VIALACTEA Report Summary

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Final Report Summary - VIALACTEA (VIALACTEA - The Milky Way as a Star Formation Engine)

Executive Summary:

1.1 Executive Summary

The project VIALACTEA brought to a common forum the major new-generation surveys of the Galactic Plane from 1μm to the radio, both in thermal continuum and in atomic and molecular lines, from Europe-funded space missions and ground-based facilities. The project has allowed to engage one of the fundamental challenges in Galactic astronomy: to quantify Galaxy-wide the relationship between the physical agents responsible for the onset and the regulation of star formation in a spiral galaxy and the resulting Rate and Efficiency of star formation, and to obtain the ingredients for a “star formation recipe” that will be a cornerstone to trace the star formation history of galaxies back to their formation.

Today for the first time, it has been possible to engage this ambitious challenge thanks to a new suite of cutting-edge Milky Way surveys that provide a homogeneous coverage of the entire Galactic Plane and that have already started to transform the view of our Galaxy as a global star formation engine. New instruments in space and on the ground have delivered information of unprecedented depth and spatial detail, covering wide swathes of the plane, and spanning the electromagnetic spectrum. The combination of near-Infrared (IR) ground surveys data, mid-IR and far-IR dust continuum obtained by ESA’s Herschel and NASA’s Spitzer and WISE satellites, with radio free-free continuum and gas-tracing atomic and molecular spectroscopy from ground-based observatories, has allowed to compile the first complete census of sites of ongoing and potential star formation in the Milky Way. VIALACTEA has devised and deployed a coherent observational paradigm for the evolutionary classification of such sites over the entire Galaxy, enabling for the first time to obtain the resolved map of the Rate of star formation in the Milky Way. The Project has provided the first complete catalogue of the outstanding and pervasive filaments that represent the pivotal structures that bring diffuse gas and dust in the Milky Way to form the new nurseries out of which the new generations of stars are currently forming. The heliocentric distances to more than one hundred thousand potential star forming sites and filaments were derived, delivering temperatures, luminosities, masses and densities for all of them.

These results have been obtained developing i) a set of new tools for the automatic extraction and characterization of complex structures from astronomical images, ii) radiative transfer codes to provide the 3D thermal tomography of star formation regions, iii) new grids of millions of theoretical models for the infrared emission from stellar nurseries, iv) data-mining algorithms for the combination of multiwavelength data, and v) expert systems for the automated analysis of molecular line surveys to extract critical kinematical information and derive distances using Galaxy rotation curves and new 3D extinction maps.

The new 3D VIALACTEA Visual Analytics interface provides integrated access and analysis of continuum and spectroscopic images together with catalogue data, managed via metadata layers in a publicly accessible Milky Way knowledge-base. The VIALACTEA Science Gateway allows the easy configuration, building and running of complex data processing and analysis workflows based on the VIALACTEA Knowledge-base.

Project Context and Objectives:

1.2 Concept and Objectives
The Milky Way Galaxy, our home, is a complex ecosystem where a cyclical transformation process brings diffuse barionic matter into dense unstable condensations to form stars, that produce radiant energy for billions of years before releasing chemically enriched material back into the ISM in their final stages of evolution. Star formation is the trigger of this process, eventually driving the evolution of ordinary matter in the Universe from its primordial composition to the present-day chemical diversity necessary for the birth of life. The importance of this topics explains the prominence of star and planet formation in the space research and mission programs of ESA and NASA.

Although considerable progress has been made in the last two decades in understanding the evolution of isolated dense molecular clumps toward the onset of gravitational collapse and the formation of stars and planetary systems, a lot remains still hidden. We do not know the relative importance of gravity, turbulence or the perturbation from spiral arms in assembling the diffuse and mostly atomic Galactic ISM into molecular dense filamentary structures and compact clumps. We do not know the relative importance of gravity or external triggering in the onset of the gravitational collapse leading to star formation, nor we know the role of magnetic field in the process. We do not know how the role played by these different agents changes from extreme environments like the Galactic Centre to the quiet neighborhoods of the Galaxy beyond the solar circle. We do not know how to quantitatively relate the different physical agents at work, to the rate and the efficiency with which they are able to turn gas and dust into stars. This lack of a ‘fundamental theory’ or, rather, of a galaxy-scale predictive model for star formation, is the key issue to be addressed by VIALACTEA.

1.2.1 Star Formation in a Global Galactic Context

The formation of stars and star clusters is by far the most important event that shapes the evolution and fate of galaxies. Stars are responsible for the global ionization of the Interstellar Medium (ISM). Their energetic stellar winds and supernova blast waves direct the dynamical evolution of the ISM, shaping its morphology, energetics and chemistry, and influencing the formation of subsequent generations of stars and planetary systems.

Stars form in Molecular Clouds, where about half of the mass in the ISM of the Galaxy is stored. Due to the strong extinction of optical light by dust grains mixed with the gas, the birth must be studied at infrared (IR) and longer wavelengths that can penetrate the clouds. The paradigm for the formation of solar-type stars via accretion from an envelope through a circumstellar disk predicts an evolution from cores to protostars, and finally pre-main sequence stars that is well matched with distinctive characteristics of their SED. The empirical classification of the SED of low mass YSOs either based on detailed modeling or on simple colour analysis, as well as the dust envelope temperature and the evolution of integrated parameters like the bolometric luminosity Lbol and the mass of the circumstellar envelope Menv, have been used as powerful tools to constrain the evolutionary stage of YSOs. The formation of low-mass stars is however complicated by the fact that they are born for the most part in clusters together with more massive YSOs. Higher mass YSOs reach the conditions for H-burning faster than the time required to assemble them, so that winds and radiative acceleration will strongly influence their late accretion phases and that of the other cluster members.

In a traditional “slow formation” picture, diffuse ISM is accumulated by large-scale perturbations such as the passage of a spiral arm. Shielding by dust and surface reactions on grains promotes the HI→H2 transition, which in turn allows the formation of other molecules that cool the cloud. Gravity, mediated by the magnetic fields leads to unstable dense clumps with typical sizes between 0.1 and 1pc, that can further differentiate into a multiplicity of cores that are typically dubbed protoclusters. Typically each core (sizes ≈ 0.01 pc), harbors a forming Young Stellar Object (YSOs) eventually leading to a single star or a close binary.

The fact that the mass function in protoclusters has a similar shape to the IMF in field stars suggests that the end-products of star formation are entirely defined as early as the clump formation stage. Therefore the detailed morphology of dense star forming structures, their mass and temperature distribution, and the timescales for their formation and for star formation inside them, hold the key to identify the dominant mechanism responsible for their formation. Ultimately, one wants to relate the end-products of star formation measured by the Star Formation Rate (SFR, stellar mass produced per unit time) and Efficiency (SFE, stellar mass produced per unit mass of available dense gas), to the physical mechanism responsible for the onset of star formation. Doing this in very different places of the Galaxy and with significant statistics is the necessary step to put star formation in the global context.

Galactic phenomenology invokes an indeterminate mixture of spontaneous and triggered star formation. Triggering agents
include radiation pressure from OB stars, compression by expanding HII regions, or fragmentation of supershells by multiple supernovae in OB associations. On larger scales it seems clear that cloud and the star formation rates are clearly enhanced in correspondence to spiral patterns, although the efficiency may not show a significant enhancement in the arms as opposed to the interarm regions; it is still unclear if spiral density waves actively induce star formation or simply assemble star-forming regions, with local feedback and triggering becoming more important within the arms. The coexistence of these phenomenologies in most of the spiral galaxies indicates a complex mix of fundamentally different physics that needs to be quantitatively related to the Rate and Efficiency of the star formation in a statistically significant fashion, in view of a bottom-up recipe to characterize star formation properties in spiral galaxies from the extreme conditions of the Galactic Centre to the much quieter neighborhoods beyond the solar circle.

1.2.2 A new-generation goldmine of Galactic Plane Surveys from Space and Ground, for a revolutionary set of data products

A new set of complete and high spatial resolution Galactic Plane Surveys needs to be assembled that will for the first time allow us to systematically attack this problem.

Near-IR: The UKIDSS Galactic Plane Survey, combined with 2MASS to provide a complete coverage. Lower extinction at 1-2μm allows the Galactic mid-plane to be probed and embedded stars revealed. The UKIDSS Galactic Plane Survey (UKIDSS, www.ukids.org) on the 4m UK Infrared Telescope on Hawaii covers the three near-IR photometric bands (J, H and K) to 18th magnitude.

Mid-IR: The GLIMPSE, WISE and MIPSGAL Surveys. The unprecedented depth (15th mag) and resolution (2") of The Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE, www.astro.wisc.edu/glimpse) by NASA’s Spitzer satellite were the first to deliver a new global view of the Galaxy at the wavelengths of 3.6, 4.5 5.8, and 8.0μm. The resulting tens-of-million sources catalogue is dominated by stars and to a lesser extent by pre-Main Sequence YSOs, with the 8.0μm channel also showing strong extended emission that probes the interaction between hot stars and molecular clouds. The Spitzer-MIPSGAL survey at 24 μm (mipsgal.ipac.caltech.edu) enables much deeper penetration into the dense molecular clouds to reveal the “first cry” of nascent intermediate and high-mass stars. Such surveys, that were initially limited to the inner third of the Milky Way Galactic Plane, have been complemented by GLIMPSE360, using Spitzer in its “warm mission”, to complete the coverage of the entire Galactic Plane at 3.6 and 4.5μm, and by the WISE satellite, that as part of its all-sky survey is covering the entire GP (although at lower resolution that Spitzer) between 3 and 25μm.

Far-IR: Herschel Hi-GAL Survey. The Hi-GAL survey (Molinari et al. 2010, 2016) is one of the main surveys carried out with ESA’s 3.5m Herschel satellite. With its unique photometric imaging of the entire |b|<1° Galactic Plane obtained in 5 bands (70, 170, 250, 350 and 500μm) with a 10-fold increase in spatial resolution (5-35") compared to IRAS, and the exceptional capabilities of its PACS and SPIRE cameras to recover dust thermal emission from cold (50K< T <10K) compact bright sources as well as diffuse and extended clouds and filaments, Herschel/Hi-GAL has delivered a transformational view of the complete evolutive path that brings cold and diffuse interstellar material to condense into clouds and filaments that fragments into protocluster-forming dense clumps.

Sub-millimetre continuum: ATLASGAL and Bolocam GP Surveys. The ATLASGAL survey (Schuller et al. 2009) has used the 12 m ESO-APEX telescope in Chile to map the Galactic Plane (accessible from the south) at 870μm, while the BGPS has extended the coverage at 1.1mm with the 10m CSO telescope for the 1st quadrant. The combination of these two surveys in the millimeter will complement the Far-IR from Herschel to yield accurate estimates of the column density and mass of dense molecular clouds and clumps, with a unique ability to probe dust at temperatures even lower than 10K.

Molecular and Atomic Line Surveys. Kinematic information on the gas phase of the same cool dust clouds imaged in the continuum can be traced using the molecular line emission. The Galactic Ring Survey (GRS, www.bu.edu/galacticring) at 46"resolution uses the 13CO (1-0) transition whilst atomic hydrogen (HI) is traced by the 21cm transition. The International Galactic Plane Survey (IGPS) has combined three interferometric surveys at 45-60" resolution (www.ras.ucalgary.ca/IGPS/) giving an ideal tool to study the transformation of atomic into molecular gas in the spiral arms. The coverage of the Galactic Plane in 12CO/13CO has been extended to complete the 1st and 2nd quadrants with the Outer GP Survey with the FCRAO antenna, and in the 3rd and 4th quadrants by the NANTEN/NANTEN2 surveys in Chile, and with the Mopra GPS in CO/13CO/C18O in Australia.

Radio continuum: The CORNISH and MAGPIS Surveys. Radio continuum provides extinction-free views of bremsstrahlung
radiation from UCHII regions. The 1.5" resolution 6 cm CORNISH survey (www.leeds.ac.uk/Cornish) used the Very Large Array in New Mexico. This is complemented over a smaller region by the 6" resolution 20 cm MAGPIS survey that traces evolved HII regions and supernova remnants (SNRs) important in triggered star formation.

1.2.3 A Revolution in Science Analysis Techniques and data handling

The volume and complexity of these new survey datasets calls for a radical re-evaluation of the current science and data analysis techniques. A number of data visualization packages exist, and yet none of them integrates data access and analysis of 2D images, catalogue source properties and spectral datacubes into a single client application. The Virtual Observatory (VO) concept of distributed data is not optimised for deep scientific exploitation of the VIALACTEA data unless an intermediate layer of astronomical metadata information is provided to homogenise the description of the data. The normal discovery services for data archives are limited to point-like objects, or compact objects that can be described with position-size information. Extended structures like clouds or complex filaments that are critical actors in the star formation process are not currently catalogued with descriptors that enable their query & access via standard SQL queries to databases.

Current building of Spectral Energy Distributions (SEDs) by naive source catalogue band-merging purely based on positional matching (e.g. in TOPCAT) does not provide additional metrics to evaluate the quality of the various associations, leading to complex SEDs that ramify more and more as the spatial resolution increases as we proceed from sub-millimeter and far-infrared wavelengths to the mid-IR and near-IR. VIALACTEA brings all of this together, to achieve the following objectives:

- To boost the scientific exploitation of space data we have developed new and carefully tailored image processing tools with the aim of carrying out detection and extraction of compact sources and filamentary structures, as well as more complex shape-finding to identify bubble-like features from large scale Galactic Plane imaging surveys both in the infrared continuum and in gas molecular lines. These software tools have been used to produce high-quality catalogues of compact objects and filamentary structures in the Galactic Plane, that are essential building blocks to achieve the VIALACTEA scientific objectives, as well as the basic data resources for the larger community to carry out scientific research.
- We have combined in a VO-compatible and interoperable way the new-generation Galactic Plane surveys from space-borne missions and ground-based observatories, most of which are the subject of considerable European investments, to obtain a sub-arcminute resolution complete and homogeneous data coverage over the entire Galactic Plane from the infrared to the radio, that will extend the usage of already available space data and will multiply by many times the exploitation potential of the individual datasets. We have exploited this new state-of-the-art Multi-wavelength Milky Way framework by defining and implementing a complete and coherent science analysis methodology that for the first time will be uniformly applied from the Galactic Centre to the outskirts of the Milky Way to map critical parameters like star formation thresholds, rate and efficiency.
- We built a new 3D representation of the Milky Way Galaxy. Estimates of the distance to the star-forming objects and structures that populate the catalogues above listed have been determined by combining all available information from Galactic rotation curve, spectroscopic survey data in molecular gas lines (e.g., CO, 13CO, C18O, NH3, CS), atomic gas surveys in the 21cm HI line and 3D extinction maps in the near- and mid- Infrared.
- We succeeded in bringing to a common playground the scientific astronomical expertise and the e-Science technological know-how of leading European research groups to develop new 3D visual analytics tools that enable time-effective steradian-scale science in Galactic star formation.

Project Results:

1.3 The Science and Technology Results

1.3.1 From diffuse ISM to dense clouds filaments: the Galaxy-wide census of extended dust and gas structures

1.3.1.1 Filamentary structures

The Galaxy-wide ubiquity of the filamentary nature of the cold, dense and potentially star-forming phase of the ISM is one of the most important and unexpected discoveries of the Herschel Galactic photometric surveys. We have developed and delivered a novel software package for the extraction and characterization of filamentary structures. The code carries out filaments detection by thresholding over the image of the multidirectional 2nd-order derivatives of the signal to identify the spine and the area of the filaments. The main physical parameters of the filament such as the width, length, mean column density, mass per unit length, etc. are then calculated.
In order to apply the package to real survey data, panoramic column density maps were assembled. Column-density maps of the entire Galactic Plane by mosaicing the Hi-GAL survey tiles in groups of five per mosaic have been completed. Each one of the obtained mosaics is a map spanning over ten longitude degrees. The calibration of each mosaic has been done by using as a reference the already calibrated Hi-GAL tiles (their calibration has been determined for the 350 and 500 μm bands by comparing directly with the Planck observations, while for 70 and 250 μm has been computed by modelling the interstellar dust emission through Planck and IRAS wavebands). This activity has been designed and carried out using the workflows design and execution facility accessible through the VIALACTEA science gateway.

The package has then been applied to the overall Hi-GAL column density mosaics and a Hi-GAL Catalogue of filamentary structures has been produced, including all structures in the Galactic Plane. It is difficult to firmly quantify the quality and the reliability of the extracted structures. Synthetic filaments experiments were done populating real Hi-GAL images with synthetic filamentary structures of arbitrary lengths, widths and shapes, and agreement with extracted features was generally within 25%.

Extensive visual checks have been down for the extracted features and quality assessments can be made based on parameters contained in the filamentary structures catalogue. The first is the contrast, that can be computed as the ratio between the average column densities computed on filaments spines and the background immediately surrounding the filaments; visual analysis showed that visually reliable features have such a contrast in excess of 5%. An additional reliability parameter is provided by the ratio between the average column density on the spines and the residual r.m.s. on the background after filament subtraction; this can be seen as a S/N estimate of the feature, and only features with this reliability parameter above 5 have been included in the catalogue.

The filamentary structures catalogue contains a wealth of information not only for the morphology of the structures, but also on their physical conditions like temperature, column density and linear masses both averaged over the filaments regions as well as at the peak positions on the filaments spines. The Filamentary structures catalogue has been incorporated into the last version of the VIALACTEA Knowledge-base and each entry can be addressed and visualised using the VIALACTEA visual analytics client.

1.3.1.2 Bubble-like structures

To characterize the role of expanding bubbles in triggering new generations of star formation in the surrounding environment, we developed an automatic shape detection algorithm to be run on Galactic plane survey images. After a first period of careful evaluation of existing algorithms, the active contour technique resulted to be the one with the highest performances on both the quality of the results and the computing time. Active contours are a family of optimisation techniques that seek to minimise some function via solving a Partial Differential Equation by gradient descent. Essentially, they are elastic curves that move in a direction which minimises some force constraint. They represent a flexible framework and are used in image processing for the delineation of an image’s objects. Although their associated framework is simple and succinct, much effort has to be devoted to finding suitable “forces” that will result in acceptable segmentations. The active contour force is simply the result of evaluating the function, which is to be optimised.

However, in the special case of astronomy, the way in which we instruct the active contour curve to move has to be highly specialised. The dense and occluded appearance of celestial data means that active contour based segmentation strategies will have to be able to cope with intensity inhomogeneity, occlusion (objects overlapping), and weak edges. Further complications associated with evolving contours on astronomy data include the fact that the starting point from which we optimise our function (the contour evolution) will largely dictate the end result, making crucial the need of a tailored initialisation step.

An initial image segmentation pipeline was composed by three steps: i) the initial stage, where the data of interest is cleaned and made amenable to further processing (the data are smoothed - without the loss of spatial resolution - and transformed so that regions of interest are made more distinct from their background: this was achieved by the use of discrete wavelet transformations and log transforming the astronomy data with localised contrast enhancement); ii) the processing stage, where the initialisation generation and growth has been implemented by active contours using Level Sets coupled with the Sparse Field Method; iii) Subsequent to the processing stage, post element analysis is conducted, implementing a robust method of reconnecting structures to mitigate the effects of the diffuse and complex nature of astronomy data that sometimes
cause problems in reaching the whole boundary of objects of interest. The validity of the bubble segmentation was checked against ground truth based segmentations in which manually drawn contours were drawn and these were compared against the output of the active contour algorithm. This analysis demonstrated that our method outperformed other active contour based methods. The initial catalogue was refined using a 5 fold grid search optimised support vector machine algorithm. We randomly split 500 training contours, as provided by astronomers, into 4 training and one testing dataset and used these with the following features: 1) Histogram of gradients, 2) Morphological descriptors (eccentricity, percentage of contour inside convex hull), 3) Bhattacharyya distance between the intensities covered by the contour and their surroundings, to optimise the parameters required by the support vector machine. This enabled us to correctly differentiate 80% of bubbles from non informative contours.

The package was run on the entire 70μm images set of Hi-GAL, and a Catalogue was generated that contains a total of 5118 candidate bubbles, providing for each one of them the coordinates and the probability of the proposed segmentation being a bubble (as determined by a support vector machine algorithm). For each proposed bubble, the corresponding segmentation image is provided as a separate fits file. The catalogue has been incorporated into the last version of the VIALACTEA Knowledge-base and each entry can be addressed and visualised using the VIALACTEA visual analytics client.

1.3.1.3 Morphological properties and radiative transfer of extended structures

A new algorithm called “Q+” for determining the three-dimensional structure of fractal distributions of point and/or compact sources has been developed. The distributions are characterised by a fractal dimension, D, an inertial range, R, and a density-scaling exponent, C. In addition, a code that constructs multiple stochastic realisations of statistically isotropic fractal density and velocity fields has been developed, so that these can be used for testing and training automated algorithms, i.e. identifying statistical measures of two-dimensional images that robustly reflect the underlying three-dimensional structures; this algorithm can also be used to initialise simulations. The code can be customized to generate standard dendrograms in two and three dimensions.

A new algorithm has been developed that generates a stack of two-dimensional maps of column-density at different dust temperatures (for example the column-density at 7, 8, 9, 10, 11, 12, 14, 18, and 25K), effectively providing a thermal tomography of the structure and analysis (see Figure 2). It works without degrading resolutions and makes no assumptions about the distribution of temperature. Indeed, there are no hidden assumptions, the algorithm just uses basic statistical mechanics to evaluate the different possible states in configuration space. It is particularly suitable for spatially resolved modelling of temperature and column densities of extended clouds, filaments and bubbles. The methodology, called PPMAP, has been incorporated into a workflow in the VIALACTEA Science Gateway and full thermal tomography for the entire Galactic Plane has been generated; an example on the RCW120 bubble is presented in Figure 2.

1.3.2 From dense clumps to stars: the Galaxy-wide census of cluster-forming dense clumps and their relationship to the progenitor structures

The measurement of the rate with which gas and dust are turned into stars requires that all potentially star and cluster-forming sites i) are identified throughout the Galaxy, ii) their basic physical parameters (mass, size and temperature) are measured, iii) their evolutionary stage is characterised and iv) their relationship to the progenitor structures is established.

1.3.2.1 The Herschel Hi-GAL photometric catalogues

A new software package has been developed to detect sources and extract their fluxes, tailored to the case of the complex and structured background present in IR/sub-mm Herschel images. The idea behind this extraction and photometry code, called CuTEx - Curvature Thresholding Extractor, is to look for the pixels in the map showing the highest curvature in the intensity maps, and highlight those regions computing the second derivative of the map itself. All the “clumps” of pixels above a defined threshold are analyzed and the ones larger than a certain area are kept as candidate detections. The output fluxes and sizes are determined by fitting elliptical Gaussian functions plus a flat surface for the background.

Extensive synthetic source experiments were carried out, where a thousand synthetic sources were randomly injected on real Herschel Galactic Plane fields and the properties of these “ground truth” sources were recovered within 20% of their input values. Different source sizes and levels of fluxes were attempted, with a full characterization of extraction flux completeness and robustness to false positive detections at each of the five Herschel/Hi-GAL bands. The Hi-GAL Compact Source
photometric Catalogues were generated at 70, 160, 250, 350 and 500μm bands for the entire Galactic Plane. The Hi-GAL photometric catalogues contain a wealth of information that can be used to assess the reliability of extracted sources. Two quantities in particular can be used in this respect: 1) The contrast between the source peak flux and the surrounding background (both provided in the catalogues), and 2) the S/N ratio between the peak flux that the residual r.m.s. of the background after source subtraction (again both provided in the catalogues). However, these two quantities in some occasions do not deliver a consistent indication, so that it is not possible at the moment to compute an absolute reliability flag on source detection. An additional figure for source reliability is the persistence of the source detection in adjacent bands; in this sense the presence of a source in the bandmerged photometric catalogues is an indication of detection reliability.

1.3.2.2 The complete census of star-forming sites in the Galaxy
The reconstruction of the full Spectral Energy Distribution (SED) of compact dust structures in the Galaxy requires that counterparts in the different bands are matched and a decision be made if they belong to the same physical source or not. This process of "band-merging" has been done over the entire Galactic Plane augmenting the Hi-GAL photometric catalogues with ancillary catalogues from MIPSGAL (24μm), MSX (21 μm only), WISE (22 μm only) on the mid-infrared portion of the spectrum, and with ATLASGAL (870 μm) and Bolocam GPS (1.1mm) for the submillimeter portion: this allowed us to obtain SEDs that cover at least three decades in wavelength. A new package has been developed to carry out counterpart matching and establishing a metric to evaluate the quality of the associations based on the relative peak distance as well as the persistence of the counterparts across the wavelength range. In addition, the package captures multiple associations when multiple objects at smaller and smaller wavelengths are found associated with one object at longer wavelengths; this is a typical occurrence in VIALACETEA as the data were acquired with telescope of comparable sizes, so that the diffraction-limited beamsize decreases with wavelength. The resulting SEDs are no longer single SEDs, but are rather "SED Trees" with branch departures at each band in which multiplicities are found; each branch is characterised by a Merit Score that helps the scientist in assessing the reliability of the SEDs during the analysis activities and in the decision of which branches to model, or model the co-added branches SEDs.

1.3.2.3 The evolutionary classification of star-forming sites in the Milky Way
We completed the characterization of a toolkit of evolutionary indicators using a "ground truth" source catalogue in well characterised evolutionary phases of the star formation process, from IRDCs to UltraCompact HII regions. We have found that the fundamental parameter that better and uniquely describes the evolutionary stage of a star-forming clump is the Lbol/Mcl ratio: this parameters spans 4 orders of magnitude at the two extremes and its variations are well matched to specific changes in the shape of the SEDs of the objects below 100 μm, the appearance of the HII regions. The Lbol/Mcl has been calibrated against the dense gas temperature in the clumps, using observations at ESO-APEX telescope of the J=12-11 rotational transition of the CH3C2H molecule, that is an excellent tracer of the temperature of very dense gas (n ≥ 105-106 cm-3) in a range between 30 and 90K. Thanks to these observations in more than 50 Hi-GAL massive clumps with 70 μm counterpart indicative of star forming activities (that we call "protostellar clumps"), we showed that three well-defined ranges of Lbol/Mcl can be identified (see Figure 3):

1. A relatively quiescent phase characterised by Lbol/Mcl ≤1 (the cyan line in the figure above) where objects are not detected in CH3C2H and therefore have inner gas temperatures below 30K, and where therefore only relatively low-mass objects may be forming. Such seeds of star formation might be either low-mass YSOs or intermediate/massive YSOs in the pristine stages of evolution. This region corresponds to the location of the distribution of most of the Hi-GAL pre-stellar clumps (the red contours).

2. An intermediate phase where 1 ≤ Lbol/Mcl ≤ 10 (between the cyan and magenta lines), in which the clump internal input power due to star formation is sufficient to warm up the envelope and be detectable in CH3C2H, but where the increase in input power does not seem to reflect in a temperature increase of the densest portions of the envelope. This area corresponds to the location of the distribution for the majority of Hi-GAL protostellar clumps.

3. A third phase with Lbol/Mcl ≥ 10 (above the magenta line), where the further dramatic increase in luminosity starts to warm up the clump more and more. The association of the L/M=10 threshold with the location in the L-M diagram where HII region counterparts to Hi-GAL sources are found (the magenta squares) is an indication that this luminosity increase is related to the
birth of the first intermediate/high-mass ZAMS stars in the clusters.

The ability of these indicators to probe the evolutionary stage of clumps detected in Hi-GAL independently of the heliocentric distance has been calibrated using well-known nearby star forming regions (Lupus, Orion, Serpens, Perseus). The Herschel imaging data from these regions have been processed to rescale them in a noise-preserving scheme to different distances up to 8 kpc, to simulate their appearance at the typical distance ranges of the Hi-GAL clumps. This showed that indeed compact clumps seen in Hi-GAL could indeed consist of very complex and structured star forming regions. We analysed the various star forming regions at all simulated distances using the same methodology used for the science analysis in the project (source extraction with CuTEx, band-merging and SED fitting); the results at all distances were each time compared with the analysis results obtained for the various regions at the native original distance.

The analysis of the mass-radius relationship that is generally used to infer conditions for massive star formation in dense clumps allowed us to discover that with more and more distant sources there is an increasing chance that a clump may be erroneously classified as a high-mass star formation site when in reality it is not. Such “false positive” occurrences were characterised for each region as a function of distance and a new prescription for a proper clump classification has been devised.

A further analysis has been completed to characterise, using the same above methodology, the influence of distance in the evolutionary classification based on the ratio Lbol/Mcl between bolometric luminosity and clump mass as well as in the estimate of the Star Formation Rates estimated from clump mass: we verified that the Lbol/Mcl is constant as a function of simulated distance, and the value of the star formation rate computed at each simulated distance is comparable to the values computed for the various regions at the native distance. These are very important results that provide solid foundations to evolutionary diagnostic tools used in VIALACTEA science results.

To complete the evolutionary classification of star formation sites detected in Hi-GAL in the Milky Way we compiled a new grid of 20 million synthetic SED models that can be used to infer the physical and evolutionary properties of the Hi-GAL clumps. The grid spans a parameter range for protocluster-forming clumps with masses Mcl between 10 and 100,000 M\[\odot\] (in 10 Log-steps), and a dust temperature Tdust between 10 and 30K. We assume that a variable fraction fcore between 1% and 50% percent of the clump mass is distributed in dense cores. The distribution of core masses has been sampled from a standard Kroupa IMF until all the mass Mcl x fcore is accounted for. At the same time, an age t_cl for the single clump between 10^{-4} and 5x10^{-5} years has been chosen and then the ages of the stars have been uniformly sampled using the above clump age as an upper limit, assuming a constant star formation rate. Once having obtained a mass and age for each compact source, the models in the Robitaille et al (2006) model grid have been searched to find the grid cell where the source + disk + envelope mass is closest to the sampled mass, and where the age is closest to the sampled age. At the end each obtained source is added to the cluster synthetic SED. The variance due to the IMF and age sampling, as well as to the other protostellar models in the Robitaille et al. (2006) models (e.g., disk mass, outflow cavity angle and inclination), is taken into account by making 10 Monte Carlo realization of the models for each Mcl, fcore, Tdust, t_cl parameters combination. The resulting grid is composed of 20 million models.

1.3.3 The 3D Galaxy
The heliocentric distance of source is the fundamental parameter needed to transform an observed flux into an absolute physical quantity. Without this crucial information no firm conclusion can be given and important uncertainty on the distance of a source turns out in a drastic uncertainty on its physical properties like the mass of a young stellar object envelope or its bolometric luminosity.

A complete set of atomic and molecular line datacubes covering collectively the entire Galactic Plane has been retrieved and incorporated in the VIALACTEA Knowledge-Base (more detail in section 1.3.5). They include: CHaMP (HCO+ 1-0), HOPS (H2O 6-1-6, 5-2-3, NH3 1-1_1-1, NH3 2-2, 2-2) , FCRAO_GRS (13CO 1-0) , MALT90 (HCO+ 1-0, HCN 1-0, N2H+ 1-0, HNC 1-0), THRUMMS (12CO 1-0, 13CO 1-0, C18O 1-0, CN 1-2-3, 0-1-2), NANTEN (12CO 1-0), OGS (12CO 1-0, 13CO 1-0), JCMT-HARP (12CO 3-2), CHIMPS (13CO 3-2, C18O 3-2), Mopra (12CO 1-0, 13CO 1-0, C18O 1-0), VGPS (HI 21cm), CGPS (HI 21cm). Metadata information has been created to homogenize the different datacubes and provide astrophysically sensible information that allows targeted queries to select, e.g., data for specific molecular transitions; this information is generally not present in the header of the
data files provided by the survey data holders.

A complete workflow has been designed and implemented to use the information above and carry out all operations needed to estimate the heliocentric distances. Starting from a user request (position and size of the region around each source) data-subcubes are extracted from all surveys in the VLKB. Spectral lines are automatically extracted and fitted from each spectrum through a three-stage pipeline mixing both non-parametric subspace state methods and Nonlinear iterative parametric Maximum Likelihood. Such a combination allows a robust and accurate recovery of molecular gas radial velocities in the Local Standard of Rest, even at low to moderate signal-to-noise ratios. For each extracted velocity component the relevant spectral channels are extracted and mapped form the cube to study the morphological properties of the gas emission; a match to the spatial emission from dust (from Hi-GAL) provides a matching score that is used to classify the most likely component to be selected, in case multiple velocity components are found for any given line-of-sight. At this point the heliocentric distance is estimated using a revised version of the Galactic rotation curve, obtained by re-analysing together a) the HII region-stellar distance catalogue by Brand and Blitz (1993), b) the HI tangent+CO-HII regions catalogue from Sofue et al. 2009, c) the maser parallax distance catalogues of star-forming regions from Reid et al. (2014) and Homma et al. (2012). Two different analytical expressions have been used to fit the data: the polynomial form (q(R) = a1 + a2 r + a3 r² with r = (R/R0) -1 ) and the BB form (q(R) = a1 (R/R0)a2 + a3). We established then the new final expression for the rotation curve as: q(R) = 226.05 (R/R0)0.035 and q(R) = 245.25 (R/R0)0.08 for the two most common adopted Local Standard of Rest (LSR) parameters which are the IAU standard R0 = 8.5 kpc, q0 = 220 km/s and the most recent adopted ones R0 = 8.34 kpc, q0 = 240 km/s respectively.

In case the source is located toward the inner Galaxy, the well-known near/far distance ambiguity is solved by cross-correlating spatially and in velocity (adopting a 6 km/s maximal difference) the source with literature catalogues of optical HII regions (stellar distance), star forming complexes, sources with maser parallax distance, IRDCs and sources with already distance ambiguity solved. In case this cross-check did not deliver a reliable decision, the velocity of the molecular gas component was analysed in HI 21cm line profiles to verify if the molecular emission corresponded to an absorption feature in HI, an occurrence that favours the near distance. Additionally, the possible location of the source along the line of sight was correlated with features in the new 3D extinction maps produced in VIALACTEA.

These new 3D extinction maps were generated using different stellar surveys (2MASS, GLIMPSE and UKIDSS) and compared their extinction profiles. A discrepancy between the UKIDSS based map and the other two led us to only consider 2MASS and GLIMPSE surveys for further analysis. We also produced maps with different pixel sizes to test the effects of spatial resolution and find the best trade-off between fine resolution and sufficient pixel statistics. This analysis revealed a 5 arcmin minimal pixel size for most sightlines in the Galactic Plane, and a 10 arcmin pixel size better suited for highly extinguished regions where dust causes a drop of the number of observed stars (Figure 4). The final maps reach out to distances of 15 kpc inside the Galactic Plane. The 10 and 5 arcmin maps were both used in the distance estimate workflow in order to be able to retrieve less extended sources as well as highly embedded structures.

The tool (with the old line fitting script) has been run on the 150217 sources of the Hi-GAL catalogue. The Galaxy has been divided in its 4 quadrants to run the distance determination programme. The large input file has then been divided into 4 smaller files corresponding to every quadrant. The tool was able to determine the velocity (and hence the distance) for 68% to 88% of the sources depending on the Galactic quadrant. The results of this run of the tool on the whole Galactic Plane survey allowed to draw our first 3D view of the Galaxy (Figure 5).

To verify the correctness of the produced distance distribution, a first check on the obtained velocities has been done by comparing the source distribution in a longitude-velocity plot with the Dame et al. (2001) plot. This comparison was successful, confirming the validity of our line profile fitting method. The provided 3D view of the Galaxy (Figure 5) has been then matched with the expected spiral arms from the model of Hou et al. (2014). As clearly shown in the figure, the general four arms structure is well matched by our data, that therefore can be used to construct our 3D model of the Milky Way.

1.3.4 The ingredients of the Milky Way as a star formation engine
1.3.4.1 The role and impact of filamentary structures

One of the fundamental results produced by the Herschel Hi-GAL survey is to show how the ISM is preferentially organised along filamentary structures. We are talking here especially of the denser fraction of the ISM, with column densities typically
above \(N(H_2)=1020\) cm\(^{-2}\), and spatial scales extending to tens of parsecs typical of molecular clouds. These structures represent a spatial scale above the filamentary structures also discovered by Herschel in nearby molecular clouds of the Gould Belt.

We have catalogued more than 30,000 such structures over the entire Milky Way, showing that these structures populate the inner and denser regions of the Milky Way as well as the relatively less dense regions in the Outer Galaxy beyond the Solar circle (Figure 6). Although filaments trace very well the distribution of the denser ISM in molecular clouds, we also find considerable structure in the more diffuse and less dense fraction of the ISM suggesting that these structures do not form out of gravitational action after a certain ISM density threshold has been reached, but are already there when the ISM starts differentiating from the diffuse cirrus, most likely for compression due to turbulent motions or shock cooling at the interface of large-scale Galactic colliding flows. Figure 8 shows that filaments are detected for column densities ranges also well below the \(A_V=1\) limit (roughly corresponding to \(5\times10^{20}\) cm\(^{-2}\)) and are therefore most likely associated with the initial phases where ISM gas is not yet fully molecular. A most important feature shown by figure 8 is the quite different column density ranges exhibited by filaments that are found associated with dense Clumps (black line) as opposed to those filaments that show no such associations (red line).

Denser filaments are more likely associated with dense clumps forming, but it is not yet clear if there is a cause-effect relationship between filaments and clumps. Figure 7 shows that when robust associations between clumps and hosting filaments are considered, there is no clear evidence of a sudden increase of clumps number density for any given filament column density. Certainly, dense clumps are also found associated with a considerable number of low density filaments, and a clear indication for a clump formation threshold is not seen in the data. We therefore conclude that filamentary structures are key entities that allow the formation of the dense clumps that are the progenitors of stellar clusters, but there is no definite temporal sequence between filaments and clumps. Our finding are suggestive of a co-evolution of the two entities, with no clear indication of a clump or star formation column density threshold.

1.3.4.2 The Galactic distribution of star formation

The estimate of the outcome of the star formation process is a key figure that can be related to the various mechanisms and agents at work in the Galaxy. The most important key-figure in this sense is the Star Formation Rate. We devised a new method to compute the SFR comparing the mass of the dense clumps with the predictions of simple evolutionary models predicting the evolution of the bolometric luminosity of dense clumps as a function of the initial clump mass, calibrated over the properties of objects in independently known evolutionary stages from IRDCs to UCHII regions. We started from very simplified analytical models assuming that a single massive YSO was forming in each clump (Molinari et al. 2008) and recently extended the prescriptions in Veneziani et al. (2016) where we considered the effect of cluster formation instead of single objects. These new prescriptions were also confirmed by a new set of numerical models of integrated SED computed for a variety of initial parameters (see section 1.3.2.3). Figure 9 reports the map of the SFR surface density of the Milky Way in \(M/yr/kpc^2\) as derived from VIALACTEA observables. The SFR has been computed following Veneziani et al. (2016) only for the protostellar clumps, where the presence of at least a 70\(\mu\)m counterpart is assumed as a valid indication of consistent star formation activity. The SFR is summed in cells of 200pc size in X and Y directions including sources at all Galactic latitudes. We defer to the next section a discussion about the relationship between the SFR and spiral arms; we here note that the total of the SFR for the entire Galaxy amounts to about 2.1 \(M/yr\), including a contribution from sources in the deep inner Galactic regions where kinematical distances are less reliable and a single distance equal to that of the Galactic Centre (8.4kpc) has been assumed. The cumulative distribution of the SFR surface density shows that about that the top 20% of the Galaxy areas where active star formation sites are found, contribute 75% of the total Galactic SFR and are for the most part located (see figure 9) in the inner 6 kpc in Galactic radius.

1.3.4.3 The role of spiral arms

It has long been debated if spiral arms play an active role as triggers of star formation in a spiral galaxy, or rather they simply act as collectors of star forming regions without intrinsically causing the onset of star formation. We investigated this in detail, by considering the spatial distribution of SFR on one side, and looking for evolutionary trends of star forming clumps as a function of position relative to spiral arms. The spatial distribution of SFR on the plane of the Galaxy is shown in figure 9.
together with the location of the major spiral arms from the literature. The figure shows on average a very good agreement between locations of high SFR and the various spiral arms. However, the agreement with spiral arm locations is also visible when the surface density of dense clumps is plotted on the plane of the Galaxy. A simple ratio between the surface density of the SFR (computed from only protostellar clumps, i.e. those with a 70μm counterpart) and the total mass density of all VIALACTEA clumps (including also the prestellar clumps), i.e. an indication of the Star Formation Efficiency SFE, yields a Galactic distribution that is much more shallow than the one shown by the SFR. In comparison to the three orders of magnitude spanned by the SFR surface density in figure 9 the SFE only spans a factor 7-8 over the entire Galaxy. There are SFE peaks localized in specific regions, but there is no indication that higher SFE areas are necessarily located all along the spiral arms. We would therefore conclude from this investigation that the main role of spiral arms is to be collectors of clumps, part of which is forming stars, rather than triggering intrinsically higher rates of star formation.

Another line of investigation that was carried forward in VIALACTEA was to determine the role of spiral arms in triggering star formation as evidenced by segregation of star-forming sources at various evolutionary stages. If the spiral shock plays a key role in inducing star formation, then we expect younger sources to be found preferentially on the “upstream” (or “entering”) side of the spiral arm, whereas more evolved sources would be “downstream” (or “leaving”). The first subject of study were the tangent points to the Centaurus and Perseus spiral arms in the fourth quadrant and found no trends in the Herschel colours which we used as proxies for evolutionary stage (i.e. blue = “young”, red = “evolved”) as a function of position with respect to tangent longitude. We noted that in the case of the Centaurus arm, the overall number of compact sources was higher on the “entering” side of the arm (roughly 70% of the sources in the considered range). In our further investigations we found other asymmetries, though not as extreme, at tangents of the Sagittarius and Norma arms (a reverse asymmetry in source counts in the latter), though no evident trend in Herschel colours at any tangent longitude, thus indicating limited or no role of spiral arms in “triggering” star formation at a specific location.

We then attempted a more general study over the entire extent of the arms. We first examined the sources in position-velocity space (where here radial velocity serves as a proxy for distance). Within the sample of Hi-GAL sources, we do not find any segregation in objects of different colours with respect to each other or to the arms. Considering young sources (young stellar objects and HII regions) known from the Red MSX Sources (RMS) survey, however, we find a suggestive offset of the RMS source velocities with respect to that of the arm. The offset is as often on the “leaving” side of the arm as it is on the “entering” side of the arm, and due to low number of RMS sources, the result remains tentative. Furthermore, the mapping between source velocity relative to the arms and the physical displacement is not a direct one. A third approach (after the tangent point and position-velocity investigations) examined the distribution of sources as a function of Galactocentric radius and azimuth: again, little evidence of evolutionary segregation was apparent.

On larger scales, we examined the global distribution of sources as a function of Galactocentric radius (Rgc) in the inner Galaxy (excluding the central 30 degrees in longitude). We examined the total source distributions as a function of Rgc and found that at the tangent point radii there are notable peaks in the source density, as has been seen in previous studies with much sparser catalogues, especially at the Centaurus arm in the fourth Galactic quadrant. Next, we focused on the relative galactocentric distributions of protostellar clumps (i.e. a clump with a 70μm counterpart) and prestellar clumps (with no 70μm counterpart); this is the simplest possible (and generally agreed-upon) evolutionary indicator. We defined the fraction of protostellar sources out of the total as the “Star Forming Fraction” (SFF). The SFF exhibits NO deviation from the mean (0.25) at any Rgc. This is further evidence confirming that the star formation rate or efficiency is NOT enhanced in the arms, but instead the arms are simply locations in which molecular clouds are accumulated. Although we detect no peaks in the SFF at specific radii, we find in figure 10 a shallow gradient in the SFF as a function of Rgc over the 3kpc to 8kpc range we study. A linear fit to the trend in this range provides a gradient of -2.6±0.2% per kpc. We thoroughly tested the effect of distance uncertainty, sampling effects and other biases and conclude that the trend is genuine. One might expect that a similar trend would arise in related quantities such as the ratio of mass in dense clumps to its host cloud mass, or the “dense gas fraction” or DGF, but we find that the DGF is independent of Rgc, indicating that some perhaps pre-existing property of clumps — in addition to the amount of dense gas — is ultimately affecting the prevalence of star formation in Hi-GAL sources. We considered other contributing factors, such as the large scale density profile of the Galaxy, metallicity gradient, changes in the interstellar radiation field intensity with Rgc and dynamical effects such as shear, but we found no “smoking gun” as to the direct cause of the observed SFF gradient. In truth, the SFF gradient is the result of a combination of some if not all of these
large scale properties of the Galaxy, and it is a challenge to modellers of galactic scale star formation to determine the dominant physical process(es) that give rise to the SFF gradient. In summary, we find a convincing indication that spiral arms in the Milky Way act only as collectors of dense material, but do not by themselves trigger specific star formation activity. The role of star formation triggering by expanding bubbles.

1.3.4.4 Triggered star formation

Triggered star formation has been a well-known mechanism with which expanding bubbles powered by HII regions of OB young stars or clusters excite new star formation events either causing the collapse by pressure of pre-existing clumps of dense ISM, or by accumulating ambient material into dense shells that then fragment and collapse. With the VIALACTEA products we are for the first time in the conditions to verify what is the role that triggered star formation plays in the overall star formation budget of the Galaxy. For this purpose we combined the information from both Spitzer GLIMPSE and Herschel Hi-GAL surveys in order to provide a broader view of the different evolutionary stages of star-forming objects in the surroundings of HII bubbles. On one hand, YSO objects were classified using IRAC fluxes taken from the GLIMPSE catalogue while, on the other hand, prestellar and protostellar clumps (star-forming sources at an earlier evolutionary stage) were taken from the Hi-GAL catalogue. This allowed us to compile tens of hundreds of star-forming sources around 1360 HII bubbles (taken from the MWP catalogue - Simpson et al. 2012). This provided us with an unprecedented statistical view of the spatial location of star-forming sources that was analyzed in more detail in surface density maps.

For each of the 1360 bubbles we produced source spatial density maps for four classes of sources in different evolutionary stages around each bubble: prestellar Hi-GAL clumps (with no 70μm counterpart), protostellar Hi-GAL clumps (with 70μm counterpart), YSOs of Class I and YSOs of Class II (from Spitzer GLIMPSE survey, the former being younger than the latter class). The pixel scale of these source density maps was then rescaled in units of each bubble's radius in order to obtain maps that could be consistently stacked to underline evolutionary trends with higher statistical significance. The results are shown in figure 11, and outline a clear trend in the distribution of sources in each stage with respect to the edge of the bubbles. While prestellar clumps are located close to the edges and slightly outside of the bubbles, protostellar clumps are found coincident to the bubbles edge; more evolved Class I YSOs are located in the inner regions of the bubbles, while the even older Class II objects are mostly found close to the centre of the bubbles. This is in agreement with the scenario of triggered star formation in which older forming objects are found closer to the centre of the bubble because they formed at the time the bubble was starting its expansion; relatively younger objects are found close to the bubble edge because they are forming now that the bubble's edge is passing by. Furthermore, dynamic ages were estimated for a subsample of 182 HII bubbles for which we found both an attributed kinematic distance and radio continuum flux measurement of the ionizing source(s). The ages were then obtained using recent models of expanding bubbles (Tremblin et al. 2014). With the information of their dynamical ages we were able to demonstrate that star-formation is more active at the earlier stages of HII bubble expansion, in particular by increasing the formation efficiency and rate. The feedback of HII bubbles has an important impact on the overall star-formation process of our Galaxy, since we find that ~40% of Hi-GAL star-forming protostellar clumps are found spatially located (in projection) in the vicinity of an HII bubble, throughout the entire inner Galactic Plane. The SFR computed using the method that we developed in Veneziani et al. (2016) for the protostellar clumps associated in projection to bubbles amounts to about 0.67 M⁄/yr, or about 30% of the total SFR of the Milky Way.

1.3.4.5 The role of cosmic rays

Cosmic rays (CRs) represent the only source of ionization of the ISM in dense molecular clouds. As magnetic fields couple to the ionised fraction of the ISM, the flux of CRs around molecular clouds may provide important hints in determining the importance of magnetic fields in the overall star formation process.

The presence of CRs is indirectly inferred from the flux of gamma rays that are generated when CRs hit dense molecular clouds. While dedicated surveys are generally able to trace the abundance of specific components of the ISM, e.g. atomic hydrogen or CO molecules, CRs are sensitive to the medium they cross in its entirety, which makes gamma-ray diffuse emission a unique tracer of the total amount of matter along a given line of sight. In particular, given a reliable model of the gamma-ray emissivities of the ISM constituents, the comparison between observed and modelled gamma-ray diffuse emission can be used to localise and quantify the abundance of dark neutral medium (DNM). DNM, despite comprising a significant fraction of the total amount of ISM in the Milky Way, escapes direct or many an indirect detection. Since the main components


of the ISM are HI and H2, gamma-ray diffuse emission can efficiently be modelled by taking into account the sole contributions of HI and H2 gamma-ray emissivities, and combining them with information about the HI and H2 distributions across the Galaxy. While HI maps can be obtained through direct observations, H2 maps are generally extrapolated from CO maps, by means of the conversion factor XCO, or from dust emission maps. Discrepancies between observed and expected gamma-ray diffuse emission can therefore be due not only to DNM, but also to a wrong CO-to-H2 (or dust-to-H2) conversion factor. Moreover, local variations of the CR background can also lead to over-/under-estimations of gamma-ray photons.

Using a simplified model of gamma-ray diffuse emission, we developed (see Deliverable 4.8) a procedure for the analysis of AGILE gamma-ray data, aimed at localising sky regions where the discrepancies between model and observations are significant, and trying to identify the possible cause of the discrepancies. This is achieved by separating the expected contributions of HI and H2 emissivities to the gamma-ray sky; a least-square fitting of the observed data quantifies the importance of each contribution. The procedure is applied to a sample of AGILE sub-maps of 20deg diameters, partially overlapping and covering, all together, the whole Galactic Plane (360x40 deg2). By looking at local variations of the HI and H2 contributions to gamma-ray diffuse emission, we searched for hints of i) cosmic ray background variations (in regions where both contributions are higher or lower than average); ii) wrong CO-to-H2 conversion factor (e.g. in regions where H2 contribution is much lower than HI contribution); iii) DNM (e.g., where excesses in the observed gamma-ray emission do not exactly match either HI or H2 distribution).

First results show a general overestimation of H2 emission by the model, suggesting a preliminary conclusion that the discrepancies found in the gamma ray observations compared to the model seem to be mostly due to an incorrect account of the molecular material only traced by CO. The possibility that the inhomogeneities in gamma rays are due to inhomogeneities of the diffuse cosmic ray flux (and hence our interest in comparing such discrepancies with the star formation properties of ISM clouds) do not seem to be favoured as this would require that observations/model discrepancies would have to be there for the atomic gas as well, which does not seem to be the case in the present study. The only exception that could point toward an excess of CR flux with respect to the model is in a roughly 20° longitude region in the Carina region around l=270°. It should be noted, however, that this location corresponds roughly to the tangent point of the Sagittarius-Carina spiral arm where dense molecular clouds complexes are found at radically different heliocentric distances along the line of sight, which makes the model predictions very uncertain due to opacity effects.

1.3.4.6 Indications for a global star formation recipe

A first look from a global perspective to the results of the VIALACTEA project already provides very important hints on some of the aspects that define the Milky Way as a star formation engine:

• Large-scale, 1-10 parsec-long filaments are ubiquitous structures in the Galactic Plane. The large fraction of high-column density material in the Galaxy is in the form of filamentary structures. More massive and dense clumps are found on filamentary structures. However, filaments do not seem to precede clumps in a temporal sequence: we see clumps developing on filaments also at relatively low column density levels, and both grow mass and density as they evolve. In other words filaments do not seem to be progenitor structures for clumps, with no significant indication for a density threshold required for the formation of clumps, but rather are channelling structures that facilitate the formation of massive clumps. They grow mass from the surrounding ISM while clumps accrete from them.

• The role of spiral arms in the star formation budget seems to be a minor one. Arms collect clouds and clumps and assemble them in more crowded regions, but do not seem to have any role in actually triggering star formation. Star forming clumps arise from other mechanisms, like gravitational fragmentation, turbulent compression or shock compression in large-scale colliding flows.

• The formation of new generations of stars arising from ISM compression due to expanding bubbles powered by already formed massive ZAMS stars seem to account for nearly 40% of the dense clumps actively forming stars in the Galaxy, and about 30% of the global SFR. Between one third and one half of the star formation in the Galaxy seems to be due to the active role played by massive ZAMS stars toward their surrounding environment.

Although very preliminarily, we do not find an unambiguous indication that the flux of cosmic rays (that are the dominant ISM ionization form in dense molecular clouds) may be inhomogeneous; the non uniformity of gamma-ray distribution with respect to model expectations may be more related with variations of the fraction of molecular ISM that is not accounted for by
molecular line spectroscopic tracers like CO.

1.3.5 Novel infrastructures for data organization, 3D visualization and analysis

1.3.5.1 The VIALACTEA Knowledge-Base

The Virtual Observatory already existing infrastructure has been deeply analyzed with the aim of finding the best environment to exploit the VIALACTEA product potentialities. With the aim to define since the beginning the data products format that will allow a smooth integration within the VO framework, a VIALACTEA Knowledge Base (VLKB) has been defined and implemented. It consists of a combination of a relational database where the VIALACTEA data and metadata are stored and a file system based stored information.

The VLKB content is deployed through a web service that follows the IVOA TAP recommendation, and requires user authentication to preserve data policy. It provides access to:

- Filamentary structures catalogue (section 1.3.1.1)
- Compact structures catalogue (section 1.3.1.2)
- Bubble structures catalogue (section 1.3.1.2)
- Survey images from Hi-GAL, MIPS-GAL, WISE, CORNISH, and 3D extinction maps.
- Full set of atomic hydrogen and molecular line data cubes survey metadata (section 1.3.3).

Besides the surveys’ metadata description available through the TAP service, the radio cubes can be searched to investigate the spatial coverage of the dataset with respect to a desired line of sight and circular region around it and, given the availability response, each cube of interest can be cut along the positional and velocity (spectral) dimensions to allow for a more efficient and less band consuming data transport over the network as well as a lighter data volume to perform subsequent scientific processing. The VLKB is specifically designed as a resource that can be queried and consumed from data analysis codes and the VIALACTEA Visual Analytics application (see section 1.3.5.2) via standard SQL queries based on position, search radius, and data type/subtype. The same search & cutout service can be accessed from web interface. The VLKB TAP and search & cutout services are designed keeping in mind the goal for an IVOA Observational Core data model compliant service for the full set of radio surveys and a unique TAP resource to expose all of the VLKB content. A dedicated service was implemented on the server side to merge adjacent datacubes. The ‘Montage’ library was used for this task, incorporating the velocity axis regridding to homogenize the velocity scale; additional parameters useful for the analysis are also reported, including the amount of undefined pixels in the datacube, overlap quality information when calculating an overlap with the region covered by the datacube, added CUNIT3 to cutout files when missing from original, vertex points to search results, and ensure that search operates only on primary HDU.

Filaments & Bubbles tableset holds all the information related to the diffuse objects identified from Hi-GAL continuum tiles (for filaments) and Hi-GAL and CORNISH tiles (for bubbles). Filamentary structures are described using 3 tables, identifying filaments as the primary complex object, branches as their components in terms of “linear” areas but also their spines (nearly 1-dimensional), and nodes as the connection points of the various branch segments that compose a filament. Bubbles are described as a unique catalogue of diffuse objects, because their roundish shape does not require further relationships among their components. Both filaments and bubbles tables are completed with positional and global details plus morphological information, contour and area representation. Contours are represented as ordered sequences of sky positions (i.e. a polygon outlining the diffuse structure), while area, i.e. celestial sphere coverage is represented in MOC format (Multi-Order Coverage Map, an IVOA Recommendation), that is an HEALPix tessellation of the diffuse object’s area to be used for easier cross-match with other positional features in the VLKB or other databases. MOCs are stored as string JSON objects in the database.

Compact sources tableset contains all the single band catalogues used by the project to build up a band-merged catalogue of compact sources. The primary input of the band merge task are the 5 single band catalogues derived from the Hi-GAL images (1.3.2.1). The full single band catalogue listing includes: Hi-GAL (PACS and SPIRE bands), ATLASGAL, BGPS, MIPS-GAL, MSX (4 bands) and WISE (all 4 bands plus the additional 2MASS fluxes already contained in the catalogue) catalogues for the Galactic Plane. The bandmerged catalogue is produced from these ones using data mining techniques included in the QFullTree tool developed in the VIALACTEA project itself (section 1.3.2.2). All of the catalogue records contain a MOC derived tessel index for quick match
against diffuse objects.

The scheme including compact source tables also includes other content, not used in the band-merging effort of the project, but used in the SED scenario investigated by the project. One table is devoted to the grid of synthetic protocluster SED evolutionary models developed in the project; this sums up to 20 million SED records to synthesize energy distributions in the bands used by the band-merging effort (section 1.3.2.3). Another one is meant to keep track of the velocity information processed using the radio cubes FITS and database used in the distance estimation process of the various sources on the Galactic Plane (section 1.3.3). Velocity records including distances was also used to input distance estimates and cartesian positions of the band-merged catalogue sources.

All the tables, for diffuse and compact sources, include positions in galactic as well as equatorial coordinate systems. Also, as already said, HEALPix derived information has been used for quick indexing reference in matching positions among the two types of source. The full set of tables and indexing used within the database server sums up to about 50GB of database space, with tables going from a few KB up to a couple of tables spanning some 10 GB.

These catalogues are accessible through a standard TAP (Table Access Protocol by IVOA) interface, its TAP_SCHEMA is part of the database where the VLKB sits, near the above described table-sets. Additionally a "XMATCH" web service was developed specifically for direct cross-match on positions between diffuse objects (filaments, bubbles) and compact sources. It is based on HEALPix tesselation and reachable by web-browser or tool/library which can do HTTP requests. The service allows to search among compact sources, filaments or bubbles by specifying the identifier of an object. Alternatively specifying a region on the sky in form of a polygon. To speed up the database queries a separate virtual machine was set up running the database server. Apart from indexing, to speed up metadata search and match an "in-memory" solution has been adopted to reduce the amount of time needed for searches on large catalogue tables.

1.3.5.2 3D Visual Analytics

A new Visual Analytics client application has been designed and implemented closely integrated to the VLKB services (see previous section) to handle in an integrated framework the different types of datasets in an astrophysically sensible fashion, via the design and implementation of specific science use-cases.

A Main Window (hereinafter named “visual query”) has been implemented to allow the users to easily query and retrieve data from the search&cutout services. The visual query allows the user to navigate into a full view of Galactic Plane (with common zoom, scroll and pan functionalities) in order to better identify the region of interest from which to start the analytic operations. The selection of the region of interest can be carried out choosing a point on the map and specifying the radius of the selection or drawing a rectangular region inside the map. When queried, the service returns the selected 2D fits image containing the user selected region. The 2D map visualization allows to add other survey images as layers on top of the visualised one. The new layers are aligned (position, scaling pixel size, rotation) to the “base image” according to the information contained into their header. The user can interact with each layer activating or deactivating the visualization, changing the opacity or changing the order in the visualization stack. It is also possible to add filaments and bubbles overlaid to the visualised 2D image. Bubbles and filaments morphological information is stored into the VLKB.

A new 3D user interface has been implemented to visualize spectral datacubes. The rendering window is split in two panel. On the left one a 3D visualization of the data (using isosurface algorithm) is shown, while the right panel shows a single slice of the velocity datacube. The possibility to have isocontours displayed on top of the selected slice has been implemented. The contours are also reported on the 2D map image. The user can obtain a 3D visualization of compact sources on the Galactic Plane selecting a region on the FITS image or specifying the coordinate in order to query the VLKB. The 3D rendering is interactive, and the user can change the colourmap selecting one of the scalar fields which are in the database. The glyphs visualization can be activated to change the shape and size of the visualised points according to the selected field in the database.

Finally, SED visualization has been implemented to support the view of tree-SEDS capturing multiple counterparts matching in the band-merged photometric catalogues (see section 1.3.2.2) contained in the VLKB. It is possible to have different fits plotted as layers that the user can activate or deactivate and the possibility to show histogram plots of the fit results. Figure 12 shows a snapshot of a typical analysis session using the Visual analytics tool.
1.3.5.3 VIALACTEA Science Gateway

The VIALACTEA Science Gateway is an application based on WS-PGRADE/gUSE that allows design and implementation of scientific workflows composed of nodes corresponding to almost any kind of executable in a convenient graphical user interface. A highly parallel execution and monitoring of these workflows is supported, as well as the use of a wide set of distributed computation infrastructures such as grids, clusters, supercomputers, and clouds. Beyond these features, the designed portal is extensible and offers a number of interfaces to extend it by adding new applications and portlets to its base capabilities.

Data Avenue capabilities that implement the data bridging service make it possible to use external storage to access data to be processed or to store results, respectively. The accessible storages can be of very diverse types: HTTP(s), SFTP, GridFTP, SRM, iRODS, S3, etc. Managing storage has become possible for the users within the portal in a graphical user interface (Data Avenue UI portlet), and also from within workflows by allowing jobs to use remote storage resources to provide inputs or store outputs, respectively. The system implements powerful integrated capabilities of WS-PGRADE/gUSE enabling brokering computational tasks to different DCIs based on their capacities and current load to achieve even more efficient workflow execution. The portal logs accurate information about potential workflow design and execution errors and offers a task execution monitoring system ensuring continuous diagnostics of the connected computational resources and automated alerting notification in case any of the DCI has become unavailable or shows any malfunctioning, respectively. The system also integrates a workflow editor requiring no external applications to construct workflows. The gateway has been connected to PBS clusters in IAPS-Rome and Catania Observatory that serve as the base computation infrastructures, DCIs for the portal. The necessary access points (head node addresses) are registered in the DCI Bridge.

The VIALACTEA scientific workflows have been designed and implemented for: map making, i.e. the production of high quality images from the raw instruments data; data mining to obtain band merged catalogues, whose entries consist of sources with associated counterparts at different wavelengths; filamentary structure detection and extraction from images. The MOSAIC workflow employs Unimap as map maker software to produce high quality mosaic images from the raw instruments data of the infrared imaging photometers onboard of the ESA Herschel satellite. The PPMAP workflow executes a Point Process MAPping (PPMAP, see section 1.3.1.3) that uses images of dust continuum emission at multiple wavelengths to produce resolution-enhanced image cubes of differential column density as a function of dust temperature and position. This workflow has been employed to perform a massive computation of the PPMAP processing on all the Hi-GAL tiles available to the VIALACTEA consortium. The Q-FULLTREE workflow performs compact source identification through band-merging (see section 1.3.2.2). The FILAMENTS workflow is designed to perform filament extraction (see section 1.3.1.1) that identifies filamentary-like extended structures on astronomical images and determines their morphological and physical parameters.

The project science gateway is affiliated with the STARnet Gateway Federation in order to ensure sustainability, maintainability, and to provide a set of collaborative services such as Single Sign On access, workflow sharing and data cloud infrastructures.

Potential Impact:

1.4 Potential Impact, Main Dissemination Activities and Exploitation of Results

The exploitation and active take-up of the VIALACTEA results has been an ambition of the project since the beginning and consequently a great effort has been put in a twofold exploitation strategy:

1) dissemination to the astronomical community:
   - the production of scientific publications dedicated to the dissemination of the project achievements to the astronomical community
   - the production of technical publications presenting to the IT community the tools developed in the framework of the project, highlighting their potential use in other scientific and technological areas
   - the organisation of two Scientific conferences open to the Star Formation Astronomical Community, to present the project results, to discuss the potential implications and to plan the future collaborative work based on the goldmine of the produced project data archives
   - the participation in scientific and technical workshop and conferences with oral contributions focused on the presentation of the VIALACTEA results
- the set up of dedicated web pages, accessible through the VIALACTEA portal, for the easy download of the VIALACTEA catalogues and of the SW tools developed within the project

2) dissemination to the public at large:
- the participation in two public outreach events, in the framework of the European Initiative “Reasearchers’ Night”, to introduce the wide public to infrared astronomy and its potentialities
- the production of high quality astronomical images of the Milky Way as observed in the Hi-GAL far infrared survey: these astonishing images allow to enhance the impact of the project’s results toward the public in outreach events
- the description of the main project results in publications in two of the most popular Italian newspapers, both on the paper editions and on the on-line editions, which can still be accessed to read the content, access the images and hear the interviews to the project PI
- the presentation of the project results to the public at large through the organisation of four public lectures
- the promotion of the project through a video on Euronews FUTURIS magazine.

Both the dissemination activities are now supported by the project portal hosted in the developed project website.

1.4.1 Publications

The project results have been disseminated through publications in both peer reviewed (mainly the astronomical scientific results) and non refereed journals (mainly the technical papers).

A total of 18 publications in refereed journals has been produced, with 3 additional papers submitted to publication. More than one publication per year of activity of the VIALACTEA PostDoc collaborators, and this can be seen by the lists provided here below, where the names of the Postdoctoral researchers in the authors lists have been underlined, to provide a measure of the level of their involvement in the project activities.

In addition, 10 technical papers in non refereed journal have been published, mainly related to contributions to IT and engineering conferences focused on scientific data archiving and analysis.

Publications in refereed journals:


Submitted to publication in peer reviewed journals:
Publications in non-refereed journals:
http://www.adass2016.inaf.it/Becciani%20Ugo


1.4.2 Participation in conferences, workshops and meetings
A total of 73 talks/seminars have been made by the VIALCTEA Consortium members to present results related to their activity within the project; 31 of these talks were given at conferences/seminars other than the two public conferences organised by the project.

1.4.3 Meetings, Workshop and Conferences
The following workshops and conferences were organised and held.

1) Workshop on 'Extended structures in galactic molecular clouds: tools and methods for automated discovery', held at University of Leeds, on October 27-28, 2015. The workshop presented the tools developed within the VIALCTEA project to the community and the latest results obtained in the field of the study star formation processes (triggered SF, filamentary cloud formation, fragmentation and evolution) from a global perspective. Refer to the workshop site http://www.physics.leeds.ac.uk/vialactea2015.html for the detailed workshop programme and presentations. Even if planned as a very specialised workshop, it was attended by more than 30 participants, with more than half belonging to the
astronomical community (European and American) external to the project.


The main conference topics are summarised here below:

- Inter Stellar Medium, Molecular clouds and Filaments: from the diffuse texture of the ISM to the backbone skeleton of the Milky Way
- Demographics of Galactic Clumps and Cluster Progenitors: conditions, timelines, rates and efficiencies of cluster and massive star formation as a function of mass and environment
- Triggering, Spiral Arms, Turbulence and Gravitation: sifting the ingredients of a Galactic Star Formation Recipe.
- The 3-D Galaxy from the near-infrared to the radio
- The Milky Way in the context of its surrounding environment, nearby galaxies and of extra-galactic star formation recipes.
- Dust and gas chemistry: the role of dust, atoms, ions and molecules in the thermodynamics of star formation, and their use as diagnostic probes and chemical clocks.
- Visual analytics, data mining and science gateways: new tools for an integrated science analysis of multi-wavelengths Galactic surveys in the Virtual Observatory framework

The Conference Programme is available at the conference website, but it is worthwhile noting that, given the high interest expressed by the community to the conference topics, a total of 69 Talks has been included in the 5 days programme, split in five main sessions: 1. Interstellar Medium, Molecular clouds and Filaments: from the diffuse texture of the ISM to the backbone skeleton of the Milky Way, 2. Demographics of Galactic Clumps and Cluster Progenitors: conditions, timelines, rates and efficiencies of cluster and massive star formation as a function of mass and environment, 3. The Milky Way in the context of environment and other galaxies, 4. Triggering, Spiral Arms, Turbulence and Gravitation: sifting the ingredients of a Galactic Star Formation Recipe and 5. The 3D Galaxy. The 19 Invited Talks provided reviews of the state of the art in all the addressed topics and the two organised sessions for Debates have been particularly active in highlighting the "Hottest" topics around which the community is discussing and organising the future work.

Two debates were focused on "Filaments and their role in the game: from fibers to ten-of-parsecs structures" and "Physics of the earliest stages of high mass star formation: state of the art and what's next to be learned/understood?" and the results of the discussions made within the working groups set-up by the debates moderators (see figure 13) have been traced real-time in a google doc that will be made available in the conference web-site.

The Conference was attended by more than 140 participants, coming from Europe, US, Japan, but also from Korea, China, Kazakhstan, Senegal. Several young researchers (PhD students and PostDocs) were present, and for 25 of them it was possible to sponsor a reduced registration fee.

The large community interest in the Conference topics is confirmed by the high number of posters (55) that have been presented and discussed intensively all along the conference duration.

1.4.4 Public Outreach activities

The public outreach activities included the participation in outreach events, the giving of public lectures, the publication of articles on newspapers, the involvement in the production of a video. Hereafter a summary of the activities per each one of the above listed categories

1.4.5 High quality images production

The production of high resolution images has been considered as one of the most important means for disseminating the project results and keeping the community informed. A great effort has consequently been put in the preparation of these images tailored for the dissemination to the public. Astronomical images are commonly characterised by a very high "dynamic range" at any scale, which means that the features brightness changes by orders of magnitudes both among adjacent locations and between distant areas.

When different wavelength bands are joined into an RGB colour image, they also usually show quite different intensities and different pixel scales. All that may lead to unclear pictures, unable to unambiguously display to the eye all the information they contain unless a suitable processing is applied. The work carried out in the framework of the project activities has been to
develop a procedure based on multi-scale local stretching and colour balancing algorithms aimed at producing a high-fidelity colour rendition of the multi-band far-infrared (FIR) maps of the Galactic Plane survey, acquired with the Herschel space observatory within the Hi-Gal project. The idea behind such processing was twofold: for the outreach, to release “eye-catching stunning images” where the relevant features like bubbles, filaments, pillars, are recognizable in a clear and sharp way; while for science, to provide visually optimised images that allow to directly compare multi-band information for bright and faint regions simultaneously. The developed enhancing algorithm has been presented to the community at the SPIE Astronomical Telescopes and Instrumentation Conference. It has been applied to the overall Galactic Plane survey, obtaining a High resolution map of the Milky Way in the far infrared that can be navigated through a dedicated web page accessible in the VIALACTEA portal. Some of the most spectacular regions were imaged in separate pictures that can be downloaded from the portal.

In figure 14 an example of the high quality images downloadable through the VIALACTEA website is provided. The figure contains only a particular of the overall image, which is referred to the W3-W4_W5 Complex located in the Outer Galaxy. The text associated to the download button for this image is reported hereafter, to provide an example of the kind of information that is provided: "The W3/W4/W5 star-forming complex is one of the most massive regions of the outer Galaxy with a total mass of $M \geq 10^5\text{M}_\odot$. The region is located in the Perseus Arm, at a distance of ~7000 light years from us. This Herschel far-infrared image reveals a forest of filamentary structures throughout the region and a population of clumps across the arches of the reflection nebulae (HII regions). The region is one of the best examples of triggered star formation, where the radiation and winds from the most massive stars in the centre have carved out the cavities and triggered the formation of a new generation of stars at the edges. For their particular shape, W4 and W5 are commonly known as the Heart And Soul Nebulae".

1.4.5.1 Participation in outreach events
Within the "Dreams" project, participation in the 2014 and 2015 events named “La notte dei ricercatori in Italia”, as part of the European Initiative "Researchers' Night". In both events, a stand dedicated to infrared astronomy and to the presentation to the public of the results of the ESA Herschel mission and of the Hi-GAL - VIALACTEA projects has been setup within the Tor Vergata Research Area, which has been open to public visits for all the night. (see figure 15).

A second activity supported by the VIALCTEA INAF IAPS Project Team in the framework of the Researchers' Night 2015 has been the organisation of guided "Walks on the Milky Way": using a 45mt long carpet (showing a map of the central part - 90° centered on the Galactic Centre -of the Milky Way as has been observed by Herschel within the Hi-GAL Survey, see figure 16), it has been possible to show to the public some of the most interesting results of the project.

Four main areas have been selected: i. the Galactic Centre, ii. The star forming regions in the Serpens Constellation, iii. the two active regions of NGC 6357 and NGC 6334, and iv. the giant molecular cloud of RCW 106. For all of them a special graphic panel has been produced (see figure 17), highlighting the most important aspects related to the region. During the "Walk" four dedicated stops have been planned, one per each panel, in which a short (5 minutes) talk was given, describing the peculiarities of the region and introducing the audience to the most relevant aspects of the Galactic star formation studies carried out within the project. Two of the IAPS PostDocs have been involved as "tourist guides" to accompany the group of visitors along the walk on the Milky Way. A total of 20 groups have been accompanied all over the event, making the tour one of the most visited activities of the event.

1.4.6 Publication of articles in newspapers
- "Il satellite Herschel svela la materia di cui sono fatte le stelle" - 22/04/2016: article published on La Repubblica Italian newspaper. The article is dedicated to the presentation to the public of the Galactic Plane maps obtained within the VIALACTEA Project. This on-line article has been published in occasion of the publication on Astronomy and Astrophysics of the paper containing one of the most important result of the Project, i.e. the first data release of the HiGAL compact Source Catalogue. The article on the newspaper included 10 images and the possibility to visualize a video compiled by stitching together several hours of Herschel observations obtained as part of the Herschel infrared Galactic Plane Survey. It spanned a vast portion – almost 40% – of the plane of the Milky Way and showed bright sources, wispy filaments and bubbling nebulas against the background of diffuse gas and dust, marking the spots where stars are being born in the Galaxy.
  (http://www.repubblica.it/scienze/2016/04/22/foto/via_lattea_incubatrice_di_stelle_ecco_il_censimento_del_satellite_herschel-138198469/1/#1). La Repubblica is the most popular Italian newspaper.
- "The recipe for the formation of stars" - July 2016: article published on a special edition of the economic magazine Platinum dedicated to Research and Innovation. The article has been published both in English and in Italian ("La ricetta per la formazione delle stelle") and is available on line at the web address [http://www.platinum-online.com/luglio-2016-filippo-antonio-de-cecco/](http://www.platinum-online.com/luglio-2016-filippo-antonio-de-cecco/). The English version is available at [http://en.calameo.com/read/003272336f52b98253be1](http://en.calameo.com/read/003272336f52b98253be1) and can be browsed to find the article at page 60. Platinum is a magazine distributed with the Italian economic newspaper Sole24ore and is mainly addressed to the business world, institutional and financial.


1.4.7 Public Lectures

- S. Molinari: "L'Astronomia Infrarossa e la nascita delle stelle", public lecture, 23/09/2015, scuderie Aldobrandini, Frascati, Roma. The lecture has been given in the framework of the activities for European Science week before the Researchers’ night 2015 event.

- A. Di Giorgio: “Guardare il cielo a varie lunghezze d'onda: l'importanza dell'infrarosso e i risultati del progetto VIALACTEA”, public lecture, 19/02/2016, Banca d'Italia Centro Donato Menichella, Roma: lecture given in the framework of the project Astrofamilies, in collaboration with INAF-IAPS and the Physics department of the Roma TRE University.


- S. Molinari: "VIALACTEA, un viaggio nella nostra Galassia", public lecture, 26/11/2016, Bergamo Science Center.

1.4.8 Production of video


The video features Consortium Members also including VIALACTEA Post Doctoral researchers.

List of Websites:

1.5 Project Public Website and Relevant Contact Details.

The project website can be accessed at [http://vialactea.iaps.inaf.it/vialactea/](http://vialactea.iaps.inaf.it/vialactea/). It has been developed to introduce the community to the project activities, providing a mean for accessing all the public project products.

The web site can be used also as the main portal for downloading the VIALACTEA project products. Two pages has been set-up for this purpose (see figure 19):

- the "Tools" page can be used to download the SW packages developed within the project: i. the Filamentary Structures Extraction Package, ii. the Bubble features extraction package, iii. the compact sources extraction package, iv. the Visual analytics client, v. the automatic sources classification tool and vi. the automatic distance determination tool. For all tools two items can be downloaded, the tools source code and the user manual with the instructions for the installation. All Tools will be made available to the public as soon as the papers containing their description (and the description of the results of the tools usage, i.e. the VIALACTEA catalogues) will be accepted.

- the "Products" page can be used to download the VIALACTEA products: i. the Catalogue of filamentary structures, ii. the catalogue of Galactic Plane bubbles, iii. the Compact source catalogue, iv. the multi-mission band-merged catalogue, v. the grid of synthetic protoclusters evolutionary models, vi. the database of kinematical information from spectroscopic surveys and vii. the 3D maps of dust extinction along the Milky Way plane. All Products will be made available to the public as soon as the papers containing their analysis will be accepted.

The VIALACTEA webpage contains also the links to the other two main products portals: the VIALACTEA Science Gateway and the VIALACTEA KnowledgeBase.

In figure 20 the VIALACTEA Science Gateway Portal is shown. Once signed in (the credentials for the access can be interactively required to the page administrator) the portal allows to use the VIALACTEA workflows engine either for running
already existing workflows or for designing new application specific workflows. On the portal, useful video tutorials are available to ease the new workflow design.
Selecting the VIALACTEA KnowledgeBase (VLKB) Button in the home page it is possible to address the page shown in figure 21, where some explanatory notes are provided to introduce the main VIALACTEA data archive. The possibility to access the VLKB using TOPCAT is described as well as the instructions on the possibility to interface to the VLKB using the Visual Analytics Client.
Finally, the webpage can be used to address the ASI Science Data Centre portal for downloading the HiGAL products using a dedicated graphical interface.

Related information

| Documents and Publications | final1-logo.pdf |

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