure 16. Checking the PBSA software and user’s interface and record of the first photonic measurement

Conclusions

We have built and verified the main functionalities of PBSA prototype
4.1.3.6. WP6: Validation of the functionality

Objectives

- Implementation of detection protocols.
- Performance validation of the PIC based label-free detection system and microfluidics.
  Comparison with other techniques.
- Environmental tests of the developments of the PBSA project.

Results

PBSA protocol

We have designed and tested a label-free immunoassay for PBSA prototype. Once produced the microfluidic cartridge and the functionalized PIC as described in the corresponding deliverables, and based on the multiple assays performed with the different proto-labs versions, we described a detailed protocol (D6.1) consisting of the next steps (Tables 6 and 7):

<table>
<thead>
<tr>
<th>Table 6. PBSA running protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summary of PBSA Running protocol for sample analysis</strong></td>
</tr>
<tr>
<td>a. Fill in the cartridge reservoirs with the corresponding reagents and solutions</td>
</tr>
<tr>
<td>b. Fill in the sample reservoirs with the corresponding samples 1 and 2</td>
</tr>
<tr>
<td>c. Fix the PIC chip to the cartridge and then to PBSA machine</td>
</tr>
<tr>
<td>d. Open PBSA software interface</td>
</tr>
<tr>
<td>e. Selection of the pre-stored running program and press run, or define a new running procedure (Table 2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7. Step by step programming PBSA running protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Programming PBSA running protocol</strong></td>
</tr>
<tr>
<td>1. Optical setting (laser, signal recording, e.g. Fig. 15)</td>
</tr>
<tr>
<td>2. Blocking buffer (vol, velocity, t)</td>
</tr>
<tr>
<td>3. Running buffer (vol, velocity, t)</td>
</tr>
<tr>
<td>4. Sample 1 pumping into the microfluidic cell (vol, velocity, t)</td>
</tr>
<tr>
<td>5. Running buffer (RB) (vol, velocity, t)</td>
</tr>
<tr>
<td>6. Secondary antibody (vol, velocity, t) if needed</td>
</tr>
<tr>
<td>7. Running buffer (RB) (vol, velocity, t)</td>
</tr>
<tr>
<td>8. Regeneration buffer (vol, velocity, time)</td>
</tr>
<tr>
<td>9. Sample 2 pumping into the microfluidic cell (vol, velocity, t)</td>
</tr>
<tr>
<td>10. Running buffer (vol, velocity, t)</td>
</tr>
<tr>
<td>11. Secondary antibody (vol, velocity, t) if needed</td>
</tr>
<tr>
<td>12. Running buffer (RB) (vol, velocity, t)</td>
</tr>
<tr>
<td>13. Regeneration buffer (vol, velocity, time)</td>
</tr>
<tr>
<td>14. End of run</td>
</tr>
</tbody>
</table>

The microfluidic cartridge was designed to run 2 samples and with several reservoirs to store different reagents. Multiple reservoirs give versatility and allow the user designing multiple
protocols as a function of the type of immunoassay used: direct label-free, sandwich, further enhanced with nanoparticles, or even enzymatic enhancement (not tested yet).

**Tests under space relevant conditions**

Any new instrumentation or device claiming for space applications needs to demonstrate its good performance under critical space environmental parameters. Radiation is one of the most critical, particularly the high-energy proton radiation and the less energetic but highly penetrating and highly abundant gamma radiation. Many instruments have been flown with electronics, optical CCDs, software, mechanical components, etc. However up to now none have used SiN waveguides-based photonic chips or electrochemical pumped microfluidics, and much less biochemical components as proteins and antibodies. Consequently, the photonic chips, the microfluidic cartridge, and the antibodies used in PBSA have been tested under space relevant radiation conditions:

1. more than twice the high energy proton radiation that a chip would receive in a 2 years mission to Mars, and
2. more than 1000 times the gamma radiation in the same mission conditions.

No significant alteration in the performance of any of the three components was observed (Figs. 17-19).

![Gamma 15krd in Comparison to Reference Failure Tube](image)

**Figure 17.** Effect of gamma radiation on the microfluidic cartridge. This amount of radiation (15 krad) does not affect the cartridges behaviour. The gamma radiated cartridges with 15krd results (black and blue) in comparison to reference failure tube. Similar effect was observed for proton radiation (not shown here. See D6.3)
Figure 18. Effect of gamma radiation on PIC. Similar behaviour of 3 rings before (left) and after irradiation (right). Similar effect was observed for proton radiation (not shown here. See D6.3)

Figure 19. Effect of high-energy proton and gamma radiation on immobilized antibodies. Antibodies anti-GroEL and anti-Bs subtilis spores (IVH1C1) were printed onto microscope slides and then irradiated with high energy protons and gamma radiation (blue, non-irradiated; red irradiated with 15 krad of protons, more than twice the radiation that antibodies could receive in a 2 years mission to Mars. The printed antibodies were used to measure different concentrations of GroEL. The plots represent the relative fluorescence. The behaviour of the irradiated (red) is similar, even slightly better, that the non-irradiated ones (blue) for the GroEL detection. For the anti-spores it is similar, although one of the spot is out of the curve
All the electrical and mechanical components selected and acquired for PBSA are space qualified by the provider, so we do not consider necessary to subject them to space environmental tests. The electrochemical pumping system and valves that retain liquids in the cartridge reservoirs need to be qualified under vacuum. We consider that valve qualification for space is out of the scope of the project and it would need extra funding.

**Conclusions**

We have developed and validated a versatile protocol for label-free near real-time detection of proteins and microbial cells in PBSA prototype

No effects on the photonic chip nor on the microfluidic cartridge was observed after high energy (protons) and gamma radiation exposure

PBSA is a prototype photonic based biosensor instrument for multiplex molecular biomarker or microbial cell detector

**4.1.4. Potential impact**

**Final results**

- The development of several activation + functionalization protocols for SiN micro-ring resonators
- A printing procedure for multiplex functionalization of PIC chips
- A multiplex label-free immunoassay protocol for PICs
- A unique microfluidic cartridge for performing the consecutive analysis of two samples by PIC and using enhancing signal procedures.
- A unique integrated PIC design for multiplex photonic detection
- And, finally, a unique prototype compact instrument for label-free near real-time multiplex immunological photonic detection.

**Potential impacts**

Although still depuration and refining improvement have to be done, PBSA can be a source of innovation that may bring new opportunities in the space and security applications. From PBSA device starting point, a list of high innovative products in high demanding markets like the ones mentioned below can be developed:

- Medicine and Veterinary: in situ and near real time assays. Our results with the antibodies to viral protein VP7 from Bluetongue virus demonstrate its utility in veterinary field. In fact, this antigen-antibody material was obtained as collaboration with another FP7 project: RAPIDIA-FIELD, devoted to the development of quick detection methods for animal pathogen in the field (farms) or small field lab. PBSA could be an excellent candidate.
- Bioterrorism and NBQ for quick and real time pathogen detection.
• Environmental monitoring application: pollution in the seas and lakes and rivers.
• Industrial applications where in-line monitoring capabilities are required inside the process.
• In the farm fisheries, where it is critical to detect the presence of pathogens or the proliferation of algae or the presence of certain toxins, the use of a continuous monitoring system would be of great utility to the industries of the sector.

Project public website: www.pbsa-fp7.eu

4.1.5. Contact details

<table>
<thead>
<tr>
<th>no</th>
<th>Partner short name</th>
<th>Organisation name</th>
<th>Country</th>
<th>Main role in the Project</th>
<th>Contact</th>
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<tbody>
<tr>
<td>1</td>
<td>INTA</td>
<td>Centro de Astrobiología (CSIC-INIA)</td>
<td>Spain</td>
<td>Coordinator, Imunosensing</td>
<td>Víctor Parro <a href="mailto:parrovg@cab.inta-csic.es">parrovg@cab.inta-csic.es</a></td>
</tr>
<tr>
<td>2</td>
<td>FHF</td>
<td>Fraunhofer ENAS</td>
<td>Germany</td>
<td>Microfluidics</td>
<td>Sascha Geidel <a href="mailto:Sascha.Geidel@enas.fraunhofer.de">Sascha.Geidel@enas.fraunhofer.de</a></td>
</tr>
<tr>
<td>3</td>
<td>DAS</td>
<td>DAS Photonics</td>
<td>Spain</td>
<td>Photonic activities</td>
<td>Sergio Peransi <a href="mailto:speransi@daphotonics.com">speransi@daphotonics.com</a></td>
</tr>
<tr>
<td>4</td>
<td>EVO</td>
<td>EVO Photonics</td>
<td>Portugal</td>
<td>System Integration, Electronic</td>
<td>Rodolfo Martins <a href="mailto:rodolfo.martins@evoleotech.com">rodolfo.martins@evoleotech.com</a></td>
</tr>
</tbody>
</table>

4.1.6. Other information
The PBSA consortium agreed to respond to the Horizon 2020 topic COMPET-4-2015 - Space exploration – Habitat management with a new proposal called “Biosensing Solutions for Environmental Monitoring in Space Installations (BIOSEMSI)”, Proposal number: 687449. The aim is to offer a versatility of biosensing methods, including PBSA, because there are many different biochemical and detection approaches from the laboratories around the world. Having several microfluidic solutions and a common versatile reader for the most common biosensing methods will have a major impact in the sector, not only for habitat management in space but for ground applications too.

We expanded the consortium with the Norwegian Technical University in Trondheim (NTNU), with expertise in procedure development for ISS monitoring, and a Spanish SME company (Laboratorio de Control Microbiológico S.L.) devoted to the microbiological sample analysis with tight contact with the actual biosensing market.

The objective of BIOSEMSI
The BioSEMSI goal is to develop and validate a sensitive, versatile, portable and user-friendly bio-affinity based biosensing system for detecting microbial (bacteria, fungi, viruses, some toxins) contamination in human habited spaces. Such goal will be achieved through the next objectives:

**Objective A.** Developing three sets of antibodies and aptamers specific for the most frequently found microbes in the air and surfaces, water reservoirs, and human fluids on board of the ISS. Develop and optimize microarray immunoassays for all of them.

**Objective B.** Development of a compact self-contained and disposable microfluidic chip system for automatic microarray immunoassay running. The chip is coupled to a universal optic reading system for fluorescence, chemoluminescence and visible light detection.

**Objective C.** On-ground validation of the biosensing system in space habitat analogues and non-space actor installations, such as industrial ecology and the fresh water reservoir management sectors.

**Objective D.** Development of procedures for environmental monitoring of space installations, particularly the ISS, as well as a data repository system for time-course follows up.

---

**HORIZON 2020**

**EU RESEARCH and INNOVATION PROGRAMME**

**BIOSEMSI**

Proposal answer to Call for proposals:

**H2020-LEIT-SPACE – Competitiveness of the European Space Sector-2015**

**Work programme topic addressed:** COMPET-4-2015 - Space exploration – Habitat management

**Project Full Title:** Biosensing Solutions for Environmental Monitoring in Space Installations

**Project acronym:** BIOSEMSI

**Type or Funding Scheme:** CP-FP (small or medium-scale focused research project)

**Coordinating Person and Contact:** Dr. Victor Parro

**Dr. Victor Parro**

**Instituto Nacional de Técnica Aeroespacial (INTA)**

**Phone:** +34-915201071 or +34-915201111

**Email:** parrogy@cab.inta-csic.es

**List of participants**

<table>
<thead>
<tr>
<th>Participant No.</th>
<th>Participant organisation name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Coordinator)</td>
<td>INSTITUTO NACIONAL DE TÉCNICA AEREOESPACIAL (INTA)</td>
<td>SPAIN</td>
</tr>
<tr>
<td>2</td>
<td>FRAUNHOFER INSTITUTE ENAS (ENAS)</td>
<td>GERMANY</td>
</tr>
<tr>
<td>3</td>
<td>DAS PHOTONICS S.L. (DAS)</td>
<td>SPAIN</td>
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<tr>
<td>4</td>
<td>EVOLEO TECHNOLOGIES (EVOLEO)</td>
<td>PORTUGAL</td>
</tr>
<tr>
<td>5</td>
<td>NORGES TEKNIK-NATURVITENSKAPELIGE UNIVERSITET, TRONDHEIM (NTNU)</td>
<td>NORWAY</td>
</tr>
<tr>
<td>6</td>
<td>LABORATORIO DE CONTROL MICROBIOLÓGICO S.L. (LCM)</td>
<td>SPAIN</td>
</tr>
</tbody>
</table>
4.2 Use and dissemination of foreground

A plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) shall be established at the end of the project. It should, where appropriate, be an update of the initial plan in Annex I for use and dissemination of foreground and be consistent with the report on societal implications on the use and dissemination of foreground (section 4.3 – H).

The plan should consist of:

- **Section A**

  This section should describe the dissemination measures, including any scientific publications relating to foreground. Its content will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

- **Section B**

  This section should specify the exploitable foreground and provide the plans for exploitation. All these data can be public or confidential; the report must clearly mark non-publishable (confidential) parts that will be treated as such by the Commission. Information under Section B that is not marked as confidential will be made available in the public domain thus demonstrating the added-value and positive impact of the project on the European Union.

**Section A (public)**

This section includes two templates

- **Template A1**: List of all scientific (peer reviewed) publications relating to the foreground of the project.


These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.
<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Main author</th>
<th>Title of the periodical or the series</th>
<th>Number, date or frequency</th>
<th>Publisher</th>
<th>Place of publication</th>
<th>Year</th>
<th>Page</th>
<th>Permanent identifiers² (if available)</th>
<th>Is/Will open access³ provided to this publication?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Integration of an optical ring resonator biosensor into a self-contained microfluidic cartridge including active, single-shot micropumps</td>
<td>Sascha Geidel</td>
<td>Sensors</td>
<td>Special Issue: Photonic sensor in space</td>
<td>MDPI AG</td>
<td>Basel, Switzerland</td>
<td>2015</td>
<td></td>
<td>yes</td>
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<tr>
<td>2</td>
<td>A Photonic Biosensor for Space Applications (PBSA)</td>
<td>Víctor Parro</td>
<td>Sensors</td>
<td>Special Issue: Photonic sensor in space</td>
<td>MDPI AG</td>
<td>Basel, Switzerland</td>
<td>2015</td>
<td></td>
<td>yes</td>
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</tr>
</tbody>
</table>

² A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).
³ Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.
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<tr>
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<th>Title</th>
<th>Date/Period</th>
<th>Place</th>
<th>Type of audience</th>
<th>Size of audience</th>
<th>Countries addressed</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>Poster</td>
<td>Sascha Geidel (ENAS)</td>
<td>BIOSENSORS 2014 World Congress (24th-Anniversary)</td>
<td>27th-30th May-2014 in Melbourne (Australia)</td>
<td>Scientific Community and industry</td>
<td>&gt;500</td>
<td>World</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Conference</td>
<td>Victor Parro (INTA)</td>
<td>EC, LET’S EMBRACE SPACE event “3rd International Space Research Conference”</td>
<td>15-16 September 2014 in Rome (Italy)</td>
<td>Space Science and Industry</td>
<td>&gt;200</td>
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<tr>
<td>4</td>
<td>Poster</td>
<td>Victor Parro (INTA)</td>
<td>International Conference on Space Optics – ICSO 2014</td>
<td>7th-10th October-2014 in Tenerife (Spain)</td>
<td>Scientific and Space Community</td>
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<td>5</td>
<td>Poster</td>
<td>Victor Parro (INTA)</td>
<td>SEA (Spanish Society for Astronomy) XI Scientific Meeting</td>
<td>18th-22th September-2014 in Teruel (Spain)</td>
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<td>6</td>
<td>Workshops about astrobiology</td>
<td>Luis Cuesta (INTA)</td>
<td>Workshops about Astrobiology</td>
<td>October-2014 to April-2015 in Several cities of Spain</td>
<td>General public and schools</td>
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<td>Spain</td>
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<td>Workshops about astrobiology</td>
<td>Luis Cuesta (INTA)</td>
<td>Science Week of Madrid</td>
<td>3th-10th November-2014 in Madrid (Spain)</td>
<td>General public and schools</td>
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<td>Spain</td>
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<td>Workshops about astrobiology</td>
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<td>Spanish Foundation for Science and Technology held in Madrid</td>
<td>October-2014 in Madrid (Spain)</td>
<td>General public and schools</td>
<td>&gt;200</td>
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<td>Roundtable</td>
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<td>10</td>
<td>Publication</td>
<td>Victor Parro (INTA)</td>
<td>Infoespacio TEDAE</td>
<td>25th March 2013 in Madrid (Spain)</td>
<td>Space Business</td>
<td>&gt;1000</td>
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<td>11</td>
<td>Poster</td>
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<td>September-2013 in Cork (Ireland)</td>
<td>Technology and Business</td>
<td>&gt;300</td>
<td>European</td>
<td></td>
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</tbody>
</table>

4 A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

5 A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).
Section B (Confidential or public: confidential information to be marked clearly)

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

The list should, specify at least one unique identifier e.g. European Patent application reference. For patent applications, only if applicable, contributions to standards should be specified. This table is cumulative, which means that it should always show all applications from the beginning until after the end of the project.

<table>
<thead>
<tr>
<th>Type of IP Rights(^5):</th>
<th>Confidential Click on YES/NO</th>
<th>Foreseen embargo date dd/mm/yyyy</th>
<th>Application reference(s) (e.g. EP123456)</th>
<th>Subject or title of application</th>
<th>Applicant (s) (as on the application)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^5\) Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

\(^7\) A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.
Part B2
Please complete the table hereafter:

<table>
<thead>
<tr>
<th>Type of Explottable Foregrounbd</th>
<th>Description of exploitable foreground</th>
<th>Confidential Click on YES/NO</th>
<th>Foreseen embargo date dd/mm/yyyy</th>
<th>Exploitable product(s) or measure(s)</th>
<th>Sector(s) of application\textsuperscript{a}</th>
<th>Timetable, commercial or any other use</th>
<th>Patents or other IPR exploitation (licences)</th>
<th>Owner &amp; Other Beneficiary(s) involved</th>
</tr>
</thead>
</table>

In addition to the table, please provide a text to explain the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/expected impact (quantify where possible)

\textsuperscript{a} A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

\textsuperscript{b} A drop down list allows choosing the type sector (NACE nomenclature) : [http://ec.europa.eu/competition/mergers/cases/index/nace_all.html](http://ec.europa.eu/competition/mergers/cases/index/nace_all.html)
4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information (completed automatically when Grant Agreement number is entered.)

Grant Agreement Number: 312942
Title of Project: Photonic Biosensor for Space Applications
Name and Title of Coordinator: Victor Parro (PhD)

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)?
   - If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports?
   - No

Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 'Work Progress and Achievements'

2. Please indicate whether your project involved any of the following issues (tick box): YES

   **Research on Humans**
   - Did the project involve children?
   - Did the project involve patients?
   - Did the project involve persons not able to give consent?
   - Did the project involve adult healthy volunteers?
   - Did the project involve Human genetic material?
   - Did the project involve Human biological samples?
   - Did the project involve Human data collection?

   **Research on Human Embryo/foetus**
   - Did the project involve Human Embryos?
   - Did the project involve Human Foetal Tissue / Cells?
   - Did the project involve Human Embryonic Stem Cells (hESCs)?
   - Did the project on human Embryonic Stem Cells involve cells in culture?
   - Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?

   **Privacy**
   - Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?
   - Did the project involve tracking the location or observation of people?

   **Research on Animals**
   - Did the project involve research on animals?
   - Were those animals transgenic small laboratory animals?
   - Were those animals transgenic farm animals?
   - Were those animals cloned farm animals?
   - Were those animals non-human primates?
**Research Involving Developing Countries**

- Did the project involve the use of local resources (genetic, animal, plant etc)?
- Was the project of benefit to local community (capacity building, access to healthcare, education etc)?

**Dual Use**

- Research having direct military use
- Research having the potential for terrorist abuse

<table>
<thead>
<tr>
<th>C Workforce Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).</td>
</tr>
<tr>
<td>Type of Position</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Scientific Coordinator</td>
</tr>
<tr>
<td>Work package leaders</td>
</tr>
<tr>
<td>Experienced researchers (i.e. PhD holders)</td>
</tr>
<tr>
<td>PhD Students</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

4. How many additional researchers (in companies and universities) were recruited specifically for this project? 3

Of which, indicate the number of men: 1
D  Gender Aspects

5.  Did you carry out specific Gender Equality Actions under the project?  ○  ○  Yes  No

6.  Which of the following actions did you carry out and how effective were they?

<table>
<thead>
<tr>
<th>Action</th>
<th>Not at all effective</th>
<th>Very effective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and implement an equal opportunity policy</td>
<td>○ ○ ○ ○ ○ ○</td>
<td></td>
</tr>
<tr>
<td>Set targets to achieve a gender balance in the workforce</td>
<td>○ ○ ○ ○ ○ ○</td>
<td></td>
</tr>
<tr>
<td>Organise conferences and workshops on gender</td>
<td>○ ○ ○ ○ ○ ○</td>
<td></td>
</tr>
<tr>
<td>Actions to improve work-life balance</td>
<td>○ ○ ○ ○ ○ ○</td>
<td></td>
</tr>
<tr>
<td>Other: Followed national parity rules</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.  Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

<table>
<thead>
<tr>
<th></th>
<th>○  Yes- please specify</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X  No</td>
</tr>
</tbody>
</table>

E  Synergies with Science Education

8.  Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

<table>
<thead>
<tr>
<th></th>
<th>○  Yes- please specify</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X  No</td>
</tr>
</tbody>
</table>

9.  Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

<table>
<thead>
<tr>
<th></th>
<th>○  Yes- please specify</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X  No</td>
</tr>
</tbody>
</table>

F  Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

<table>
<thead>
<tr>
<th>Discipline</th>
<th>○  Main discipline(^\text{10}): 1.3, 1.5, 2.2, 2.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>○  Associated discipline(^\text{10}):</td>
</tr>
<tr>
<td></td>
<td>○  Associated discipline(^\text{10}):</td>
</tr>
</tbody>
</table>

G  Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community?  ○  X  Yes  No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

<table>
<thead>
<tr>
<th></th>
<th>○  No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>○  Yes- in determining what research should be performed</td>
</tr>
<tr>
<td></td>
<td>○  Yes - in implementing the research</td>
</tr>
<tr>
<td></td>
<td>○  Yes, in communicating /disseminating / using the results of the project</td>
</tr>
</tbody>
</table>

\(^{10}\) Insert number from list below (Frascati Manual).
11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>☑</td>
<td></td>
</tr>
</tbody>
</table>

12. Did you engage with government / public bodies or policy makers (including international organisations)?

<table>
<thead>
<tr>
<th></th>
<th>Yes- in framing the research agenda</th>
<th>Yes - in implementing the research agenda</th>
<th>Yes, in communicating / disseminating / using the results of the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

<table>
<thead>
<tr>
<th></th>
<th>Yes – as a primary objective (please indicate areas below - multiple answers possible)</th>
<th>Yes – as a secondary objective (please indicate areas below - multiple answer possible)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>☑</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

13b If Yes, in which fields?

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Energy</th>
<th>Human rights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audiovisual and Media</td>
<td>Enlargement</td>
<td>Information Society</td>
</tr>
<tr>
<td>Budget</td>
<td>Enterprise</td>
<td>Institutional affairs</td>
</tr>
<tr>
<td>Competition</td>
<td>Environment</td>
<td>Internal Market</td>
</tr>
<tr>
<td>Consumers</td>
<td>External Relations</td>
<td>Justice, freedom and security</td>
</tr>
<tr>
<td>Culture</td>
<td>External Trade</td>
<td>Public Health</td>
</tr>
<tr>
<td>Customs</td>
<td>Fisheries and Maritime Affairs</td>
<td>Regional Policy</td>
</tr>
<tr>
<td>Development Economic and Monetary Affairs</td>
<td>Food Safety</td>
<td>Research and Innovation</td>
</tr>
<tr>
<td>Education, Training, Youth</td>
<td>Foreign and Security Policy</td>
<td>Space</td>
</tr>
<tr>
<td>Employment and Social Affairs</td>
<td>Fraud</td>
<td>Taxation</td>
</tr>
<tr>
<td></td>
<td>Humanitarian aid</td>
<td>Transport</td>
</tr>
</tbody>
</table>
### 13c If Yes, at which level?
- Local / regional levels
- National level
- European level
- International level

### H Use and dissemination

#### 14. How many Articles were published/accepted for publication in peer-reviewed journals?
2

To how many of these is open access\(^{11}\) provided?

- How many of these are published in open access journals?

- How many of these are published in open access repositories?

To how many of these is open access not provided?

Please check all applicable reasons for not providing open access:
- Publisher's licensing agreement would not permit publishing in a repository
- No suitable repository available
- No suitable open access journal available
- No funds available to publish in an open access journal
- Lack of time and resources
- Lack of information on open access
- Other\(^{12}\): ..............

#### 15. How many new patent applications (‘priority filings’) have been made?
("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).

#### 16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).

<table>
<thead>
<tr>
<th>Trademark</th>
<th>Registered design</th>
<th>Other</th>
</tr>
</thead>
</table>

#### 17. How many spin-off companies were created / are planned as a direct result of the project?

*Indicate the approximate number of additional jobs in these companies:*

#### 18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

<table>
<thead>
<tr>
<th>Increase in employment, or</th>
<th>In small &amp; medium-sized enterprises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safeguard employment, or</td>
<td>In large companies</td>
</tr>
<tr>
<td>Decrease in employment,</td>
<td>None of the above / not relevant to the project</td>
</tr>
<tr>
<td>Difficult to estimate / not possible to quantify</td>
<td></td>
</tr>
</tbody>
</table>

#### 19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent \((FTE = \text{one person working fulltime for a year})\) jobs:

*Indicate figure:*

---

\(^{11}\) Open Access is defined as free of charge access for anyone via Internet.

\(^{12}\) For instance: classification for security project.
Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?
   - Yes
   - No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?
   - Yes
   - No

22. Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?
   - Press Release
   - Media briefing
   - TV coverage / report
   - Radio coverage / report
   - Brochures / posters / flyers
   - DVD / Film / Multimedia

23. In which languages are the information products for the general public produced?
   - Language of the coordinator (Spanish)
   - Other language(s)
   - English


**FIELDS OF SCIENCE AND TECHNOLOGY**

1. **NATURAL SCIENCES**
   1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
   1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
   1.3 Chemical sciences (chemistry, other allied subjects)
   1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
   1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2. **ENGINEERING AND TECHNOLOGY**
   2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
   2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
   2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as
geodesy, industrial chemistry, etc.; the science and technology of food production; specialised
technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology
and other applied subjects)

3. **MEDICAL SCIENCES**
   
   3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology,
   immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
   
   3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery,
   dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
   
   3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. **AGRICULTURAL SCIENCES**
   
   4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry,
   horticulture, other allied subjects)
   
   4.2 Veterinary medicine

5. **SOCIAL SCIENCES**
   
   5.1 Psychology
   
   5.2 Economics
   
   5.3 Educational sciences (education and training and other allied subjects)
   
   5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography
   (human, economic and social), town and country planning, management, law, linguistics, political
   sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary,
   methodological and historical S1T activities relating to subjects in this group. Physical anthropology,
   physical geography and psychophysiology should normally be classified with the natural sciences].

6. **HUMANITIES**
   
   6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as
   archaeology, numismatics, palaeography, genealogy, etc.)
   
   6.2 Languages and literature (ancient and modern)
   
   6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art
   criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind,
   religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and
   other S1T activities relating to the subjects in this group]
2. **FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION**

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

**Report on the distribution of the European Union financial contribution between beneficiaries**

<table>
<thead>
<tr>
<th>Name of beneficiary</th>
<th>Final amount of EU contribution per beneficiary in Euros</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTA</td>
<td>429,795.89</td>
</tr>
<tr>
<td>2. ENAS</td>
<td>301,014.00</td>
</tr>
<tr>
<td>3. DAS</td>
<td>497,075.00</td>
</tr>
<tr>
<td>4. EVOLEO</td>
<td>241,962.60</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,469,847.49</strong></td>
</tr>
</tbody>
</table>