Institut d'Estudis Espacials de Catalunya

Annual Report

2018

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Index

Introduction

The Institute of Space Studies of Catalonia

IEEC (Institut d'Estudis Espacials de Catalunya) is a research institute that studies all areas of space and space sciences, including astrophysics, cosmology, planetary science, Earth observation and space engineering. Its mission is to push the frontiers of space research from the scientific and technological domains for the ultimate benefit of society.

The specific objectives are to:

- Promote astronomical and space research;
- Become an internationally recognised centre in order to attract talent and foster collaborations both locally and worldwide;
- Be an efficient agent of knowledge, innovation and technology transfer in its field;
- Carry out science awareness in society by communicating scientific culture.

IEEC ranks among the best international research centres, producing a large number of high-impact publications and leading key world-class projects. This is the result of over twenty years of top-quality research work in collaboration with renowned international institutions. IEEC also develops instrumentation for multiple space missions thanks to a team of engineers with extensive experience in the aerospace sector and in sectors with a high value in innovation. As a private non-profit foundation, IEEC can have a versatile relationship with private industries and companies that ultimately manufacture the qualified flight hardware.

IEEC was established in February 1996 to foster space R&D in Catalonia. It currently has a Board of Trustees composed of the Generalitat de Catalunya, the University of Barcelona (UB), the Autonomous University of Barcelona (UAB), the Polytechnic University of Catalonia (UPC) and the Spanish Research Council (CSIC). IEEC also belongs to the Institució CERCA - Centres de Recerca de Catalunya.

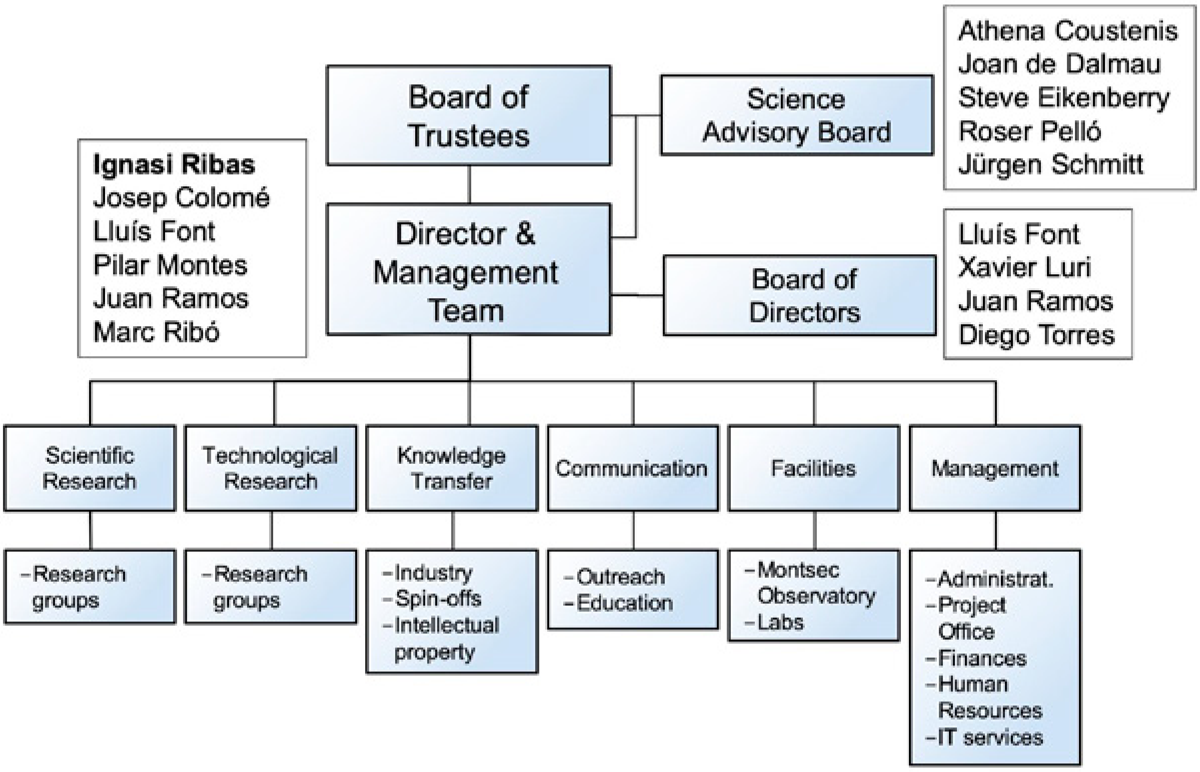
IEEC is structured in the form of four Research Units, which constitute the core of the R&D activity. Each of these units was created and is governed by the rules of one of the academic institutions that are members of the Board of Trustees. The Research Units are:

- Institute of Cosmos Sciences - ICCUB (UB)
- Center of Space Studies and Research - CERES (UAB)
- Research Group in Space Sciences and Technologies - CTE (UPC)
- Institute of Space Sciences - ICE (CSIC)

The agreements between IEEC and the academic institutions in the Board of Trustees allow for the exchange of personnel and funds. Scientists and technicians from the Research Units can simultaneously act as members of their institutions and as members of IEEC upon their approved affiliation.

The organisation chart of IEEC is shown in Figure 1. IEEC has a Director, nominated by the Board of Trustees, who is assisted by a Management Team. The organisation of each Research Unit is independent and the four directors are members of the Board of Directors. Furthermore, an external Scientific Advisory Board (SAB) is nominated by the Board of Trustees. Its role is to evaluate the quality of the scientific and technical outputs of the institute and advise on the strategic planning of the institute as well as the overall organisation.

Figure 1: IEEC organisation chart



Contact person: director@ieec.cat

IEEC Annual Report 2018

IEEC is proud to present its Annual Report for the year 2018. This document gathers the outcomes and the main results of the research activities and projects that have been carried out by the nearly 200 IEEC members.

2018 has been a very fruitful year. Scientific productivity in terms of bibliometrics has attained an all-time record, with a total of 378 refereed publications as registered in the Web of Science database, including three publications in each of Nature and Science journals. Over 85% of the publications have appeared in the highest impact journals within their fields (first quartile). We are also strengthening the collaborative ties within IEEC, with 30 publications having co-authors from two units and one publication with co-authors from three units. Most of the publications are associated to the area of Astronomy & Astrophysics, but there is also a non-negligible number of publications in other fields, most notably engineering (electronics, aerospace) and geosciences (remote sensing, meteorology). A selection of highlights covering both scientific results and technical accomplishments is included in this volume.

IEEC is responsible for the operation of the Montsec Astronomical Observatory (OAdM) and, in particular, its Joan Oró robotic 80-cm telescope. You will find a full report of its activities, which include science observations (mostly time-series photometry for various applications - exoplanets, asteroids, variable stars etc.) and also an ambitious satellite surveillance and tracking (SST) programme funded by the Spanish Centro de Desarrollo Tecnológico Industrial (CDTI).

Furthermore, OAdM is also gradually becoming more involved in the area of nanosatellites. New VHF/UHF antennas were installed during 2018 and these represent the seed of a future nanosatellite communications station. 2018 was an important year for OAdM since it celebrated its 10th anniversary and also inaugurated two new instruments, called LAIA, a large-format imager, and ARES, a mid-resolution spectrograph.

An important aspect of the activity of IEEC is to promote and support key projects, with particular focus on those that involve groups from different units. This volume provides detailed reports on the activities of the key projects within IEEC, namely the LISA & LISA Pathfinder missions, the Cherenkov Telescope Array project (including a contract to manufacture ASICs for the Large-Size Telescope 1), the ARIEL mission, and the Nanosatellite project (which received funding via the “Producte” call of the Generalitat de Catalunya).

You will be able to judge how incredibly active these projects have been and all the great results and accomplishments they have obtained. Recognising this as a key aspect for IEEC, Dr. Alberto García-Rigo joined in 2018 as a member of the Project Support Office with the objective of providing support to key projects and identifying areas of common expertise that are worth exploiting, for example, for eventual applications to EU and ESA funding calls, among others. During 2018 he has been instrumental in organising the portfolio of expertise within IEEC.

Innovation and knowledge transfer activities at IEEC have continued in 2018. Different research areas have captured the interest from industrial, academic or governmental partners around the world to transfer some achievements to market applications. The satellite services at the OAdM observatory, the high-performance nanosatellite platform, the work on space image compression standards and on-board data handling and transfer, the solutions for high-accuracy positioning and for navigation and positioning services, or the GNSS-R spaceborne mission for ocean altimetry applications are some examples of new and innovative concepts granted in 2018 that contributed to put space technology at the service of society.

IEEC has collaborated with the Summer schools organised by the units, and has provided support to several professional meetings. It is also worth emphasising that we at IEEC deeply believe in the value and need to communicate our results to the public and to help the media by providing expert advice on specialised news within the area of knowledge of our researchers. We take this commitment very seriously and, thus, IEEC members have been involved in literally hundreds of science outreach activities during 2018, which include, public talks, events, media appearances, dissemination events etc. Worth noting here are the collaborations with CosmoCaixa on the organisation of a very successful series of conferences and with the Sónar festival in its 25th anniversary celebration event dubbed Sónar Calling GJ 273 b.

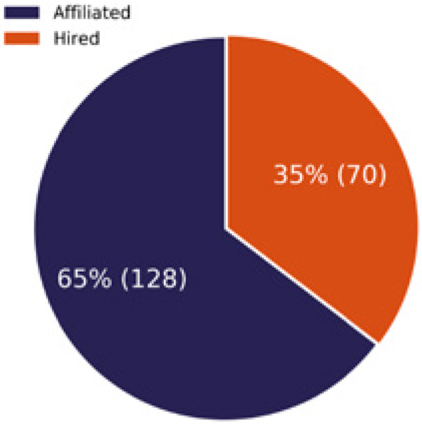
To improve even further internal and external communication, we signed a contract with Science Wave, a company specialising in science communication. Science Wave has helped us to improve our image (e.g., through the release of a new website with enhanced functionality, www.ieec.cat) and the quality of our outreach products, in particular press and social media materials. Internally, we have worked a great deal to clarify the affiliation policy and set explicit rights and duties that IEEC members (both staff and affiliated) have to obey. The good news is that this effort has attracted new researchers and groups to join IEEC. Worth mentioning are: Dr. Manuel Domínguez-Pumar and Dr. Vicente Jiménez, from CTE, who work on the development of new micro- and nano-silicon based sensors for industrial and space applications and have developed anemometer sensors for two Mars missions; Prof. Francesc Gòdia, from CERES, the lead scientist of the MELISSA Pilot Plant, which is a demonstrator of a closed loop life support system; and Dr. Joan Serra, from CERES , who focuses his activity on data compression methodologies for space applications. These are just a few examples of a number of faculty members, postdocs, students and engineers that have joined IEEC during 2018. We warmly welcome all of them and wish for a productive relationship with IEEC and an even more successful 2019 and years to come!

Personnel

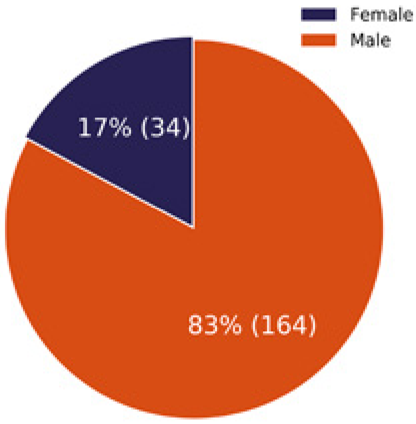
The statistics, tables and graphs illustrate the distribution of IEEC's personnel according to their work situation, gender, scientific unit and role.

Total personnel: **198**	Male: **164 (83%)**	Female: **34 (17%)**
	Hired: **70 (35%)**	Affiliated: **128 (65%)**

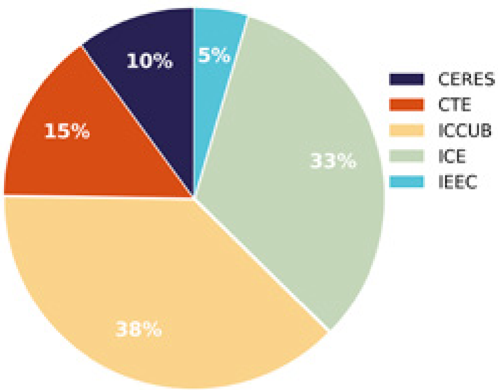
	IEEC	ICE	CERES	ICCUB	CTE	TOTAL
	Core Staff					
Administration & IT & PO	5					5
OAdM	4					4
	Affiliated members					
Research & engineers (faculty)		27 (19)	19 (8)	54 (21)	28 (20)	128 (68)
	IEEC contracts					
Administration & services		2		1		3
Researchers & engineers		25	1	16	1	43
PhD Students		11		4		15
	TOTAL					
	9	65	20	75	29	198



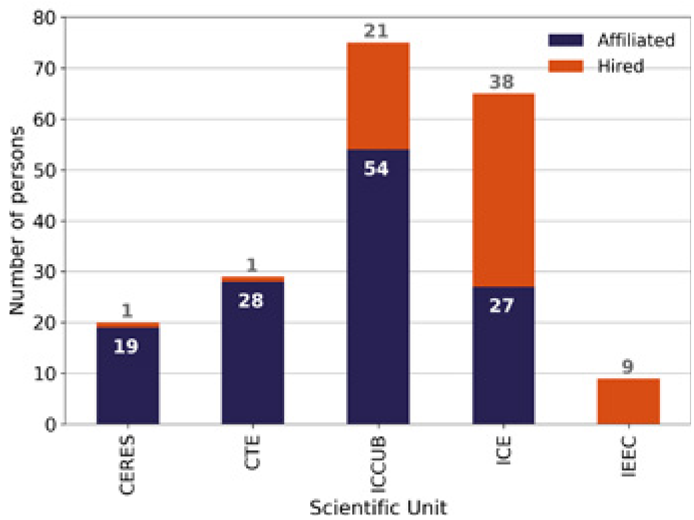
Personnel per work situation



Personnel per gender

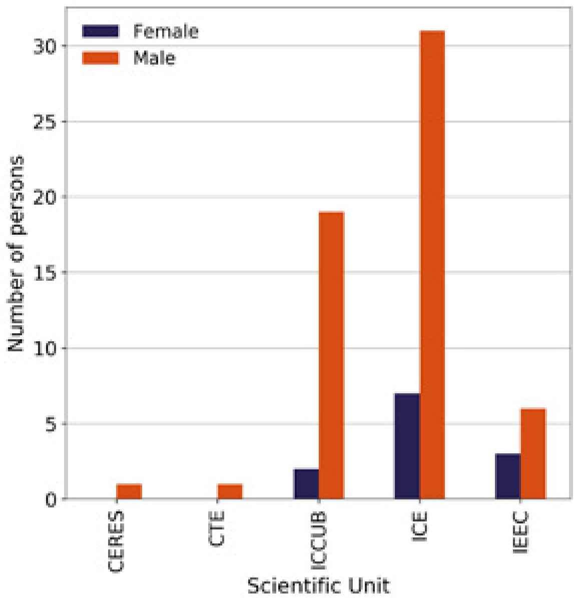


Personnel per scientific unit

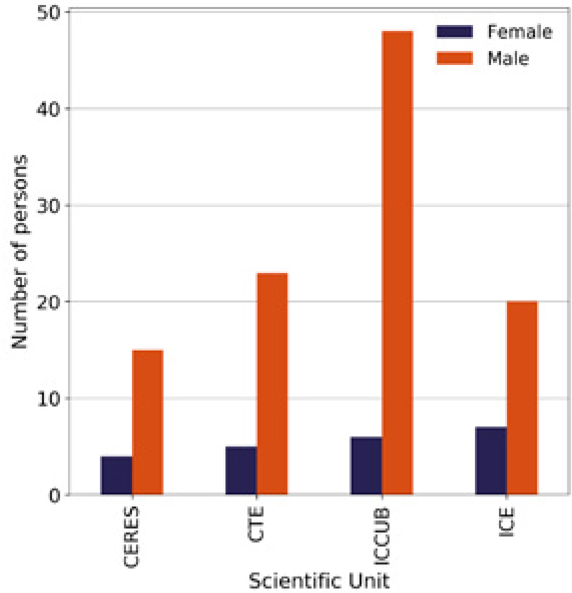


Personnel per work situation and scientific unit

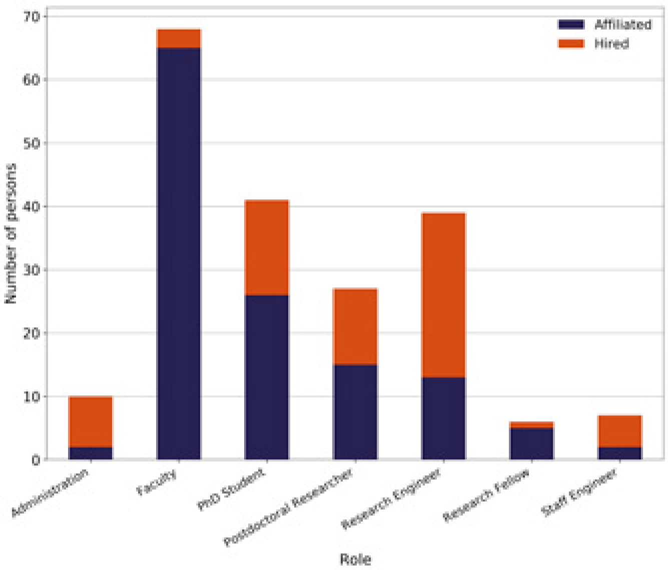
Personnel



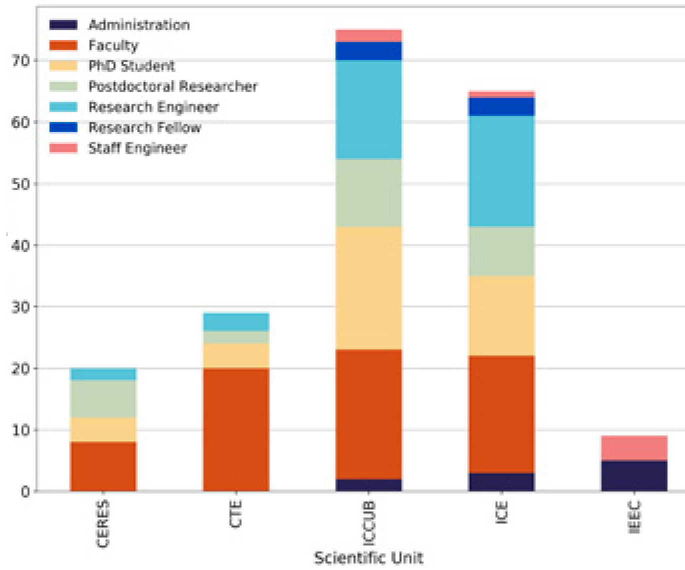
Hired personnel per scientific unit and gender



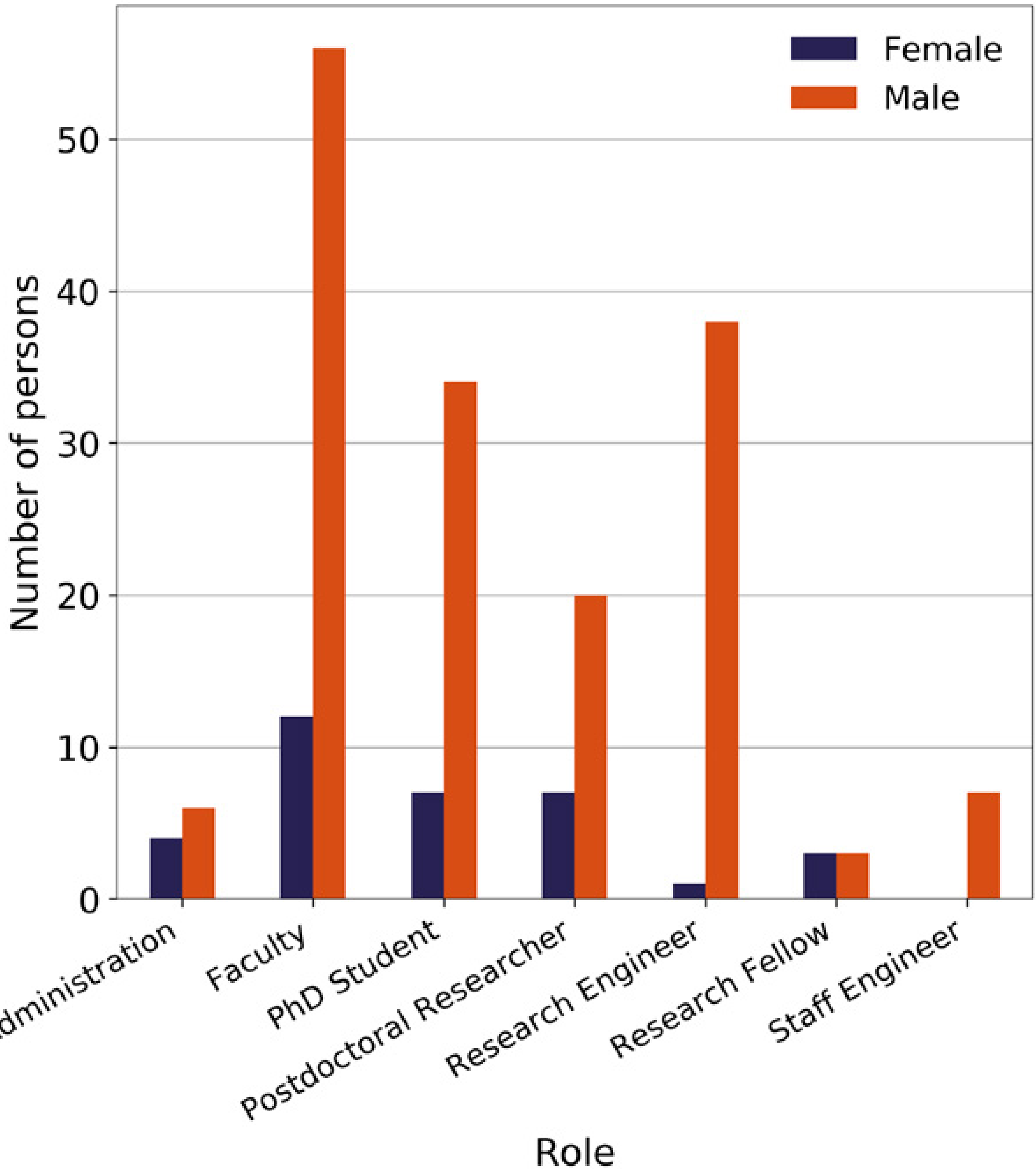
Affiliated personnel per scientific unit and gender



Personnel per work situation and role



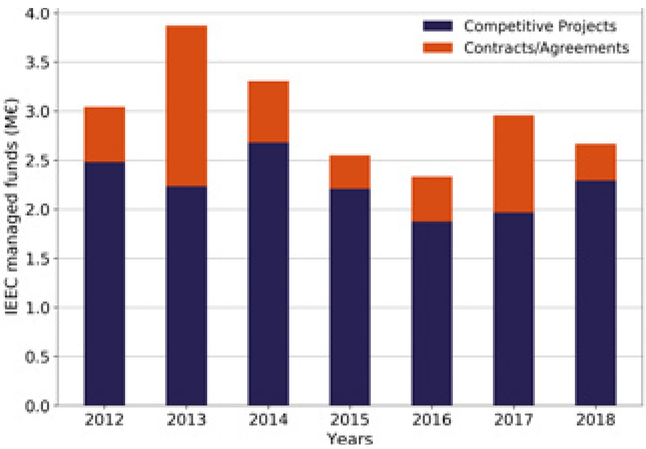
Personnel per role and scientific unit



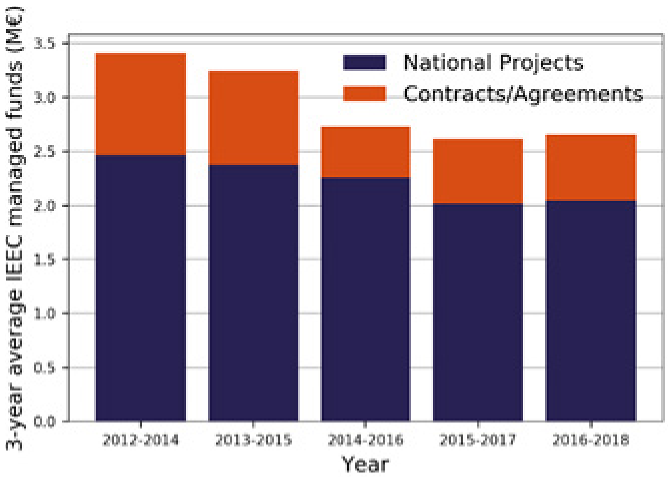
Personnel per role and gender

Projects

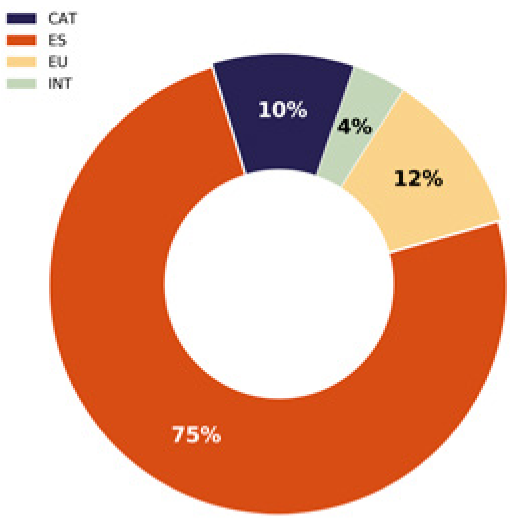
The plots and graphs below show the funding secured and managed by IEEC, including base funding from the competitive projects and contracts/agreements with industry. Data for several years are shown to illustrate the time evolution.



Incomes per year and project class



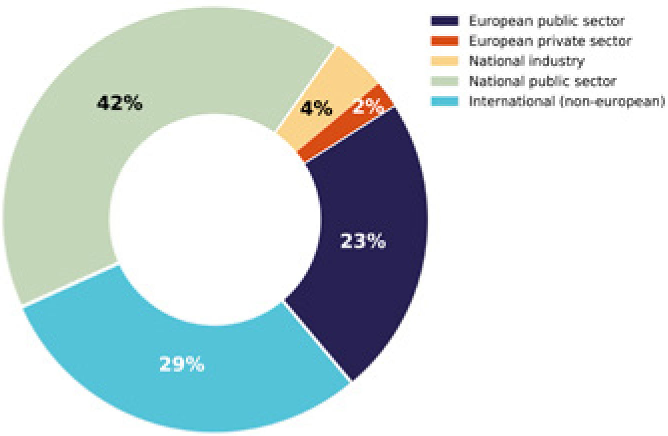
Triennial mean incomes per year and project class



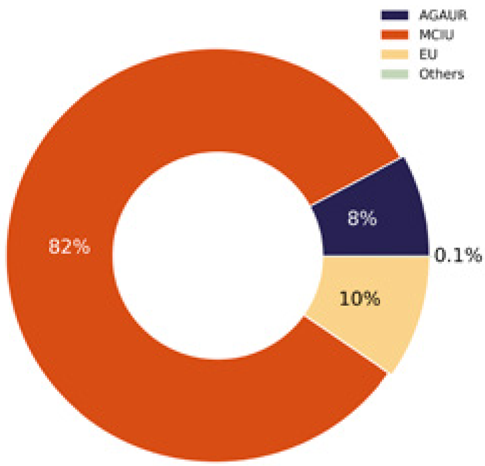
Incomes per geographical area

Contracts/Agreements	Incomes (k€)
European public sector	79.8
European private sector	7
National industry	14.5
National public sector	144.8
International (noneuropean)	102,3

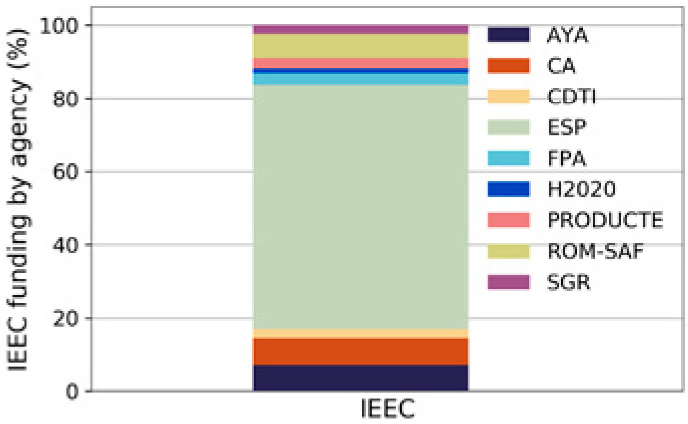
Competitive Projects	Incomes (k€)
AGAUR	188.7
MCIU	1973.8
EU	229.2
Others	1.9



Incomes from contracts/agreements



Incomes from competitive projects

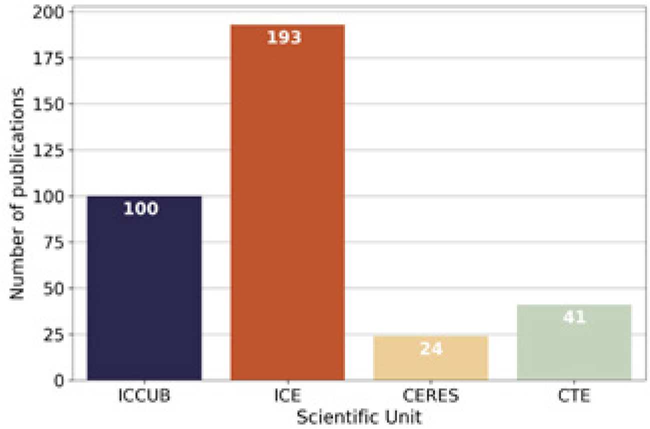


Incomes per programme

- AYA: Astronomy and Astrophyiscs (MCIU Competitive Grants)
- CA: EU Cost Action
- CDTI: Spanish Centre for the Development of Industrial Technology
- ESP: Space Investigation (MCIU Competitive Grants)
- FPA: Space Investigation (MCIU Competitive Grants)
- H2020: European Comission Horizon 2020
- PRODUCTE: Product (Gencat AGAUR Competitive Grants)
- ROM-SAF: Radio Occultation Meterology Satellite Application Facility (EUMETSAT)
- SGR: Research Groups Support (Gencat AGAUR Grants)

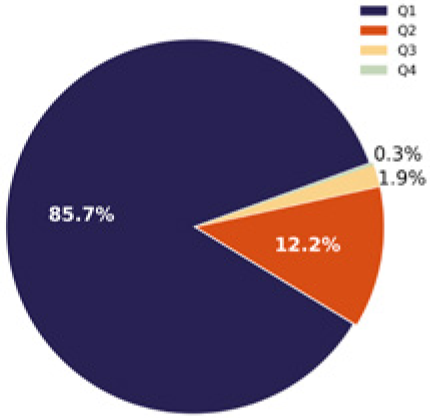
Publications

Graphical summary of the total scientific and technical publications authored by IEEC members according to the Scientific Unit, journal quartile, journal, scientific subject and author.

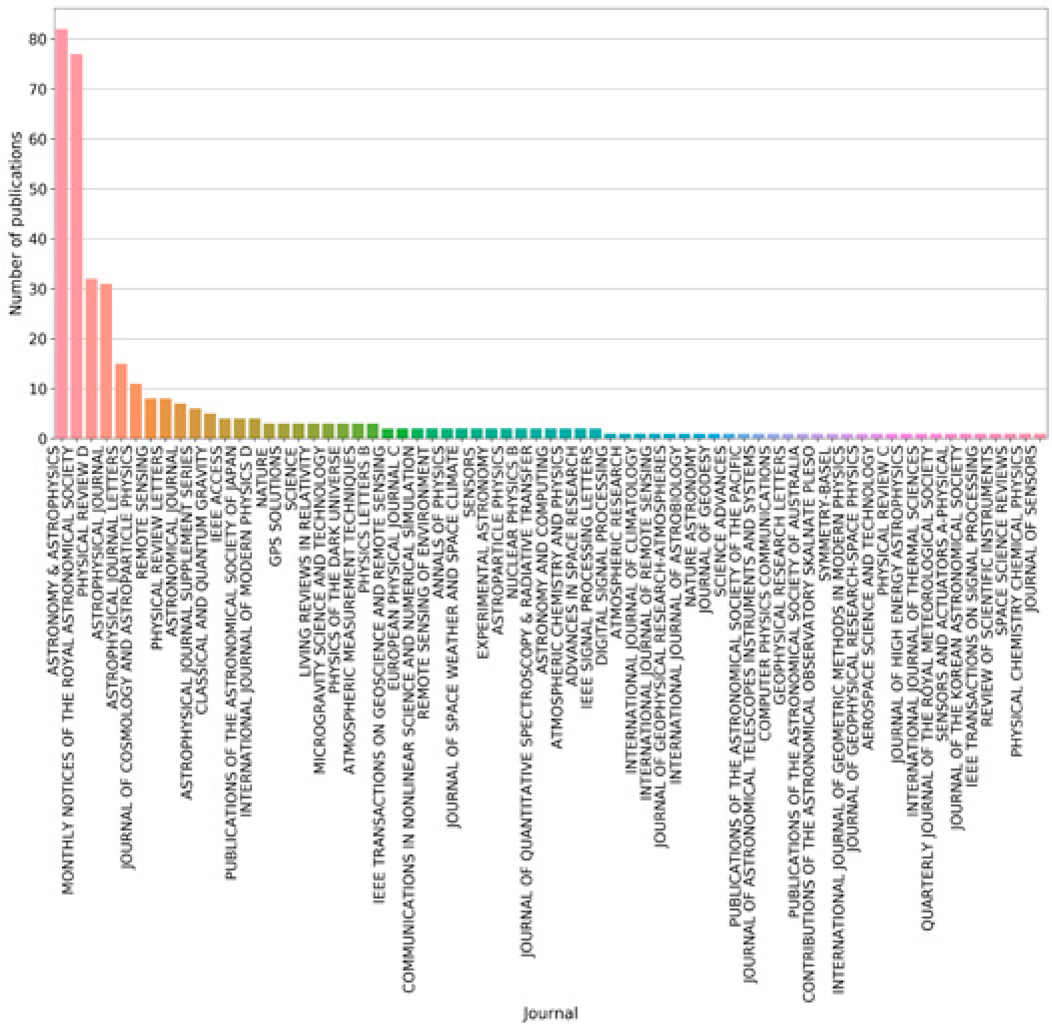


Number of publications per scientific unit

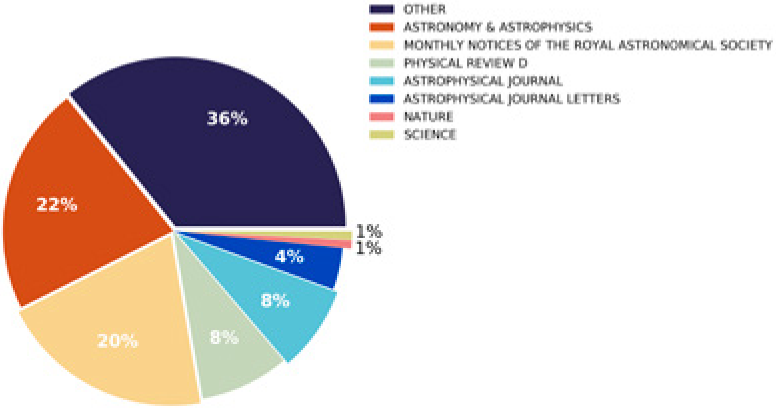
The total number of publications include the 20 publications done by authors at Universitat de les Illes Balears (UIB).



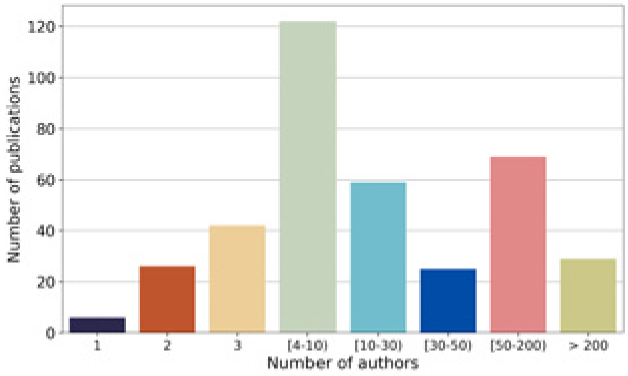
Number of publications per journal quartile



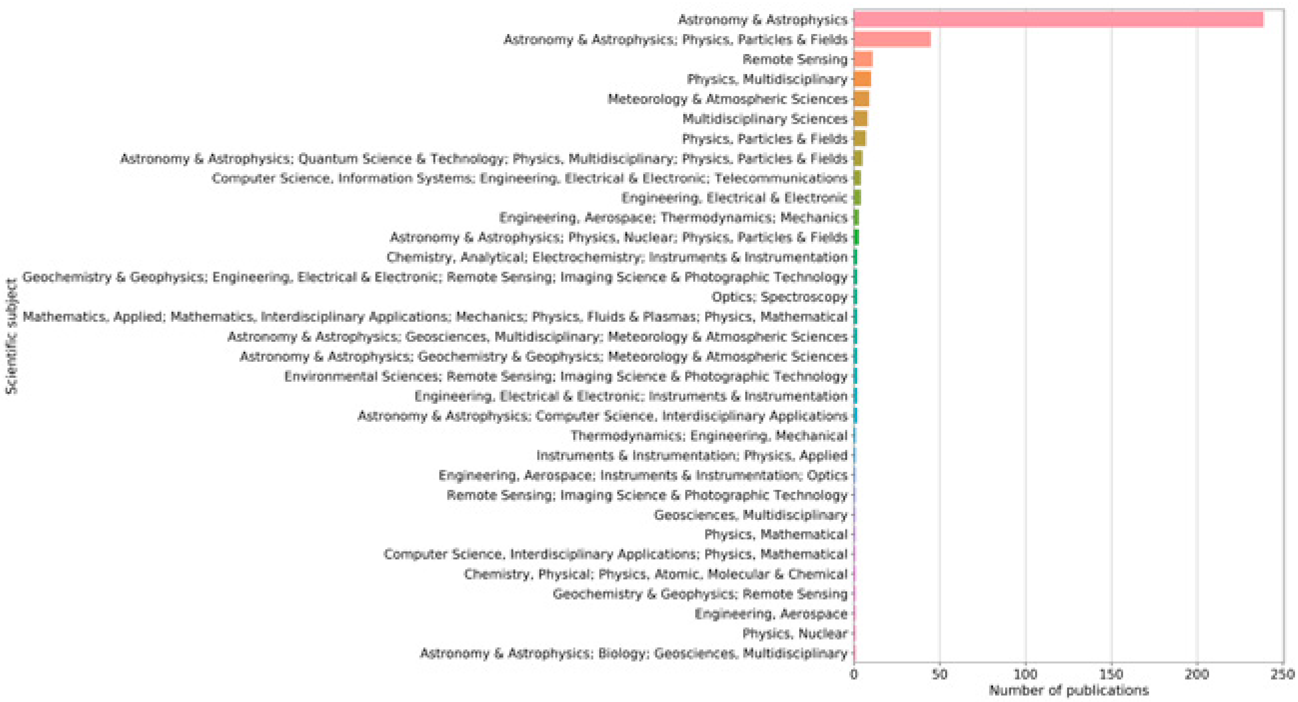
Number of publications per journal



Publications per journal



Number of publications per number of authors



Number of publications per subject

Moreover, some publications were performed in collaboration between authors at different IEEC's scientific units. These are:

- ICCUB + ICE = 4 publications
- CERES + ICCUB = 14 publications
- ICE + CTE = 6 publications
- ICCUB + CTE = 4 publications
- ICE + ICCUB + CTE = 1 publication

Montsec Astronomical Observatory

Celebrating 10 years of successful operation of this leading infrastructure for astronomical research, satellite services, and climate and environment monitoring.

The Montsec Astronomical Observatory (OAdM, www.oadm.cat) is a scientific infrastructure that is managed by IEEC by virtue of an agreement with the Direcció General de Recerca of Generalitat de Catalunya. It is located at 1570 meters high in the Montsec mountains, 50 km north of the city of Lleida, in the municipality of Sant Esteve de la Sarga and near Ager, in the Catalan pre-Pyrenees. This area is recognised as one of the most suitable ones on the European continent for astronomical observation, thanks to the combination of weather conditions and the low effect of light pollution. It is, undoubtedly, an exceptional sky.

The OAdM comprises four facilities for research in astronomy, among others. The astronomical equipment consists of three robotic telescopes: Telescopi Joan Oró (TJO, managed by IEEC-Generalitat de Catalunya), Telescopi Fabra-ROA Montsec (Reial Acadèmia de Ciències i Arts de Barcelona and Real Observatorio de la Armada) and XO-Montsec (IEEC). In addition, it houses a camera for the detection of fireballs and hazardous near-Earth asteroids (AllSky Camera, IEEC). The Observatory also hosts an automatic station of the Meteorological Service of Catalonia (Servei Meteorològic de Catalunya, SMC), an environmental quality measurement station of the XVPCA network (Institut de Diagnosi Ambiental i Estudis de l’Aigua – CSIC) and several antennas for low orbit satellites’ communications installed and managed by the Universitat Politècnica de Catalunya and IEEC.

The main goals of OAdM are to provide tools to carry out cutting-edge research in astronomy, to provide the necessary support to exploit OAdM facilities, to serve as testbed for the development of new astronomical instrumentation, and to provide space-related services to public institutions and industry. In this context, the largest telescope, the TJO, the XO-Montsec wide field telescope and the AllSky Camera are directly managed by IEEC. The main feature of the TJO is its robotic operation, so that the performance of observations and the decision-making process in case of incidences are carried out automatically and without human intervention (without “in situ” or remote personnel supervising the operation).

The scientific facilities of the OAdM have yielded important findings in the fields of exoplanets, supernovae or solar system research. Moreover, they have contributed to the tracking of satellites and the monitoring of the atmospheric quality in the Montsec area. During 2018, IEEC achieved different milestones at OAdM, from several technical developments to the 10 years of operations of the Observatory. Below we make a summary of these milestones.

Figure 2: Left: Aerial view of the Montsec Astronomical Observatory (OAdM) showing the TJO (dome), the TFRM (large container), the XO (small hut-like container on bottom-left) and the SMC/XVPCA station (container on the top-right). Right: Side view of OAdM displaying the TJO (right) and the TFRM (left) with a clear sky in the background.

The project of placing an astronomical observatory at the Montsec emerged in the early 90’s, having the biochemist from Lleida, Joan Oró, together with the foundation that bears his name as the main ideologists. The main equipment of the OAdM began operations in on 24 October 2008, and the first telescopes installed have been fully operational since 2010. Joan Oró is the name given to that first telescope, which is still one of the 1-meter-class telescopes most technologically advanced in the world.

Montsec Astronomical Observatory

Ten years after its inauguration, the Montsec Astronomical Observatory has become a key research infrastructure in the Catalan ecosystem and in the connected world. Many people have contributed to this project and many more keep it alive by using its facilities and pushing for their improvement.

Joan Oró Telescope

The Joan Oró Telescope (TJO) has a 0.8-m primary mirror with an overall F/9.6 optical system in Ritchey-Chrétien configuration. The TJO was supplied by Optical Mechanics Inc. (OMI) and was equipped with a fully automatic 6.15-m dome manufactured by Baader Planetarium GmbH. Since its first scientific use, the TJO has had different high-performance CCD cameras for astronomical imaging (MEIA, MEIA2 and now LAIA, see below) with a set of Johnson-Cousins UBVRcIc filters. Since 2018, the TJO also has a spectrograph (ARES, see below). In addition, several associated instruments for environment monitoring are acquiring data continuously: two weather stations, a GPS antenna and a storm detector, among others. A fiber-optics connection with 100 Mbps bandwidth provides external communication necessary for remote access. A complex software architecture manages all observatory operations. This architecture is mainly managed with OpenROCS, an open-source software developed to control robotic observatories. Low-level telescope and dome control are conducted through the TALON software.

Since 2013, the TJO is operating in routine mode and is providing useful data that are distributed through the OAdM web portal and also through the node of the Spanish Virtual Observatory. The telescope carries out multi-purpose astronomical observations and is also a testbed to develop new instrumentation. The TJO offered around 70% of its available time in 2018 to the international astronomical community, with the sole requirement of maximising the scientific and technical performance of the instrumentation. In this regard, IEEC established a Time Allocation Committee that evaluates the proposals submitted by the scientific community, makes a time allocation and assigns a relative priority.

The TJO became a full member of the EU system for Space Surveillance and Tracking (SST) in 2016, being one of the few optical telescopes in Spain that proved their capacities to become a member of this network. The main goal of the associated European programme is to develop a network of telescopes capable to detect and track satellites and space debris. The TJO has been participating in this network with tracking mode service since then.

At the end of 2018, OAdM had 103 registered users, 52 of them from IEEC, 16 from other Spanish institutions, and 35 from international institutions. From 2013 to 2018, the call for proposals has been permanently opened and users have been guaranteed with less than a month response time (which is pushed down to one week in case of urgent proposals). In this way, the TJO can better exploit its flexibility as robotic telescope and therefore can react to transient events, new discoveries, etc.

Data production and duty cycle improved in 2018 and confirmed a continuous evolution of these parameters. On the other hand, the number of proposals received has been constant to 9 during the last 3 years (2016-2018). The new instrumentation, a double call for proposals starting in 2019 and a more user-friendly web page and proposal handling tool are expected to improve the tendency. The SST programme and the extension of the existing scientific programs have compensated the relatively low number of proposals received.

Science with the TJO

The TJO is a general purpose facility and, as such, it carries out a variety of observations related to various science cases. Given its size, the main scientific niche for TJO is the time-domain astronomy, where high-cadence, continuous observations are the primordial requisite. Its main advantage is a flexible operation mode allowing for the monitoring of sources for extended time periods and also the possibility of a rapid reaction time, potentially as short as a minute or less. Given such features, the possible science cases for TJO include:

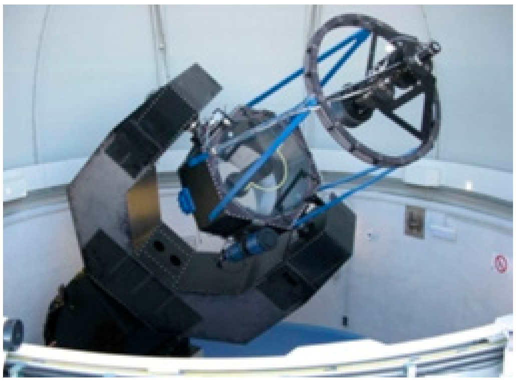


Figure 3: The Joan Oró Telescope (TJO).

- Exoplanet research (possibly follow-up of known transiting planets or targeted searches of individual objects);
- Eclipsing binaries (to understand stellar properties and structure);
- Pulsating variables (probing the stellar interior);
- Evolved variable stars (giants and supergiants);
- Stellar activity (to understand the magnetic dynamo and to calibrate the time-decay of such activity);
- Variability of active galaxy nuclei (related to the stochastic accretion process);
- Solar System objects (follow-up of asteroids, near-Earth objects, comets);
- Supernovae (with the added value of obtaining early photometry);
- X-ray binaries (rotational variability and accretion phenomena);
- Novae (also with possible early data);
- Optical counterparts of Gamma Ray Bursts (GRBs);
- Any transient phenomena in general.

Montsec Astronomical Observatory

The science cases above require important flexibility in the night scheduling, which allows the system to react rapidly to observational alerts related to GRBs, new supernovae and similar time-critical events. The participation in the networks of robotic observatories enables the carrying out of, for example, observations requiring continuous time coverage. Similarly, the TJO can be used as a support facility for space missions to collect photometric and astrometric data. The TJO offers time to the astronomical community via competitive proposals, peer-reviewed by an independent Time Allocation Committee (TAC).

During 2018, the TJO participated in different scientific projects, including the study of Solar System objects, monitoring of exoplanet transits, characterisation of M dwarf stellar activity, monitoring of novae, or studies of newly discovered black hole X-ray binaries, type Ia supernovae or Gaia transients, such as the ones producing microlensing events.

It has to be emphasised that 2018 saw an increase in the number of refereed publications using TJO data. In particular, photometric data of Barnard's Star was used to contribute to the discovery of the Barnard b exoplanet, a result published in the Nature journal.

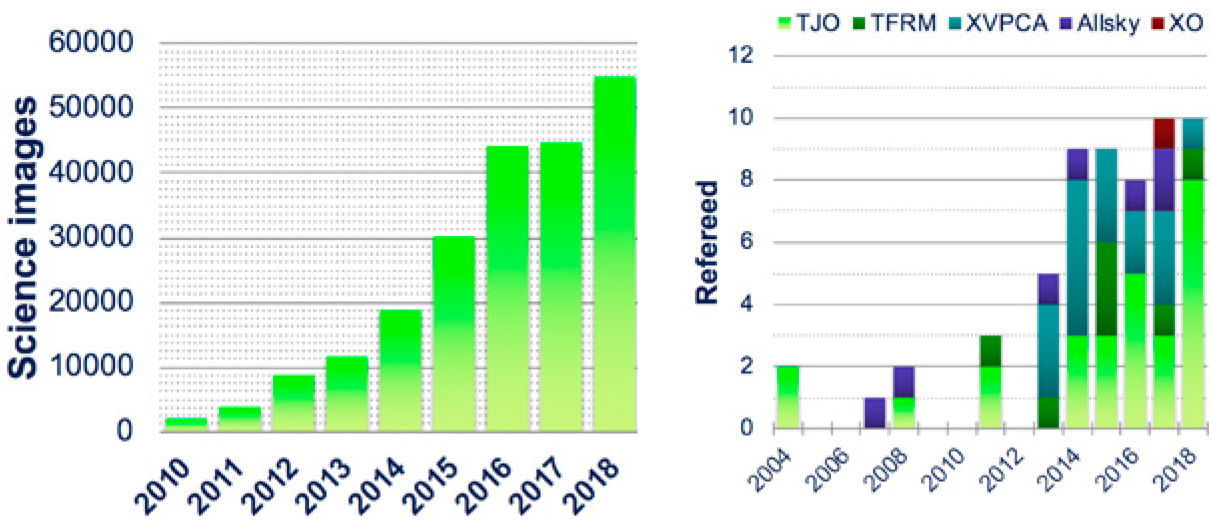


Figure 4: Increasing number of scientific images obtained with the TJO. Right: Refereed publications with OAdM facilities.

Observation statistics

- Useful time (night-time hours with good weather conditions): 1669 h (54.3% of total night time)
- Time acquiring data (regardless of quality): 1510 h (90.5% of total night-time with goodweather)
- Time acquiring useful data: 1220 h (81.2% of total night-time with good weather) → Duty cycle

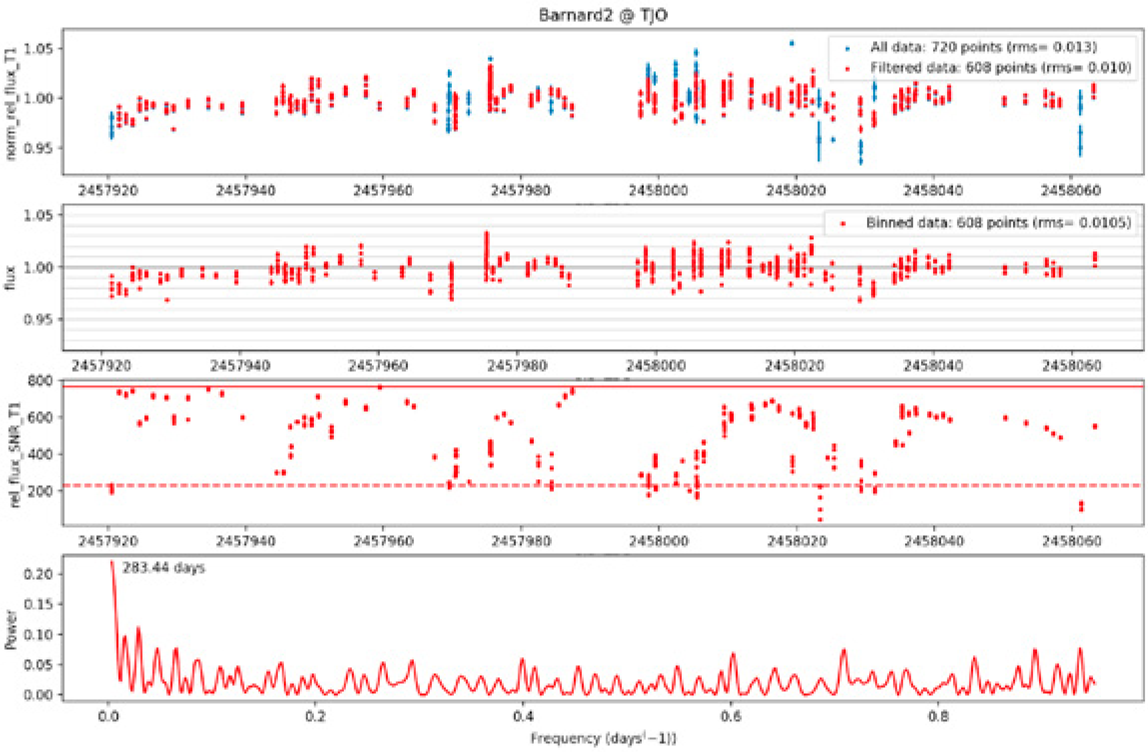


Figure 5: TJO observations of Barnard's Star.

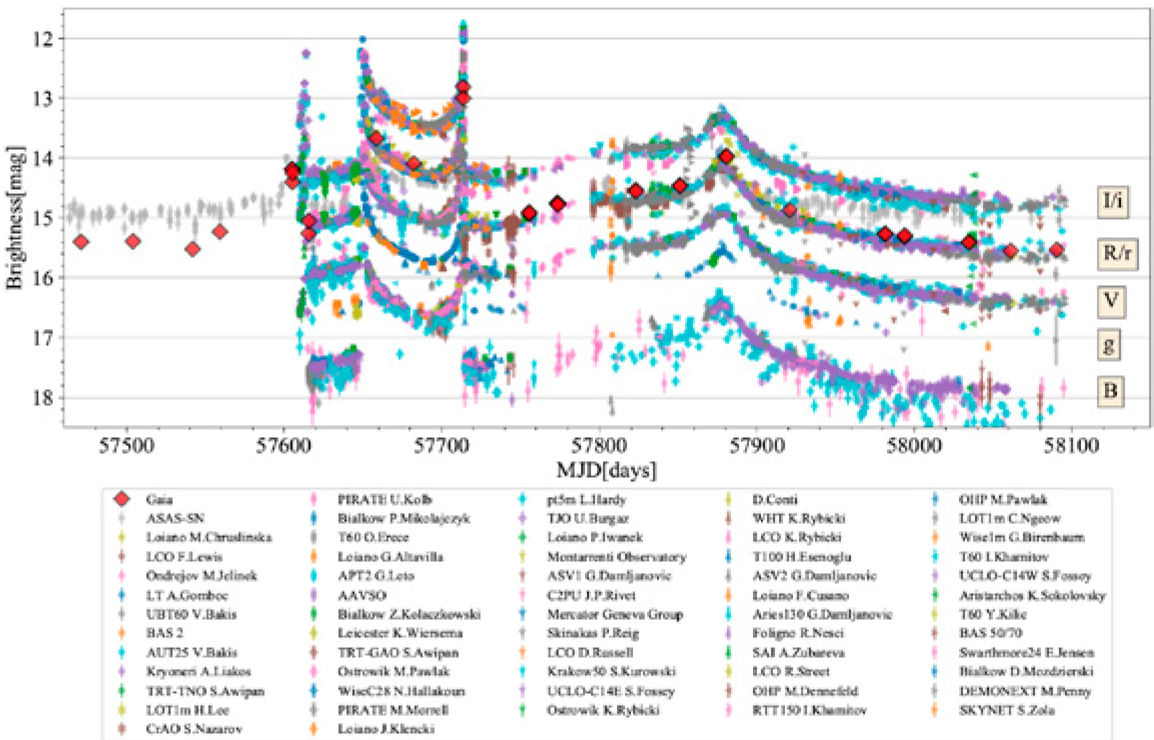


Figure 6: Light curve of the binary microlensing event Gaia16aye in the Northern Galactic Disk, including data from the TJO (from https://arxiv.org/abs/1901.07281).

Montsec Astronomical Observatory

Aluminisation of the TJO primary mirror

Figure 7: The primary mirror of TJO with the new aluminium layer.

In June 2018, the astronomers and technical staff of the OAdM carried out the dismantling of the primary mirror of the Joan Oró telescope (TJO). The 80 cm mirror, weighting around 110 kg, was carried to the Calar Alto observatory in Almería, which had the necessary infrastructure for the cleaning of the mirror and the vacuum chamber for injecting a new layer of aluminium. The operation, one of the most delicate ones that has been performed in the maintenance of the TJO, and which was carried out for the last time in 2013, was successfully completed. Afterwards, the OAdM astronomers could measure an increase in reflectivity of the mirror between 60 and 65% in the different filters available to the MEIA2 imaging instrument at that time.

LAIA, the new camera at the TJO

A new wide field camera was installed and commissioned at the TJO during 2018, with regular observations starting in November. The new CCD camera, named LAIA (Large Area Imager for Astronomy) is an Andor iKon XL 230-84. It is installed at the Cassegrain focus of the telescope and takes advantage of the same filter wheel previously used by MEIA and MEIA2 instruments. The new LAIA camera has a detector with a 4k x 4k format, which provides a non-vigneted field of view of 30 arcmin diameter in the TJO, about 4 times larger than that of the previous MEIA2 camera, maintaining a similar resolution.

Figure 8: Image of the Orion Nebula obtained with LAIA, the new wide field camera of TJO.

This upgrade of the main instrument of the telescope provides higher quality data to the observers, allowing also to expand the capabilities of the TJO in fields such as the study of solar system objects, the detection and monitoring of novae and supernovae, or the tracking of satellites and space debris. The observations conducted in 2018 with LAIA at the TJO showed great improvements in the photometric and astrometric accuracy of the system thanks to the sensor characteristics of the new camera.

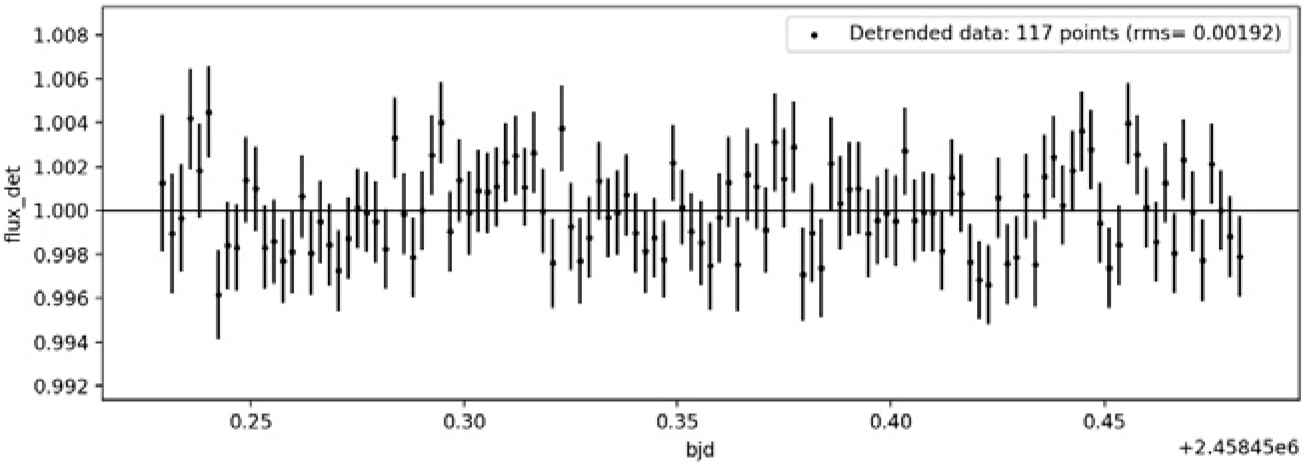


Figure 9: Photometric lightcurve obtained with LAIA of an R=14 red dwarf with dispersion below 0.2%.

ARES, the new spectrograph at the TJO

ARES is the first spectrograph installed at the TJO. Its dispersion system is composed by two VPHs developed by Wasatch Photonics, providing the two spectral windows and maintaining a high overall throughput. Both VPHs are mounted on a carriage (prepared to hold up to three VPHs), allowing a fast change from one VPH to the other. The system provides a resolution of 12,000 and can operate in two different wavelength regions: green 495-529 nm (including the MgI triplet) and red 634-678 nm (including the Hα line). The commissioning phase took place in 2018, with shared-risk observations to start in 2019. We hope that this spectrograph, with high-efficiency optics, will greatly improve the scientific appeal of the TJO.

The first results indicate that a signal-to-noise ratio of 100 can be attained in a 1-hour integration for V=13 mag targets. ARES will open the door to using the TJO for a variety of new science cases, including chemical abundance determination, measurement of radial velocities and monitoring of stellar activity through the Hα feature. While there are numerous photometric robotic telescopes in the world, only a few of them have spectroscopic capabilities. ARES puts the TJO at world-class level.

Montsec Astronomical Observatory

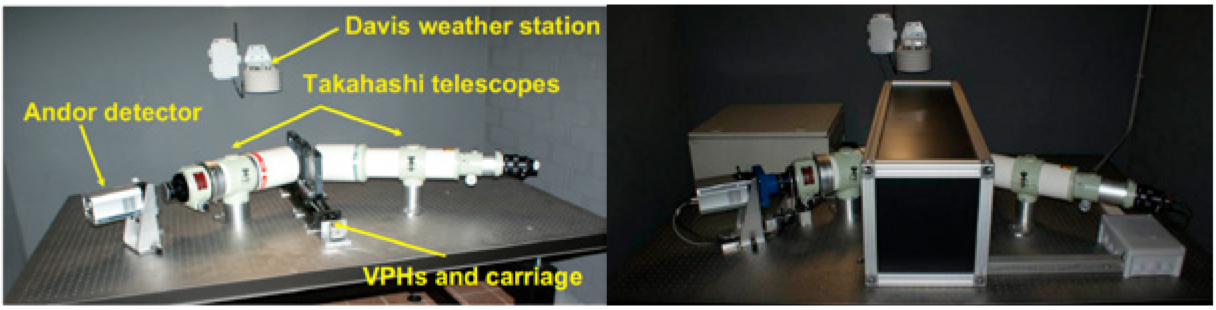


Figure 10: The ARES spectrograph at the TJO (left: being built; right: final setup).

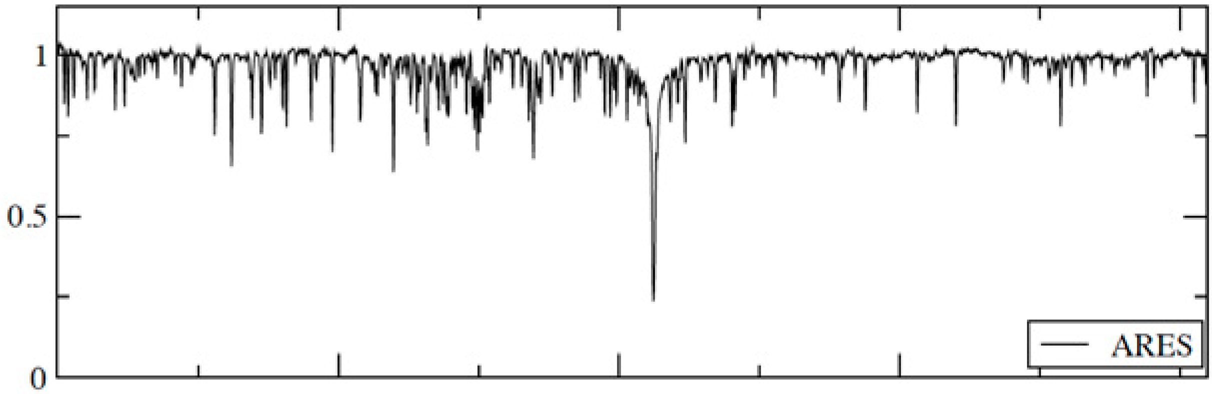


Figure 11: Spectrum of the Moon obtained with ARES.

In summary, with the aluminising of the primary mirror made in June 2018, the beginning of operations of the new wide field camera LAIA in November 2018, and the commissioning of the ARES spectrograph during the second semester of 2018, the Joan Oró Telescope has experienced the most important improvements in its first 10 years of operations.

Ground station for satellite communication, wifi and radiolink

During 2018, a ground-based antenna for communication with low-Earth orbit satellites in the UHF and VHF bands was installed at OAdM. Antenna computing services were also installed in the building of the TJO. In the near future, a S-band antenna will also be added to enhance the communication bandwidth.

In parallel, there have been discussions to provide wifi access to Sant Esteve de la Sarga and other small villages. A new radiolink for the company ENDESA was installed to guarantee a secondary communications system in case of emergency in three hydroelectric generators of the Montsec area.

Figure 12: Left: Ground station antenna. Right: Antenna computing services.

Outreach

During 2018, the web page of OAdM was fully refurbished and integrated into the new IEEC webpage, with improved access, design and visibility. In this context, images obtained with the TJO or news regarding the OAdM were regularly uploaded on the web page and shared with our followers on twitter (@IEEC_space). Outreach activities were also conducted in Sant Esteve de la Sarga to explain the activities carried out at the OAdM. Other outreach activities were also conducted in the context of the recently approved Geoparc Conca de Tremp - Montsec, with the goal of promoting synergies with other facilities of the Montsec area. IEEC also provided support to the Centre d'Observació de l'Univers (COU) for the demonstration they organised to celebrate their 10th anniversary in June 2018. Finally, it must be noted that the OAdM can be visited a Sunday per month from May to September, provided a reservation has previously been made. During 2018, the OAdM was visited by around 150 people.

Facilities And Key Projects

Nanosatellites

Space-based observations have transformed our understanding of Earth, its environment, the Solar System and the Universe at large. In this context, nanosatellites (1-10 kg) are gaining momentum as an important means to address targeted science and private services and public research.

IEEC is promoting this emerging technological area benefiting from the gained know-how and expertise in space in the last two decades and is pushing for partnerships that maximise scientific and commercial applications for Catalan industry and academia. The market of nanosats in Spain, and especially in Catalonia, is still in its beginnings, nonetheless the experience of the IEEC team in space research is at a very high level.

During the past decades, driven by increasingly advanced science questions, space observatories have become more sophisticated and more complex, with costs often growing to billions of euros. Although this kind of ever-more-sophisticated missions will continue into the future, small satellites ranging in mass between 500 kg to 0.1 kg – from microsatellites (10 kg-100 kg), nanosatellites (1-10 kg) and even picosatellites (0.1-1 kg) – are gaining momentum as an additional means to address targeted science questions in a rapid and possibly more affordable manner. Within the category of small satellites, CubeSats have emerged as a space-platform defined in terms of $(10\ cm)^3$-sized units of approximately 1.3 kg each called “U’s”. This modularity allows for greater structures such as 2U, 3U, 4U, 6U or even 12U by attaching them. Historically, CubeSats were developed as training projects to expose students to the challenges of real-world engineering practices and system design. Yet, their use has rapidly spread within academia, industry and government agencies, both nationally and internationally.

The CubeSats are transforming the space industry by providing access to economic or scientific business activities by making traditional applications “more” effective and affordable and generating new opportunities. Due to its relative low cost and economy of scale it is possible to think, for example, in constellations for earth observation of tens of hundreds of small satellites that guarantee continuous coverage all the time.

In the last 15 years, more than 1100 nanosats have been launched into space, but it was not until 2013 that a significant and sustained increase in the number of satellites in orbit (100 u / year) was observed. Currently, there are around 200 nanosats actively operating, of which only 0.5% are 6 units (6U), while the rest are smaller dimensions (1-3U) and, therefore, have a limited number of capabilities. However, the next wave of nanosatellites will be based mainly on 6U and 12U sizes.

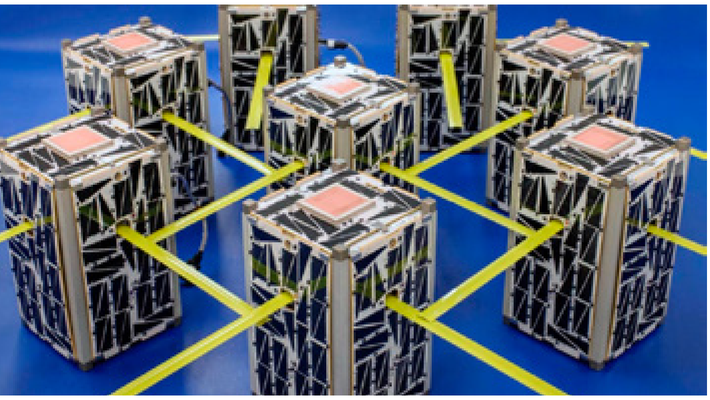


Figure 13: The CubeSat satellite. Credit: NASA.

Cubesats offer a disruptive solution for accessing space. They still have in some cases poorer performance than current solutions (commercial satellites), but performance and capabilities increase at a fast rate and at a low cost by current enabling technologies. However, the actual success rate is lower than 50%. Extreme vacuum conditions, ionising radiation of solar and interspatial origin, and thermal stress experienced by the Cubesats in the space environment make it especially challenging to design and operate them as any other aircraft.

In order to increase this rate, the degree of technical maturity, TRL, has to be improved to make the CubeSats a viable business. To attain a high TRL, the subsystem must be in a flight-ready configuration with all supporting infrastructure such as mounting points, power conversion and control algorithms in an integrated unit.

CubeSats are launched through one of the following four alternatives: obtaining a rideshare or “piggyback” on board a vehicle with an established primary satellite; buying a dedicated small launch vehicle; ridesharing with a group of CubeSats on a “cluster launch”; or being a hosted payload permanently attached to another satellite. As of the end of 2018, most CubeSats were being deployed as secondary payloads on large rockets (piggyback). Rideshares are often challenging for CubeSat operators because they have design constraints due to the “do no harm” requirement for secondary payloads. There are other downsides to ridesharing. CubeSat operators have no control over the orbit, and they have to go where the primary payload is going. Their schedule is also driven by the schedule of the primary payload. This can be cost-effective, but it is also limiting the variety of orbits available for science CubeSats. Moreover, in the next years the demand for CubeSats launches will grow exponentially. However, the growth of primary loads has been more or less stable in the last year and there is not a higher increase planned in the years to come. So there is potential market for launching smaller payloads as CubeSats. Several companies have emerged to offer and develop vehicles for launching smaller payloads such as: PLD space, Virgin Orbit, Rocket Lab or PSLV. As an example of cluster launch, Space X launched 64 nanosatellites using a Falcon 9 rocket on 3 December 2018.

Nanosatellites

Activities related with nanosats carried out at IEEC

Nanosatlab

The new facilities of Nano-Satellite and Payload Laboratory (UPC NanoSat Lab) were inaugurated on 21 November 2018. The lab is located at the Technical University of Catalonia - UPC BarcelonaTech (Campus Nord). It is a cross-departmental initiative belonging to the Barcelona School of Telecommunications Engineering (ETSETB - TelecomBCN) and with the support of IEEC. The lab activities cover, among others, the design and manufacturing of satellite systems including: antennas, communication systems, implementation of communication protocols, solar energy harvesting and management, high-efficiency power supplies, software engineering and programming, embedded computers and microcontrollers, satellite payloads, design methods for reliable and testable systems, and the fundamentals of mission analysis.

The lab's industry-grade equipment allows for the testing and qualifying of nano-satellite systems (up to 6U) in space-like conditions. It has class ISO 7 cleanroom with a thermal-vacuum chamber and vibration shaker table, to simulate the deep space conditions and launching phases. In addition, two ad-hoc ground stations for VHF and UHF bands have been installed at the Montsec Astronomical Observatory to operate the launched missions.

Figure 14: The Nano-Satellite and Payload Laboratory (UPC NanoSat Lab), located at the Technical University of Catalonia - UPC BarcelonaTech (Campus Nord).

Catalan Cubesat Platform

In November 2016, IEEC applied for a grant to the Agaur for the development of a nanosatellite platform in the call "Producte". The project was granted in September 2017, and ran until January 2019. The objectives of the project were to develop a sufficiently versatile HW and SW platform with the capability to be adapted and integrated easily to different missions. During the initial phase of analysis of requirements and specifications it was found that one of the key elements common to any nanosatellite was the on-board computer and the communications system. It was decided, therefore, to develop an on-board computer with sufficient computing power communication bus speed to be able to process information on board and therefore reduce the flow of data to the ground, and a generic reconfigurable communications subsystem (Software Defined Radio) that could allow the implementation of different communication protocols and general purpose receivers as radiometers, GNSS etc. The developed system is modular and scalable, and therefore different types of missions can easily be adapted from a single 1U cubesat, where payloads do not require a great demand for data processing and storage, until missions where large volumes of data are required with high sampling rates (for eg. multispectral sensors, multi-channel GNSS-R receivers, radiometers etc.).

The development of this project requested the participation of 15 researchers and engineers from IEEC at ICCUB, ICE and CTE with different areas of expertise in space subsystems. IEEC collaborated in the organisation of two summer courses related with Nanosatellites. From 10 - 14 July 2017, the ICC-UB organised a summer course on nanosatellites providing a comprehensive introduction to the basic concepts of nanosatellite design and construction with keynotes and workshops given by experts in the field from industry and research centres some of them from IEEC. A new edition of this workshop is scheduled for the summer of 2019. From 17 - 21 July 2018, UPC hosted the Young Professionals in Space (YPC) summer course. More than 100 students from around the world attended the course. It was organised in a boot camp and included keynotes from scientists, practitioners, engineers and leaders of the space industry and agencies. The students learned the key aspects of small satellites by integrating a Cansat during the lab sessions. On the last day, the cansats built by the students were launched with small scale rocket from Alcolea de Cinca, in collaboration with the Spanish branch of Tripoli Rocketry Association.

IEEC participated in the Sonar +D activity by giving a two-hour workshop on nanosatellites. Sonar +D is one of the many activities organised in parallel with the Sonar electronic music festival in Barcelona. The participants in the workshop received a basic kit to assemble a 1:1 scale model of a 1U cubesat and during the workshop they integrated a basic system with an OBC, a display and a communication system to send data from a sensor of temperature and pressure. The launch was simulated by means of a balloon for meteorological sounding.

Ongoing projects

IEEC will actively continue with the nanosat project in 2019. As mentioned before, a ground station for tracking nanosatellites from the Montsec Astronomical Observatory has been installed. In 2019 a new antenna for TM/TC communications in the S band will be installed. IEEC is also studying the integration of this ground station facility in a more broad network of ground stations for global nanosatellite operation.

Continuing with the results of the Catalan Cubesat Platform, IEEC is exploring its use on a future constellation of nanosatellites for IoT with an active role in the definition of the requirements of this constellation and the system engineering needs.

Facilities And Key Projects

The Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA) is the next generation ground-based observatory for gamma-ray astronomy at very-high energies (VHE) (~20 GeV – ~300 TeV). With more than 100 telescopes located in the northern and southern hemispheres, CTA will be the world's largest and most sensitive high-energy gamma-ray observatory, improving by a factor of 10 the sensitivity of current Air Imaging Cherenkov Telescopes (IACT). Together, the northern and southern CTA arrays will constitute the CTA Observatory (CTAO), which will be the first ground-based gamma-ray observatory open to the worldwide astronomical and particle physics communities as a resource for data from unique, high-energy astronomical observations. This is expected to significantly boost the scientific output of CTA by engaging a much wider research community. Additionally, CTA will feed its data into a virtual observatory, which will allow scientists to probe multiple data centres seamlessly and transparently, provide analysis and visualisation tools and give other observatories a standard framework for publishing and delivering services using their data.

A variety of VHE gamma-ray emitters have been already identified, including pulsars, pulsar wind nebulae, binary systems, active galactic nuclei, gamma ray bursts, among others. In addition, CTA will also explore frontiers in physics searching for the nature of Dark Matter and the possible violation of Lorentz Invariance.

IACTs image the very short (between 5 and 20 ns long) and faint flash of Cherenkov radiation generated by the cascade of relativistic charged particles, known as an Extensive Air Shower (EAS), produced when a very-high-energy gamma ray strikes the atmosphere. The total area on the ground illuminated by this flash corresponds to some hundreds of square meters. The Cherenkov light is focused into the telescope camera through highly-reflective mirrors. The camera then captures and converts it into data.

While the northern hemisphere array will be more limited in size and will focus on CTA's low- and mid-energy ranges from 20 GeV to 20 TeV, the southern hemisphere array will span the entire energy range of CTA, covering gamma-ray energies from 20 GeV to 300 TeV. Three classes of telescope will be distributed in the northern and southern hemisphere based on their sensitivity: The Small-Sized Telescope (SST), with a diameter of about 4 m, Medium-Sized Telescope (MST), 12 m diameter, and Large-Sized Telescope (LST), 23 m diameter. Because the SSTs are tuned to be the most sensitive to detect high-energy gamma rays, they are more ideal for the southern site's detection of higher-energy gamma rays, while the MSTs and LSTs will be installed on both sites.

Figure 15 : Northern Hemisphere Site Rendering including the two MAGIC telescopes. Credit: Gabriel Pérez Diaz, IAC, SMM.

CTA was included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) and promoted to a Landmark project in 2018. It is one of the "Magnificent Seven" of the European strategy for astroparticle physics published by ASPERA, and highly ranked in the "strategic plan for European astronomy" (leaflet) of ASTRONET. In addition, CTA is a recommended project for the next decade in the US National Academies of Sciences Decadal Review. Figure 15 shows an artistic view of the Northern array, which is being constructed at the Roque de los Muchachos observatory in the Canary island of La Palma. CTA has come a long way since its conception in 2005 when the Spokespersons of the four running Cherenkov Telescope collaborations (MAGIC, HESS, VERITAS and CANGAROO) met in Heidelberg to try to define the future of the field. According to the current schedule, CTA operations should begin in 2022 and the array construction be finished in 2025. Today, more than 1,420 project participants from 31 countries are engaged in various activities from construction to scientific development of the facility. It is supported financially by the governmental scientific funding agencies of many of these countries, as well as the European Union. Representatives of these agencies form the governing Council of CTAO GmbH. IEEC members at ICE, ICCUB and CERES have been very active in the definition of the concept and in the development of CTA since the very beginning thanks to their participation in MAGIC. Actually, the birth of CTA Consortium took place in a meeting in Barcelona hosted by ICCUB and organised by the three IEEC units involved in CTA (plus IFAE). The main activities of the IEEC members until 2018 are described below.

Physics prospects for CTA

IEEC members have contributed in a significant way to the definition of the CTA Key Science Projects (KSP) made by the CTA Consortium (Science with the Cherenkov Telescope Array, CTA Consortium, Published by World Scientific Publishing Co. Pte. Ltd., ISBN #9789813270091, arxiv:1709.07997). In particular, IEEC members have been co-editors of the book and the chapters on synergies and core-programme overview, as well as co-editors of the Dark Matter Programme and the KSPs on Transients and Cosmic Ray PeVatrons. In this context, IEEC members have contributed to the use cases on transient sources for the CTA Real Time Analysis (RTA) system. Simulations have also been conducted for the CTA studies on binary systems and on prospects for Lorentz Invariance Violation searches.

The Cherenkov Telescope Array

Electronic developments for CTA

IEEC members have designed, produced and tested several Application Specific Integrated Circuits (ASICs) for the pre-amplification and amplification of the signals and for the level 0 trigger system of the Large Size Telescope (LST) and Medium Size Telescope (MST) of CTA. These ASICs will allow for a significantly better performance than available components in the market and with a significantly smaller power consumption and heating. The Pre-Amplifier for CTA (PACTA) is part of the LST1 already installed at ORM, and IEEC signed a contract and, in 2018, it delivered 10.000 PACTA units to the University of Tokyo for the following three LSTs of CTA-North (LST 2-4). The Amplifier for CTA (ACTA) is part of the MSTs that will include the camera developed by the NectarCAM consortium, in particular the first MST prototype, MST1, which is planned to be installed at ORM in the near future. The L0-trigger ASIC is part of LST1 and MST1 prototypes. IEEC members have also designed, produced and tested another ASIC, the Multiple Use SiPM Integrated Circuit (MUSIC), a pre-amplifier to work with Silicon Photo-Multipliers, which might be used for the Small Size Telescopes (SSTs) and/or for future upgrades of LST and MST cameras.

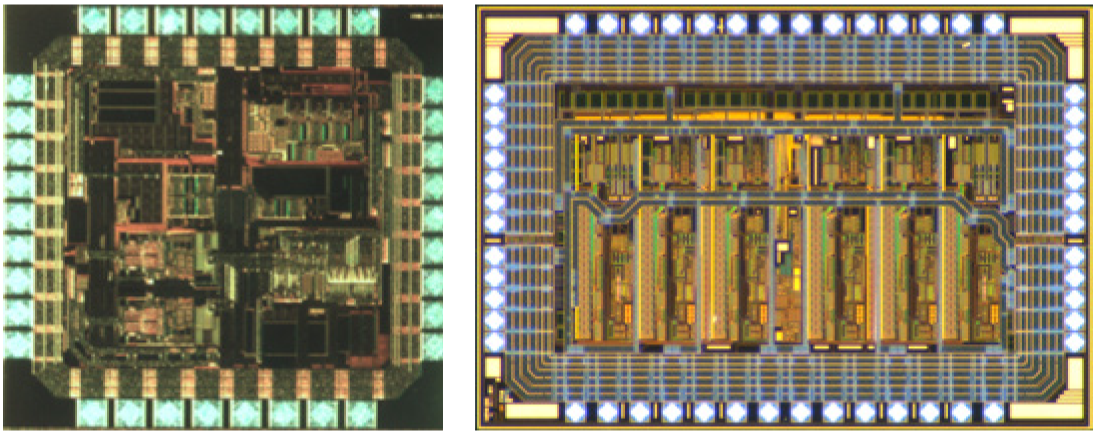


Figure 16: Left: The Pre-Amplifier for CTA, PACTA. Right: The Amplifier for CTA, ACTA.

Figure 17: The Large Size Telescope 1 at Observatorio del Roque de los Muchachos, inaugurated on 10 October 2018.

First Large Size Telescope at ORM

The IEEC members involved in CTA helped the Spanish community to push for the candidacy of La Palma as the host site of CTA-North, which was finally selected. On 10 October 2018 the first prototype of the Large Size Telescope (LST1) was inaugurated at the Observatorio del Roque de los Muchachos. LST1 includes developments by IEEC, in particular electronics and control software. This is a milestone for the CTA project. The commissioning of LST1 started in 2018 and is planned to finish in 2019.

Coordination of CTA Array Calibration and Environmental Monitoring

IEEC members have been coordinating this project since 2013 and participated in coordination meetings with the CTA Observatory and other involved projects on a monthly basis. As part of these duties, IEEC represented CTA in the SUCOSIP, the committee for the study and coordination of the site properties of the two IAC-owned observatories at the Canary Islands of Tenerife and La Palma. An outcome of this work established the potential impact of adaptive optics lasers at large optical telescopes, like the GTC, the TMT or ELT, on CTA.

Weather monitoring system prototype

IEEC members are coordinating weather monitoring activities within the Environmental Monitoring project. In 2018, a collaboration was established between the CERES and ICE groups together with the CTA group of DESY-Zeuthen to design a weather monitoring system prototype that includes an interface to the Telescope Control Unit ACS foreseen for LST1, the first Large Size Telescope that is already being commissioned in La Palma, a prototype stand-alone data acquisition system, and a test bench for prototypes of the CTA monitoring database and of the CTA Graphical User Interfaces.

Commissioning of the CTA Barcelona Raman LIDAR prototype

Also as part of the Environmental Monitoring project, an advanced Raman LIDAR optimised to fulfil the requirements of CTA is being commissioned at the UAB campus. It is a key instrument to obtain the range-resolved and wavelength dependent atmospheric transmission in the line of sight of the telescopes, required to estimate the extinction of the Cherenkov light in its way to the telescope reflector surface. This Raman LIDAR has been designed and built as a collaboration between IEEC members, the IFAE group of CTA and other CTA members from Padova (Italy). It includes very innovative elements as a 1.8 m diameter telescope and 8 mm liquid light guide. In 2018, we started the commissioning phase and demonstrated that the concept works.

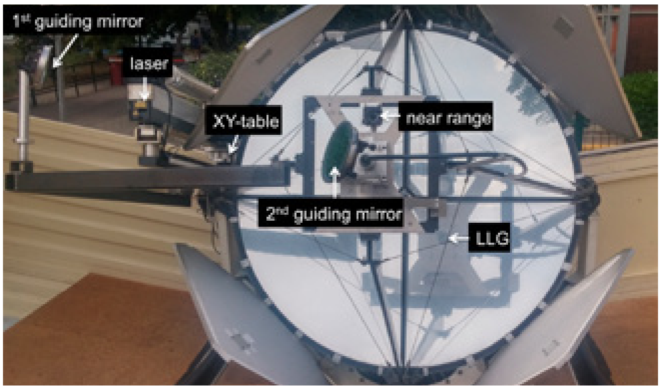


Figure 18: Front view of the Barcelona Raman LIDAR prototype.

The Cherenkov Telescope Array

CTA Scheduler

Scheduling software applications for the operation of telescopes and space missions contribute to improving the scientific and technological exploitation of astronomical facilities. IEEC is playing a leading role in the development of this type of Scheduler software that can be applied to observatories with multiple constraints, including different sites. That allows extending this expertise also to the concept Multi-Facilities Scheduling, which is of extreme relevance in the context of the multiwavelength/multi-messenger era of the large infra-structures foreseen in the next decade. In particular, IEEC is leading the Scheduler software for the CTA observatory in which two sites with multiple subarrays are planned.

The CTA operation and scheduling will be challenging regarding the system complexity (i.e., different operation modes and parallel operation of subsets of telescope or sub-arrays are foreseen) and the required balance between flexibility and rapid response to scientific alerts. A significant fraction of the total available dark time will be filled with proposal-driven observations and all observations will be performed in a largely automatic fashion under the control of a very few professional operators. A software demonstrator for the CTA Scheduler that implements a prototype algorithm and a simulation platform (see the following figure) have been developed. The results obtained with the demonstrator go hand-in-hand with the associated scientific research and are being used in the design of the strategies to maximise the impact CTA will have in relevant areas of high-energy astrophysical research. In addition, the importance of the scheduler that is now considered by the CTA Consortium as a critical building block of the control software layer has been proved.

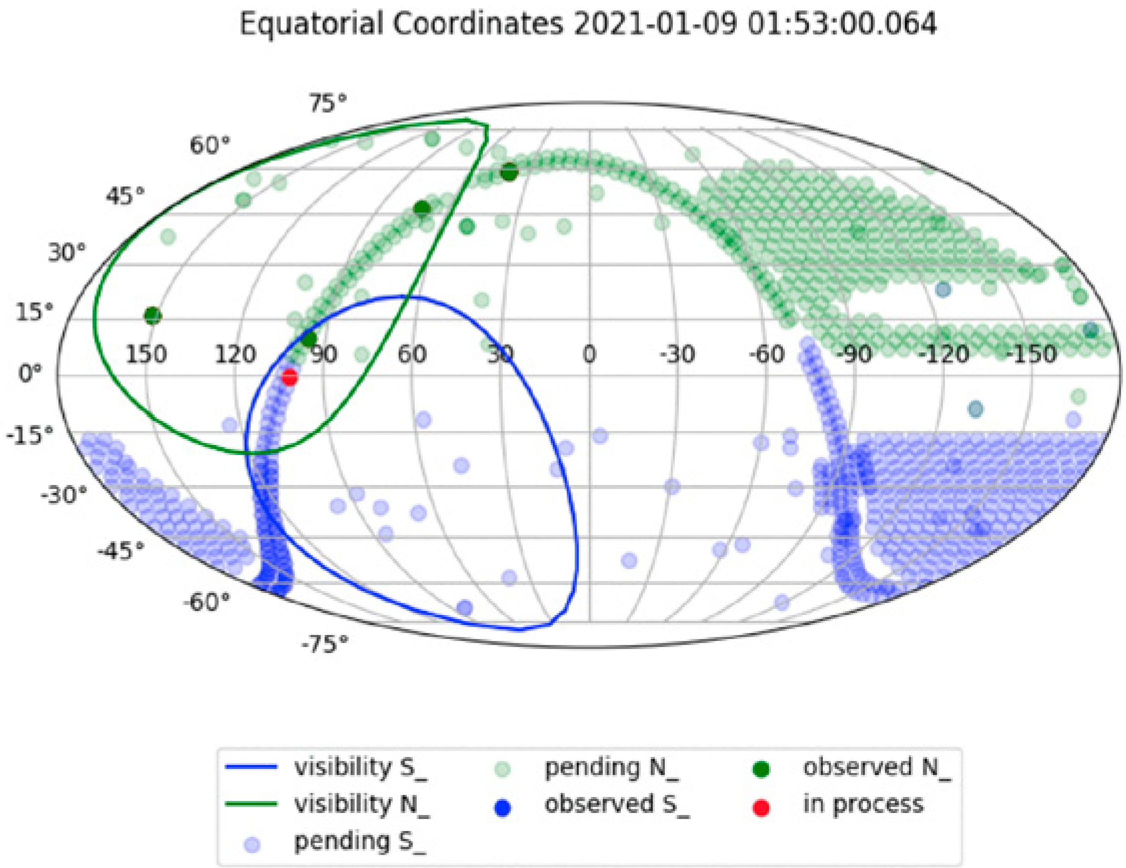


Figure 19: Snapshot of a planned observation (in red) where both sites (CTAN & CTAS) pointed simultaneously. The FoV of each one is marked in green and blue. The observation planned pending and observed are marked in light green and blue bullets respectively.

Facilities And Key Projects

LISA & LISA Pathfinder

The Gravitational Astronomy Group – LISA at ICE carries out its research principally in the field of gravitational wave astronomy. This area emerged in 2015 with the first detection of gravitational waves, which were awarded with the 2017 Nobel Prize in Physics.

The group works mainly at the band of low frequencies (around 1 mHz), where the detection can only be done from space. In this sense, the group leads the Spanish contribution to the LISA (Laser Interferometer Space Antenna) mission and has also led the Spanish contribution to the precursor mission of technological demonstration, LISA Pathfinder. The main activities of the group in these two missions are developed under a National Plan of the Spanish Ministry for Space Research (ESP2017-90084-P on 2018) and the quality group name funded by the Generalitat de Catalunya (SGR-1469).

LISA Pathfinder was a mission of the European Space Agency (ESA) to demonstrate the technology needed to perform Gravitational Wave Astronomy in the low frequency band. It was launched on 3 December 2015 from the Kourou spaceport in French Guiana, and it performed the scientific operations from 1 March 2016 until 30 June 2017. On 18 July 2017, the last command was sent to the spacecraft, disconnecting it permanently after 16 successful months of scientific measures.

Currently, the IEEC-CSIC group continues to work on analysing data from the different experiments of LISA Pathfinder. The mission tried the fundamental concept of gravitational wave detection in flight. It contained two masses of test in free fall with an optical (laser) metrology system that controlled and measured its relative movement with precision without precedents (picometers). LISA Pathfinder used the state-of-the-art technologies to minimise non-gravitational forces that can act on the test masses as well as perform measurements.

Thanks to the great success of the experiments carried out on the LISA Pathfinder mission, on 2 June 2017, the Senior Program Committee (SPC) officially selected LISA as ESA's large class (L-class) third mission, L3, with a launch planned for 2034.

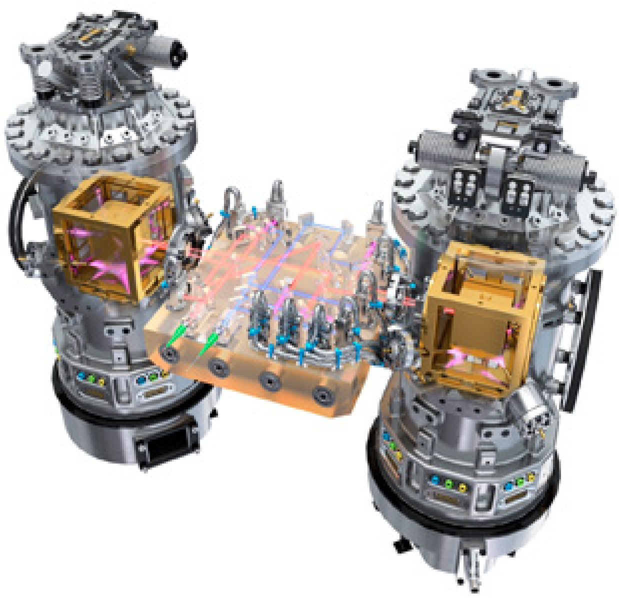


Figure 20: The payload of ESA's LISA Pathfinder mission, the so-called "LISA Technology Package" (LTP), where all scientific experiments of the mission were carried out. Credit: ESA.

LISA consists of a fleet of three satellites that will be located in a separate triangular formation of 2.5 million km and connected by laser beams, following the Earth in its orbit around the Sun. The main objective of LISA is to carry out scientific experiments by means of the low frequency gravitational waves detection from the most extreme phenomena of the Universe, such as the fusion of black holes a million times more massive than the Sun.

Following the successful experience of the LISA Pathfinder mission, the contribution of the IEEC-CSIC group to LISA is the Data and Diagnostic Subsystem. The Data subsystem consists of the mission payload computer along with all the corresponding software. The Diagnostic subsystem consists of a series of sensors and actuators of high precision and stability, together with all the associated electronics, which will provide essential information about the environment of the LISA measurement system. The diagnostics are: thermal (sensors and thermal actuators), magnetic (magnetometers, coils and electromagnetic antenna) and radiation (radiation monitor).

LISA & LISA Pathfinder

On the other hand, the group also works in the so-called land segment of LISA. This includes the development of a mission simulator, analysis algorithms for the future scientific exploitation of LISA data, and the design of a processing centre for this data. On a more theoretical level, the group also works on the description/simulation of LISA's main gravitational wave sources to obtain templates of the gravitational waveforms necessary for the data analysis and the correct estimation of the physical parameters of the sources.

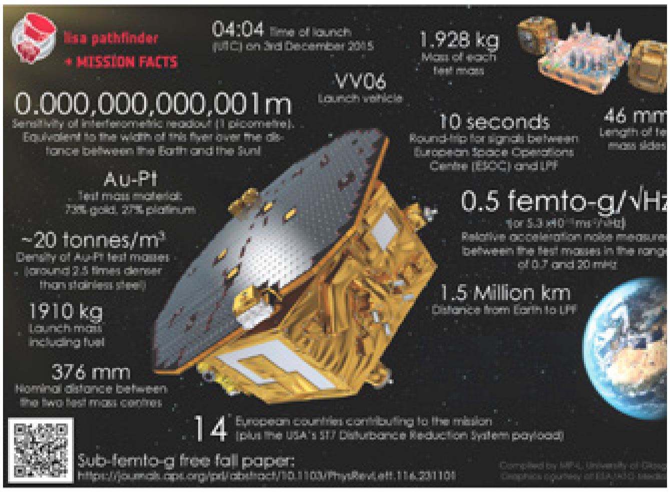


Figure 21: LISA Pathfinder mission infographics showing some important mission data that reflects its uniqueness. Credit: ESA and University of Glasgow (UK).

Finally, the group uses its experience, which covers all the different aspects of Gravitational Wave Astronomy, to participate in other future gravitational wave experiments: third-generation terrestrial detectors, atomic interferometric-based detectors etc. The group will contribute in these infrastructures with their knowledge in experimental techniques of measurement at low frequencies as well as in the theory and analysis of data.

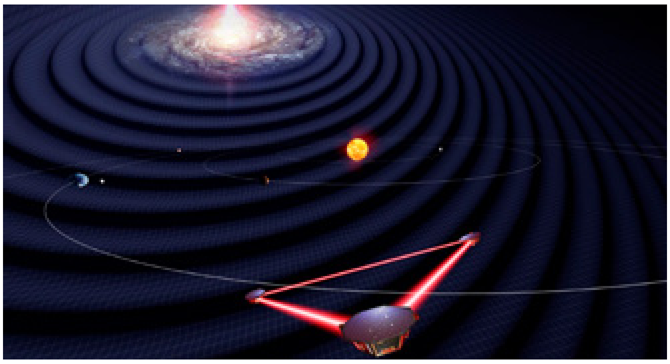


Figure 22: Artistic representation of the LISA mission. A constellation of three spacecraft following a heliocentric orbit around the Sun following the Earth can be seen. At the back, a representation of the emission of gravitational waves by a binary system of supermassive black holes.

During 2018, the group worked in all the areas described above. From the analysis of the experiments of LISA Pathfinder, several papers have been published in international journals, such as the article published by the collaboration LISA Pathfinder, entitled “Beyond the Required LISA Free-Fall Performance: New LISA Pathfinder Results down to 20 mHz,” in the prestigious journal Physical Review Letters. This article explains how after the 2016 tests, where the initial objectives of the mission were already achieved, a series of improvements were implemented; for example, a way to reduce gas pressure around the masses was found, which could otherwise create viscous forces and suppress the effect of the inertial forces derived from the satellite rotation. As a result, compared to the results of 2016, noise was reduced to the differential acceleration in a factor greater than 3 for the frequency range to which LISA will work. The relevance of this result derived on the article been chosen as a “highlighted Letter” by the publisher of the publication (only one out of every six articles in this prestigious journal are chosen as highlighted).

Apart from this very important result, other results were published in 2018 about galactic cosmic ray flow measurements with the radiation monitor of LISA Pathfinder; calibration of the dynamics of the LISA Pathfinder system; precision control of the electrical charge to the isolated masses in free-fall of LISA Pathfinder; the use of the propulsors provided by NASA (the ST7 mission) to LISA Pathfinder etc.

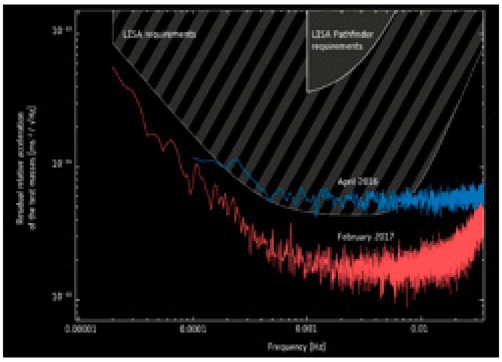


Figure 23: Final results of the LISA Pathfinder mission on the noise level reached in the relative acceleration between the test masses in free fall. The results are much better than the initial requirements of the mission, both in the noise level and in the frequency bandwidth, and even better than the requirements of the LISA mission.

Carlos F. Sopuerta is currently a member of the Board of the Consortium of LISA that organises the contributions of the member states to the useful load of LISA, and Miquel Nofrarias is the “Data and Diagnostics Lead” of the “LISA Instrument Group” (LIG), representing the Spanish contribution to the mission. In addition, Carlos F. Sopuerta is a member of the “LISA Science Study Team” (SST) of ESA and Miquel Nofrarias is “Data and Diagnostics Lead “in the “LISA System Engineering Office” of ESA. These positions have been exercised throughout 2018. Moreover, members of the Gravitational Astronomy Group - LISA participated in different working groups of the LISA Consortium during 2018.

Facilities And Key Projects

ARIEL

ARIEL (Atmospheric Remote-sensing Exoplanet Large-survey) is an ambitious mission planned to answer fundamental questions about how planetary systems form and evolve by investigating the atmospheres of a statistically significant sample of planets orbiting stars other than the Sun. It was selected in March 2018 by the European Space Agency (ESA) for its M4 medium-class science mission, due for launch in mid-2028 by Arianespace's 6-2 variant of its Ariane 6 rocket.

Although we have found thousands of exoplanets, their essential nature remains largely mysterious: there is no known, discernible pattern linking the presence, size or orbital parameters of a planet to the nature of its parent star. We have little idea whether the chemistry of a planet is linked to its formation environment, or whether the type of host star drives the physics and chemistry of the planet's birth and evolution. ARIEL is conceived to observe a large number of transiting planets for statistical understanding, including gas giants, Neptunes, super-Earths and Earth-size planets around a range of host star types using transit spectroscopy in the visible and infrared spectral range and multiple narrow-band photometry in the optical. ARIEL will focus on warm and hot planets to take advantage of their well-mixed atmospheres which should show minimal condensation and sequestration of heavy materials compared to their colder Solar System siblings. Warm and hot atmospheres are expected to be more representative of the planetary bulk composition. Observations of warm/hot exoplanets and in particular of their elemental composition (especially C, O, N, S, Si) will allow the understanding of the early stages of planetary and atmospheric formation during the nebular phase and the following few million years.

The ARIEL payload is a low-resolution (R=100–200) spectrograph and photometer on a 1-m class telescope to cover the visible and infrared spectral range from 0.5 µm to 7.8 µm. This wavelength range covers all the expected major atmospheric gases from for e.g. H_2O, CO_2, CH_4 NH_3, HCN, H_2S through to the more exotic metallic compounds, such as TiO, VO and condensed species. ARIEL will provide a representative picture of the chemical nature of exoplanets and relate this directly to the type and chemical environment of the host star. While some of the planets observed may be habitable, the main focus of the mission will be on exotic, hot, giant and Neptune-size planets in orbits very close to their star.

ARIEL is designed as a dedicated survey mission for combined-light spectroscopy, capable of observing a large and well-defined 1000-planet sample within its 3.5-year mission lifetime. Transit, eclipse and phase-curve spectroscopy methods, whereby the signal from the star and planet are differentiated using knowledge of the planetary ephemerides, allow us to measure atmospheric signals from the planet at levels of 10–100 part-per-million (ppm) relative to the star and, given the bright nature of targets, also allows more sophisticated techniques, such as eclipse mapping, to give a deeper insight into the nature of the atmosphere. These types of observations require a stable payload and satellite platform with broad, instantaneous wavelength coverage to detect many molecular species, probe the thermal structure, identify clouds and monitor the stellar activity. The spacecraft will be placed in orbit at Lagrange Point 2 (L2) of the Sun-Earth system, a gravitational balance point beyond the Earth's orbit, where the spacecraft is shielded from the Sun and has a clear view of the whole night sky. This will maximise its options for observing exoplanets discovered previously by other missions.

The ARIEL mission concept is developed by a consortium of more than 70 institutes from 17 countries. IEEC is one of the co-PI institutes (co-PI: Ribas) and leads the Spanish contribution (PI: Ribas; National Project Manager: Colomé), which also includes the Instituto de Astrofísica de Canarias and the Universidad Politécnica de Madrid. IEEC, through groups at the CSIC and the UB, participates in various aspects of the mission, as shown in the figure below regarding the technical involvement.

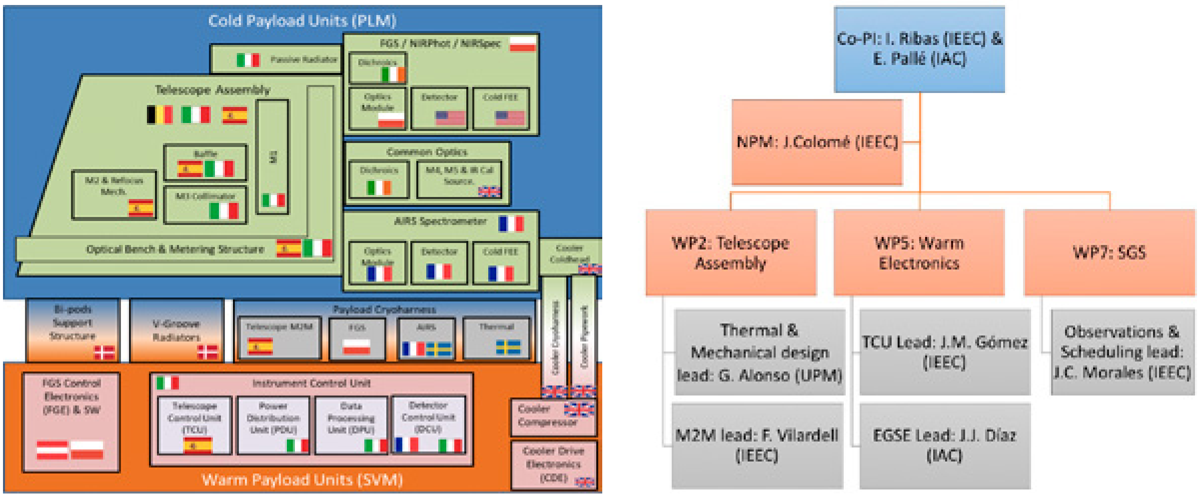


Figure 24: Left: ARIEL Payload Hardware block diagram. Right: Structure of the ARIEL Spanish responsibilities.

ARIEL

IEEC is responsible for the design, implementation, assembly and verification of the Telescope Control Unit (TCU). The TCU performs the thermal monitoring and control of the telescope and payload module, and the control of the IR calibration lamp. It also controls the M2 refocusing mechanism under operation from the ground. This may be a stand-alone unit, although it is to be studied further during the assessment phase. It will also implement command handling, data formatting and the communication to the spacecraft. IEEC is using the expertise gained in previous missions (Solar Orbiter and LISA Pathfinder) on the development of flight electronics and software to contribute to the consolidation of the requirements and the evolution of the design. IEEC is also responsible for the design and manufacture of the mechanisms of the secondary mirror (M2M) refocusing system. The M2 re-focusing system is necessary to ensure that the telescope is in best focus and meets wave-front error requirements when in operations and it is located on the M2 mirror. This telescope component is very close, both at logical and physical levels, to the warm electronics and software of the TCU and, therefore, lending IEEC responsibility on a critical part of the ARIEL payload, from the electro-mechanics to the software logics. Furthermore, IEEC leads the mission planning task by using our expertise on scheduling techniques to optimise operations and study the impact of mission design requirements. This is a key building block of the Science Operations Assumptions Document (SOAD) and is the basis to define the Science Ground Segment of the mission.

The selection of the mission in 2018 has given way to the start of Phase B1, which will culminate in 2020 with the Mission Adoption Review (MAR) and the subsequent adoption of the mission by the ESA Space Programme Committee. During this phase, Technology Readiness Level (TRL) 6 must be achieved by all subsystems and in particular the M2M system, which will require greater development activity. Therefore, the main technological tasks during 2018 were focussed on the study and design of the engineering solutions that the mission will have to implement. For example, the following figure illustrates the proposed design of the TCU made at IEEC. A first proof of concept was designed to check the initial approach to the thermal measurement. It is based on an architecture that uses a current source, instead of a classical approach based on half-bridge or full-bridge. The results are promising. This solution shall now be upgraded to work with 46 thermistors (+ 46 redundant) and the different characteristics between them: Cernox-1050 for precise readings and DT-670 silicon diodes for thermal housekeeping.

With regards to mission planning, over the course of 2018 we have been undertaking an exhaustive mission performance analysis using Artificial Intelligence technologies (i.e., Evolutionary Algorithms) with the goal of optimising the observations and sample selection.

The science work package structure of ARIEL was redefined in 2018 and it is leading the Stellar Activity WP, as well as participating in the Ephemeris WP. The main scientific tasks during the year have focused on studying the effects of stellar activity on transit spectroscopy, due to the spectrophotometric variability caused by starspots, and on collaborating in the selection of the target sample.

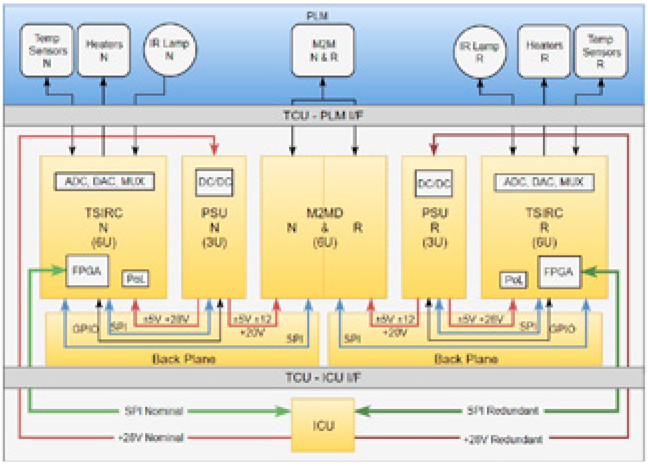


Figure 25: ARIEL TCU system block diagramsystem block diagram.

An analysis has been performed on the need to acquire contemporaneous multi-band photometry together with the ARIEL observations to better characterise stellar variability and thus be able to correct out the effects on the acquired spectra. The results obtained so far are very encouraging so they can demonstrate a mitigation of the activity signal by a factor of 20-30 from the visible to the near infrared.

This is possible by reconstructing the stellar surface for each epoch where a transit event occurs and then subtracting the effect from occulted and unocculted starspots. Using the StarSim 2.0 tool, developed in house, to perform the inversion of the light curves. The methodology is illustrated in Figure 26. Further investigation along this line is warranted, with the main goal of reaching the required level of precision of 10-100 parts-per-million for most of the ARIEL 1000-planet sample.

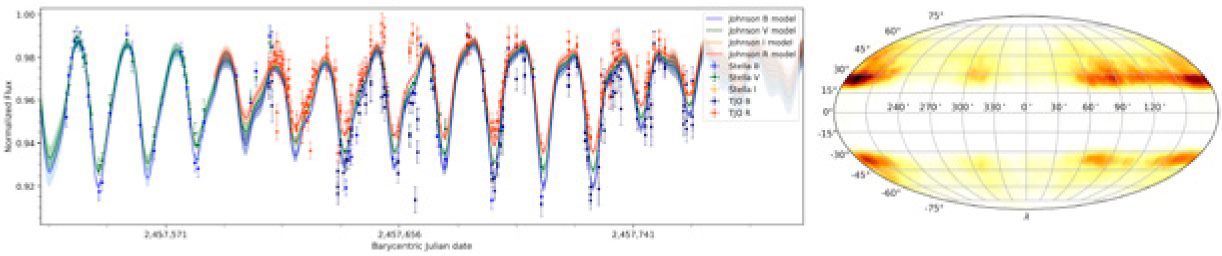


Figure 26: Reconstruction of the surface of transiting planet host WASP-52 using multi-band photometry and the StarSim 2.0 algorithm.

Knowledge Transfer & Innovation

One of the main missions of IEEC is the transfer of the generated knowledge and space technologies to industry and investors, in order to achieve great impact and benefit for the institute, companies and society. The institute has an important technological development from its scientific production of excellence, structured in four scientific-technological units able to raise challenges in the knowledge frontier, and led by a highly competitive team in space science and instrumentation with a high degree of internationalisation.

This great complementarity between the scientific and technological fields is based on the fact that space is not just a research object in itself, but also a means to pave the way for new methodologies and technologies to generate knowledge. Research in the space science field has historically – especially over the last few decades – caused a transformation of the world we live in.

The activity in the technological area is also developed from joint projects with companies in the aerospace and Information and communications technology business.

Success innovation cases

High-performance on-board computer, data handling and SDR platform for nano-satellites

Built upon the successful expertise of LISA Pathfinder, the 3Cat series cubesats (from UPC NanoSat Lab), Solar Orbiter and Gaia, IEEC has developed a high-performance platform for cubesats with multipurpose uses that can be adapted to different commercial and scientific purposes.

The platform provides a robust on-board computer with redundancy to control the spacecraft state and telecommands, a versatile software-defined radio based on a high end FPGA SoC providing high-speed downlink capabilities, a powerful on-board data handling system, and an efficient on-ground telecommand and basic data handling framework.

This solution will push the nanosat concept to its limits, allowing to achieve performances for which larger-sized missions would be required otherwise.

Agència de Gestió d'Ajuts Universitaris i de Recerca AGAUR | Generalitat de Catalunya | UNIÓ EUROPEA Fons Europeu de Desenvolupament Regional

This work was funded by the the Agència de Gestió d'Ajuts Universitaris i de Recerca of the Generalitat de Catalunya through project 2016 PROD 00076 , including European Regional Development Funds.

Satellite tracking data with the TJO robotic telescope at the OAdM

The TJO robotic telescope at the OAdM is performing satellite tracking services since 2014. These activities are done in the framework of the EU Horizon 2020 programmes and through agreements with the Spanish CDTI institution that is the country node of the European Space Surveillance and Tracking (EUSST) Consortium. IEEC carried out daily based observations in 2018 that were devoted to contribute with satellite tracking data, and implemented several upgrades to the TJO infrastructure to improve the performance of the system for satellite data extraction. In particular, the main instrument camera upgrade was completed in 2018.

Success innovation cases

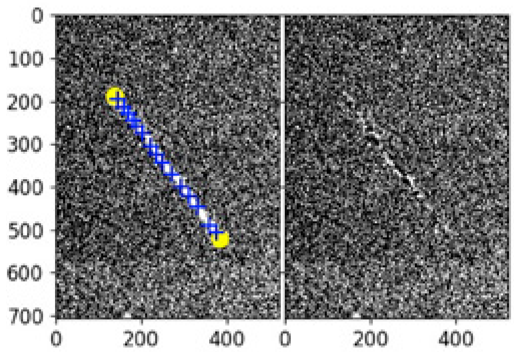


Figure 27: Detection and measurement of an artificial satellite with LAIA imager at the TJO.

This work was funded with funding from the European Union's Copernicus and Galileo programmes under grant agreement 237/G/GRO/COPE/16/8935 and from the European Union's Horizon 2020 research and innovation programme under grant agreement No 713762.

Low-Complexity Near-Lossless Multispectral & Hyperspectral Data Compression

The Consultative Committee for Space Data Systems (CCSDS) is an international organisation for the development of communications and data systems standards for spaceflight. The Space Link Services Area within CCSDS is in charge of developing efficient space link communications systems. CERES contributed to the definition of the recent standard CCSDS 123.0-B-2, Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression. Blue Book. Issue 2. February 2019.

This work was funded by the French Space Agency (Centre National d'Etudes Spatiales) under a knowledge transfer contract.

High-Speed Integrated Satellite Data Systems For Leading EU Industry

This project aims to develop and validate innovative technologies to significantly improve space on-board data handling and transfer capabilities, primarily for Earth Observation and partly also for Telecom future missions. These activities are done in the framework of the EU Horizon 2020 programme. CERES contributed with the development of an open source implementation of the recent standard CCSDS 123.0-B-2, Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression.

This work was funded by the European Commission's Horizon 2020 research and innovation programme under grant agreement No 776151.

Image Coding for Earth Observation Satellites

This project aims to develop and validate innovative technologies to improve the capacity for downloading Earth Observation data from satellites, partly through the exploitation of the temporal redundancy in addition to the spectral redundancy. CERES contributed by defining novel source coding (data compression) techniques to increase the transmission efficiency.

This work was funded by the former Spanish Ministry of Economy and Competitiveness and by the European Regional Development Fund under grant agreement TIN2015-71126-R.

HANSEL – Navigation and GNSS in Smart Cities

The objective of this project is to develop an experimental platform to showcase the potential of future navigation and positioning services in the context of Smart Cities. One of the key elements of the platform is the remote processing of 5G/GNSS signals, which enables the deployment of ultra-low power positioning devices, remote signal authentication as well as the exploitation of crowdsourcing data for interference detection/localisation and signal quality monitoring.

This project carried out at CERES is funded by the European Space Agency under contract AO/1-9494/18/NL/CRS.

GINTO5G – GNSS Integration into 5G Wireless Networks

This project carried out at CERES explores the synergies between GNSS and 5G technologies with a twofold objective: first, to provide high-accuracy positioning for demanding applications such as autonomous driving and UAVs; second, to provide ultra-low power positioning for emerging IoT applications. In order to achieve these objectives, a software platform has been developed for the performance and coverage analysis of GNSS/5G signals. The results are backed by an extensive experimentation campaign and contributions to the 5G standardisation groups have been presented.

This project is funded by the European Space Agency under contract AO/1-9045/17/NL/AS.

Knowledge Transfer & Innovation

EGNOS v3 NLES LLA

This project addresses the design, simulation and implementation of the long loop algorithm (LLA) in charge of steering the EGNOS v3 signal generated at the NLES ground stations and broadcast by a set of geostationary satellites. By properly steering this signal on ground, the uplink hardware and propagation effects can be compensated so that the broadcast signal actually received by the EGNOS users appears as it had been generated on-board of the satellites. This allows EGNOS v3 signals to be processed straightaway by GNSS receivers, as if they were conventional GNSS signals subject to the same propagation effects.

This project is carried out at CERES and is funded by the European Space Agency with Airbus as prime contractor and Indra as the NLES subcontractor.

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GNSS-R ocean altimetry performance software simulator

Since 2016, ICE and the Shanghai Spaceflight Institute of Tracking, Telemetry, Control and Telecommunication (TT&CT) have maintained a cooperation programme, focused on advancing GNSS-Reflectometry (GNSS-R) scientific research and technological developments.

TT&CT leads the development of the Chinese FY meteorological satellites series, and it is planning to built a GNSS-R spaceborne mission for ocean altimetry applications. This cooperation has led to an international technology transfer contract, in which ICE has designed, developed and delivered an GNSS-R ocean altimetry performance software simulator for the definition of the TT&CT's GNSS-R mission.

Figure 28: ICE and the Shanghai Spaceflight Institute of Tracking, Telemetry, Control and Telecommunication (TT&CT) have maintained a cooperation programme since 2016.

10,000 purpose-designed integrated circuits for the Cherenkov Telescope Array

ICCUB has delivered to Tokyo University more than 10,000 ASICs to equip the cameras of 3 Large Size Telescopes of the Cherenkov Telescope Array (CTA). These ASICs, called PACTA, were chosen among different prototypes to become a common component for both the Large Size Telescopes (LSTs) and the Medium Size Telescopes (MSTs). The ASICs have been designed, produced and tested in-house. The quality control of the chips produced, performed by a robotic system, showed an excellent yield: above 99% of the ASICs fulfilled all requirements.

This work was funded by the Tokyo University (Japan) under a transference contract signed by IEEC.

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Contact person: kto@ieec.cat

ASTERICS

The Astronomy ESFRI & Research Infrastructure Cluster (ASTERICS) network is a collaborative project in astronomy and astroparticle physics. Its main goals are to jointly work on common solutions for shared challenges by different research infrastructures, share and expand knowledge, experience and developments to advance innovation and science, and collaborate to make exchanges among people and instruments, as well as to create the right conditions for multi-messenger astrophysics.

The work is done in the context of the European Strategy Forum for Research Infrastructures (ESFRI) research infrastructures and other related infrastructures in astronomy and astroparticle physics. The mission of ESFRI is to support a coherent and strategy-led approach to policy-making on research infrastructures in Europe, and to facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level. An ESFRI research infrastructure is a facility, resource or service with the unique ability to conduct top-level research activities.

The objective of ASTERICS is to help Europe's world-leading observatories work together to find common solutions to their Big Data challenges, their interoperability and scheduling, and their data access. Efficient planning of the observations, data access, interoperability with other astronomical resources and archives, and knowledge extraction from observations are just some of these challenges.
The facilities supported by the ASTERICS programme include the Square Kilometre Array (SKA), a radio telescope currently being built at two locations in Australia and South Africa, as well as precursor/pathfinder experiments. Also the Cherenkov Telescope Array (CTA), the first high-energy gamma-ray world-wide observatory, comprising two large arrays of Cherenkov telescopes in the two hemispheres.

Other involved facilities are KM3NeT, a telescope at the bottom of the Mediterranean Sea aiming to detect ghostly neutrino particles from space; or the Extremely Large Telescope (ELT), an optical and infrared telescope currently being built by ESO in Chile.

Other facilities benefitting from ASTERICS support include forthcoming experiments such as the Einstein gravitational-wave Telescope (ET), the Euclid Space Telescope and the Large Synoptic Survey Telescope (LSST), and current facilities such as the Low Frequency Array (LOFAR), the High Energy Stereoscopic System (H.E.S.S.), Major Atmospheric Gamma Imaging Cherenkov (MAGIC), the gravitational-wave detector Advanced Virgo and the European Very Large Baseline Interferometry Network (EVN).

The project is led by the Netherlands institute for radio astronomy ASTRON, with a consortium of 22 European partner institutions, including ICE. The funding was made through the European Union's Horizon 2020 Framework Programme, which is the biggest EU Research and Innovation programme ever with nearly 80 EUR million of funding over 7 years (2014 to 2020).

ICE is leading the scheduling of the algorithms for large and distributed infrastructures (sub-arrays, multiple sites etc.) as well as the coordination of multi-facility to conduct multi-messenger science. In multi-messenger astrophysics, multiple facilities observe target objects using different messengers and wavelengths to obtain a more comprehensive picture of events. Hence, it is important to schedule the observations carefully in order to make efficient use of the assets and maximise their time on-source. Many factors must be taken into account, such as the weather, instrument availability and target visibility at each facility. Data access policies and the provision of platforms to enable schedule sharing and optimisation also need to be considered.

Using CTA and SKA, an algorithm for scheduling pre-planned coordinated observations has been developed. This algorithm has been extended to enable quick follow-up campaigns after transient alerts. A team of developers worked closely together with end users in a Scrum framework to develop software that allows the LOw Frequency ARray (LOFAR) telescope to respond rapidly to external triggers from other instruments. LOFAR can now start conducting observations within 5 minutes of receiving an alert. After receiving an alert, researchers can use the full capabilities of the LOFAR array. They search for bright, low frequency radio flashes from transients such as neutron star mergers and fast radio bursts. After a transient event researchers make a snapshot image of the region from which the gravitational wave source is thought to originate and search for new sources appearing in the images. In the future, the newly commissioned rapid response mode for LOFAR will be used to search for a bright radio flash at the time of the merger.

Within the network, the following events were organised during 2018:

- First Policy Forum, 17 - 18 January 2018, Nice, France;
- Second ASTERICS Citizen Science Workshop, 22 - 24 January 2018, Trieste, Italy;
- ASTERICS ALL-HANDS meeting, 14 - 15 March 2018, Amsterdam, The Netherlands;
- Fourth ASTERICS Technology Forum, 16 - 17 April 2018, Edinburgh, United Kingdom;
- Second ASTERICS-OBELICS International School, 04 - 08 June 2018, Annecy, France;
- Second European Data Provider Forum and Training Event, 27 - 28 June 2018, Heidelberg, Germany;
- Third ASTERICS-OBELICS Workshop, 23 - 26 October 2018, Cambridge, United Kingdom;
- Fourth ASTERICS Virtual Observatory School, 20 - 22 November 2018, Strasbourg, France.

Figure 29: ASTERICS helps Europe's world-leading observatories work together to find common solutions to their Big Data challenges, their interoperability and scheduling, and their data access. Credit: ASTERICS.

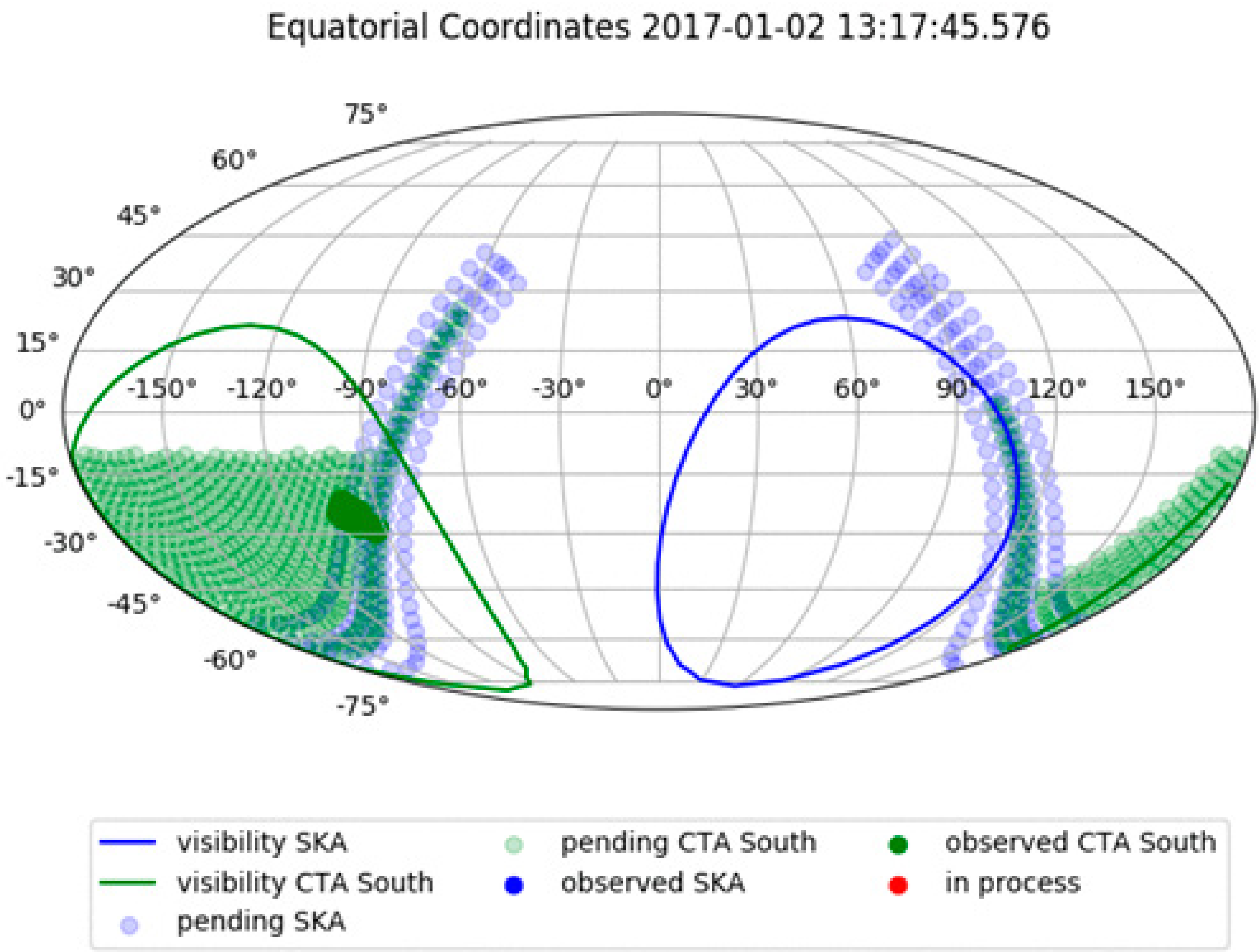

Figure 30: Example of possible schedule combining SKA and CTA South arrays. Credit: Josep Colomé (ICE) and Alan Bridger (UK Astronomy Technology Centre).

PHAROS

The multi-messenger Physics and Astrophysics of Neutron Stars (PHAROS) network is an ESF-COST Action lasting four years (autumn 2017-2021) aimed at studying neutron stars via a multi-disciplinary approach. The recent discovery of gravitational waves will allow in the following years an unprecedented view of previously invisible parts of the Universe. This will unravel the physics of the most compact stars, neutron stars, which are unique objects whose emission encompasses all the available multi-messenger tracers: electromagnetic waves, cosmic rays, neutrinos and gravitational waves. These relativistic stars are also unique laboratories where not only the most extreme gravity and electromagnetism can be probed, but also the strong and weak interaction can be studied in regimes that have no hope of being explored on Earth. The study of these objects transcends the traditional astrophysical approach and requires a multidisciplinary effort that spans from particle and nuclear physics to astrophysics, from experiment to theory, from gravitational waves to the electromagnetic spectrum.

This COST Action is led by ICE and comprises 109 proposers from 30 different countries. It has the ambitious goal of tackling key challenges in the physics involved in neutron stars by facing them via an innovative, problem-based approach, that hinges on focused, interdisciplinary working groups. Each group will have all the diversified expertise needed to tackle different open aspects of the physics of neutron stars, and will provide to the different communities several tools and deliverables prepared in a shared language, and of easy access for scientists coming from different physics, ranging, for example, from nuclear physics to radio astronomy. Furthermore, a key priority of this action is promoting enthusiastic students and young researchers from all over Europe via training, mobility, equal opportunity and outreach activities, which will grow and spread the Action’s innovative multi-disciplinary approach. Collaboration is an indispensable feature of high-quality and innovative research, and the deeper we dive into specific exciting and complex fields, the more the need of brainpower and resources from complementary kinds of expertise is of crucial importance.

The management of PHAROS, in accordance with the COST rules, is based on the election of an Action Chair (AC) and Vice-Chair (AVC), and of a Management Committee (MC) that will oversee all the activities of the Action. To facilitate the flexibility of the decision making tree, a Core Group was elected in the first Action meeting, which encompasses the Action Chair and Vice-Chair, the Working Group Leaders, and other key roles in the Action planning.

Two members of IEEC at ICE have important roles within this network. Nanda Rea has been elected as Action Chair of Pharos and Laura Tolos is the Working Leader of Working Group 1, whose scientific aim is to establish the Equation of State of dense matter.

Short Term Scientific Missions (STSM) are planned within the network, representing a great opportunity for all scientists to exchange visits, nurture collaborations, or develop new ones. STSMs are aimed at fostering collaboration, sharing new techniques and infrastructure that may not be available in other participants' institutions or laboratories.

Within the network, the following events were organised during 2018:

- Neutron Stars: towards a general view (WG5 meeting), 19 - 21 March 2018, Rome, Italy;
- Superfluids and superconductors in neutron stars: from the laboratory to astrophysical observations (WG2 meeting), 9 - 11 April 2018, Warsaw, Poland;
- Modified gravity and neutron stars (WG3 meeting), 10 - 12 April 2018, Barcelona, Spain;
- Neutron Stars in Lisbon (WG1+WG3 meeting), 12 - 13 April 2018, Lisbon, Portugal;
- European Pulsar Timing Array meeting (WG2+WG3+WG4 meeting), 18 - 20 April 2018, Norwich, United Kingdom;
- Neutron star EoS and superconductivity (WG1+WG2 meeting), 26 - 28 September, 2018, Coimbra, Portugal;
- Magnetic field formation and evolution in neutron stars (WG4+WG5 meeting) Mid-November 2018, Saclay, France;
- NS merger training workshop (WG3+WG5 meeting), 12 - 16 November 2018, Bertinoro, Italy.

The disk of our Galaxy is recovering from a past perturbation

The Gaia data reveal new shapes in the positions and velocities of the stars in the disk, which indicates that the disk has experienced a strong gravitational perturbation from which it is still recovering.

Most of the stars in our Galaxy including our Sun, move in a disk-like component and give the Milky Way its characteristic appearance on the night sky. As in all fields in science, motions can be used to reveal the underlying forces, and in the case of disk stars they provide important diagnostics on the structure and history of the Galaxy. But because of the challenges involved in measuring stellar motions, samples have so far remained limited in their number of stars, precision and spatial extent.

This has changed impressively with the second Data Release of the Gaia mission which became available in April 2018. In a work led by IEEC researcher at ICCUB Teresa Antoja, by exploring the phase space (positions and velocities) of the stars in the disk measured by Gaia, researchers have discovered special structures and shapes. The most outstanding is a spiral shape in the diagram combining the vertical position and vertical velocity of the stars. These structures were not observed before and not even predicted by contemporary models.

While the first impression of the authors was to think that there could be a problem in the data or in the calculation of the velocities from the Gaia measurements, they soon came to the conclusion that the features were real and were indicating that something special had occurred to our Galaxy.

A first modelling with basic laws of Galactic dynamics told them that the new structures indicate that the disk is recovering from an out of equilibrium state. A disk in equilibrium would show a smooth phase space distribution but, instead, they find these clear shapes standing out. These could be explained if a perturbation strongly affected the orbits of the disk stars: when the perturbation finishes, the orbits of stars have to return to their equilibrium state and in this process (“phase-mixing”) a spiral shape appears in the vertical position-velocity plot, which curls more and more with time, eventually disappearing when the orbits reach equilibrium again.

The analysis of the degree of curling of the spiral leads the authors to infer that the disk was perturbed between 300 and 900 Myr ago. Very interestingly, this time matches current estimations of the previous pericentric passage of the Sagittarius dwarf galaxy, where this dwarf was closest to our Galaxy and could have had the strongest effects on the disk. The gravitational impact of the Sagittarius dwarf galaxy is, therefore, the main suspect.

There are several far-reaching implications of this work. The findings challenge the most basic premise of stellar dynamics of dynamical equilibrium, and show that modelling the Galactic disk as a time-independent axisymmetric component, although being common practise, is definitely incorrect. It seems to be a very responsive and time-varying disk. This discovery marks the start of a new era when, by modelling the richness of phase space substructures, it is possible to determine the gravitational potential of the Galaxy, its time evolution and the characteristics of the perturbers that have most influenced our home in the Universe.

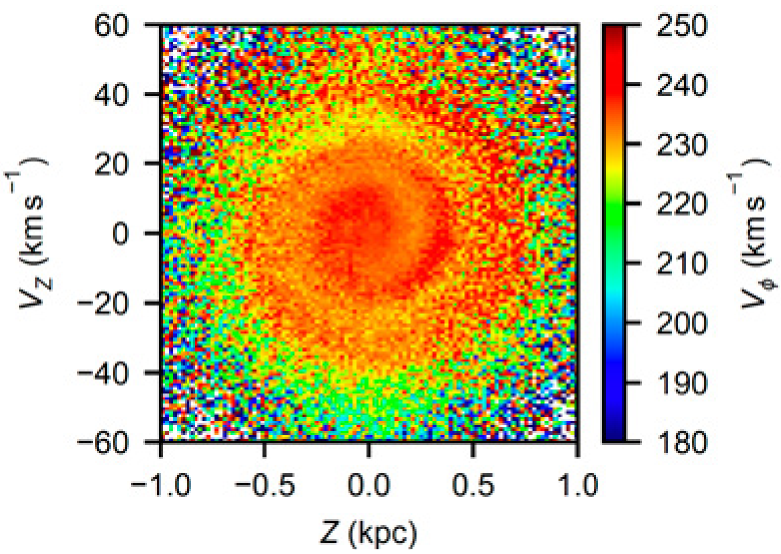

Figure 31: Spiral shape revealed in the diagram combining the vertical positions of the stars in the disk (Z) and their vertical velocity (VZ) when colour-coded as a function of their rotation velocity (Vϕ). The data was obtained from the Gaia mission. A clear spiral shape shows up, which indicates that the disk of our Galaxy is strongly responding to a perturbation. Credit: Antoja et al., 562, Nature, 2018.

Contact person:

ICCUB
Teresa Antoja, Research Fellow
tantoja@ieec.cat

Launch of ³Cat-1

The CubeCat-1 nanosatellite, developed by a team of students led by the IEEC researcher at CTE Adriano Camps, was successfully launched on 29 November 2018, at 5:28 AM (CET), with six experiments on board. The launch was carried out from the Sriharikota space base, India.

The definitive launch of the CubeCat-1 has been achieved four and a half years after the scheduled date. Several setbacks with previous launchers had prevented it to be launched before: the war between Russia and Ukraine in 2014 and the explosion of a Falcon 9 in flight in 2015 forced the team to look for another alternative. Finally, the launch of the small satellite was made with the Polar Satellite Launch Vehicle shuttle (PSLV-C43), which took off from the Satish Dhawan Space Center, in the town of Sriharikota, India, carrying on board the HysIS satellite and about thirty nanosatellites from eight different countries. CubeCat-1 was the only Spanish nanosat that traveled on this shuttle.

After performing the tasks of tuning into orbit, the satellite was finally ready to start the different experiments focused on Earth observation and validation of space technologies on 3 December 2018. The monitoring of the CubeCat-1 is carried out by the Nanosat Lab (UPC) team from the communications station located at the IEEC Montsec Astronomical Observatory (Sant Esteve de la Sarga, Lleida).

The CubeCat-1 has six different payloads to validate or test different technologies in space:

- A graphene transistor developed by the Royal Institute of Technology (KTH) of Stockholm, Sweden, will be tested to study the effect of space conditions (radiation and thermal cycling) in its behavior;
- A COTS (Commercial Of The Shelf) Geiger counter to study the effect of highly charged energetic particles and the impact of radiation on the other experiments on board the nanosatellite;
- A resonant microelectromechanical system that will serve to measure, for the first time in situ, how monatomic oxygen attacks a polymer of interest in electronic applications; this experiment is important since monatomic oxygen is very reactive and is present in low altitude orbit;.
- An experimental new energy harvesting beacon created in the Nanosat Lab based on high efficiency Peltier cells that will send a short beacon using only the harvested energy;
- A wireless energy transfer experiment to study the impact of charged particles on the power transmission between to small antennas separated a few centimeters;
- A low resolution camera that will allow you to take pictures of Earth from space.

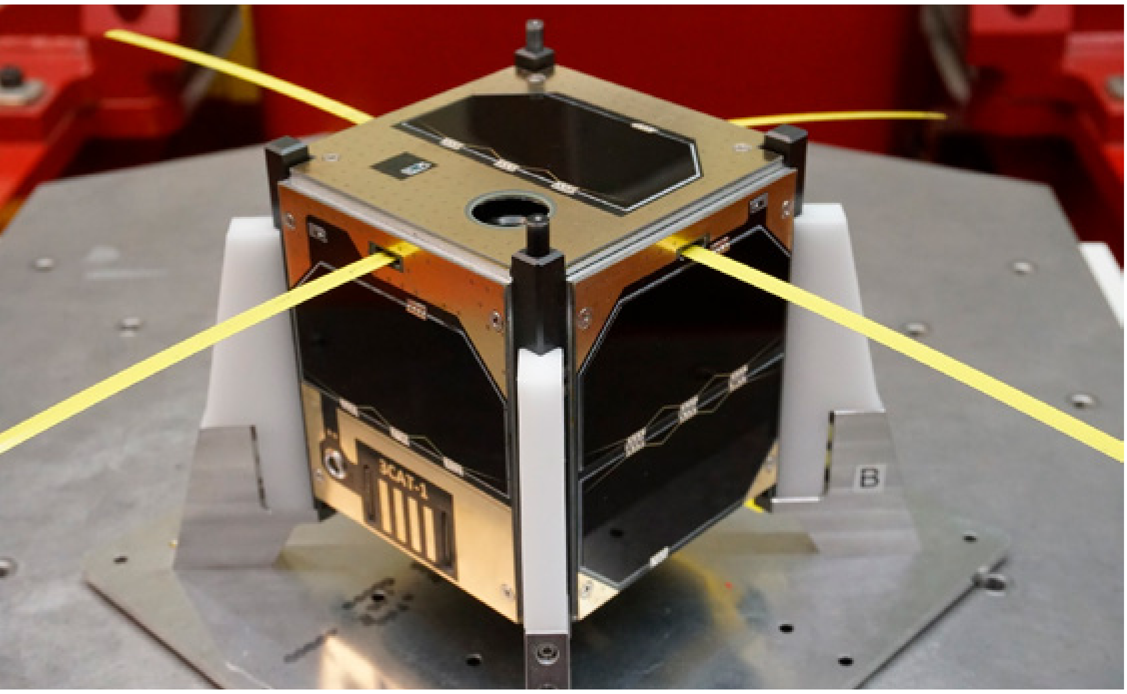

Figure 32: Image of the CubeCat-1 with the communication antennas deployed before integration in the deploying box before launching. Credit: UPC-NanoSat Lab.

Contact person:
CTE
Adriano Camps, Faculty
camps@ieec.cat

Spaceborne experiment ROHP-PAZ successfully launched in 2018

The ROHP experiment, aboard the PAZ satellite, aims to prove a new measurement concept conceived at IEEC.

The first months of data confirm the experiment hypothesis, making this sensor the only one with the capacity to resolve coincident atmospheric thermodynamic profiles and heavy precipitation.

A team of IEEC researchers at ICE, led by Estel Cardellach, conducts the experiment aboard the Spanish satellite PAZ called "Radio-Occultation and Heavy Precipitation" experiment (ROHP-PAZ). The research team conceived a new measurement concept in 2009, merging the characteristics of the radio occultation (RO) measurements using signals of the Global Navigation Satellite Systems (GNSS), and those of the scattering techniques off hydrometeors using the 2-polarisation components of the signals. GNSS RO is a mature atmospheric sounding technique that provides vertical profiles of thermodynamic variables, while the innovative aspect is the dual-polarisation extension added in the ROHP-PAZ.

The new concept, called GNSS Polarimetric RO (GNSS PRO), is being proved in the ROHP-PAZ experiment. This spaceborne experiment was successfully launched on 22 February 2018. The hypotheses of the experiment are: (1) that its innovative capability to acquire the GNSS signals at two linear polarisations can be used to extract information about precipitation, with high sensitivity to heavy precipitation; and (2) that this can be done while maintaining the thermodynamic profiling skills of the RO technique. The measurement principle is based on the polarimetric phase shift between H- and V-polarised signals, received after forward scattering off rain droplets, acting as a "radar of opportunity". This is done through a dual-polarisation RO antenna pointing to the limb of the Earth in the anti-velocity direction for capturing setting occultations, and a modified GNSS RO receiver to track the signals of the horizontal (H) and vertical (V) antenna ports in an independent yet synchronous way.

The first 2-polarised GNSS RO signals observation from space were acquired on 10 May 2018, when ROHP-PAZ was switched on. The system has continued to acquire PRO signals since then, and it is planned to continue operations until the end of the satellites lifetime (five years' nominal life). These signals are now being used to study the potential detection and quantification of heavy rain from the differences between the phase-delays of GNSS signals propagating through large rain droplets in their vertical and horizontal components. The first results, recently published, confirm the hypothesis of the experiment. With the successful outcome, GNSS PRO becomes the first sensor technology with capabilities to resolve coincident thermodynamic and precipitation profiles in extreme rain events, with potential for improving our understanding of these type of phenomena.

As part of the commissioning phase and cal/val activities, extensive co-locations have been searched between ROHP-PAZ profiles, Global Precipitation Measurements mission observations and other precipitation and cloud sensors products. The current studies are refining the retrieval algorithms and they are also meant to assess the complementarity between these type of measurements (including the thermodynamic profiling) and other measurements techniques and weather and climate models.

At the end of the commissioning phase, the IEEC servers will be the access point for polarimetric data. "Standard" non-polarimetric RO products will be disseminated in near-real time to worldwide weather services thanks to agreements with NOAA and UCAR, organisations that will process the thermodynamics profiles and disseminate them within three hours of their acquisition, through the World Meteorologic Organisation's (WMO's) GTS system.

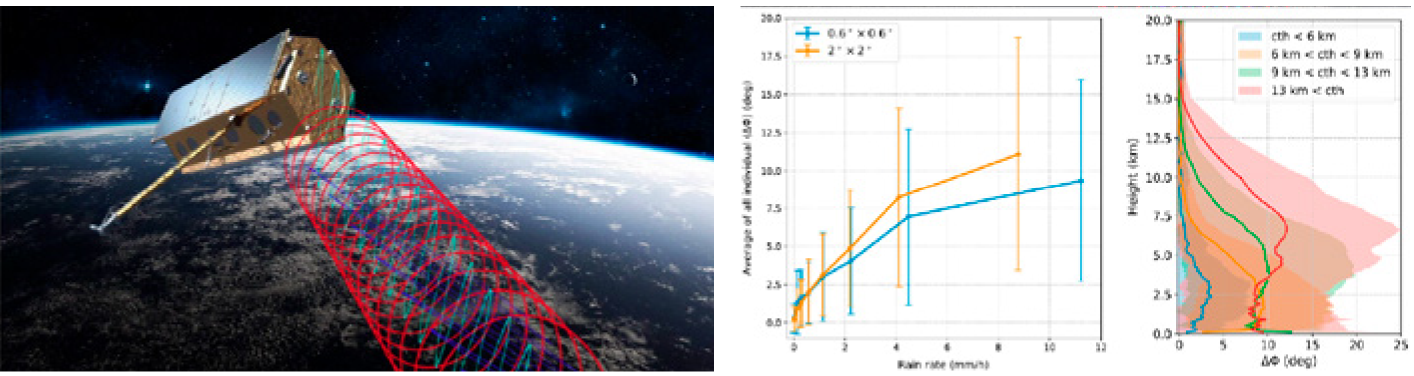

Figure 33: Left: Artistic view of PAZ and reception of GNSS PRO signals. Credit: hisdeSAT. Right: Results from the first five months of data, showing that the polarimetric phase shift (Df) is linked to hydrometeors. Credit: Cardellach et al., GRL, 2019.

Contact person:

ICE
Estel Cardellach, Faculty
estel@ieec.cat

Highlights

Euclid getting ready to fly

A group of IEEC researchers at ICE has successfully delivered the Filter Wheel Assembly (FWA) of the NearInfrared SpectroPhotometer (NISP) instrument for ESA's Euclid satellite.

The Euclid satellite instruments are in the final stages of integration before the launch. Euclid is an ESA medium-class astronomy and astrophysics space mission. It aims at understanding why the expansion of the Universe is accelerating and what is the nature of the source responsible for this acceleration that physicists refer to as dark energy. Dark energy represents around 70% of the energy content of the actual Universe and, together with dark matter, it dominates the Universe matter-energy content. Both are mysterious and of unknown nature, but it is known that they control the past, present and future evolution of the Universe.

Euclid is now in its final phases of integration and testing, with its launch planned for June 2022. The spacecraft will be put to an orbit around the second Sun-Earth Lagrange point (L2), 1.5 million kilometres from Earth, in the opposite direction to the Sun. This orbit offers optimum operating conditions for Euclid: a benign radiation environment, which is necessary for the spacecraft's sensitive detectors, as well as very stable observing conditions, which are sufficiently far away from the disturbing Earth-Moon system. Euclid will share a spot in this region with other emblematic missions such as Herschel, Planck, Gaia and the James Webb Space Telescope.

Euclid will explore how the Universe evolved over the past 10 billion years to address questions related to fundamental physics and cosmology on the nature and properties of dark energy, dark matter and gravity, as well as on the physics of the early universe and the initial conditions which seed the formation of the cosmic structure.

The imprints of dark energy and gravity will be tracked by using two complementary cosmological probes to capture signatures of the expansion rate of the Universe and the growth of cosmic structures: Weak gravitational Lensing and Galaxy Clustering (Baryonic Acoustic Oscillations and Redshift Space Distortion).

The complete survey represents hundreds of thousands of images and several tens of Petabytes of data. About 10 billion sources will be observed by Euclid out of which more than 1 billion will be used for weak lensing and several tens of million galaxy redshifts will also be measured and used for galaxy clustering. The scientific analysis and interpretation of these data will be led by the scientists of the Euclid Consortium.

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Figure 34: Flight Model of the Filter Wheel Assembly (FWA) of the NearInfrared SpectroPhotometer (NISP). Credit: Institute of Space Science (IEEC-CSIC) and Institut de Física d'Altes Energies.

The IEEC research group at ICE led by Francisco Castander, together with the Institute for High Energy Physics (IFAE, Institut de Física d'Altes Energies), is responsible for providing the filter wheel assembly (FWA) for the near infrared spectrophotometer (NISP) instrument of the telescope. Last December, the Flight Model of the FWA for integration in the NISP was delivered. The wheel was formally accepted by ESA.

The group, along with the Port d'Informació Científica (PIC) of the Universitat Autònoma de Barcelona (UAB), also provides high-resolution simulations of the structure of the Universe for later comparison with the observations and data to be obtained with the satellite. IEEC is responsible for the Simulations Organisation Unit of the Euclid Science Ground Segment. PIC will house the Spanish Science Data Centres for Euclid. In 2018, in collaboration with the University of Zurich, the research group released to the collaboration the Flagship Simulation that served as input for the Science Performance Verification 2 of the mission and the Mission Critical Design Review (CDR). The Flagship Simulation is the largest N-body simulation run to date.

Contact person:

ICE
Francisco Castander, Faculty
fjc@ieec.cat

Highlights

TWINS booms: the newest Mars weather service

NASA's InSight Mars Lander landed on Mars on 26 November 2018. Researchers from IEEC - UPC have participated in the design and fabrication of the wind sensor of the TWINS instrument: what NASA has called "the Newest Mars Weather Service". The instrument is already providing air temperature and wind velocity measurements.

On 26 November 2018, NASA's InSight Lander arrived on the Mars surface. Following the "seven minutes of terror", the Entry-Descent-Landing (EDL) phase of the mission, the spacecraft successfully landed on the Elysium Planitia. The lander brings a large set of instruments including: a seismometer (SEIS), a heat flux probe (HP3), a radio instrument for measuring the wobble of Mars' North Pole (RISE) and a weather station (TWINS).

The objective of the instrument is to contribute to the understanding of the Mars climate, as well as its geology. Wind force and directional patterns affect dust transport, which is a key factor in shaping Mars surface. Additionally, the instrument will also help the SEIS instrument by providing information on the possible interferences produced by wind on the seismic signals.

The TWINS instrument is a direct heritage of the REMS instrument present in the Curiosity Rover that landed on Mars in 2011. It has been developed by the Astrobiology Center (CSIC-INTA), in collaboration with CRISA, the IEEC-UPC Micro-and-Nano Technologies group, and other entities.

The wind sensor is composed of two cylindrical booms placed on the lander. The lander has made a “selfie” in which both booms can be clearly seen. Wind speed and direction is obtained by measuring the tangential wind velocity at three points of each boom. Four silicon dice are present at each one of these points. The tangential wind velocities are obtained by monitoring the tiny changes in heat transfer from each die to the atmosphere. The silicon dice have been fabricated at the Clean Room of the Micro and Nanotechnologies (MNT) group of the IEEC-UPC.

The researchers of the MNT group, led by the IEEC researcher Manuel Dominguez Pumar, are already working for a new version of the sensor for the MEDA instrument (Mars Environmental Dynamics Analyser) for NASA’s Mars2020 rover. Additionally, the group is developing a miniature spherical wind sensor for future Mars probes.

Wind sensing and dust transport are key factors in the advance towards the future human exploration of Mars and also for closer missions such as Mars Sample Return.

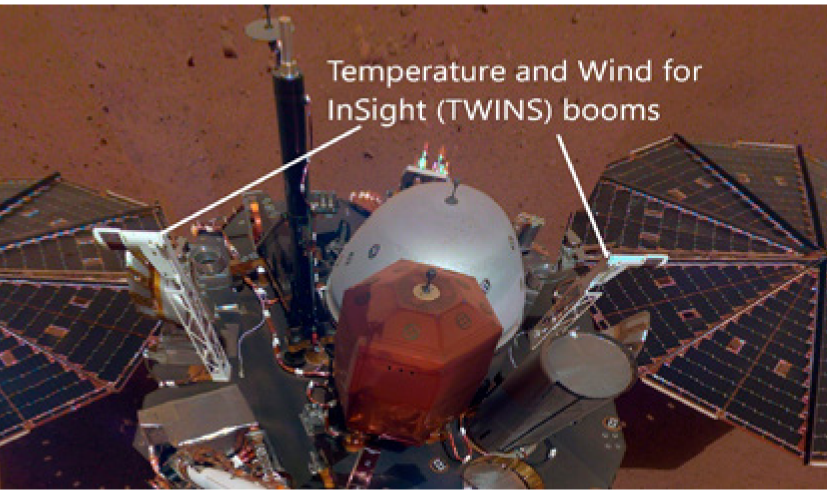


Figure 35: “Selfie” made by the lander in which the booms of the wind sensors can be clearly seen. Credit: NASA.

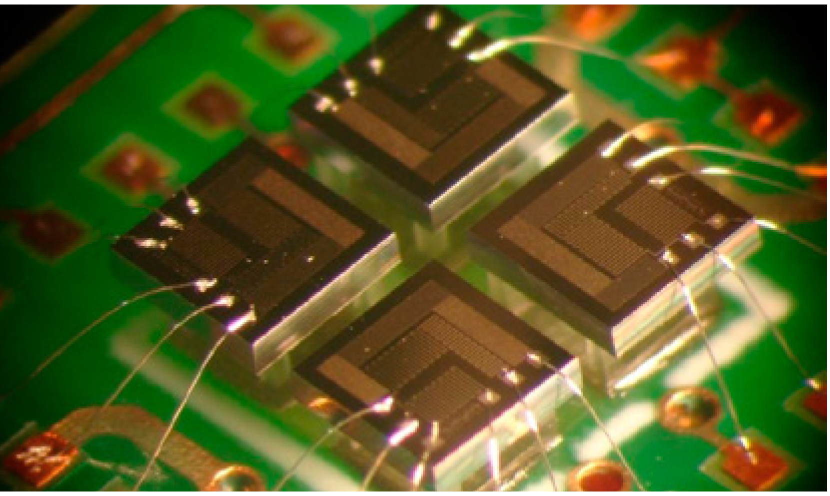


Figure 36: Detail showing 4 silicon dice, with deposited Platinum resistors, of the first prototype of REMS and TWINS sensors. Credit: Micro and Nanotechnologies (MNT) group, Dep. Electronic Engineering, ETSETB, Universitat Politècnica de Catalunya.

Contact person:
CTE
Manuel Domínguez-Pumar, Faculty
manuel.dominguez@ieec.cat

Highlights

MAGIC and Fermi-LAT telescopes trace origin of a rare cosmic neutrino

For the first time, astrophysicists have localised the source of a cosmic neutrino originating outside the Milky Way thanks to the measured association with a flaring source of gamma-rays detected with MAGIC and Fermi-LAT telescopes.

Neutrinos are tracers of cosmic-ray acceleration: electrically neutral and traveling at nearly the speed of light, they can escape the densest environments and may be traced back to their source of origin. High-energy neutrinos are expected to be produced in blazars: intense extragalactic radio, optical, x-ray, and, in some cases, γ-ray sources characterised by relativistic jets of plasma pointing close to our line of sight. Blazars are among the most powerful objects in the Universe and are widely speculated to be sources of high-energy cosmic rays. These cosmic rays generate high-energy neutrinos and γ-rays, which are produced when cosmic rays accelerated in the jet interact with nearby gas or photons.

On 22 September 2017, the cubic-kilometer IceCube Neutrino Observatory detected a ~290-TeV neutrino, automatically generating an alert that was distributed worldwide within 1 minute of detection and prompted follow-up searches by telescopes over a broad range of wavelengths. On 28 September 2017, the Fermi Large Area Telescope Collaboration reported that the direction of the neutrino was coincident with a catalogued γ-ray source, 0.1° away from the neutrino direction.

The source, a blazar known as TXS 0506+056 at a measured redshift of 0.34, was in a flaring state at the time with enhanced γ-ray activity in the GeV range. Follow-up observations by the Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes for about 41 hours, from 1.3 to 40.4 days after the neutrino detection, revealed periods where the detected γ-ray flux from the blazar reached energies up to 400 GeV. Measurements of the source were also completed at x-ray, optical and radio wavelengths. Models associating neutrino and γ-ray production were investigated and a correlation of the neutrino with the flare of TXS 0506+056 was found as statistically significant at the level of 3 standard deviations (sigma). The steep spectrum observed by MAGIC is concordant with internal gg absorption above ~100 GeV entailed by photohadronic production of a ~290-TeV neutrino, corroborating a genuine connection between multi-messenger signals. The energies of the γ-rays and the neutrino indicate that blazar jets may accelerate cosmic rays to at least several PeV. The observed association of a high-energy neutrino with a blazar during a period of enhanced γ-ray emission suggests that blazars may indeed be one of the long-sought sources of very-high-energy cosmic rays, and hence responsible for a sizable fraction of the cosmic neutrino flux observed by IceCube.

This is the very first time that both neutrinos and gamma rays are confirmed to stem from proton parents and shows the potential of multi-messenger astronomy.

Two research groups from IEEC at ICCUB and CERES are involved in this research as members of the MAGIC collaboration, and one researcher at ICE as a member of the Fermi-LAT collaboration.

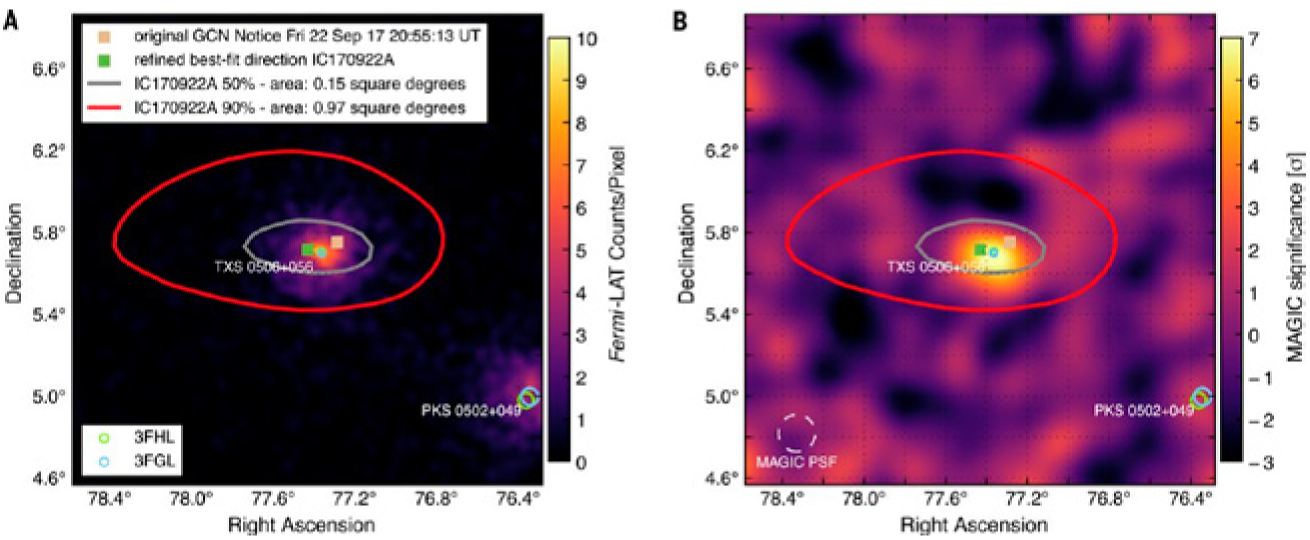


Figure 37: Fermi-LAT and MAGIC observations of IceCube-170922A's location. Credit: The IceCube Collaboration et al., Science, DOI: 10.1126/science.aat1378, 2019.

Contact person:

CERES
Lluís Font, Faculty
lluis.font@ieec.cat

The first nayed-eye superflare detected from Proxima Centauri

The Evryscope observes the most energetic flare in Proxima Centauri, constraining the habitability in the closest exoplanet.

Octavi Fors and Daniel del Ser, IEEC researchers at ICCUB, in collaboration with a team of astronomers at the University of North Carolina at Chapel Hill (UNC-CH, USA), detected the first naked-eyed superflare of Proxima Centauri, the closest star to our Sun. As a result of such a detection, together with further observations and modelling, the authors constrained the habitability in Proxima b, the planet orbiting Proxima Centauri and our closest exoplanet.

The Evryscope is an innovative telescope that acquires an image of the whole observable sky every two minutes. This allows to continuously monitor the brightness of millions of stars with an unprecedented combination of time resolution and sky coverage. The Evryscope South was deployed on May 2015 at Cerro Tololo Inter-American Observatory (CTIO, Chile). A second Evryscope was deployed on October 2018 at Mount Laguna Observatory (California, USA), in collaboration with the San Diego State University. The combined observation of these two Evryscopes allows all-sky monitoring every two minutes in two different filters.

Flares in active stars such as Proxima Centauri were already known phenomena. Typically, these events cause the stars to increase their brightness up to ten times (10x) with respect to their value when in quiescent state. On March 2016, Evryscope detected a 35x superflare in a scale of two minutes. In shorter scales, such as that of the human eye (fractions of a second), the brightness increase is up to ~70x, making Proxima Centauri bright enough to be detected with the naked eye.

During the 2.2 years of analysed Evryscope data, other 23 less energetic flares were also detected in Proxima Centauri by this telescope. As a result, the authors statistically derived that one superflare occurs every ~5 years in that star.

Superflares such as the one detected on Proxima Centauri irradiate the atmosphere of its potentially-habitable planet (Proxima b) with powerful (UV) radiation and high flux of protons. This results in a serious diminishing of the planetary ozone. The authors estimated that, assuming an initial Earth-like atmosphere, 90% of the ozone in Proxima b would be lost within five years of repeated flaring, and complete depletion would occur within ~100,000 years. As a consequence, life on Proxima b surface would struggle to survive these extreme conditions of strong UV radiation and absence of ozone, totally different to the current ones on Earth.

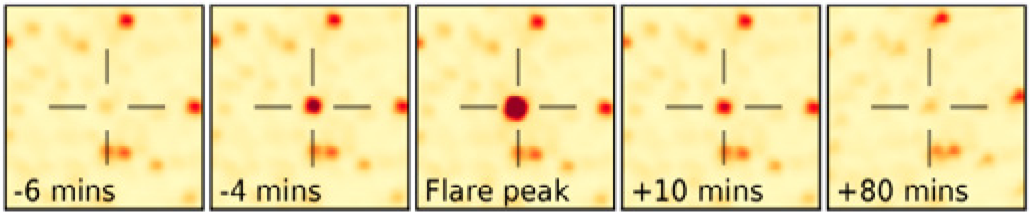


Figure 38: The Proxima superflare, observed by the Evryscope in March 2016, during which Proxima Centauri increased in brightness by ~70x and irradiated the potentially-habitable planet Proxima b with lethal doses of UV radiation. Credit: Howard et al., ApJ Letters, 860, 2, 2018.

Figure 39: Artist's impression of a flaring red dwarf star similar to Proxima Centauri. Credit: NASA's Goddard Space Flight Center/S. Wiessinger.

Contact person:
ICCUB
Octavi Fors, Postdoctoral Researcher
octavifors@ieec.cat

The second release of the Gaia catalogue

In addition to the location of 1,700 million stars, the second catalogue includes the distance, movement and colour of more than 1,300 million stars in the Milky Way and the nearest galaxies.

On 25 April 2018, the second release of the Gaia mission catalogue (Gaia-DR2) was published by ESA. It contains almost 1,700 million of sources, including the astrometry for more than 1,300 million stars, the colours for about 1,400 million and the radial velocities more than 7 million. For the first time, the new catalogue provides also physical parameters, as effective temperature, radius and luminosity, for tens of millions of sources. Gaia DR2 is the most complete and accurate astrometric catalogue ever published. The data is available through the Gaia Archive.

The DR2 catalogue is revolutionising the concepts about the formation and evolution of the Milky Way. As an example, the study of the motion of millions of stars in the solar neighbourhood and beyond has allowed to detect the footprint of the interaction of a small galaxy with the Milky Way disk 300-800 millions of years ago (see note in this memory for more details). Gaia data has also revealed new open clusters unknown until now, thanks to the unprecedented accuracy of the proper motions, which allows distinguishing the open clusters' stars from the field stars. In both cases, members of a IEEC researchers team at ICCUB have been involved in the studies.

The Gaia catalogue is the final product of a long chain of processes and algorithms. Our team leads the management and development of the Gaia Archive and especially its Data Mining framework. Every day, the Gaia spacecraft sends to ground more than 30 GB of data. These data are distributed to six data processing centres, responsible for the processing of Gaia's data with the final objective of producing the Gaia catalogue.

The Barcelona Data Processing Centre (DPCB) is one of these processing centres. The hardware used at DPCB in Gaia operations is located at the BSC (specifically the MareNostrum supercomputer), whereas the team at IEEC-ICCUB carry out the management, operations, development and tests.

In this way, the IEEC-ICCUB team CUB has also developed the Initial Data Treatment (IDT). The IDT system carries out the reconstruction and initial processing of the raw data as soon as it arrives on the ground, including a first reconstruction of the satellite attitude (or pointing of its telescopes), the determination of the locations and brightness of the objects measured, the Cross-Match (linking the observations to their corresponding catalogue sources and creating new ones if necessary), and a first treatment of the image distortion caused by the radiation damage on the CCDs. Its operation is accurately monitored on a daily basis with thousands of plots and statistics, as well as automated reports.

Another system developed at IEEC-ICCUB is IDU (Intermediate Data Updating). It reprocesses all the accumulated raw data using the most up-to-date calibrations obtained by the core astrometric solution and other systems, giving a higher coherence between all the scientific data and correcting any possible errors or incorrect approximations from previous iterations. Probably the most complex and hardest task in IDU (in terms of computation) is the calibration of the instrument response including the correction of the radiation damage, which is carried out with the highest possible detail.

Figure 40: First Gaia sky map in colour based on DR2 data. Credit: ESA/Gaia/DPAC, A. Moitinho / A. F. Silva / M. Barros / C. Barata, University of Lisbon, Portugal; H. Savietto, Fork Research, Portugal.

Contact person:
ICCUB
Gaia team

The Dark Energy Survey publishes the data obtained during its first three years

The period of collecting scientific data to map an eighth of the sky in unprecedented detail comes to its end and the collaboration has publicly released the first three years of data.

Scientists from the Dark Energy Survey (DES) announced the release of the first three years of data. This first public distribution of mapping data contains information on about 400 million astronomical objects, including both distant galaxies, at distances of billions of light years, and stars in our own Galaxy. DES is a collaboration of more than 400 scientists from 26 institutions in seven countries.

DES scientists are using this data to study dark energy, the mysterious force believed to be responsible for the Universe's accelerating expansion. Some of their findings were also presented at the special session of the Washington meeting. As part of that session, they also announced the discovery of eleven new stellar currents, remnants of smaller galaxies, dismembered and devoured by the Milky Way.

The data cover the entire DES exploration area (about 5,000 square degrees, or an eighth of the sky) and include more than 100,000 exposures taken with the Dark Energy Camera (DECam). The images correspond to hundreds of terabytes of data and are made public along with catalogues of hundreds of millions of galaxies and stars. DES data can be accessed publicly.

The DECam camera, the primary tool of the Dark Energy Survey, is one of the most powerful digital imaging devices. It was assembled and tested at Fermilab, the DES-led laboratory, and it is mounted on the 4-meters Victor M. Blanco telescope at the Cerro Tololo Observatory in Chile.

The DES-Spain group, formed by CIEMAT, IEEC-CSIC, IFAE and UAM/IFT, made an outstanding contribution to the construction of DECam. In particular, it designed, built and validated the electronics. Moreover, it also implemented the guidance system, among other contributions. It is one of the founding partners of the DES collaboration, with funding from MINECO, IEEC, CSIC and Generalitat de Catalunya.

One discovery made by using this dataset is the detection of eleven new stellar streams around our Galaxy, the Milky Way, some of which can be seen in the following figure. Our cosmic home is surrounded by a massive halo of dark matter, which exerts a powerful gravitational pull on small and nearby galaxies. The Milky Way grows by attracting, dismembering and absorbing these smaller galactic systems. As their stars are torn out, they form streams along the sky that can be detected with the DECam. But even with such powerful instrument, these stellar streams are extremely difficult to find, as they are composed of a relatively small number of stars spread over a large area of the sky.

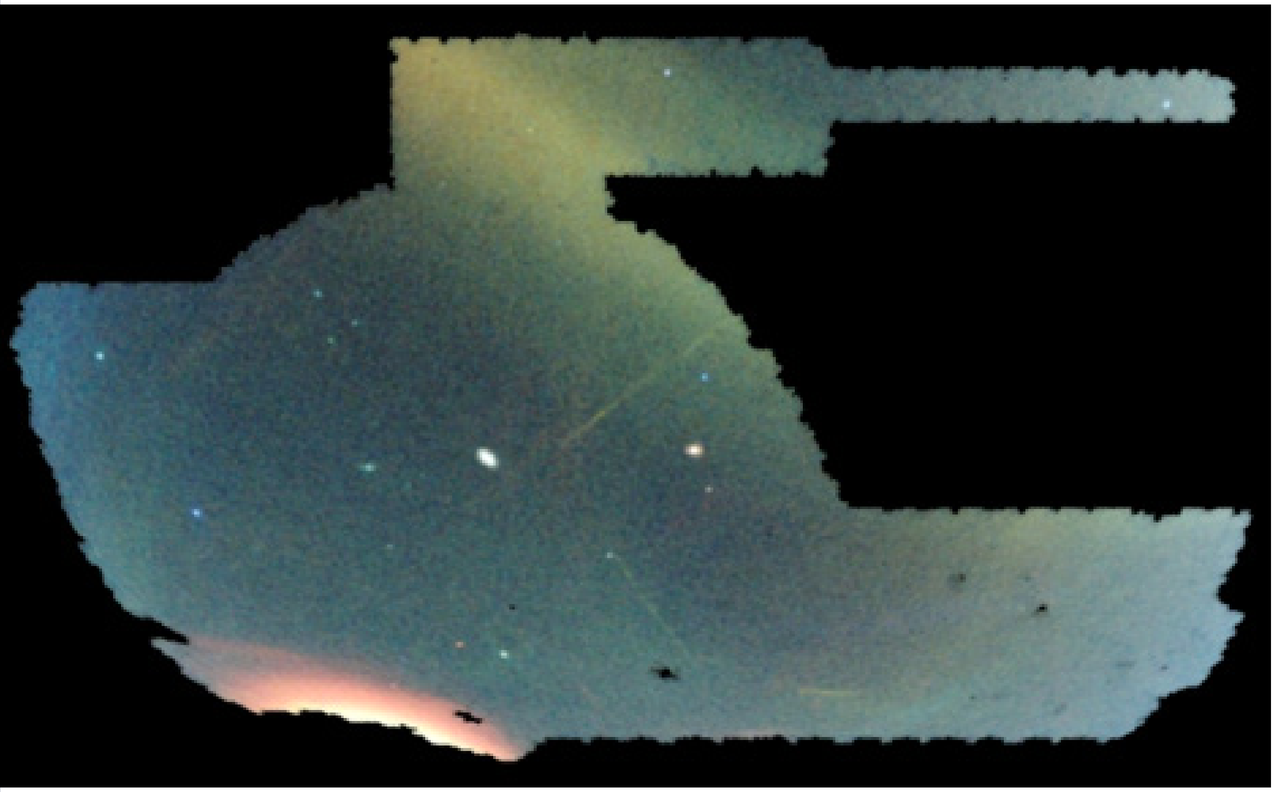


Figure 41: DES map of 1/4 of all the Southern Sky.

Contact person:
ICE
Enrique Gaztañaga, Faculty
gazta@ieec.cat

Highlights

The MELiSSA Pilot Plant operates three interconnected compartments in continuous mode for the first time

MELiSSA (Micro-Ecological Life Support System Alternative) project has successfully operated three interconnected compartments at the Pilot Plant in UAB Campus for a long term period under continuous and controlled conditions.

MELiSSA is the acronym for Micro-Ecological Life Support System Alternative, an innovative Project of the European Space Agency that was initiated as part of a research programme on life support technologies, in order to facilitate long duration manned space missions. These types of missions can not be performed without regenerative life support systems like MELiSSA that will drastically reduce the amount of logistics needed to support the crew (without recycling, 30T for a 1000 days Mars mission). For this, a regenerative circular system is proposed, with the generation of edible material from higher plants and microalgae, revitalisation of atmosphere for respiration, recovery of water, and recycling of the wastes generated by the crew and plant growth. The MELISSA project is targeting ideally 100% of recycling of all chemical elements, i.e. a fully self-sustainable ecosystem without any resupply. In terms of processes, control, stability, safety, robustness, this target represents a very high challenge.

The recycling challenges of MELISSA are reinforced by the closed environment conditions and the presence of humans. As a consequence, intensive characterisation, safety analysis comprehensive integration, verification, validation and qualification activities are mandatory steps in the development and validation of MELiSSA.

The MELiSSA project is an international and multidisciplinary collaboration with a core team of fourteen partners, including SCK/CEN (Mol, Belgium), VITO (Mol, Belgium), University of Ghent (Ghent, Belgium), University of Mons (Mons, Belgium), Universitat Autonòma de Barcelona (Barcelona, Spain), University of Guelph (Guelph, Canada), University Clermont Auvergne (Clermont-Ferrand, France), SHERPA Engineering (Paris, France), Enginsoft (Bergamo, Italy), University of Napoli Federico II (Napoli, Italy), University of Lausanne (Lausanne, Switzerland), IPStar (Vught, The Netherlands) and the MELiSSA Foundation (Brussels, Belgium). The coordination of the Consortium is done by ESA, at the request of the rest of the partners. As the project develops, more and more European companies and organisations are contributing to the joint venture, bringing complementary expertise where needed (today more than 50 organisations from 12 countries have contributed to MELiSSA). The scientists and engineers in MELiSSA are from various horizons (academic organisations, industries) and gather a comprehensive multidisciplinary expertise (microbiology, modelling, process engineering, biotechnology, system engineering, nutrition, automation, genomics, proteomic, etc.). The MELiSSA Pilot Plant has been established as an External Laboratory of ESA at UAB, where the technology developments from the Consortium are integrated and demonstrated during long-term continuous operation under controlled conditions.

Figure 42: MELiSSA Pilot Plant Bioreactors.

In 2009, the second generation laboratory for the MELiSSA Pilot Plant at UAB started its activities, providing a world class research and development facility. Since then, several achievements have been made in the progressive construction of the different blocks comprising the MELiSSA Pilot plant. To be highlighted, the operation of three compartments of the MELiSSA Pilot Plant during a long term period under continuous and controlled operation was successfully achieved, standing proof of the scientific and technological capacities of the Consortium.

These three compartments were a nitrification bioreactor, a microalgae photobioreactor and an animal isolator as a crew mock-up. In parallel, solid progress has been achieved as well for space demonstration such as the photobiorecator ARTEMISS on board ISS and nitrifying bacteria exposure to space (NITRIMEL) within a Russian satellite. Three members of IEEC-CERES are participating in the development of the MELiSSA Pilot Plant, lead by Prof. Francesc Gòdia from UAB, Department of Chemical, Biological and Environmental Engineering.

Contact person:

CERES
Francesc Gòdia, Faculty
francesc.godia@ieec.cat

Hunting the seeds of supermassive black holes

Finding the elusive intermediate-mass black holes could help better understand what the "seeds" for the largest black holes in the early Universe were.

Black holes that contain between about one hundred and several hundred thousand times the mass of the Sun are called "intermediate-mass" black holes, or IMBHs. This is because their mass places them in between the well-documented and frequently-studied "stellar-mass" black holes at one end of the mass scale and the "supermassive black holes" found in the central regions of massive galaxies at the other.

While several tantalising possible IMBHs have been reported in recent years, astronomers are still trying to determine how common they are and what their properties teach us about the formation of the first supermassive black holes.

A research team led by the IEEC researcher at ICE Mar Mezcua used a large campaign, called the Chandra COSMOS-Legacy survey, to study dwarf galaxies, which contain less than one percent the amount of mass in stars as our Milky Way does. The characterisation of these galaxies was enabled by the rich dataset available for the COSMOS (Cosmic Evolution Survey) field at different wavelengths, including data from NASA and ESA telescopes. The X-ray data were crucial for this search because a bright, point-like source of X-ray emission near the centre of a galaxy is a telltale sign of the presence of a black hole. The X-rays are produced by gas heated to millions of degrees by the enormous gravitational and magnetic forces near the black hole.

The research team identified forty growing black holes in dwarf galaxies. Twelve of them are located at distances more than five billion light years from Earth and the most distant is 10.9 billion light years away, the most distant growing black hole in a dwarf galaxy ever seen. One of the dwarf galaxies is the least massive galaxy found to host a growing black hole in its centre.

Most of these sources are likely IMBHs with masses that are about ten thousand to a hundred thousand times that of the Sun. These IMBHs could be the seeds that eventually evolve into supermassive black holes and could explain why some supermassive black holes grow more rapidly than the galaxies they inhabit. The latter is based on another study, also led by Mezcua, of 72 galaxies located at the centre of galaxy clusters at distances ranging up to about 3.5 billion light years from Earth. By comparing the properties in X-ray and radio waves of these galaxies, the authors found that the black hole masses were about ten times larger than masses estimated by another method using the assumption that the black holes and galaxies grew in tandem. This challenges the long-held idea that supermassive black holes grow in lockstep with their galaxies, and could be explained if the supermassive black holes in galaxy clusters grew from IMBHs formed in the early Universe.

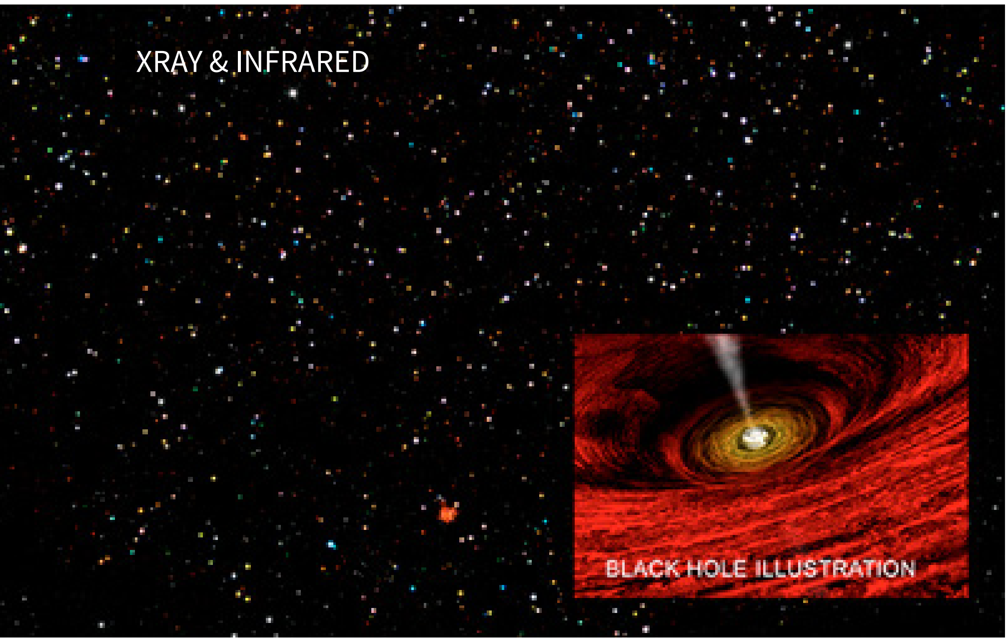


Figure 43: Chandra X-ray data from the COSMOS survey, equivalent to about 4.6 million seconds of observing time. The colours represent different levels of X-ray energy detected by Chandra. Red: lowest-energy X-rays; green: medium band; blue: highest-energy X-rays. Most of the coloured dots are black holes. Grey: data from the Spitzer Space Telescope. Inset: artist's impression of a growing black hole in the centre of a galaxy. Credit: X-ray: NASA/CXC/ICE/M. Mezcua et al.; Infrared: NASA/JPL-Caltech; Illustration: NASA/CXC/A.Hobart

Contact person:
ICE
Mar Mezcua, Research Fellow
mezcua@ieec.cat

Highlights

The ICCUB joins the Virgo Collaboration to study gravitational waves

Virgo can detect massive gravitational events from 170 million light years away. ICCUB is helping to process and analyse vast amounts of data more efficiently.

More than a century ago, Einstein predicted the existence of gravitational waves – perturbations in the space-time fabric caused by the motion of massive bodies. Unlike electromagnetic waves (such as visible light, radio frequencies or gamma rays), gravitational waves are very difficult to observe. They require large, complex and expensive observatories.

Two decades ago, international collaborations were created for this purpose: LIGO in the United States and Virgo in Europe. More than a thousand experts all over the world are contributing to this effort – around 400 in Virgo. Three observatories were built for this purpose: two in the US (Livingston and Hanford) and one in Europe. The latter is called the European Gravitational Observatory (EGO), in Cascina, near Pisa, Italy.

EGO runs a laser interferometer with two perpendicular arms (3 kilometres each and operating in vacuum) and a very complex instrumentation. The effect of gravitational waves is so tiny that it can easily be confused with seismic movements or noises in the observatory area, so the detectors must be as isolated as possible from the environment. It requires 10-meter high super-attenuators, high-efficiency mirrors (made from the purest glass in the world and polished to the atomic level), low-noise photodetectors, high power and stability lasers, many seismic and noise sensors spread all over the observatory site, and high-performance data acquisition and processing systems. Variations in mirror positions are measured to less than the diameter of a Hydrogen atom, but even smaller variations in the length of the laser arms can be measured – reaching about a billionth of a nanometre.

Virgo can detect gravitational waves in the range of roughly 10 Hz to 10 KHz – similar to the audible range, so it is often said that it allows to «listen» to the Universe. Currently, Virgo can detect phenomena up to 170 million light years away, reaching over 100.000 galaxies. The higher its sensitivity is, the farther it can reach and, thus, more events can be detected and observed.
At the present moment, limitations in the sensitivity only allows to detect phenomena that generates the biggest gravitational waves in the Universe, such as collisions between black holes or neutron stars. All this setup generates a vast amount of data. During the 3rd observational run (or «O3»), starting April 2019, Virgo will generate about 1 PB in one year – and even more will be generated in future runs. It shall be processed using complex algorithms to try to find different types of tiny signals buried in the noise, so large computational facilities spread all over Europe will be required.

IEEC researchers at ICCUB will contribute to the project by taking advantage of the expertise acquired in other projects that also deal with large amounts of data and complex algorithms, such as the Gaia mission of ESA or the LHCb experiment at CERN. Their experts will review the overall computing model, the software management and the data handling approach, aiming at an efficient use of the expensive computing facilities. For example, adequate interfaces are needed to use the different architectures and peculiarities of data processing centres forming the European Grid computing infrastructure, and to efficiently exchange data between them. Data analysis software is developed by many different people with different coding expertise, so common tools and policies are needed as well. Moreover, they also intend to improve some of the data analysis pipelines, such as those that try to fit a waveform template (generated with astrophysical models and simulations) to the signal. Finally, they will also contribute to the electronics and instrumentation upgrades that will allow reaching even better sensitivity, such as low-noise and high-speed analog-to-digital converters. All this will help Virgo reaching even better sensitivities and, thus, routinely detecting and analysing many more gravitational waves.

Figure 44: Aerial view of the Virgo site showing the Mode-Cleaner building, the Central building, the 3km-long west arm and the beginning of the north arm. Credit: The Virgo collaboration/CCO 1.0

Contact person:
ICCUB
Jordi Portell, Staff Engineer
portell@ieec.cat

Discovery of the first resolved triple white dwarf

IEEC researchers at CTE discover the first resolved triple white dwarf by means of the data provided by the second data release of the Gaia satellite.

White dwarfs are the most typical endpoints of stellar evolution. They form after their main sequence progenitors have gone through the most relevant nuclear burning phases and have lost their outermost layers. White dwarfs are about as massive as the Sun but have the size of the Earth. As a result, they are very dense and are mostly composed of degenerate matter. It is the pressure of the degenerate electrons that prevents white dwarfs from undergoing gravitational collapse. Because white dwarfs are compact objects, they have some peculiar properties. For instance, if a white dwarf exceeds a mass of ~1.4Msun (where Msun is the mass of the Sun), the pressure of the degenerate electrons is unable to support the mechanical structure and gravitational collapse triggers nuclear reactions which lead to a type Ia supernova explosion.

A Type Ia supernova explosion is one of the most energetic events occurring in the Universe. As a consequence, they can be detected at extremely large distances, which makes them ideal tools in cosmology. Indeed, it was using these supernovae that in 1998 it was discovered that the expansion of the Universe is accelerating, a discovery which was awarded the Nobel Prize in Physics in 2011. It has to be emphasised however that we currently do not know what the progenitors of these important explosions are. The two classical scenarios for type Ia supernovae are the single- and the double-degenerate channels. In the single-degenerate channel a white dwarf accretes matter from a non degenerate companion thus growing in mass near 1.4Msun.

In the double-degenerate channel two white dwarfs in a close binary merge due to the action of gravitational waves and the resulting merger has a mass near 1.4Msun. Both channels however present advantages and drawbacks and, as a consequence, the progenitor problems remain an open issue.

An additional way of producing a type Ia supernova explosion involves the existence of a hierarchical triple system formed by two inner white dwarfs and a tertiary outer companion. The presence of the outer companion significantly alters the evolution of the inner binary. In particular, it drives Lidov-Kozai oscillations (the eccentricity of the inner orbit and the mutual inclination varies periodically) which may result in the collision of the inner white dwarf binary. If the white dwarfs of the inner binary are massive enough, the collision can hence lead to a type Ia supernova explosion. However, no such system has been yet identified until now.

In a work carried out by IEEC researchers at CTE, they report the discovery of the first resolved triple white dwarf. They identified the triplet thanks to parallaxes and proper motions recently provided by the second data release of the Gaia satellite. From optical spectroscopic observations, they determined the masses of the three white dwarfs, which, together with the astrometric data provided by Gaia, allowed them to study the future evolution of the triplet. Their results indicate that the probability for collision of the inner white dwarf binary is low, however, if that were the case, such an event would likely produce a type Ia supernova explosion.

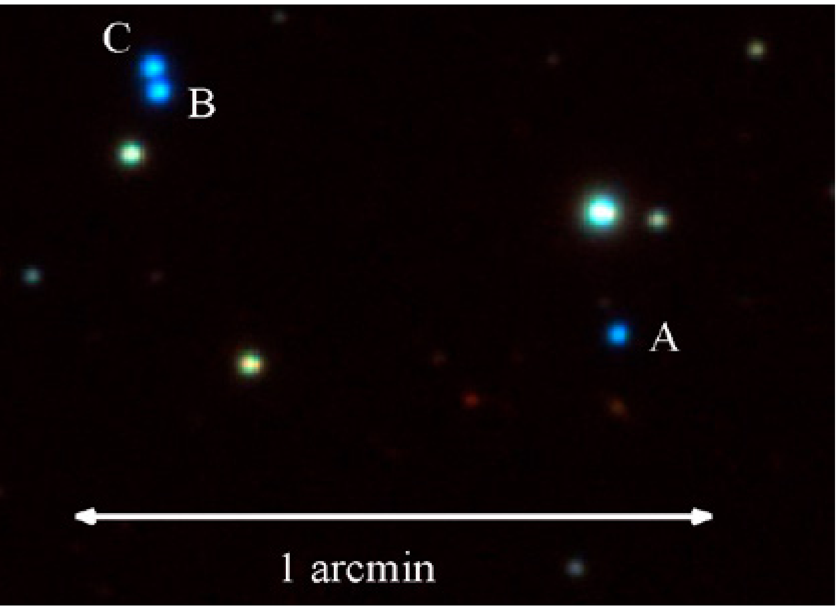


Figure 45: PanSTARRS composite g,i,y image of the triple white dwarf system. The three components are labelled as A, B and C. Credit: Pan-STARRS telescope.

Contact person:
CTE
Alberto Rebassa-Mansergas, Postdoctoral Researcher
alberto.rebassa@ieec.cat

Planet discovered orbiting the second closest stellar system to the Earth

Measurements from high-precision instruments reveal a cold super-Earth around Barnard's star.

At only six light-years from us, Barnard's star appears to move across Earth's night sky faster than any other star. This red-dwarf star, smaller and older than our Sun is among the least active red dwarfs known and represents an ideal target to search for exoplanets with various methods. Since 1997, several instruments have been gathering a large amount of measurements on the star's subtle back-and-forth wobble. An analysis of the data collected up to 2015, including observations from HIRES/Keck, and ESO's HARPS and UVES spectrometers, suggested the wobble could be caused by a planet with an orbital period of about 230 days. To confirm this, however, more measurements were deemed necessary.

Trying to see if the result could be confirmed, a team of IEEC researchers at ICE, led by Ignasi Ribas, regularly monitored Barnard's star with high precision spectrometers such as the CARMENES (Calar Alto Observatory in Spain) and also HARPS and HARPS-N. This technique consists of using the Doppler effect on the starlight to measure how the velocity of an object along our line of sight changes with time. The analysis used observations from seven different instruments, spanning 20 years, making this one of the largest and most extensive datasets ever used for precise radial velocity studies. The combination of all data led to a total of 771 measurements.

A clear signal at a period of 233 days arose again in the re-analysis of all the measurements combined. This signal implies that Barnard's star is approaching and moving away from Earth at about 1.2 m/s – approximately the walking speed of a person – and it is best explained by a planet orbiting it.

After a very careful analysis, the team is over 99% confident that the planet is there, since this is the model that best fits the observations. However, caution should still be exercised because natural variations of the stellar brightness resulting from starspots can produce similar effects to the ones detected. Follow-up observations are already happening at different observatories to collect more data to nail the case in the future.

The planet candidate, named Barnard's star b (or GJ 699 b), is a super-Earth with a minimum of 3.2 Earth masses. It orbits its cool red parent star every 233 days near the snow-line, a distance where water would be frozen. In the absence of an atmosphere, its temperature is likely to be about -150 °C, which makes it unlikely that the planet can sustain liquid water on its surface. However, its characteristics make it an excellent target for direct imaging using the next generation of instruments such as NASA's Wide Field InfraRed Survey Telescope (WFIRST) and maybe for observations from the ESA mission Gaia.

Exoplanets so small and so far away from their parent star have not been discovered before using the Doppler technique. This means that astronomers are getting better at finding and exploring a relatively new kind of planets outside our Solar System. With the next generation of instruments, these capabilities can only expand. This discovery is a boost to continue on searching for exoplanets around our closest stellar neighbours, in the hope that eventually we will come upon one that has the right conditions to host life.

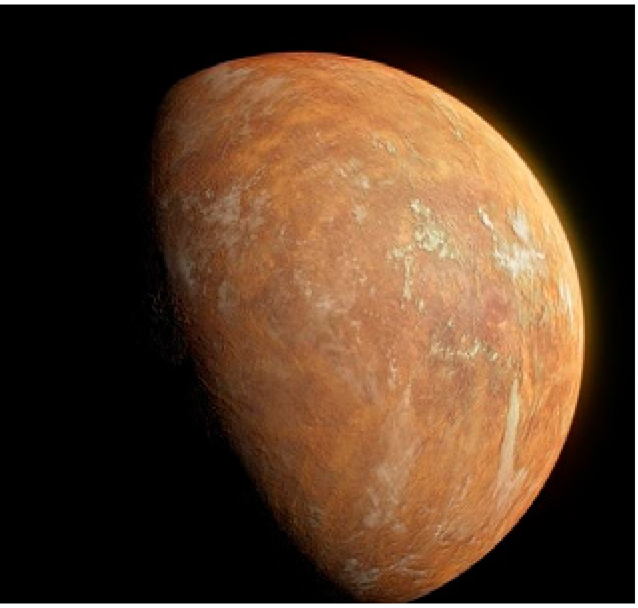


Figure 46: Artist's impressions of Barnard's star b. Credit: Left: IEEC/Science-Wave - Guillem Ramisa. Right: ESO/M. Kornmesser

Contact person:
ICE
Ignasi Ribas, Faculty & IEEC director
iribas@ieec.cat

Satellite Navigation Systems: Contribution to new missions and new applications

IEEC researchers at CERES have made key contributions to the European Global Navigation Satellite Systems (EGNSS), including Galileo first generation (G1G), Galileo second generation (G2G) and EGNOS third generation (EGNOSv3).

IEEC researchers at CERES have actively contributed to all missions of the EGNSS, including different generations of Galileo and EGNOS satellite navigation and augmentation system.

In Galileo first generation (G1G), the IEEC-UAB research group has participated in the definition of the Open Service Navigation Message Authentication mechanism for the Galileo Open Service (OS-NMA). The proposed method will help protect users against the increasing risk of being spoofed with counterfeit signals and has actually become a cornerstone for Galileo to become the reference GNSS in civil navigation authentication.

The IEEC-UAB researchers are also present in the definition of Galileo second generation (G2G), where the group will contribute with its expertise in receiver technology to the design of new signals compatible with the envisioned trends and evolution of future GNSS receivers.

The contribution to G1G and G2G missions is complemented by the participation in the third-generation EGNOS satellite augmentation system (EGNOSv3). The researchers are involved in the implementation of the long loop algorithm of the Navigation Land Earth Stations, a set of ground stations generating the EGNOS signal that is uplinked and then broadcast by a geostationary satellite. The algorithm being developed is in charge of pre-compensating the uplink propagation effects so that the broadcast signal appears like a true GNSS signal, which is generated in the satellite.

Apart from the contribution to the different missions of the EGNSS, an intense activity has been carried out to foster new applications. This has led to the release of a new service that allows the remote processing of GNSS signals through a cloud computing platform. The service, branded as "cloudGNSSrx", allows users to upload a binary file with the raw GNSS signal samples gathered by a radiofrequency front-end. The result of the remote processing is the computed user's position and time, as well as additional information on signal quality monitoring.

Remote processing of GNSS signals is very well-suited for emerging applications in the context of Internet of Things (IoT) and Smart Cities, where miniaturised sensors can now benefit from positioning information without the need of embedding a power-hungry GNSS chipset on-board. Additionally, the remote processing of GNSS signals enables the access to advanced features such as interference, multipath and spoofing detection, as well as signal antireplay protection. The latter is of the utmost importance for critical and commercial applications requiring a certified position solution.

The paradigm shift brought by the remote processing of GNSS signals actually received the attention of the latest issue of the GNSS User Technology Report released by the European GNSS Agency (GSA). Therein, the cloud GNSS receiver developed by SPCOMNAV/UAB was acknowledged as one of the most promising technologies for future ubiquitous position, navigation and time.

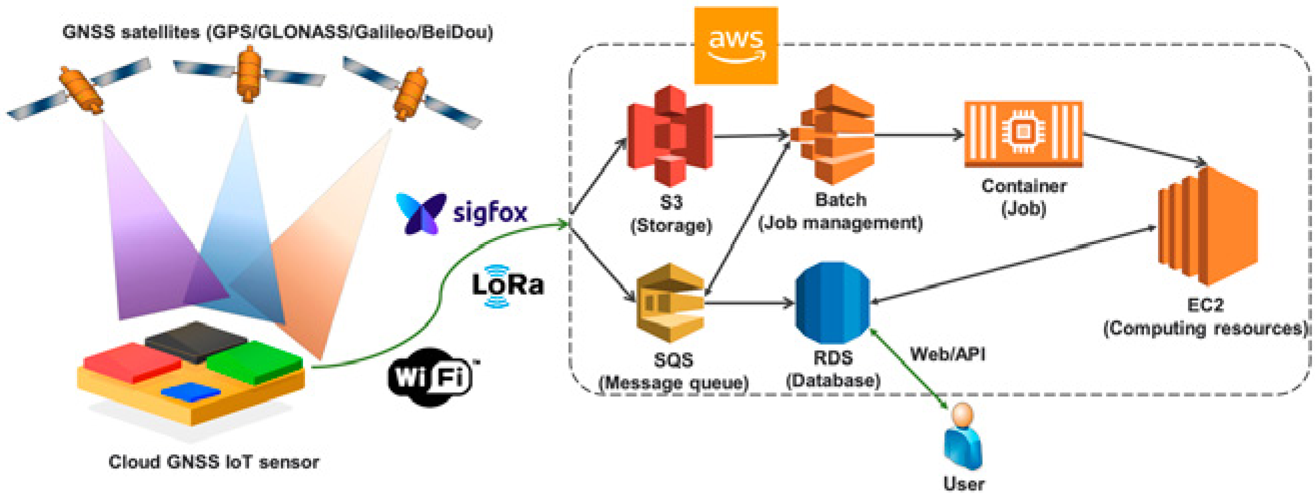


Figure 47: Representation of the cloud GNSS receiver. An IoT positioning use case is represented, where GNSS signals are gathered and sent to the remote platform by an IoT sensor. Credit: Signal Processing for Communications & Navigation (SPCOMNAV), Dpt. of Telecommunications and Systems Engineering, Universitat Autònoma de Barcelona

Contact person:

CERES
Gonzalo Seco-Granados, Faculty
gonzaloseco@ieec.cat

Milky Way halo has stars coming from the disk

The analysis of two stellar overdensities at the interface between the outer disk and the halo of the Milky Way indicates that their stars come from the Galactic disk.

Our Galaxy has had an active evolutionary history, dominated by star formation, accretion of cold gas and, very importantly, by the merging and gravitational interaction with dwarf satellite galaxies. The galactic stellar halo, the faint and roughly spherical component of the Galaxy, contains rich fossil evidence of these interactions, in the form of stellar streams, substructures and chemically distinct stellar components.

A group led by the IEEC researcher at ICE Aldo Serenelli has spectroscopically investigated 14 stars that belong to two of such substructures. The substructures, known as the A13 and the Triangulum-Andromeda (TriAnd) overdensities, are located at about 5 kpc from the galactic disk and more than 15 kpc from the galactic centre which suggests an association with the galactic halo. But A13 is located above the galactic disk while TriAnd is located below, on the opposite side of the disk. The distance determination was obtained using spectroscopic and photometric observations in combination with theoretical evolutionary models of stars developed by Serenelli.

The spectroscopic analysis was performed with high-resolution spectra obtained using the Keck telescope in Hawaii and ESO's Very Large Telescope in Chile. The chemical composition of these stars shows remarkable similarities among members of each substructure and also between substructures. And, even more remarkably, their composition very closely matches that of stars in the Milky Way disk rather than those in the galactic halo. This provides compelling evidence that these stars formed within the galactic disc and are not the debris of a dwarf galaxy that merged with the Milky Way, a common origin of halo stars.

This finding opens up the question of what dynamical process has ejected these stars from the disk to the halo; explaining how stars formed in the disk are now found that far away from the disk and at large Galactocentric distances is a challenge. In this work, a plausible scenario was explored that could explain these observations. Using dynamical simulations of the interaction and merger of a satellite dwarf galaxy with the Milky Way it was shown that during the merger the tidal forces excite vertical oscillations and flare the galactic disk, which naturally explains the existence of stellar overdensities well above and below the Galactic midplane.

Results show that oscillations of the galactic as a whole are excited during a merging event and that stellar migration can occur as a result, relocating stars to distant locations from their birthplace. These oscillations contribute significantly to the dynamical evolution of the Milky Way, which reveals itself as much more complex than anticipated.

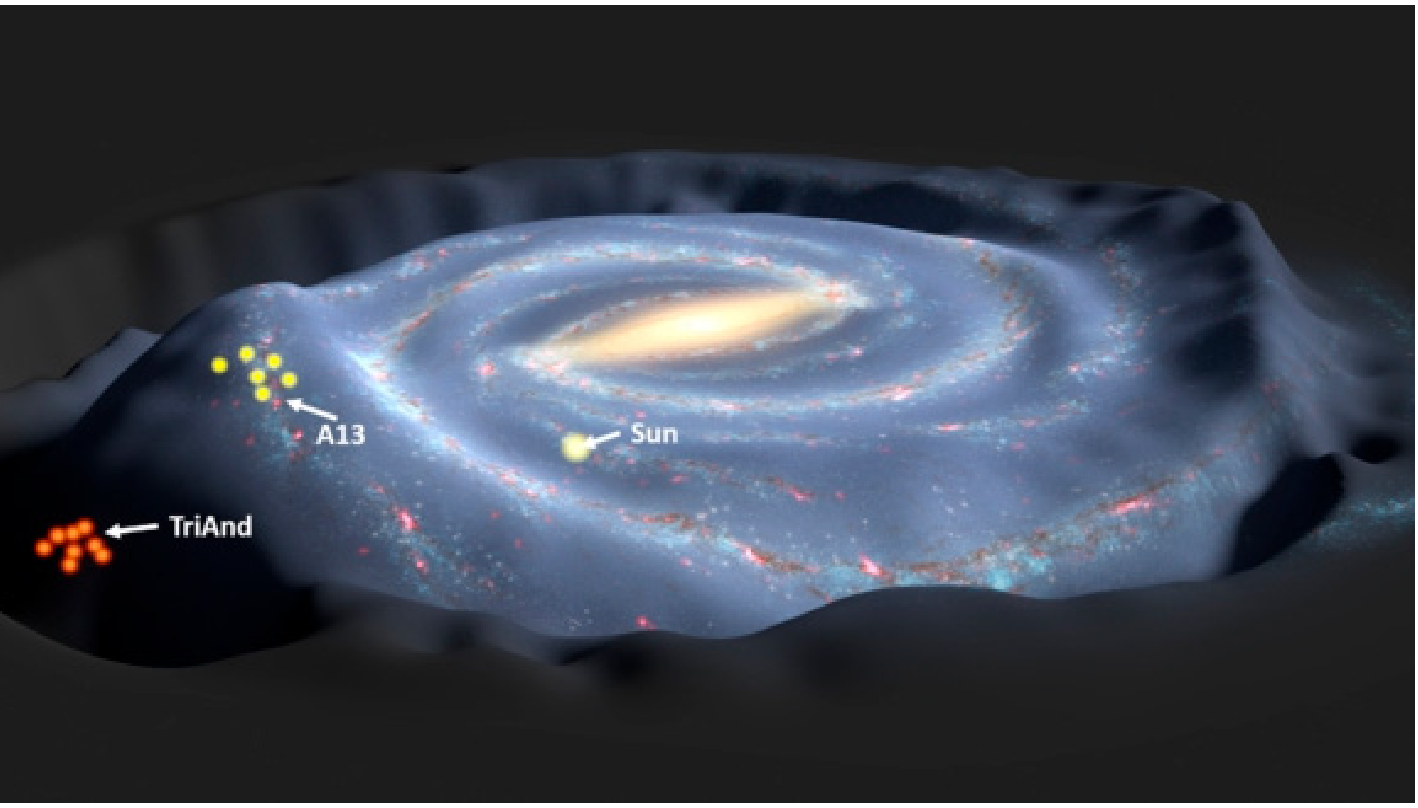


Figure 48: The A13 and TriAnd overdensities, and galactic oscillations of the Milky Way.
Credit: T. Mueller/NASA/JPL-Caltech

Contact person:

ICE
Aldo M. Serenelli, Faculty
aldos@ieec.cat

What gamma-ray pulsars are X-ray bright and why?

A new theoretical pulsar emission model has been developed in order to prognosticate the possibility of detecting X-rays emission of a gamma-ray pulsar.

Pulsars are dense, magnetic relics of massive stars and are amongst the most extreme objects in the Universe. Originally detected through their radio emission, pulsars are now known to also emit other types of radiation. Some of this emission is standard thermal radiation – the type that everything with a temperature above absolute zero emits. But in pulsars, non-thermal radiation can also be created by synchrotron emission and curvature emission. Both processes involve charged particles being accelerated along magnetic field lines, causing them to radiate light that can vary in wavelength from radio waves to gamma-rays.

The IEEC researcher at ICE Diego Torres has developed a model that combines synchrotron and curvature radiation to predict whether pulsars detected in gamma-rays could also be expected to appear in X-rays.

Despite the extreme precision of the observations and the underlying complexity of the processes involved, just four physical parameters suffice in the model to fit the spectrum of all gamma and/or X-ray pulsars known, disregarding whether they are normal or millisecond pulsars, detected in X-rays, gamma-rays, or both.

When analysing the fits for all pulsars, relevant correlations of the model parameters appear, explaining the different observational behaviours. This model answers at once what process is behind the emission spectra and how the spectral variety arises. It explains intricacies such as why flat spectra at low and high energies has been detected. Moreover, it provides a predictive tool by which to identify new X-ray pulsars.

Together with a team led by Jian Li, Torres selected three gamma-ray emitting pulsars that they expected, based on the model, to shine in X-rays. Not only did they detect X-ray pulsations from all three of the pulsars, but they also found that the spectrum of the X-rays detected was exactly as predicted from data having 6 orders of magnitude larger energy.

This discovery already represented a significant increase in the total number of pulsars known to emit non-thermal X-rays and helps us better comprehend the interaction between particles and magnetic fields in pulsars and beyond.

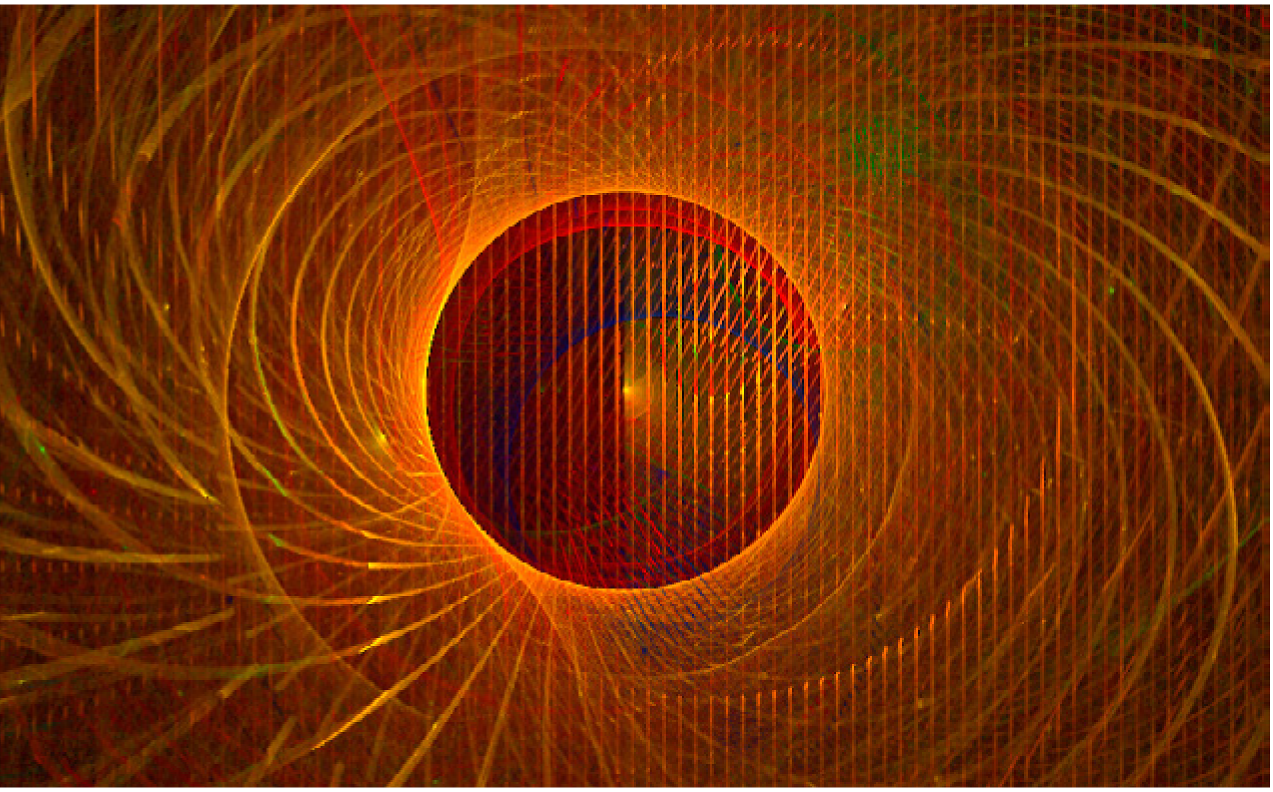
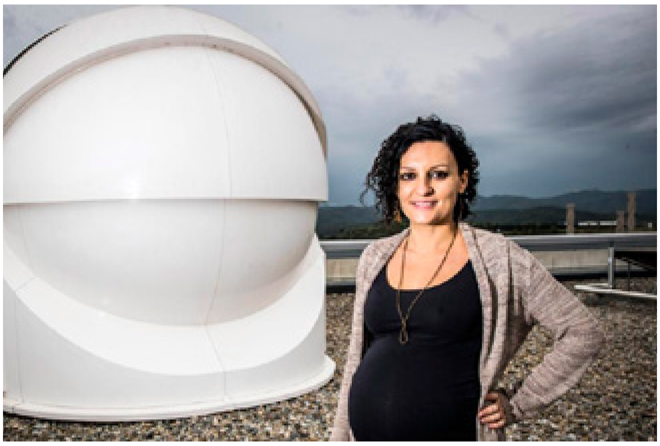


Figure 49: Artistic representation of a pulsar, with its chaotic magnetosphere and the twist of the magnetic lines. Credit: D. F. Torres/Jwidlfire v. 3.30

Contact person:
ICE
Diego F. Torres, Faculty
dtorres@ieec.cat

Margarida Hernanz (ICE) designated co-PI of the Wide Field Monitor instrument to be on board the Chinese-led eXTP (enhanced X-ray Timing Polarimetry) mission.

ARIEL, in which Ignasi Ribas (ICE) is co-PI and leads the Spanish contribution, selected as ESA's M4 science mission.

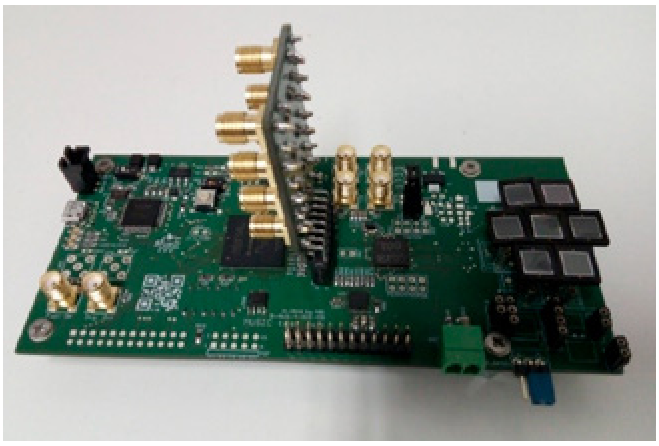


Nanda Rea (ICE) awarded with the Premi Nacional de Recerca Talent Jove 2017 prize for her discoveries about neutron stars.

Jordi Torra (ICCUB, deceased) distinguished with the Medalla Narcís Monturiol 2018 medal for his contribution to ESA's space astrometry missions Hipparcos and Gaia. In the picture, Àngels Ferrer, Jordi Torra's wife, receiving the award.

Inauguration of the NanoSat Lab facilities (CTE), with a team formed by UPC's Telecom and Electronics students and faculties.

I. Ribas (ICE) awarded with the Premi Ciutat de Barcelona de Ciències Experimentals i Teconologia 2018 prize for his discovery of the Earth-like exoplanet Barnard's Star b.



ICCUB signed an agreement with the company Scientifica International, SLU to collaborate in high-tech projects and bring the technologies developed at ICCUB to the market.

Collaboration with the organisation of professional meetings

The 2018 Conference on Strong and ElectroWeak Matter (SEWM 2018) took place from 25 to 29 June 2018 at CosmoCaixa Barcelona, organised by researchers from IEEC at ICE and ICCUB. The meeting had about 90 registered participants.

The focus of the conference was the theory of the Standard Model and beyond at finite temperature and density and in and out of equilibrium, including applications to cosmology, astrophysics and relativistic heavy-ion collision experiments. In the framework of this congress, Professor Barry C. Barish, 2017 Nobel Laureate in Physics, offered an open outreach conference at CosmoCaixa on the discovery of gravitational waves, where he discussed his personal involvement in this historical event for the whole of Physics.

Figure 50: Upper left: Open conference by Prof. Barry Barish at Cosmocaixa. Upper right: Group picture of participants in SEWM 2018. Below: Opening session of the XIII Scientific Meeting of the Spanish Astronomical Society (SEA). Credit: SEA.

IEEC acted as sponsor of the XIII Scientific Meeting of the Spanish Astronomical Society (SEA), which was held from 16 to 20 June 2018 in Salamanca. As on previous occasions, the idea behind this meeting is to create a forum for scientific discussion, where the most recent results can be presented and debated, to promote new lines of collaboration, and to encourage the community to organise itself to address future challenges. The conference is designed as a meeting place where any astronomer finds something interesting and where young members can advance their research careers.

Collaboration with the organisation of Summer Schools

The 2nd Institute of Space Sciences Summer School was held in July 2018. This series of international schools is organised by ICE with the collaboration of IEEC. The second edition was dedicated to Gravitational Wave Astronomy. The main goal of the school was to present the basic foundations of Gravitational Waves: From the detection principles and technology, to the revolutionary science that can be made and its impact on Astrophysics, Cosmology, and Fundamental Physics; including the modeling of the gravitational-wave emission and the data analysis techniques. There were 39 participants at the Master's and PhD level from 13 different countries.

Figure 51: Left: Opening session of the Summer School with C. F. Sopuerta and I. Ribas.
Right: Group picture of the participants in the ICE Summer School.

Figure 52: A group photo of the attendees of the Technoweek.

The Barcelona Technoweeks are a series of meeting point events around a technological topic of interest for both academia and industry, organised by ICCUB in collaboration with IEEC.

They include comprehensive multidisciplinary keynote presentations by world experts that are combined with networking activities to foster collaboration among participants. The third edition of the Technoweek, held in July 2018, included a course on solid state radiation detection, from physics and electronics fundamentals to the state-of-the-art methods in radiation (X-ray, gamma-ray, charged particle) and visible light detection and applications. Lectures, a participant poster session and presentations from industry professionals were combined with social events. The programme included a series of practical laboratories on medical imaging, hybrid pixel detectors and Monte Carlo simulation tools for photon-electron interactions with matter. The third Technoweek was aimed at researchers, postdocs, PhD students and industry professionals, working in related fields: particle detectors, astronomy, space, medical imaging, scientific instrumentation, material analysis, neutron imaging, process monitoring and control, etc. The meeting offered a good opportunity for young researchers to meet with senior experts from academia and industry.

Young Professionals in Space (YPS) is a Summer school that was held in July 2018, organised by CTE with the collaboration of IEEC. It is an initiative to bring together scientists, professionals, engineers, industry leaders and space agencies in a single space to discuss recent research advances, technical advances, existing opportunities and emerging space technologies.

Figure 53: A group photo of the participants in the Young Professionals in Space Summer School at UPC.

Figure 54: Preparing the Cansats (left) and participants looking out for the CanSats after their launch (right).

PHD Theses

Author: **Maria Teresa Atienza García**
Department/Institute: Universitat Politècnica de Catalunya. Departament d'Enginyeria Electrònica
Title: Identification and Control of Diffusive Systems Applied to Charge Trapping and Thermal Space Sensors
Date: 13 February 2018
Director: Manuel Domínguez-Pumar and Vicente Jimenez Serres

Author: **Carlos Eduardo Moyano Cambero**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Genètica i de Microbiologia
Title: Physico-chemical properties of chondritic meteorites: clues on the origin and evolution of their parent bodies
Date: 6 July 2018
Director: Josep Maria Trigo-Rodríguez

Author: **Daniel Galindo Fernández**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Study of the extreme gamma-ray emission from Supernova Remnants and the Crab Pulsar
Date: 27 July 2018
Director: Josep Maria Paredes i Poy and Roberta Zanin

Author: **Ali Jasim Mohammed**
Department/Institute: Universitat Politècnica de Catalunya. Departament de Física
Title: Dynamics and Physical Processes Involving extreme Temperatures in the Iberian Peninsula and Iraq
Date: 3 October 2018
Director: David Pino González and Marta Alarcón Jordán

Author: **David Chaparro Danon**
Department/Institute: Universitat Politècnica de Catalunya. Departament de Teoria del Senyal i Comunicacions
Title: Applications of L-band missions for environmental research
Date: 15 October 2018
Director: Maria Piles Guillem and Mercé Vall-llossera Ferran

Author: **David Gómez Casco**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Telecomunicació i Enginyeria de Sistemes
Title: Non-coherent acquisition techniques for high-sensitivity GNSS receivers
Date: 6 November 2018
Director: Gonzalo Seco Granados and José Antonio López Salcedo

Author: **A. V. Timoshkin**
Department/Institute: Tomsk State Pedagogical University
Title: Fluid models of accelerating Universe
Date: 8 November 2018
Director: Sergei Odintsov

Author: **Jorge Querol Borrás**
Department/Institute: Universitat Politècnica de Catalunya. Departament de Teoria del Senyal i Comunicacions
Title: Radio frequency interference detection and mitigation techniques for navigation and Earth observation
Date: 9 November 2018
Director: Adriano José Camps Carmona

Author: **Manuel Moreno Ibáñez**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Física
Title: Impact hazard associated with large meteoroids from disrupted asteroids and comets
Date: 23 November 2018
Director: Josep Maria Trigo-Rodriguez and Maria Gritsevich

Author: **Daniel del Ser Badia**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: TFAW: Noise filtering through the use of the Wavelet Transform in Astronomy Photometric Data
Date: 21 December 2018
Director: Octavi Fors Aldrich and Jorge Núñez de Murga

IEEC participates in Sónar Festival

Sónar is a festival of electronic and experimental music based in Barcelona that celebrated its 25th anniversary in 2018 with a call for extraterrestrial intelligence. Under the name "Sónar Calling GJ273 b", the festival organised the first series of radio transmissions in history sent to a nearby potentially habitable exoplanet and containing specially-composed music. Sónar and IEEC established a collaboration by which IEEC agreed to provide scientific advice on various aspects. Such aspects included the identification of a suitable target for the transmission, the securing of a powerful transmitting antenna, and the design and encoding of the transmitted messages.

The transmitting facility was identified by IEEC. There are only a dozen antennas around the world that meet the necessary requirements (mainly have a sufficiently powerful emitter), and access is not straightforward. Negotiations led to the establishment of an agreement with EISCAT to use a 32-m radar antenna in Tromsø (Norway). Once the facility was secured, IEEC performed the selection of a target that could be observable from the high latitude of the antenna. The optimal target would be a nearby star with at least one planet within the stellar habitable zone that could therefore potentially sustain life on its surface. After extensive evaluation, the selected target was GJ 273 (Luyten's Star), only 12.4 light years from Earth, which was found to host two rocky planets, one of them, known as GJ 273 b (or Luyten's Star b), being potentially habitable. IEEC also dealt with the most technical aspects of the transmission. The message could not be limited to a simple digital music transmission disregarding whether potential recipients would be able to decode it. IEEC analysed the problem, from the point of view of interstellar communication (emission power, bit rate, etc.) and from the point of view of the content of the message, trying to maximise the probability of detection and decoding by a possible extraterrestrial intelligence.

To maximise the chances of reception and identification, the transmission was performed on three consecutive days, roughly at the same time. The message started with a simple and "artificial" signal to highlight its non-natural (or intelligent) origin. The design, performed by IEEC, was done under the premise of a "self-decoding message", so that the message itself provides increasingly complex information.

There were two transmission events, one on 16, 17 and 18 October 2017, and the other one on 14, 15 and 16 May 2018, from the EISCAT antenna in Tromsø.

The structure of all transmitted messages, which lasted for about two hours, were identical, starting with a “Hello” header, containing sequences of prime numbers, followed by a tutorial, and finally encoded music. For the first transmission, IEEC, in collaboration with METI International (Messaging Extra-Terrestrial Intelligence), designed a small digital music tutorial, providing basic concepts such as frequencies and harmonics. For the second transmission, the tutorial was designed in collaboration with Canadian astrophysicist Dr. Yvan Dutil who, back in 1999 and together with his colleague Stéphane Dumas, defined a small “dictionary” of symbols or concepts, each described with an image of a few pixels. The tutorial section of the message presents the different concepts step by step, as if we were teaching a baby to speak. The main body of the message, which is the only part that changed from transmission to transmission, contained 38 musical pieces curated exclusively by Sónar and created by artists related to the festival. Considering the very slow data rate of only 500 bits per second, the musicians composed pieces lasting just 10 seconds and of very low digital sound quality.

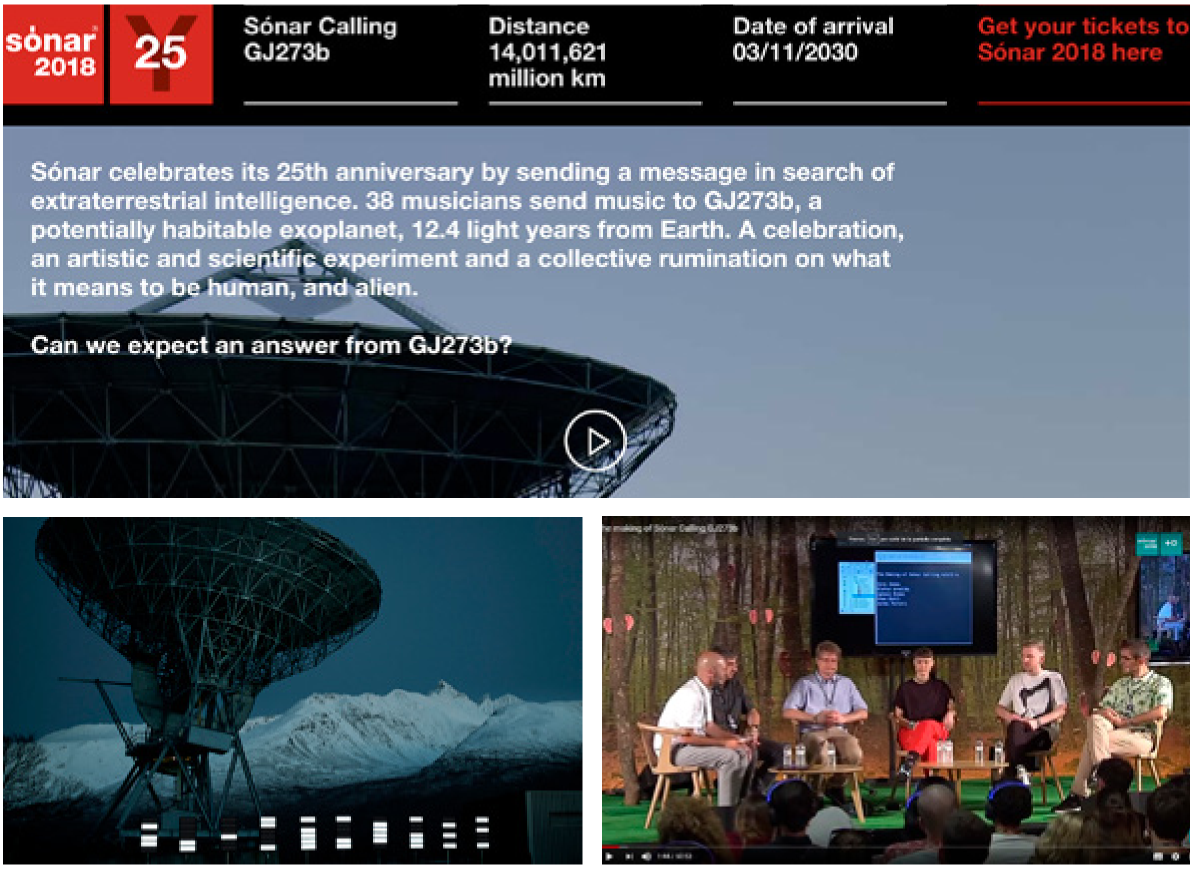


Figure 55: Left: EISCAT 32-m antenna in Tromsø, the transmitting facility. Right: “The making of Sonar Calling GJ 273 b” event at Sonar+D. From left to right: Lluís Nacenta (Hangar director & Sonar advisor), Ignasi Ribas (IEEC), Yvan Dutil (tutorial design), Zora Jones (musician), Ólafur Arnalds (musician) and Jordi Portell (IEEC).

Unlike the majority of previous communications, the message was designed with scientific and technical rigour. From a scientific point of view, Sónar Calling GJ 273 b was unique as it directed a transmission to a specific nearby exoplanet that may offer the necessary conditions to host life. The encoding, cadence and power used to send the message were also unique and significantly increase the chances of it being received and understood by a non-terrestrial intelligence. The design of the message by IEEC was propaedeutic: each section of the message contains the necessary information to decode the next section. The message contained both basic information about humanity and several pieces of music. From a musical standpoint, this project was innovative due to the active participation of a significant number of renowned musicians who created special musical pieces to be sent to Luyten's Star b. The answer, should this happen, could arrive in just 25 years, coinciding with the 50th anniversary of the Sónar festival.

IEEC at the Sónar+D and Maker Faire with "How to build a Nanosat" workshop

The Nanosats group at IEEC prepared a workshop that was held both at the Sonar+D festival (14 June) and the Maker Faire (16 June). The workshop at Sonar+D began with a presentation on nanosatellite technology followed by a hands-on session in which groups of 4-5 people worked on the construction of a full-scale small satellite model. IEEC experts guided the participants to familiarise themselves with the electronics, mechanical and software components and their basic functions: video camera, Wi-Fi communication, LED lighting etc. A simulated launch with helium balloon of the nanosatellites built by the teams was done at the end of the session. The activity that IEEC carried out at the Maker Faire was a presentation of live nanosatellite models and there was a series of practical demonstrations of nanosatellite technology.

Figure 56: Inauguration of the series of conferences "The new frontiers of Astrophysics". Credit: CosmoCaixa.

IEEC collaborates with CosmoCaixa in the organisation of a series of conferences

The series of conferences "The new frontiers of Astrophysics" was held from 4 April to 9 May in CosmoCaixa and was jointly organised by IEEC and Fundació La Caixa. There were four conferences given by researchers invited by IEEC that addressed hot topics of research within Astrophysics.

The titles and speakers were:
- Pulsars: magnetic monsters and future GPS for interstellar trips, by Nanda Rea;
- Observing the light of the farthest universe, by Licia Verde;
- The dawn of gravitational wave astronomy, by Alicia M. Sintes Olives;
- The frozen moons of the gas giants as possible habitats, by Athena Coustenis.

The conferences had excellent attendance, with a varied audience of about 200 people of all levels and ages.

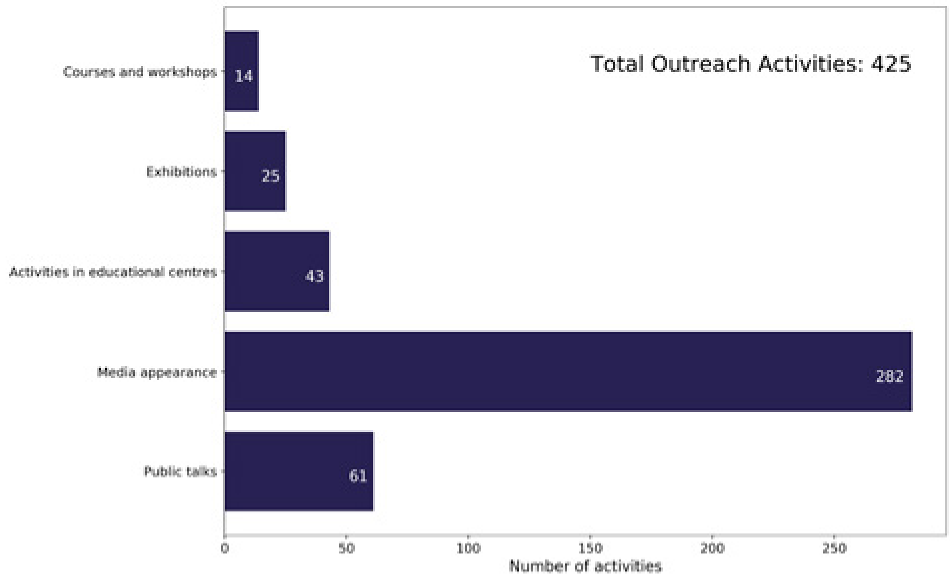
IEEC participates in the organisation of the FIRST LEGO League

On 2018, members of IEEC at UPC participated in the organisation of a new edition of the FIRST LEGO League (FLL), the international robotics tournament for young people. More than 200 primary and secondary students participated at the qualifying rounds held at the Campus North of Barcelona on 27 January and 3 February 2018.

Figure 57: 200 primary and secondary school children have participated in the FIRST LEGO League organised by UPC. Credit: UPC.

Organised by UPC in collaboration with the Scientia Foundation, FLL is a tournament in which the students research a real-world problem such as food safety, recycling, energy, etc. and are challenged to develop a solution. Using LEGO MINDSTORMS Education robots, they must design, build and program a robot, which must then compete on a table-top playing field. The challenge of the 2018 edition was called HYDRO DYNAMICS and it was dedicated to the human water cycle, aimed at improving the way we look for, transport, use or dispose of water.

Outreach statistics



Contact person: comunicacio@ieec.cat

Figure 56: Messier 16, Pillars of Creation. Credit: Montsec Astronomical Observatory.


IEEC
Institut d'Estudis
Espacials de Catalunya
Generalitat de Catalunya
Universitat de Barcelona
CSIC
UAB
Universitat Autònoma de Barcelona
UPC
Institució CERCA
Centres de Recerca de Catalunya