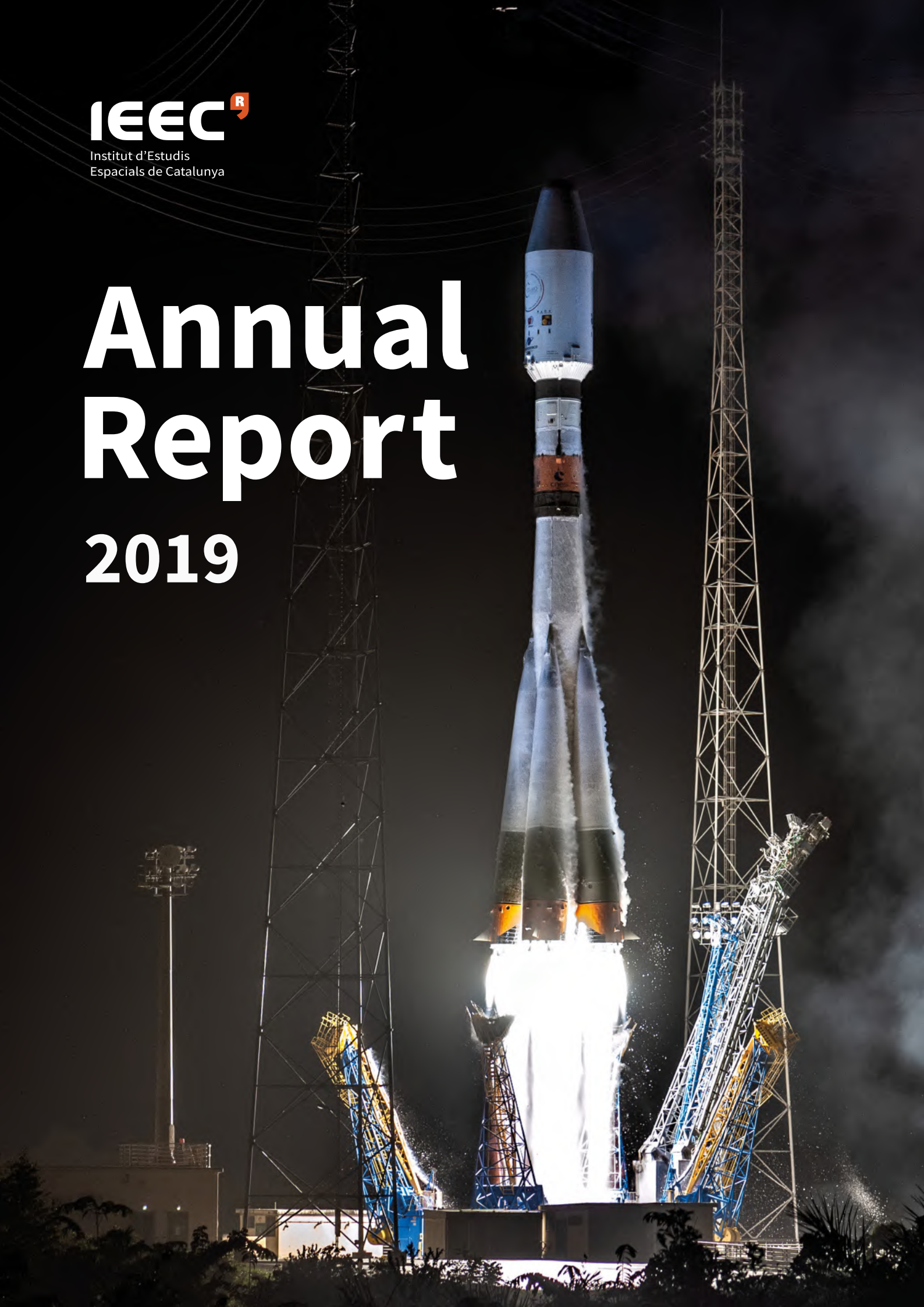
IEEC
Institut d'Estudis
Espacials de Catalunya

Annual Report 2019



Cover image: Liftoff of the Soyuz VS23 vehicle carrying onboard the CHEOPS mission. Credit: Arianespace. In December 2019, the CHEOPS mission for the study of exoplanets was launched from French Guiana. This was one of the last events of the year and illustrates how the combined effort of many people with different roles and expertise can make a dream happen. Besides the difficulties, dreams can be achieved!

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IEEC

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Preamble

The document in your hands provides an account of the main results, accomplishments and events that have been carried out by IEEC and its members throughout 2019. The year started off with the sad passing of former Director Professor Jordi Torra on February 26. Prof. Torra was a member of the ICCUB and University of Barcelona and acted as Director of IEEC from 2015 to 2017. He gave IEEC a push that, among many other things, kicked off the nanosatellite program, which, as you will see below, is now gaining momentum and already attaining successes. He will be deeply missed.

In spite of the sad news, 2019 has been a highly successful year in many aspects. Firstly, we have produced a total of 373 refereed publications according to the Web of Science database, most of them (92%) appearing in the journals with impact factors ranking in the first quartile of their fields, including Nature and Science. Congratulations are in order to Dr. Juan Carlos Morales on receiving the 2019 Premi Ciutat de Barcelona on Experimental Sciences and Technology for his publication in the Science journal!

Besides the sheer number, it is very noteworthy that the publications from IEEC are cited over 4 times more frequently than the world average in their respective areas. Collaboration between the units has also strengthened, as reflected by the number of publications with co-authors from more than one unit, and by the various transversal projects with cross-participation. A selection of research highlights resulting from the publications and also from other technical activities can be found in this volume, and you will see that they cover many of the areas of scientific expertise of IEEC members: dark energy, meteorites, comets, evolved stars, galactic astronomy, galactic dynamics, exoplanet discoveries, pulsars, newborn stars, GRBs at TeV, Gaia mission exploitation, asteroseismology, and so on. This volume also reports on professional meetings that received IEEC support during 2019, and training activities such as Summer schools and PhD theses.

One of the major facilities that IEEC is managing is the Montsec Astronomical Observatory (OAdM) and 2019 has been full of activity. The Joan Oró robotic 80-cm telescope (TJO) has participated in various photometric monitoring campaigns (including exoplanets, asteroids, comets, variable stars, transient sources, etc) that have led to a number of high-profile publications. The TJO has been delivering high-quality data for the satellite surveillance and tracking (SST) programme funded by the Spanish Centro de Desarrollo Tecnológico Industrial (CDTI) with the new LAIA large-format imager in full operations. Furthermore, the plan to make OAdM a satellite ground station infrastructure is progressing. A new S-band antenna was installed in mid 2019, allowing for data download from nanosatellite missions. OAdM has also been very active in outreach, with talks and events, joint activities with the GeoParc Conca de Tremp, and media appearances.

IEEC members vigorously participate (and have leadership roles) in a variety of space missions and ground-based instrumentation projects, addressing areas such as cosmology, high-energy astrophysics, astrometry, exoplanets, gravitational waves, radio occultations, Earth observation, solar physics, Earth global positioning, etc. IEEC is particularly promoting a subset of key projects that are of special relevance for several reasons but most importantly because they involve participants from several research units. Many developments have occurred in these projects during 2019.

One of the key projects is the development of a nanosatellite platform, which was initially funded via a Producte project from AGAUR and that is currently supported with IEEC structural funds. A group of 15 scientists and engineers from IEEC have been developing a HW and SW platform (high performance computers, software-defined radio module) that can be easily integrated into different missions. In 2019, the group won the “Call to Orbit’’ competition, and their project, 4DCube, may have a launch opportunity in the near future. Thanks to the developed expertise, IEEC has signed a collaboration agreement with the company SatelIoT to provide technical advice in the development of a nanosatellite constellation. Another key project, the Cherenkov Telescope Array (CTA), has had some successful milestones, including commissioning activities of the Large-Size Telescope 1 (LST1) and the implementation of a weather monitoring prototype. And, very importantly, IEEC is participating in the LST2-4 camera tender, (issued by the IAC), which should ensure the availability of funding for future activities within CTA. The IEEC LISA key project group has been pushing the mission forward by entering a more detailed phase of study, particularly by developing a prototype of the LISA temperature subsystem. And, finally, activities within ARIEL, another IEEC key project, have also been hectic, with lots of technical developments in our various subsystems (telescope, electronics & ground segment) aimed at successfully passing the Mission Adoption Review in 2020. This review, together with the improved science definition of the mission, should culminate with the formal adoption of ARIEL also in 2020. A full report of the main developments by these key projects during 2019 is provided here, together with an account of other mission and project milestones in highlight format.

Innovation results have been strong in 2019, with plenty of contracts with industry and space agencies (ESA, CNES, CDTI,...) to deliver hardware and software products, algorithms, and data. Along the same lines, IEEC’s Project Office has been extremely active by promoting new projects and providing support to research groups, including the management of two COST actions. A strong additional push has resulted in an increased number of project submissions and knowledge transfer activities, which you will find duly accounted for in this

report. Another of IEEC's offices, the Communication Office, under the coordination of the company Science Wave, has expanded in 2019 by incorporating Dr. Rosa Rodríguez to the team, who holds various roles and responsibilities. Among these is to keep in contact with IEEC scientists and engineers to carry out outreach and promotion actions. This has led to disseminating many results by IEEC members and to the organization and participation in a large number of outreach activities and media events (literally hundreds), including the Splashdown Festival, the World Space Week, the Maker's Faire, OAdM's Open Doors, Women in Aerospace Barcelona Chapter, among many others.

Another major milestone in 2019 was the celebration of the 1st IEEC Forum on February 6, marking the 23rd anniversary of the foundation of the institute. More than 100 IEEC members and invited participants gathered to share one full day of interesting talks, debates and informal conversations. Given the enthusiastic reception, this event is here to stay and you can already save the dates around Feb 6 every year to meet with IEEC colleagues and to celebrate.

Finally, I would like to close this preamble by warmly welcoming the new members that have joined IEEC during 2019 and by wishing you all a year 2020 full of joy and successes!

Dr. Ignasi Ribas, Director of IEEC
director@ieec.cat

Presentation

The Institute of Space Studies of Catalonia

The Institute of Space Studies of Catalonia (IEEC) is a research institute that was established to promote the development of activities related to space in Catalonia in its aspects of training, research, and innovation. The ultimate goal is to collaborate and participate in the development, promotion, dissemination and transfer of knowledge of all kinds of activities, studies and projects related to space technology and scientific research from and of space, for the benefit of society.

The specific objectives are to:

- Promote astronomical and space research
- Become an internationally recognized 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 to 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 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, each belonging to one of the Trustee institutions, which constitute the core of the R&D activity.

The Research Units are:

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

The Research Units were created and are governed by the rules of their respective academic institutions, and have full scientific and management independence. 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. All senior scientific personnel at IEEC are affiliated staff members from one of the Research Units.

The organisation chart of IEEC is shown in Figure 1. The Board of Trustees is the highest governing board of IEEC. They nominate a Director, 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 on the overall organisation.

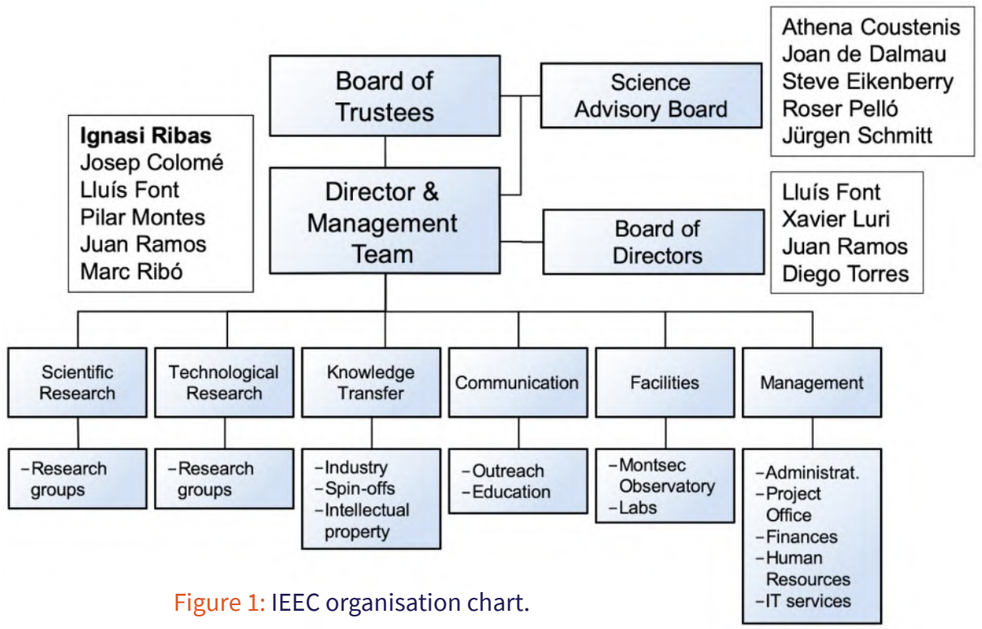


Figure 1: IEEC organisation chart.

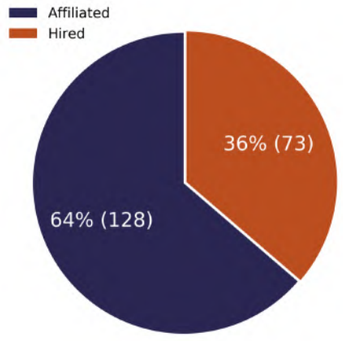
Personnel

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

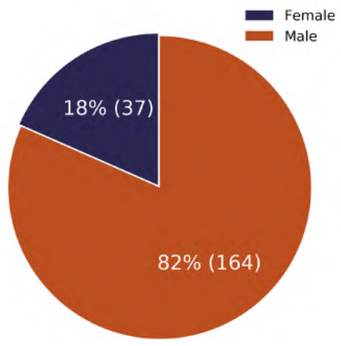
Total personnel: **201**	Male: **164 (82%)**	Female: **37 (18%)**
	Hired: **73 (36%)**	Affiliated: **128 (64%)**

	IEEC	ICE	CERES	ICCUB	CTE	TOTAL
	Core Staff					
Administration & IT & PO	5					5
	Affiliated members					
Research & engineers (faculty)		29 (19)	19 (8)	55 (21)	28 (20)	131(68)
	IEEC contracts					
Administration & services		2		1		3
Researchers & engineers	1	29	1	15		46
PhD Students		11		4	1	16
	TOTAL					
	6	71	20	75	29	201

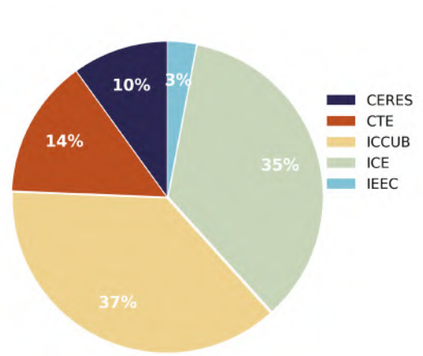
Personnel



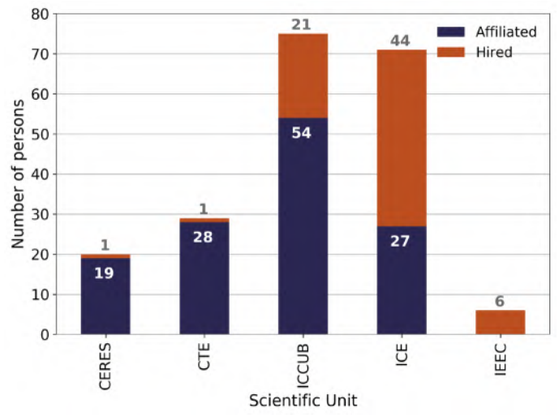
Personnel per work situation



Personnel per gender

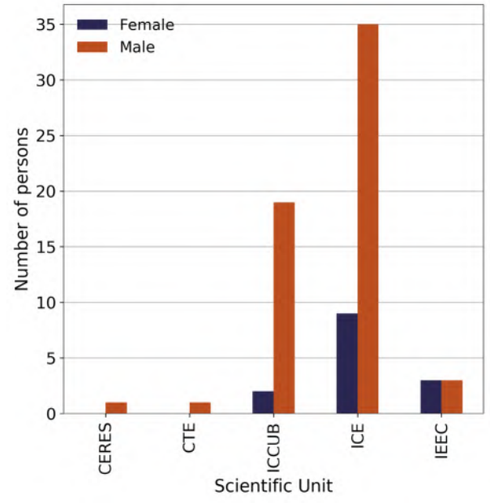


Personnel per scientific unit

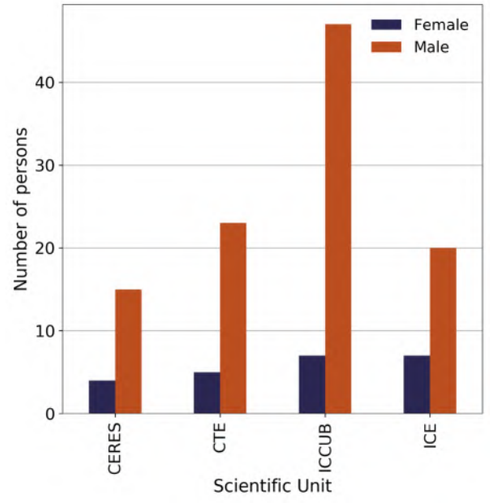


Personnel per work situation and scientific unit

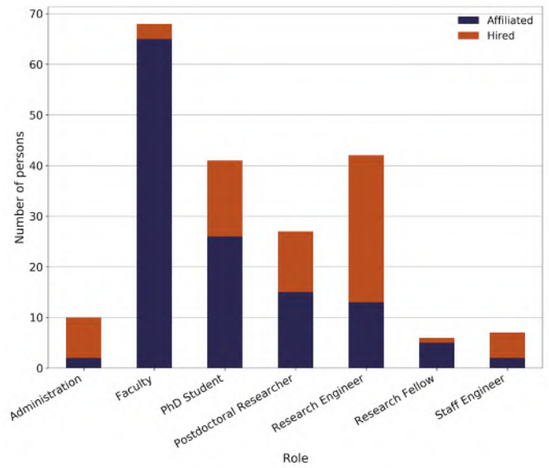
Personnel



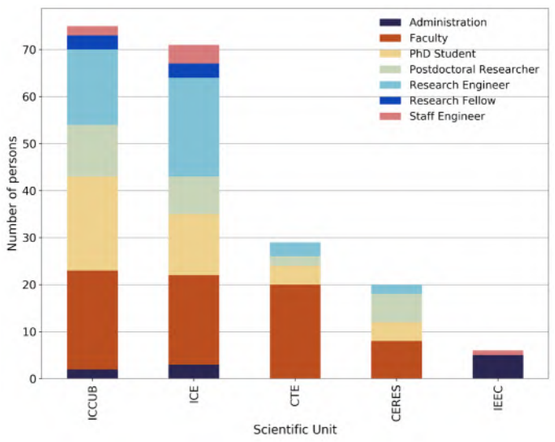
Hired personnel per scientific unit and gender



Affiliated personnel per scientific unit and gender

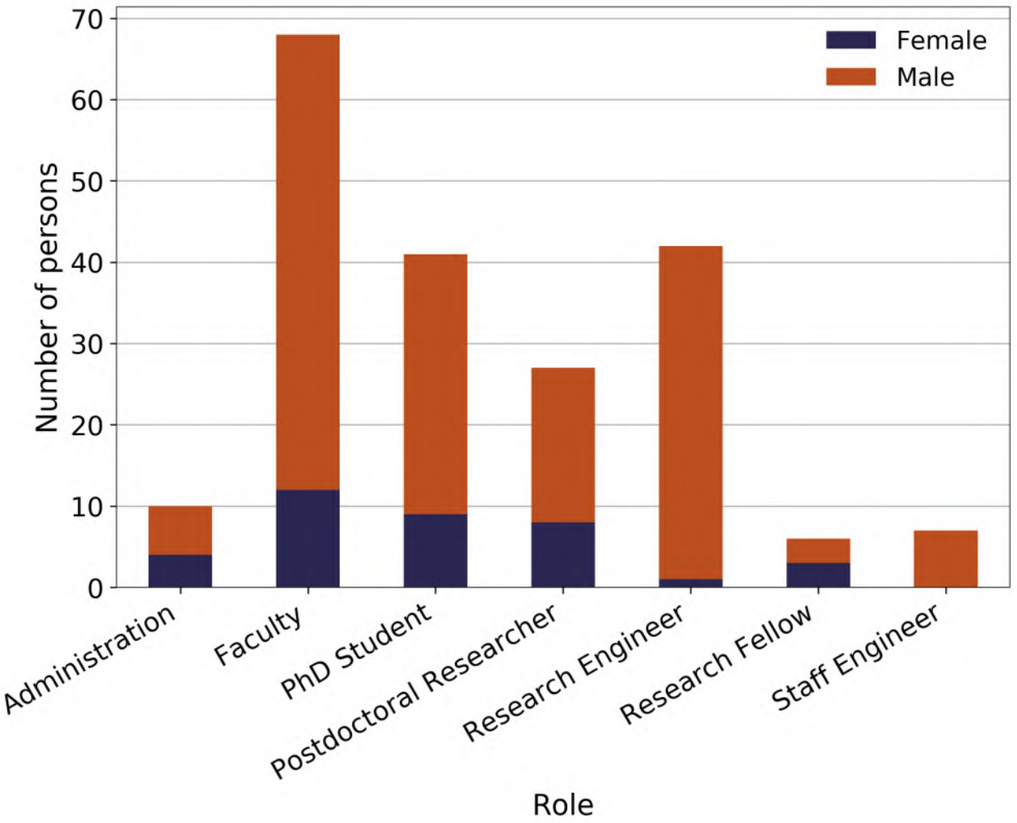


Personnel per work situation and role



Personnel per role and scientific unit

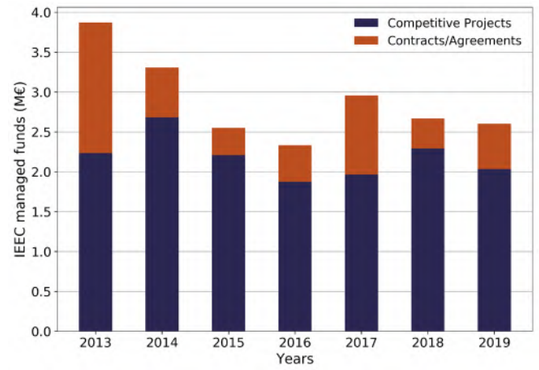
Personnel



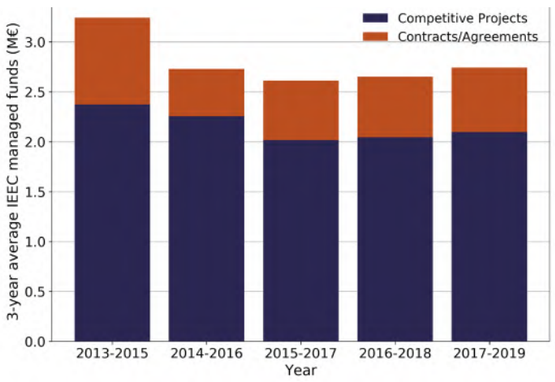
Personnel per role and gender

Projects

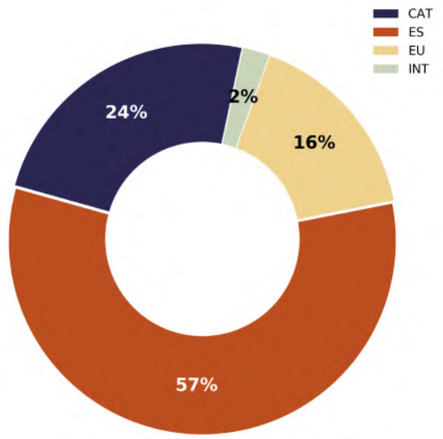
The plots and graphs below show the funding secured and managed by IEEC, including base funding from the competitive projects and contracts/agreements with industry. Data for several years are shown to illustrate the time evolution.



Incomes per year and project class



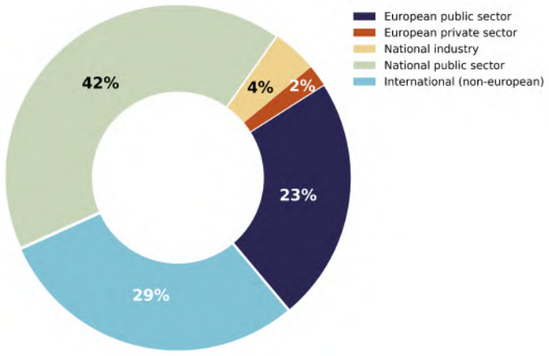
Triennial mean incomes per year and project class



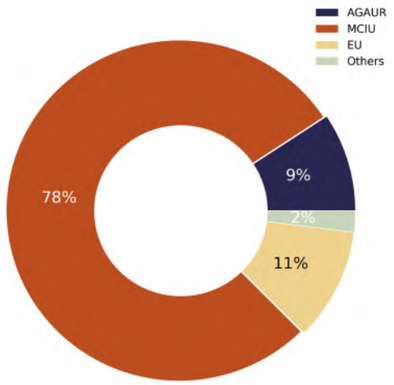
Incomes per geographical area

Contracts/Agreements	Incomes (k€)
European public sector	198.4
European private sector	17.8
National industry	25.3
National public sector	71.7
International (noneuropean)	240

Competitive Projects	Incomes (k€)
AGAUR	188.5
MCIU	1588.1
EU	215.6
Others	40.3



Incomes from contracts/agreements



Incomes from competitive projects

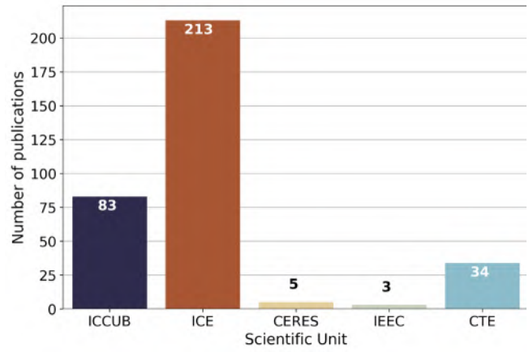
IEEC participates in the following programmes:

- AYA: Astronomy and Astrophyiscs (MCIU Competitive Grants)
- CA: EU Cost Action
- CDTI: Spanish Centre for the Development of Industrial Technology
- CTP: Science Core Technology Programme (ESA)
- ESP: Space Investigation (MCIU Competitive Grants)
- FPA: Particle and Acceleration Physics (MCIU Competitive Grants)
- H2020: EU Framework Programme for Research and Innovation (Horizon 2020)
- MOSAIC: Multidisciplinary drifting Observatory for the Study of Arctic Climate
- PGC: Knowledge Generation R&D Projects (MCIU Competitive Grants)
- PRODUCTE: Product (Gencat AGAUR Competitive Grants)
- ROM-SAF: Radio Occultation Meterology Satellite Application Facility (EUMETSAT)
- RTI: Research Challenges (MCIU Competitive Grants)
- SGR: Research Groups Support (Gencat AGAUR Grants)

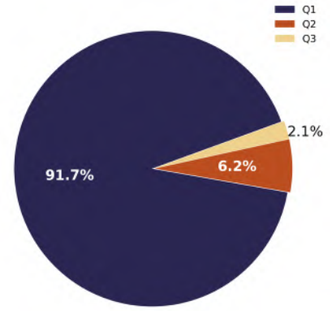
Publications

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.

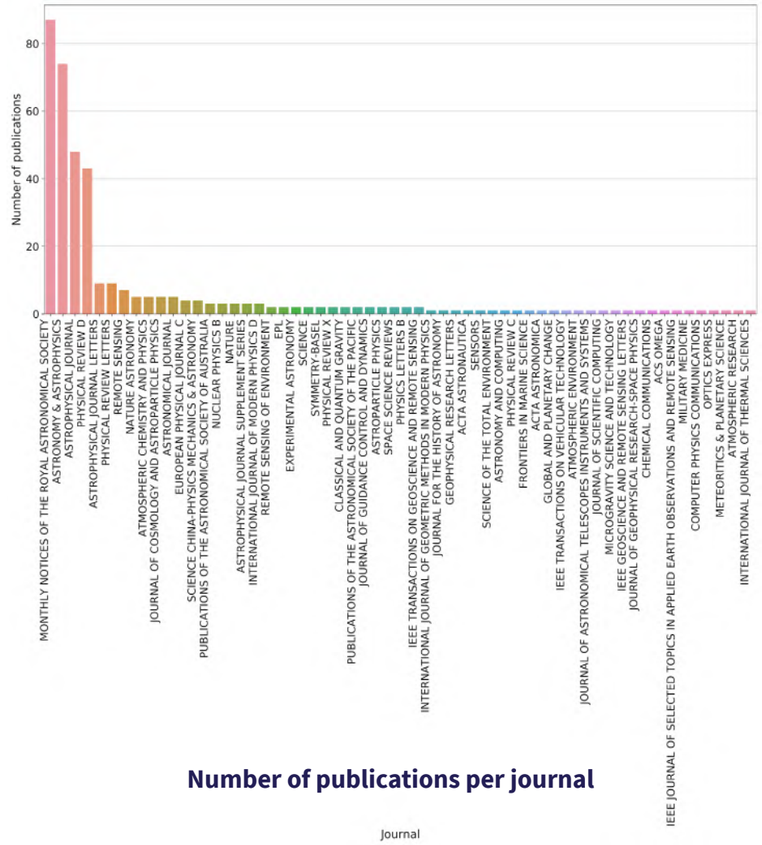
In the total number of publications, there are also included 35 publications done by authors at Universitat de les Illes Balears (UIB).



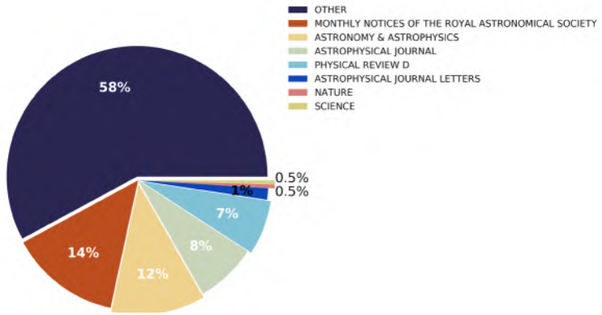
Number of publications per scientific unit



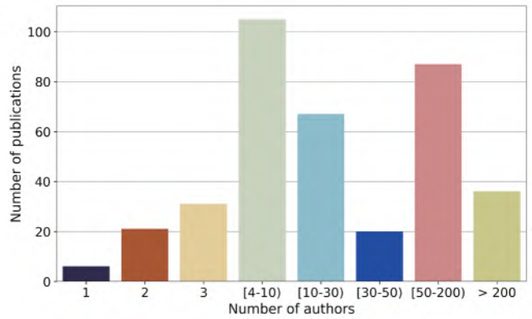
Number of publications per journal quartile



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 = 9 publications
- ICE + CTE = 3 publications

Facilities And Key Projects

Montsec Astronomical Observatory

A 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 altitude in the Montsec mountain range, 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 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 on 24 October 2008, and the first telescope installed has been fully operational since 2010. Joan Oró is the name given to that first telescope, which is still one of the 1-meter-class robotic telescopes most technologically advanced in the world. A decade 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.

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 2019, IEEC achieved different milestones at OAdM. Below we make a summary of these milestones.

Figure 2: View of OAdM displaying the TJO (right) and the TFRM (left) with a clear night sky in the background.

Montsec Astronomical Observatory

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. TJO is equipped with a high-performance CCD camera for astronomical imaging (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, in combination with a suite of software modules developed in-house, like the telescope scheduler (ISROCS), the data pipeline (ICAT) and the task execution control (OCS). Low-level telescope and dome control are conducted through the TALON software. Finally, the management of proposals submitted by users is conducted with a web application called MUR that is accessible at mur.ieec.cat.

The Large Area Imager for Astronomy (LAIA) CCD camera is an Andor iKon XL 230-84. It is installed at the Cassegrain focus of the telescope and can be used together with a filter wheel. The 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 with a pixel size of 0.4”x0.4”.

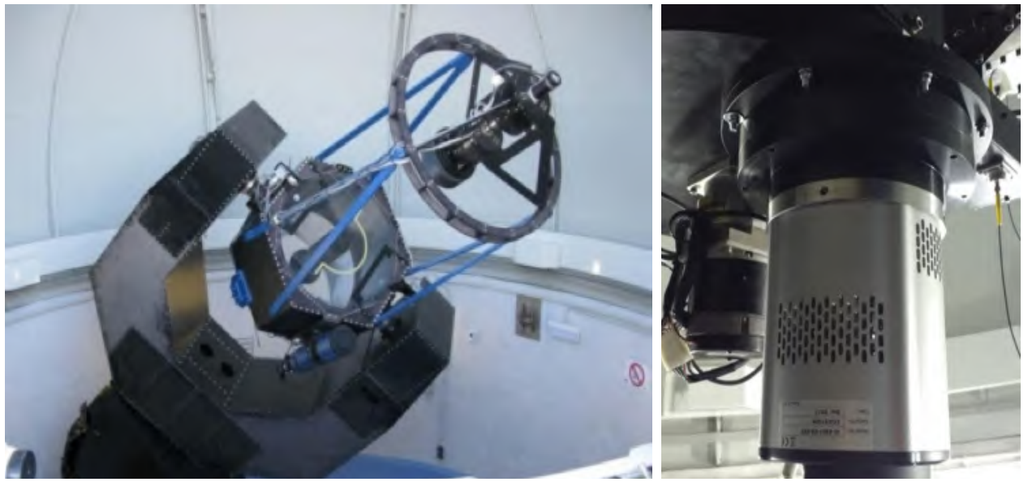


Figure 3: Left: The Joan Oró Telescope (TJO). Right: The LAIA camera.

The ARES spectrograph is composed by two VPHs developed by Wasatch Photonics, providing the two spectral windows and maintaining a high overall throughput. 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). ARES, installed in 2018, opens the door to using the TJO for a variety of new science cases. Shared-risk scientific observations have started in 2019, already showing interesting results. 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.

Since 2013, the TJO has been 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 2019 to the international astronomical community, with the sole requirement of maximising the scientific and technical performance of the instrumentation. In this regard, IEEC has 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 of detecting and tracking satellites and space debris. The TJO has been participating in this network with tracking mode service since then.

At the end of 2019, OAdM had 127 registered users at MUR, 54 of them from IEEC, 28 from other Spanish institutions, and 45 from international institutions. This represents about a 25% increase in the number of registered users compared to 2018. This is primarily due to the new scheme of two calls for proposals implemented in 2019, with more advertising inside IEEC, at Spanish level and with international collaborators. This scheme, together with the new instrumentation, increased the number of proposals received, from 9 per year during 2016-2018 to 13 per semester in 2019 (most of them resubmitted in the second semester). This also increased the telescope pressure time, with a fraction of requested over available scientific time of about 1.2. In addition, TJO also received five proposals requesting Director Discretionary Time (DDT) for urgent and/or relevant observations to be conducted before waiting for the next call for proposals. The TJO, being a robotic telescope with its flexible scheduling, is perfectly suited to react to transient events, new discoveries, etc.

It must be noted that data production and duty cycle improved slightly in 2019 and confirmed a continuous evolution of these parameters.

Observation statistics

- Useful time (night-time hours with good weather conditions): 2092 h (69.1% of total night time)
- Time acquiring data (regardless of quality): 1929h (92.2% of total night-time with good weather)
- Time acquiring useful data: 1804h (86.2% of total night-time with good weather) ➔ Duty cycle

Montsec Astronomical Observatory

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:

- 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 (including GW follow up).

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).

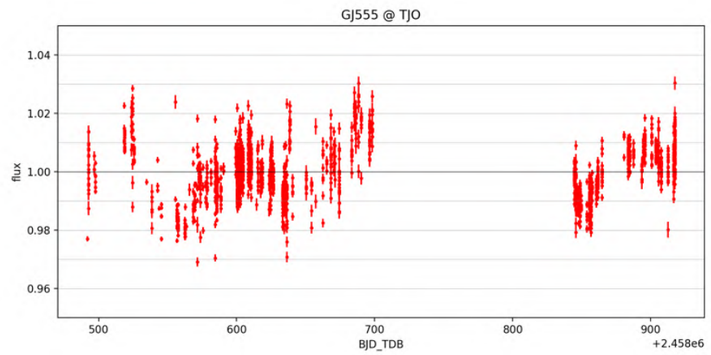


Figure 4: Photometric light curve obtained with LAIA of an R=10 red dwarf star within the CARMENES follow-up program at the TJO, providing a rotational period of 95 d.

Montsec Astronomical Observatory

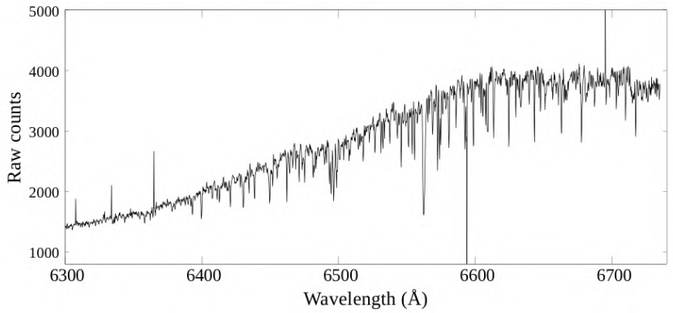


Figure 5: Spectrum of the G=7.4 magnitude supergiant star BD +59 274 obtained with a 30-min exposure with ARES.

During 2019, the TJO participated in different scientific projects, including the study of Solar System objects or interstellar comets, monitoring of exoplanet transits, characterisation of M dwarf stellar activity, monitoring of novae or different types of pulsars in binary systems, studies of newly discovered black hole X-ray binaries, type Ia supernovae, Gaia transients, such as the ones producing microlensing events, or faint galaxies.

It has to be emphasised that 2019 saw an increase in the number of refereed publications using TJO data. In particular, photometric data of the star GJ 3512 was used to contribute to the discovery of GJ 3512 b exoplanet, a result published in the Science journal.

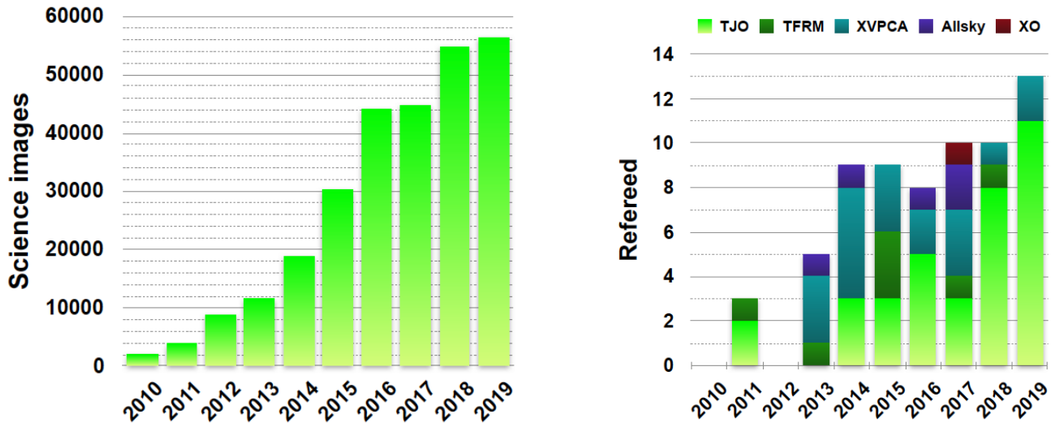


Figure 6: Left: Increasing number of scientific images obtained with the TJO. Right: Refereed publications with OAdM facilities.

In summary, with a very efficient use of the LAIA camera and the start of shared-risk scientific observations with the ARES spectrograph, 2019 has been a very productive year for the Joan Oró Telescope.

Ground station for satellite communication

During the last two years there has been a significant effort towards building a ground station for communication with low-Earth orbit satellites. The privileged ubication of the Montsec Astronomical Observatory free of obstacles in the horizon and a clean electromagnetic enviroment makes this facility ideal for a ground station. An antenna to work in the UHF and VHF bands was installed at OAdM in 2018, together with computing services in the building of the TJO. In 2019, a 3-meter dish S-band RX antenna was also installed to enhance the communication bandwidth.
These antennas are controlled by an automated software in charge of scheduling and data retrieval through an optical fiber connection to the Barcelona Operation Center. A REST API is used to interface with the Operation Center to request passes or download retrieved data.

Figure 7: S-band ground station antenna (with the AllSky Camera visible to its left).

Figure 8: VHF/UHF ground station antenna.

Outreach

During 2019, outreach activities were conducted in Barcelona and Tremp in the context of the Geoparc Conca de Tremp - Montsec, with the goal of promoting the Geoparc and the synergies with other facilities of the Montsec area. An outreach talk about the OAdM was also given at a High School in Balaguer. On the other hand, the OAdM can be visited on a Sunday per month from May to September, provided a reservation has previously been made. During 2019, the OAdM was visited by around 170 people. Regarding social networks, in June 2019 the TJO obtained an image of the Moon that was shared via Twitter in July 2019, to celebrate the 50th anniversary of the landing of humankind on a celestial body. Finally, in September 2019 TJO made observations of the interstellar comet C/ 2019 Q4 (Borisov), which were also shared via Twitter.

Figure 9: Panoramic view of OAdM displaying the TJO (left) the S-band antenna (right) with the Milky Way in the background. Credit: Kike Herrero (IEEC).

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, during the last decades a change in how we access space has taken place. This change has been named “New Space”. The paradigm of a big industry building, launching and operating big satellites has shifted in part to another industry around universities, research centers, startups and small companies that build small satellites, sometimes called nanosatellites (1-10 kg) by their size and mass in contrast to the heaviest satellites with a mass up to 7000 kg (i.e. TerreStar 1, launched by an Ariane 5 in 2009) that can accomplish whole scientific and commercial missions.

In the last years, IEEC has been promoting the emerging New Space benefiting from the know-how and expertise gained in space missions and technologies in the last two decades and is pushing for partnerships that maximize scientific and commercial applications for Catalan industry and academia.

Catalan Cubesat Platform

This project has been one of the capstone projects at IEEC that has embraced the collaboration of 15 researchers and engineers from IEEC at ICCUB, ICE and CTE. It started with a grant from 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. The developed system is based on a high performance computer (OBDH) with and FPGA to control a Software Defined Radio module (SDR) that allows to implement different communication protocols (i.e. GNSS, NB-IoT, Lora, etc.) and RF signal processing. An On Board Computer (OBC) gives support and control for the other two subsystems, OBDH and SDR.

The IEEC is exploring different possible applications, commercial and scientific. One of them is the 4DCube project explained below.

Nanosatellites

4DCube

The IEEC team that was working in the call “Producte” was one of the 10 winners of the ‘Call to Orbit’ competition organized by Open Cosmos Ltd. in partnership with ESA. The competition offers valuable assistance for space applications and technologies to reach orbit helping to move ideas from proof-of-concept to in-Orbit Demonstration and validation readiness.

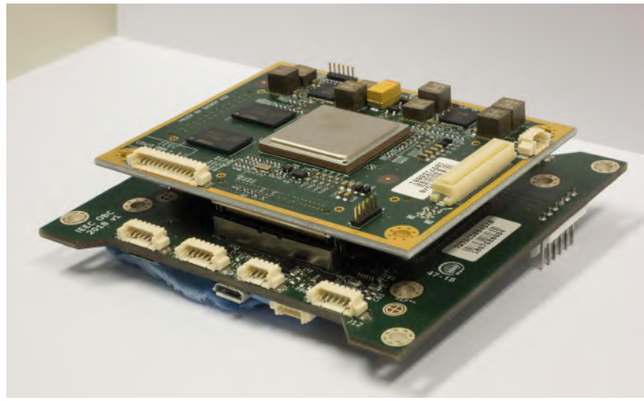


Figure 10: Image of the OBDH and OBC boards of the Catalan Cubesat Platform developed at IEEC.

The project Debris Detection at Dawn and Dusk CubeSat (4DCube) proposes a multi-mission approach to detect and track small-sized debris (<10cm) using optical sensors and advanced image processing algorithms. In particular, composite debris pose a serious risk for other spacecraft, not taken into account so far by debris-associated projects and cannot be detected by radar as the metallic debris. They are considered a major concern due to their large number (over 166 million according to ESA estimations), as well as their significant orbital velocities, which can be as high as 16 km/s. Moreover, they can decompose due to multiple factors (for instance, Ultraviolet radiation), and move independently from the magnetic field lines, among other distinct features compared to metallic debris.

The main objectives of the project are:

Figure 11: Logo of the 4DCube project.

(1) the identification and tracking of small-sized composite debris in Low Earth Orbit (LEO) . Recent analysis have been conducted by IEEC members proving that it is feasible to deploy an in-situ instrument for such purpose based on parallax (Carmona et al. 2017, “CASTOR: An in-situ instrument for small debris detection”)

(2) validate IEEC’s multi-purpose high-performance technological platform for cubesats to be ready for In-Orbit Demonstration tailored for debris detection and characterization thanks to its high throughput capabilities for image processing. This platform has been developed in-house to enable solutions requiring high computing resources.

Nanosatellites

SatelIoT

IEEC signed during 2019 a Collaboration Agreement with the startup SatelIoT. The agreement with Sateliot is to provide them technical advice in the development of a nanosatellite constellation to provide global connectivity for Internet of Things (IoT) applications.

Nanosatlab

The Nano-Satellite and Payload Laboratory (UPC NanoSat Lab) was inaugurated on 21 November 2018. It is located at the Technical University of Catalonia - UPC BarcelonaTech (Campus Nord). 2019 has been a crucial year for the lab. On one side, the Flexible Microwave Payload - 2 (FMPL-2) on board 3Cat-5/A, and the two UHF Intersatellite Links of the FSSCat mission were environmentally qualified, and tested and delivered to the satellite integrator. The launch of FFSCat (explained later) was planned for 9 September 2019, but due to the explosion of the Vega flight VV15, the launch of the flight VV16 was postponed to June 2020.

Figure 12: FSSCat mission.

Figure 13: S-Band antenna installed at Montsec Astronomical Observatory facilities.

On the other hand, a team of students of the UPC NanoSat Lab, led by Prof. Ramos, won the IEEE Geoscience and Remote Sensing (GRSS) 2nd Student Grand Challenge valued as 30 k$ to develop a payload of opportunity for a 3U CubeSat to be launched by UAE in 2021. This payload is an L-band microwave radiometer combined with hyperspectral camera for analysis of soil moisture and downscaling. Moreover the payload, will use the radiometer receiver to make a radio frequency interference map of the Earth.

Additionally, the S-band antenna of the Montsec ground station was commissioned, and it is now fully operational, ready to receive data from FFSCa mission.

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 (~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 visualization tools and give other observatories a standard framework for publishing and delivering services using their data.

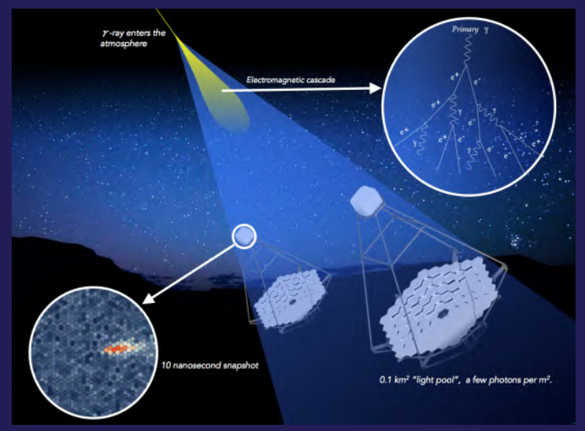


Figure 14: How IACTs indirectly detect a VHE gamma ray. Source: CTA Consortium.

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. A scheme of how IACTs work is shown in Fig 14.

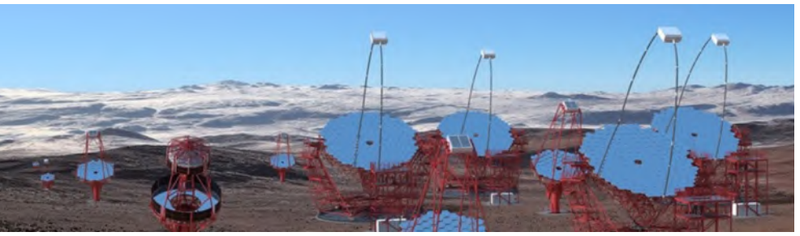


Figure 15: Artistic view of the Southern Hemisphere Site showing the three types of Cherenkov telescopes. Credit: Gabriel Pérez Diaz, IAC / Marc-André Besel, CTAO.

The northern hemisphere array is being constructed at the Roque de los Muchachos Observatory (ORM) in the Canary island of La Palma. It will be more limited in size and will focus on CTA's low- and mid-energy ranges from 20 GeV to 20 TeV, while 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 Size Telescope (SST), with a ~ 4 m diameter, Medium Size Telescope (MST), 12 m diameter, and Large Size 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. Fig. 15 shows an artistic view of the Southern array, which will be constructed near ESOs Paranal Observatory in Chile.

CTA has come a long way since its conception in 2005 when the Spokespersons of the 4 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 (Figs. 16 and 17). 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 gGmbH.

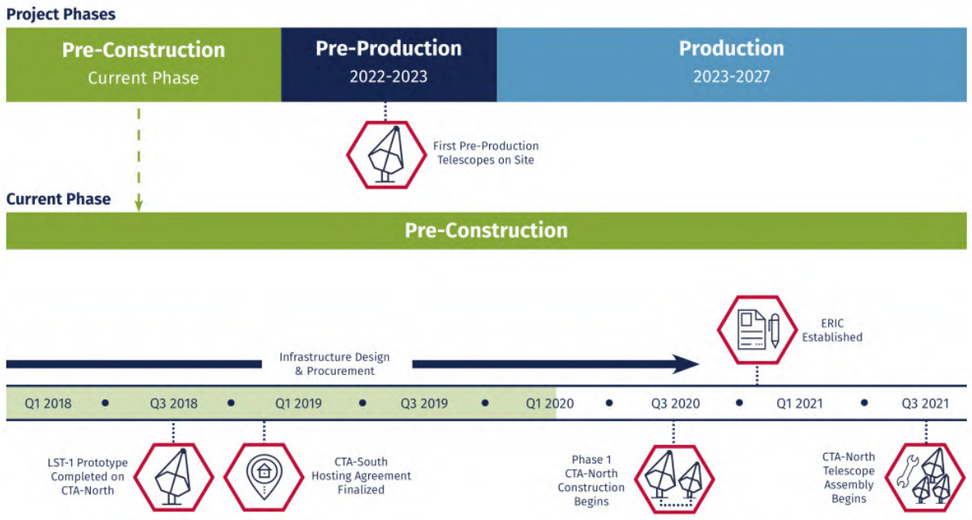
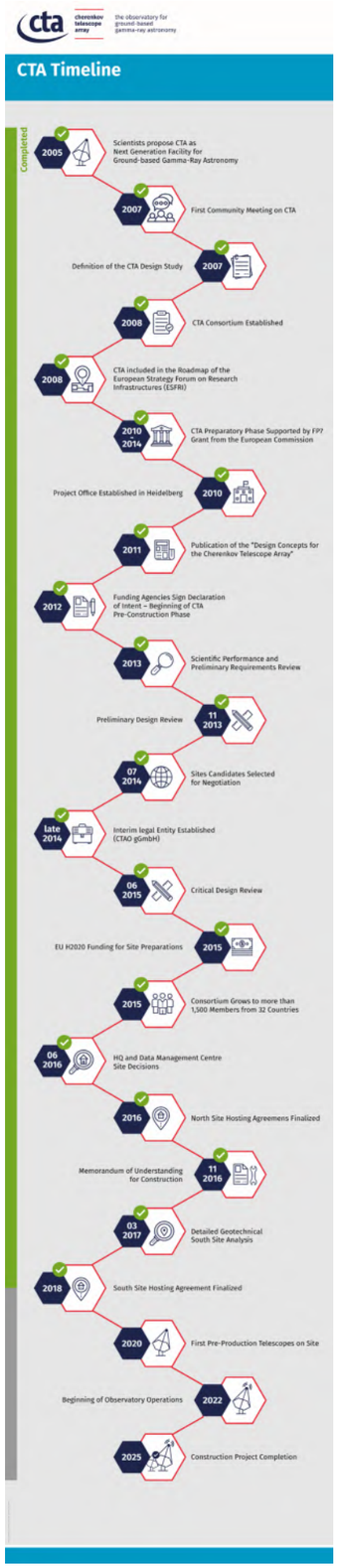


Figure 16: Current status of CTA project. Source: CTA Consortium.



The more than 180 VHE gamma-ray sources detected by the current generation of IACTs (HESS, MAGIC and VERITAS) suggest that extreme particle acceleration is more common in nature than expected. VHE gamma-ray emitters include pulsars, pulsar wind nebulae, binary systems, active galactic nuclei and gamma ray bursts, among others. With the improvement in sensitivity a thousand source detections over the lifetime of the observatory is expected, making a significant impact on three major themes of study: Understanding the origin and role of relativistic cosmic particles, probing extreme environments and exploring frontiers in Physics (searching for the nature of Dark Matter and the possible violation of Lorentz Invariance).

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 units involved in CTA (plus IFAE). They have also been very active helping the CTA Spanish community to push for the candidacy of La Palma as the host site of CTA-North, which was finally selected. The main activities of the IEEC members until 2019 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.). 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 system. Simulations have also been conducted for the CTA studies on binary systems and on prospects for Lorentz Invariance Violation searches.

Figure 17: CTA Timeline. Credit: CTA Consortium.

The Cherenkov Telescope Array

Electronic developments for CTA

IEEC members at ICCUB 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 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. During 2019, a first prototype of the MST-NectarCAM has been tested in Berlin and front end boards with ACTA and L0-trigger ASICs have been produced to fully equip the complete MST1 camera. 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 future upgrades of LST and MST cameras. This is being studied in cooperation with the University of Geneva.

Figure 18: The Large Size Telescope 1 at Observatorio del Roque de los Muchachos

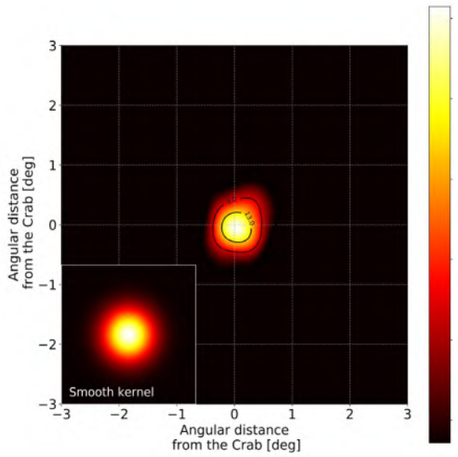


Figure 19: First signal detected from Crab Nebula by LST1 on 23 November 2019

Commissioning of LST1

IEEC members at ICE and ICCUB are members of the first Large Size Telescope (LST1) that was built at the CTA-North site and inaugurated in October 2018 (Fig. 18). LST1 includes developments by IEEC, in particular camera electronics. The commissioning phase is expected to finish in 2020. The first gamma-ray signal was detected on 23 November 2019 coming from the Crab Nebula (Fig. 19), which is considered the standard candle in very high energy astronomy.

The Cherenkov Telescope Array

Construction of LST2, LST3 and LST4 telescope cameras

The construction of the three remaining large-size telescopes (LST2-4) started in 2019, and several tendering calls were triggered from the Institute of Astrophysics of the Canary Islands (IAC) to carry out the construction of the different parts of the system.

The IEEC and the IFAE institutes submitted a joint offer for the delivery of the elements for the construction, assembly, integration and verification of the full cameras. The contract was awarded to this offer and the execution is done by a “Unión Temporal de Empresas” (UTE). The IEEC team at the UB contributes with the camera electronics.

A second offer was submitted by the IEEC, involving teams from ICE and CERES, for the production of the Camera Control Software to allow the data acquisition of the Cherenkov radiation with the camera detector and the calibration light, and the use of weather sensors to provide a high-logic behavior ensuring the correct instrument operation. The tendering process is not resolved at the moment of writing this annual report.

Coordination of CTA Array Calibration and Environmental Monitoring

IEEC members from CERES have been coordinating, since 2013, all activities related with the definition of the strategy for telescope intercalibration, on-line characterization of the atmosphere, monitoring of the absolute energy and flux scales of CTA, monitoring of the environmental conditions, and control of systematic uncertainties. An IEEC-CTAO research agreement has been signed to provide CTAO with services such as assistance with observatory systems engineering, the CTAO costbook, and participation in system reviews. Moreover, IEEC members have actively participated in the definition of the CTA-North array, an activity led by the systems engineering division of the CTA Observatory

Weather monitoring system prototype

IEEC members from CERES are coordinating weather monitoring activities within the Environmental Monitoring project. In 2019 a weather station was acquired and the implementation of a weather monitoring prototype started. Such a prototype includes an interface to the Telescope Control Unit ACS foreseen for the first Large Size Telescope that is being commissioned in La Palma, a stand-alone data acquisition system, and a test bench for prototypes of the CTA monitoring database and of the CTA Graphical User Interfaces. This prototype is being developed in collaboration with the DESY-Zeuthen group of CTA.

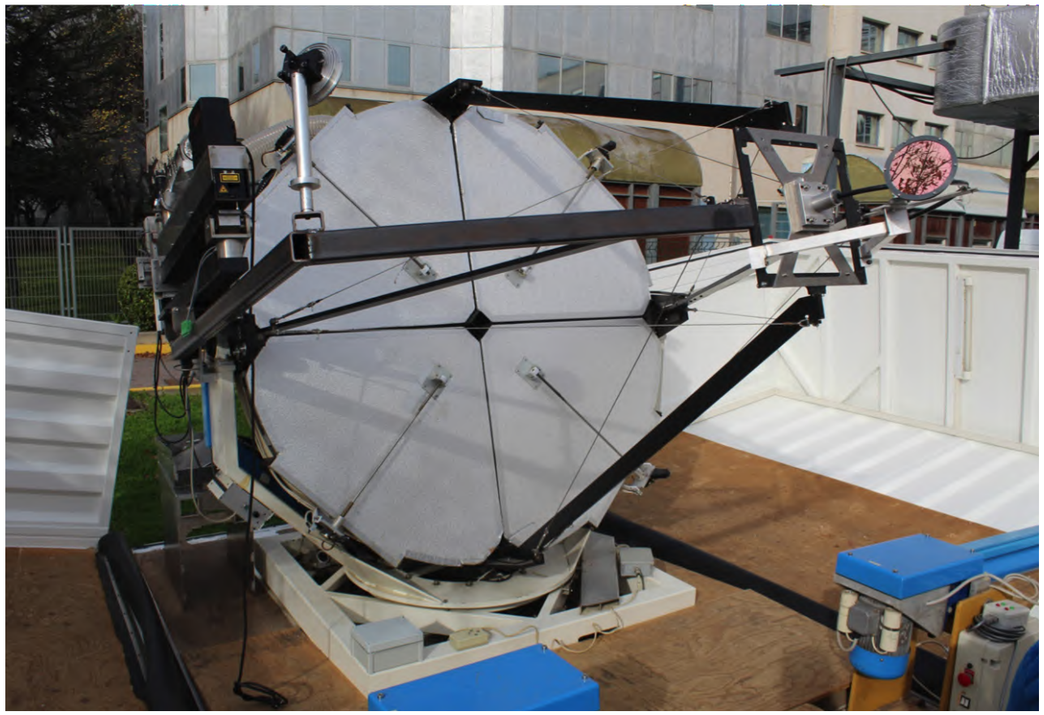


Figure 20: The Barcelona Raman LIDAR prototype.

Commissioning of CTA Barcelona Raman LIDAR prototype

As a part of the Atmospheric characterization project, an advanced Raman LIDAR optimised to fulfil the requirements of CTA is being commissioned at the UAB campus (Fig. 20). Such optimisation led to the inclusion of very innovative elements that are not present in commercial LIDARs. It is a key instrument to obtain, in less than 2 minutes, the range-resolved and wavelength dependent atmospheric transmission along the line of sight of the telescopes, required to estimate the extinction of the Cherenkov light on its way to the telescope reflector surface. In 2019, the prototype was recognised by CTAO as the first official CTA pathfinder instrument. The CTA Barcelona Raman LIDAR prototype is a joint effort of IEEC members from CERES, the IFAE group of CTA, and other CTA members from INFN Padova (Italy) and from the University of Nova Gorica (Slovenia).

Figure 21: The Barcelona Raman LIDAR prototype.

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/multimessenger era of the large infra-structures foreseen in the next decade. In particular, the IEEC unit at the CSIC 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 subarrays 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.

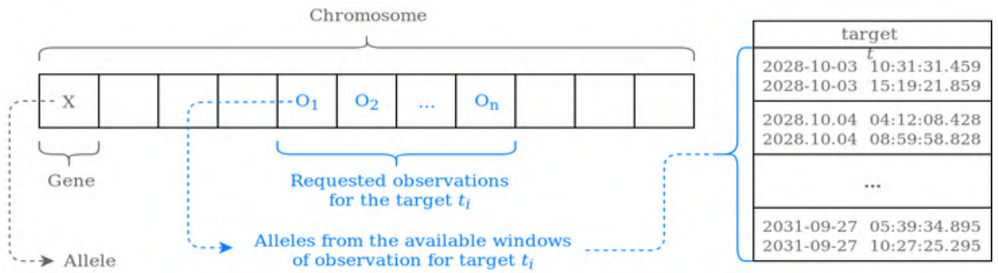


Figure 22: Schedule solution representation with a Genetic structure. Credit: CTA Consortium.

In 2019, the formal agreement for the development of the Array Control And Data Acquisition (ACADA) work package was signed by the CTA Project Office and the different contributors. This work package is devoted to the construction of the software that provides the high-level control for the operation of the observatory at the CTA sites and delivers the scientific and other data to other CTA systems for further processing and use. The Short-term Scheduler is one of the high-level sub-systems of ACADA and is under the responsibility of the ICE. The definition of the specifications and the preliminary design at sub-system level are the first deliverables for the current phase of ACADA that was initiated with the KO meeting.

On the technical side, new developments on the AI algorithms for time scheduling have been carried out in 2019. The current approach is based on Multi-Objective Evolutionary Algorithm that uses a knowledge representation as illustrated in the Fig. 21. New constraints have been added to consider coordinated scheduling of different facilities: a new feature that is necessary to cover scientific cases that require the coordinated observation considering CTA-N and CTA-S (i.e., GW follow-up) or the potential synchronization with other observatories, like SKA.

Facilities And Key Projects

LISA & LISA Pathfinder

Space-borne gravitational wave detection

LISA consists of a fleet of three satellites that will be located in a triangular formation separated by 2.5 million km and connected by laser beams, following the Earth in its orbit around the Sun (see Fig. 23). The main objective of LISA is to detect low frequency gravitational waves from the most extreme phenomena in the Universe, such as the fusion of black holes a million times more massive than the Sun. LISA was selected as the third large-class (L-class) mission of the European Space Agency (ESA) by its Senior Program Committee (SPC) on 2 June 2017, with a launch expected in 2034 and a cost for ESA of 1050 million Euros (to which we have to add the contributions of the ESA member states to the payload and others from space agencies like NASA and JAXA).

LISA is an all-sky monitor that will offer a wide view of a dynamic cosmos using Gravitational Waves as new and unique messengers to unveil The Gravitational Universe. It will provide the closest ever view of the infant Universe at TeV energy scales, has known sources in the form of verification binaries in the Milky Way (ultracompact binaries), and can probe the entire Universe, from its smallest scales near the horizons of black holes, all the way to cosmological scales. The LISA mission will scan the entire sky as it follows behind the Earth in its orbit, obtaining both polarisations of the Gravitational Waves simultaneously, and will measure source parameters with high sensitivity in the low-frequency band (see Fig. 24) for a representation of the main LISA gravitational-wave sources in relation to the LISA instrument sensitivity). From these measurements we expect revolutionary discoveries in Astrophysics, Cosmology and Fundamental Physics.

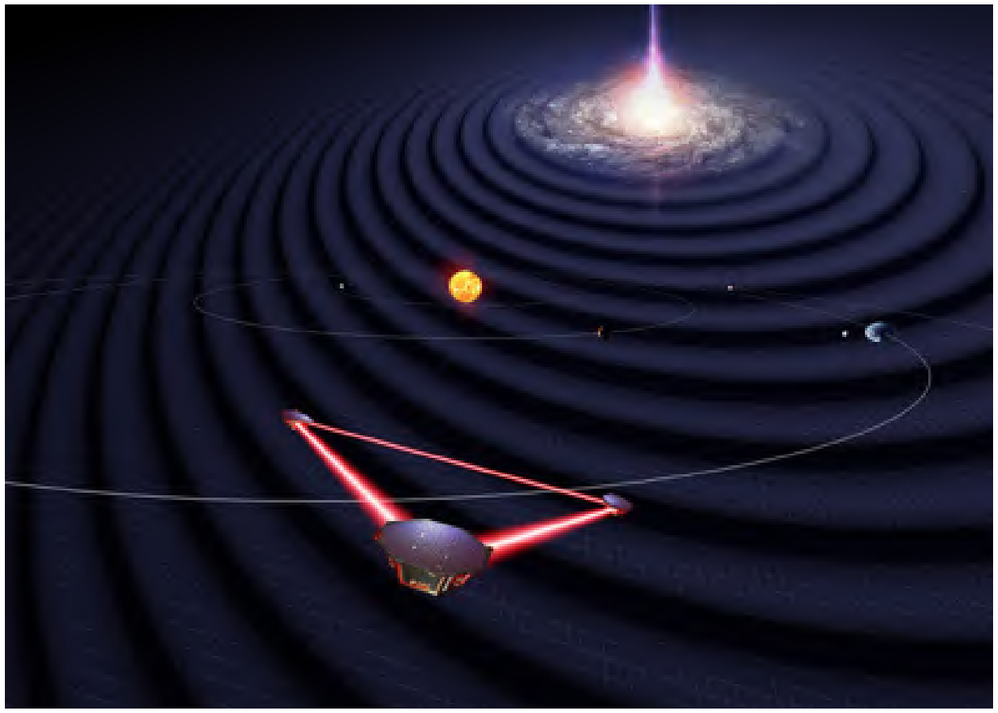


Figure 23: Artistic representation of LISA (the ESA-L3 mission). The constellation of three spacecraft is seen following a heliocentric orbit around the Sun following the Earth. In the background, a representation of the emission of gravitational waves by a binary system of supermassive black holes.

The selection of LISA was mostly a consequence of the great success of the LISA Pathfinder mission of ESA, which successfully demonstrated the main technology for LISA. LISA Pathfinder tested the fundamental concept of gravitational wave sensing in flight (see Fig. 25): it contained two test masses in free fall together with an optical metrology (laser) system that monitors and measures its relative motion with precision without precedents (picometers). LISA Pathfinder used the most advanced technologies to minimize the non-gravitational forces that can act on test masses and take measurements. Inertial sensors, a laser metrology system, a drag-free control system and an ultra-precise propulsion system made this a unique space laboratory. LISA Pathfinder also had a payload from NASA, an alternative micro-propulsion system. The success of the LISA Pathfinder mission was shown as an acceleration noise sensitivity curve much better than the required initially (improvement factors are typically 5-1000 depending on the frequency range) and very close to the one required by the LISA mission. Later, by implementing a series of improvements, such as the reduction of the gas pressure around the test masses, the LISA Pathfinder achieved an improvement in the differential acceleration noise by a factor greater than three for the range of frequencies in which LISA will work (see Fig. 25). These results were much better than the initial requirement for LISA Pathfinder and better than the requirement for LISA (see Fig. 26).

LISA & LISA Pathfinder

The Gravitational Astronomy Group

The Gravitational Astronomy Group of IEEC at ICE conducts its research primarily in the area of Gravitational Wave Astronomy. The group leads the Spanish contribution to the LISA mission and has led the Spanish contribution to the precursor technology demonstration mission, LISA Pathfinder. To understand the relevance of the group to the LISA mission, it is important to mention that Carlos F. Sopuerta is currently a member of the LISA Consortium Board, which organizes the member states' contributions to the LISA payload and a member of the "LISA Science Study Team" (SST) of ESA. Miquel Nofrarias is the Data and Diagnostics Lead from the LISA Instrument Group (LIG), representing the Spanish contribution to the mission and also a member of ESA's LISA System Engineering Office (SEO). Josep Colomé acts as the Spanish LISA National Project Manager (NPM. In parallel, members of the Gravitational Astronomy Group - LISA participate in different working groups of the LISA Consortium such as

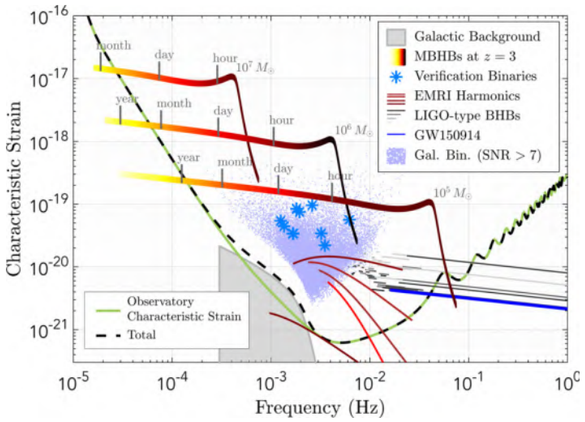


Figure 24: Examples of gravitational-wave sources in the frequency range of LISA, compared with its sensitivity for a 3-arm configuration. The data are plotted in terms of dimensionless 'characteristic strain amplitude'. The tracks of three equal mass black hole binaries, located at z = 3, are shown. The source frequency (and SNR) increases with time, and the remaining time before the plunge is indicated on the tracks. The 5 simultaneously evolving harmonics of an Extreme Mass Ratio Inspiral source at z = 1.2 are also shown, as are the tracks of a number of stellar origin black hole binaries of the type discovered by LIGO. Several thousand galactic binaries will be resolved after a year of observation. Some binary systems are already known, and will serve as verification signals. Millions of other binaries result in a 'confusion signal', with a detected amplitude that is modulated by the motion of the constellation over the year; the average level is represented as the grey shaded area. Credit: LISA Consortium.

the "LISA Data Processing Group" (LDPG), the group developing a mission simulator, and the group developing data analysis algorithms and other tasks required by LISA science; and the "LISA Science Group" (LSG), where the different subgroups develop simulations of the major gravitational wave sources for LISA and conduct Astrophysics, Cosmology, and Fundamental Physics studies to maximize the scientific return of the mission.

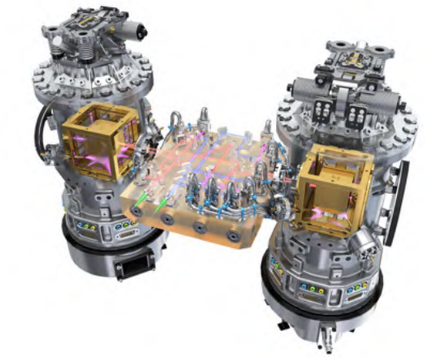


Figure 25: ESA's LISA Pathfinder payload, the "LISA Technology Package" (LTP), where all of the mission's science experiments were performed. Credit: ESA.

The main activities of the group in these two missions are carried out thanks to a project of the National Plan of the Ministry for Space Research (ESP2017-90084-P during 2019) and the name of the Generalitat's funded quality group (SGR-1469). The group contribution to LISA, following the successful experience of the LISA Pathfinder mission, is the Data and Diagnostics Subsystem. The Data subsystem consists of the mission payload computer along with all the corresponding software (both operating system and applications software). The Diagnostics subsystem consists of a series of sensors and actuators of high precision and unprecedented stability, together with all the associated electronics, that will provide essential information about the environment of the LISA measurement system. Diagnostics are: Thermal (sensors and thermal actuators), Magnetic (magnetometers, coils and electromagnetic antenna), Radiation (radiation monitor).

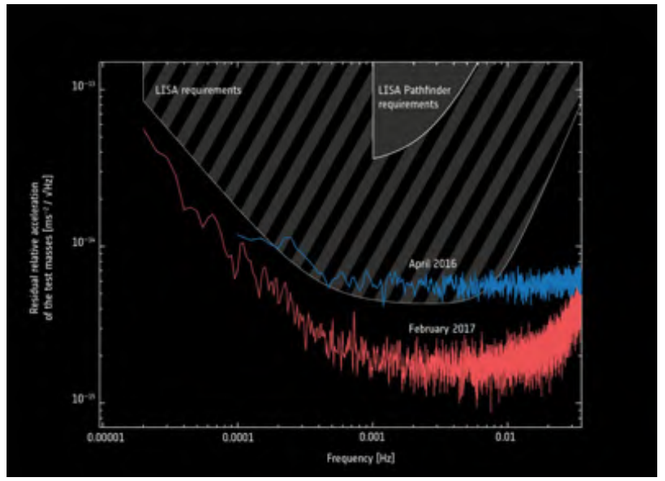


Figure 26: Parasitic differential acceleration of LISA Pathfinder test masses as a function of the frequency. The data refers to a ~13 day long run taken at a temperature of 11 °C. Data is compared with LISA Pathfinder requirements and with LISA requirements. Fulfilling requirements implies that the noise must be below the corresponding shaded area at all frequencies.

Related to the technological development, it is worth mentioning that, thanks to the expertise and leadership acquired with LISA Pathfinder, the Gravitational Astronomy Group at IEEC is currently leading the ESA contract 'LISA Enhanced Temperature Subsystem' (LETS) which plans to develop a first prototype (TRL4) of the future LISA temperature subsystem. This includes technological improvements in the read-out and an ultra-stable test bench to be installed at ICE premises. Figure 5 shows one of the electronic boards being developed under this contract. M. Nofrarias is leading from IEEC this international effort together with the German Space Agency (DLR) and SENER Aerospacial.

LISA & LISA Pathfinder

Moreover, the Gravitational Astronomy Group group works in the so-called LISA ground segment. This includes developing a mission simulator, analyzing algorithms for future scientific exploitation of the LISA data, and designing a data processing center. On a more theoretical level, the group also works on the descriptions/simulations of the main sources of gravitational waves for LISA to obtain templates of the gravitational waveforms needed for data analysis and the correct estimation of physical parameters of the sources. In addition, different studies of Astrophysics, Cosmology and Fundamental Physics are being carried out to maximize the scientific return of the LISA observations and to achieve all the scientific objectives described in the scientific case "The Gravitational Universe". Finally, the Gravitational Astronomy group uses its experience, which covers all the different aspects of Gravitational Wave Astronomy, to take part in other future gravitational wave experiments: Third generation ground-based detectors (The Einstein Telescope project), advanced gravitational-wave ground-based detectors based on atomic interferometry (the project ELGAR = European Laboratory for Gravitation and Atom-interferometric Research), etc. The group will contribute to these infrastructures its knowledge in experimental techniques of measurement at low frequencies as well as its expertise in theoretical studies and data analysis techniques for Gravitational Wave Astronomy.

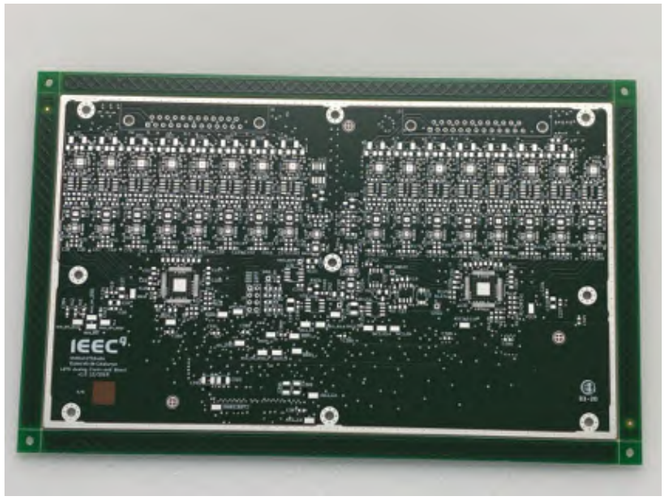


Figure 27: Analogic breadboard of the LETS (LISA Enhanced Temperature Subsystem) read-out. The objective of this development led by IEEC under an ESA contract is the design, implementation and test of a prototype of the future LISA temperature subsystem including sensors, read-out electronics and an ultra-stable test bench.

IEEC

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. The ARIEL payload is a low-resolution (R=20–100) spectrograph and photometer (3 channels) on a 1-m class telescope (0.62 m2 collecting area) to cover the visible and infrared spectral range from 0.5 µm to 7.8 µm.

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. Therefore, the key science questions ARIEL will address are: 1) What are exoplanets made of?; 2) How do planets and planetary systems form?; and 3) How do planets and their atmospheres evolve over time?

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. While some of the planets observed may be habitable, the main focus of the mission will be on hot, giant and Neptune-size planets in orbits very close to their star. This will permit to take advantage of their well-mixed atmospheres, which are expected to be representative of the planetary bulk composition. The ARIEL wavelength range contains features from all expected major atmospheric gases from e.g. H2O, CO2, CH4, NH3, HCN, H2S through to the more exotic metallic compounds, such as TiO, VO, and condensed species. 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. 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.

esa

ARIEL is designed as a dedicated survey mission capable of observing a large and well-defined 1000-planet sample within its 4-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. These observations require a stable payload and satellite platform. ARIEL 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. The 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. The IEEC, through groups at the CSIC and the UB, participates in various aspects of the mission, as shown in Figs. 28a and 28b, which illustrates the technical involvement.

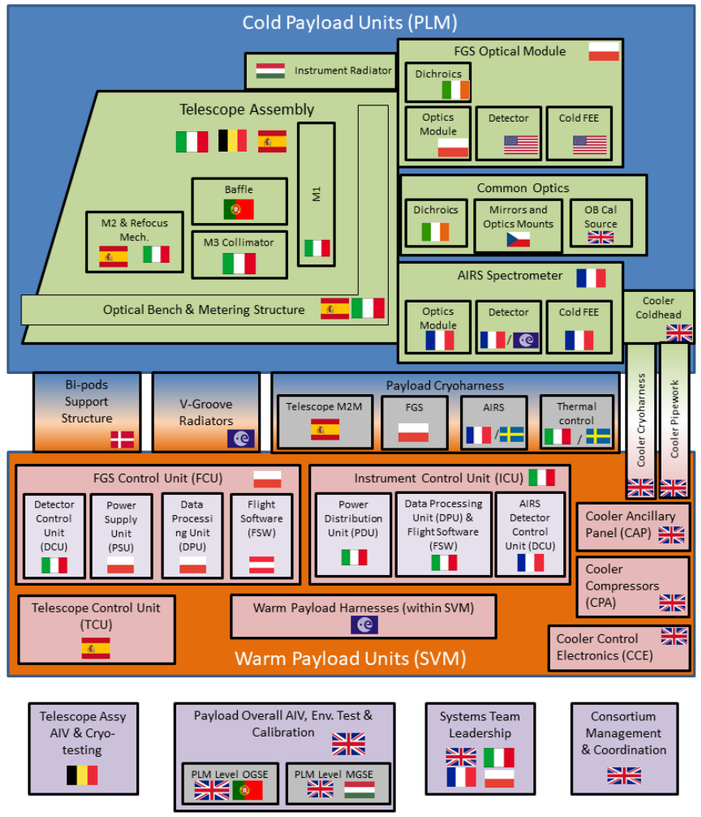


Figure 28a: ARIEL Payload Hardware block diagram.

ARIEL

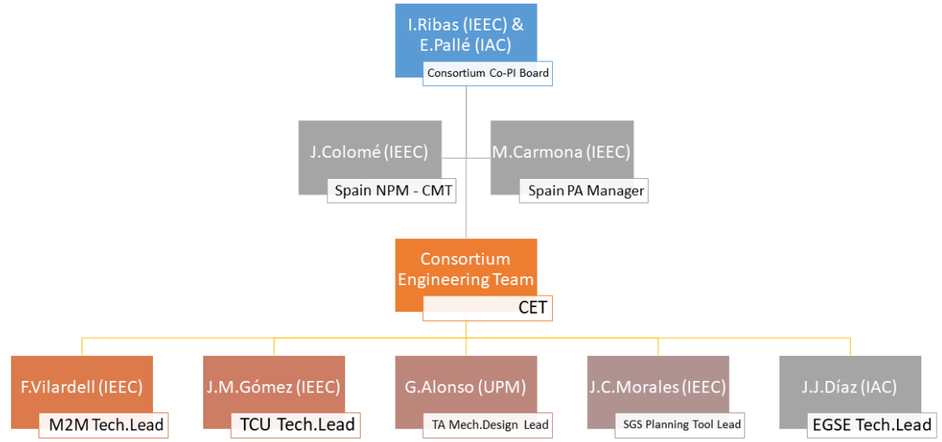


Figure 28b: Structure of the ARIEL Spanish responsibilities.

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; drives the On-Board Calibration Source (OBCS); and controls the M2 refocusing mechanism (M2M) under operation from the ground. The TCU has become a stand-alone unit, under the responsibility of the Spanish consortium. Presently is a sub-system of the telescope assembly, jointly with the M2M. 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) for 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 optimize operations and studies 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.

ARIEL

The activity during 2019 has been focused on developing Phase B1 of the mission, which will culminate in 2020 with the Mission Adoption Review (MAR) and the subsequent adoption of the mission by the ESA Space Program Committee. During this phase, Technology Readiness Level (TRL) 6 must be achieved by all subsystems, and in particular the M2M system, which requires greater development activity. Therefore, the main technological tasks during 2019 were focused on the study and design of the engineering solutions that the mission will have to implement. For example, Fig. 29 illustrates the proposed design of the TCU made at IEEC. A first bread-board (BB) was designed to check the initial approach to 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. The same procedure has been followed for the OBCS drive. A first version of the tungsten filament control has been designed as a BB. The system has been characterized, and it is awaiting tests with the tungsten filament. Also a circuit to drive the LEDs is under design. Images of the thermal measurement BB and the tungsten filament drive can be seen in Figure 30.

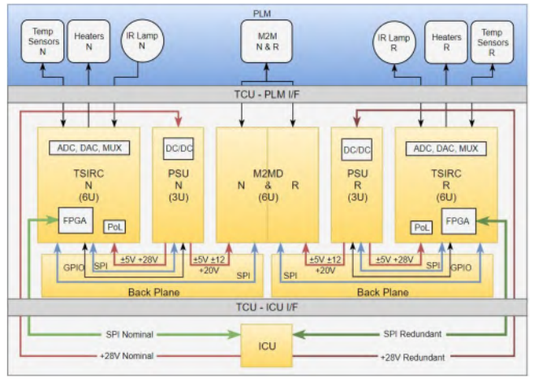


Figure 29: ARIEL TCU system block diagram

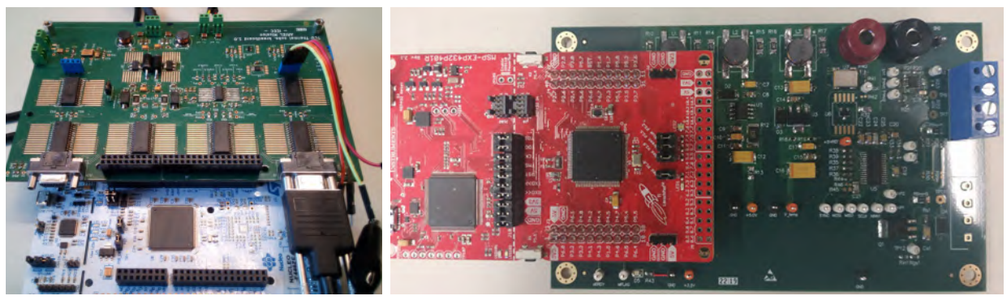


Figure 30: Thermal control (left) and tungsten filament drive (right).

The M2M development activity was initiated in 2019 under the ESA Core Technology Program (CTP). The activity includes all the phases required to consolidate the M2M requirements and to bring M2M to TRL6 by the time of MAR. In particular, the activity is testing the capability of the M2M actuators to operate at the ARIEL required temperatures. The ARIEL M2M actuators are based on the Euclid actuators (Fig. 31a), but with an improved design to increase the range of motion and to make them operational at a temperature of around 50K. A preliminary M2M assembly design was also provided during 2019, and delivered with the corresponding design document (Fig. 31b). The M2M design foresees a titanium structure with aluminum interfaces. Three degrees of freedom are included in the mechanism to ensure the proper focusing of the telescope when operating at L2.

Figure 31a: Euclid M2 actuator.

With regards to mission planning, we have to consider that the goal of the survey is to observe around 1000 planets with different levels of signal-to-noise ratio by accumulating transit and/or occultation events of exoplanet systems as well as few phase curves. These are time-constrained events that need to be properly selected in order to optimize the scientific outcome of the mission and the duty cycle. With this purpose we are designing a scheduling software tool based on Artificial Intelligence to calculate the mission plan. In particular, we have considered Multi-Objective Evolutionary Algorithms that efficiently explore the large parameter space of this problem in look for the optimal solution fulfilling several objectives at the same time. During 2019, we have worked on upgrading the code to take into account the ARIEL mission constraints. Besides, we made use of the scheduling tool to assess the feasibility of the mission, demonstrating that it is possible to achieve the science goals of the mission in terms of the number of planets surveyed while optimizing the time usage (see Fig. 32a and 32b). Several representative lists of targets have been used. Furthermore, we have also evaluated the impact of some mission constraints on the scheduler, such as the field of regard of the telescope, the duration of transit/occultation observations or the observation of phase curves, for instance. A Technical Note with the description of all the results was drafted in preparation for the mission selection review documentation.

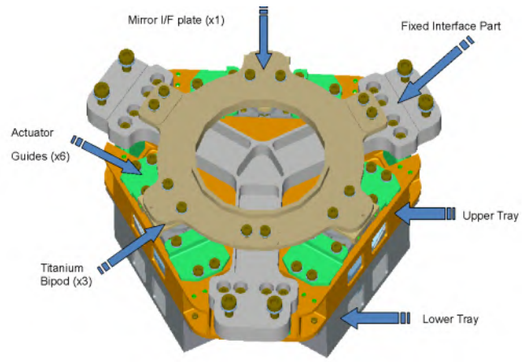


Figure 31b: M2M assembly current baseline design

ARIEL

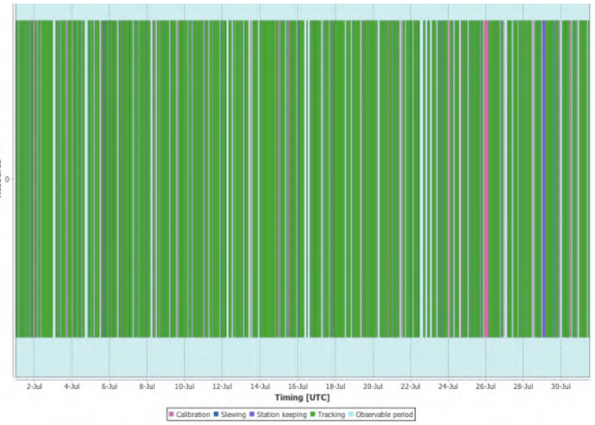


Figure 32a: Example of a schedule of the first month of the mission. Different colors indicate the satellite operations: target observations (green), slew of the telescope (blue), calibration observations (magenta) and housekeeping maneuvers (violet).

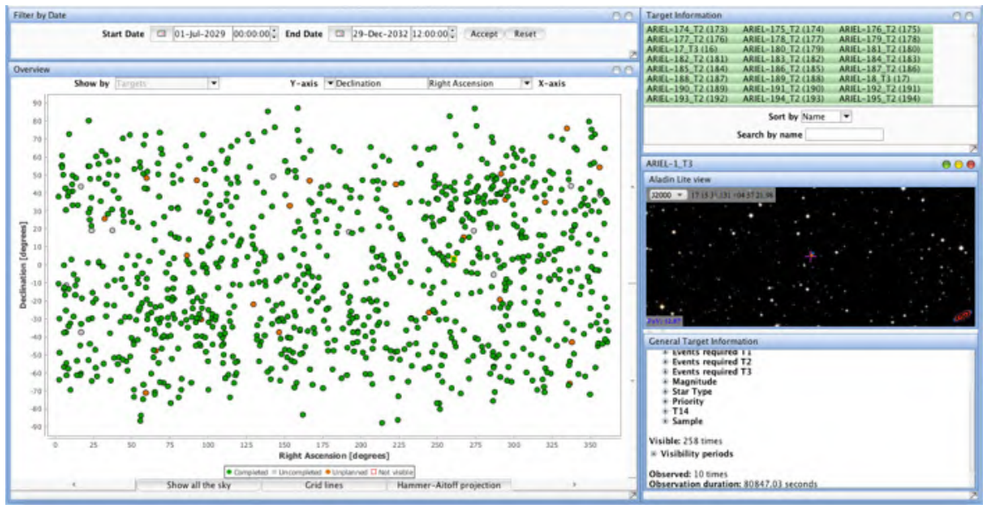
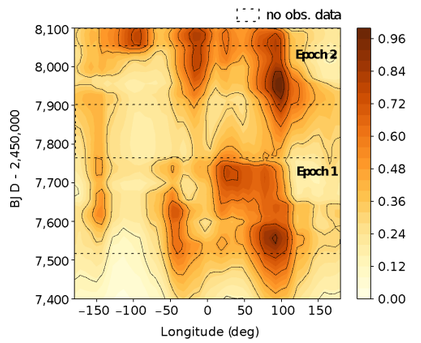


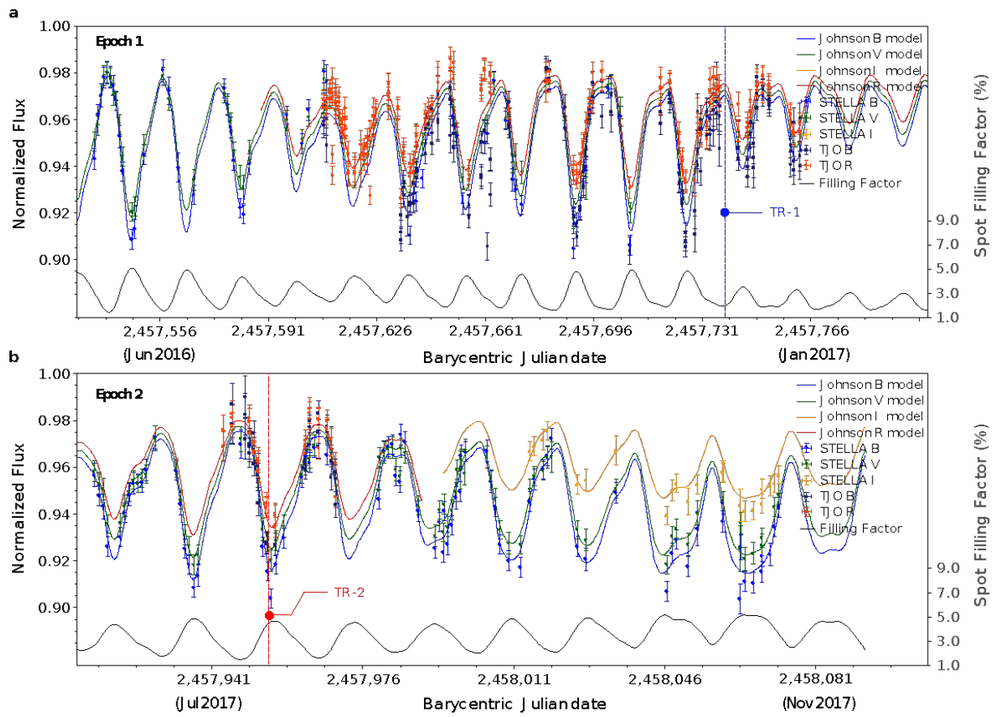
Figure 32b: Image of the IEEC Scheduling Analysis Tool front-end. A simulation of the ARIEL mission plan is shown as an example. The plot in the left panel represents the distribution of targets on the sky and their observation completeness level (green, sequence completed; grey, sequence not completed; orange, targets not planned). Sky chart of the star and observational properties are provided in the right panels.

On the scientific side, we are 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. Most of our focus has been on analyzing the potential benefits of having contemporaneous multi-band photometry together with the ARIEL observations to better characterize stellar variability and thus be able to correct out the effects on the acquired spectra.

As a test case, we analyze ~600 days of multi-band photometry from the TJO and STELLA telescopes of the exoplanet host star WASP-52. We model the observations with our own StarSim tool to perform the inversion of the light curves. We are able to reconstruct a probability map of active longitudes and the relevant stellar active region parameters of WASP-52. The inversion of BVRI photometry results in a heterogeneous surface composed of dark spots with a mean temperature of 825±150 K lower than the photospheric value. We furthermore show that we can use these results to study the chromatic effects on the depths of exoplanet transits obtained at different epochs and corresponding to different stellar spot distributions. The methodology is illustrated in Figs. 33a, 33b and 33c. In the case of WASP-52 b, which has peak-to-peak photometric variations of ~7% in the visible, the residual effects of unocculted dark spots on the measured transit depth after applying the correction resulting from our model are about 40 ppm at 550 nm and 10 ppm at 6 μm. Thus, we demonstrate a mitigation of the activity signal by a factor of 20-30 from the visible to the near infrared, which should allow ARIEL to fulfill its science goals. The upgraded StarSim algorithm and its application to WASP-52 and the ARIEL mission will be published in an upcoming paper.



Figures 33a, 33b and 33c: Reconstruction of the time-variable surface of transiting planet host WASP-52 using multi-band photometry from the TJO and STELLA telescopes and the StarSim algorithm.



Knowledge Transfer

One of the main missions of IEEC is to facilitate the transfer of the generated knowledge and space technologies, in order to achieve greater impact and benefit for the institute, companies and society. The institute carries out innovation and knowledge transfer activities and the results in different research areas have sparked interest in industrial, academic and government institutions around the world.

The institute has an important technological development portfolio from its scientific production of excellence, structured in 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.

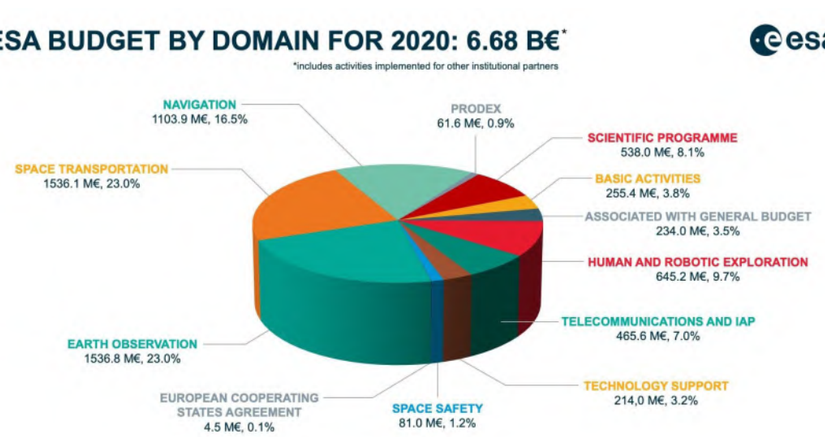
Collaboration with the space industry, especially that of the so-called Traditional Space and, to a lesser extent, with that of the New Space, are mainly performed through industrial contracts funded by state-level projects (Spanish Plan Estatal de I+D+i) aimed at the construction of large scientific missions (e.g., LISA Pathfinder, Gaia, Solar Orbiter, etc.). This funding mechanism for industrial contributions is the usual for ESA missions. It requires the active participation and leadership of IEEC researchers and engineers in the definition and construction phase of the mission, in order to attain significant responsibilities and contributions for high visibility. The success of participation in those missions has a strong impact in the industrial network and allows the export of high value-added technologies. IEEC is particularly effective in this regard and currently leads the Spanish contribution in ESA missions such as LISA, ARIEL and the Chinese mission participated by ESA, eXTP. This current success builds on a track record of top scientific excellence, on the technological expertise acquired over the past two decades and on the capability to manage large projects.

With regard to collaboration with the New Space industry, agreements are established and technological development projects are executed, especially in the field of Earth observation. IEEC has collaborated, for example, with companies such as Spire (UK), Tyvak (USA) and GomSpace (Denmark), and IEEC has ongoing missions for the launch of nanosatellites in the framework of technology demonstration programs of the ESA. It is also important to mention the commitment to develop capacities of the ground segment or downstream, with a satellite communications station, and technologies for data compression, management, and processing for various applications.

As an important final remark, IEEC also receives key support from the transfer office belonging to the different trustee institutions for technology scouting and valorisation. These support teams have usually contributed with patenting analysis and legal assessment, and they can positively complement the key knowledge held at IEEC about space technologies, specific contractual patterns (i.e., ESA contracts), and how innovative solutions can fit in the present and future industrial needs.

Success innovation cases

Examples of new and ongoing transfer and innovation agreements in 2019 include the satellite tracking services at OAdM, the high-performance nanosatellite platform, the development of data compression standards and on-board data management, the solutions for high precision positioning in navigation systems, or the launch of GNSS reflectometry missions for applications in ocean altimetry and Earth observation, among others. Knowledge transfer is made through direct contracts and agreements with industry, with agencies (ESA, GSA, EUMETSAT) and government entities (China, Korea, etc.), and through European consortia within the framework of projects of the H2020 program.



Figures 34: ESA Budget by domain for 2020.

Hereafter there is the list of the new and ongoing innovation and transference projects where the PI is an IEEC member and/or its management is in charge of IEEC and/or one (or more) of its scientific units. The activities are grouped by topic -following ESA topics as reference, as shown in Fig. 34 that illustrates the ESA budget distributed by domain for 2020- to label most of the innovation activities carried out by the research groups, and the area of knowledge involved.

Scientific Programme

Goal: R&D technology development for scientific missions (CTP, PRODEX, ...)

KTT Contract: Enhancement temperature measurement for LISA

ESA contract to develop a Technology Development Activity to achieve a system for an 'Enhanced temperature measurement for LISA' and with the goal to design of a prototype temperature subsystem (TRL4) for the LISA space mission increasing one order of magnitude the performance (1 uK/√Hz) down to 1mHz. The leadership for the specific tasks is allocated to the three different partners: design of front-end electronics (IEEC), design of ultra-stable test bench (DLR), integration, verification and test (IEEC), roadmap to TRL6 (SENER).

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Coordinator: Miquel Nofrarias
Funding Institution: ESA (Contract No. 4000127051/19/NL/BW)
Partners: DLR, SENER
Duration: 01/09/2019-30/09/2020

Earth Observation

Goal: remote sensing concepts for the observation of the Earth from high platforms and from outer space

KTT Contract: Continuous development and operations phase of a EUMETSAT satellite application facility on radio occultation meteorology

The Radio Occultation Meteorology Satellite Application Facility (ROM SAF) is a decentralized processing centre associated with EUMETSAT with its own product archive and also working on new algorithms. ROM SAF is responsible for operational processing of GRAS radio occultation (RO) data from the Metop satellites and also reprocesses RO data from other missions. The ROM SAF delivers bending angle, refractivity, temperature, pressure, humidity, and other geophysical variables in near real-time (for NWP users) and in offline (for research use), as well as reprocessed Climate Data Records (CDRs) and Interim Climate Data Records (ICDRs) for users requiring a higher degree of homogeneity of the RO data sets.

EUMETSAT

Coordinator: Estel Cardellach
Funding Institution: EUMETSAT (Ref: ROM SAF CDOP-3)
Partners: DMI, MetOffice, ECMWF
Duration: 01/03/2017-28/02/2022

KTT Contract: FSSCat Validation Experiment in MOSAIC

Contract with the European Space Agency to deploy a GNSS reflectometry system of characteristics similar to the ones in the cubesat FSSCat, in the year-round Arctic campaign MOSAiC. The aim of the activity is to contribute to the validation of the FSSCat payload through in-situ observations on the sea ice of the Arctic. This activity is hosted by the experimental set up led by IEEC in the Contract 'GNSS-R in MOSAiC' (ESA contract corresponding to RFQ 5001025474).

Coordinator: Adriano Camps
Funding Institution: ESA (Ref: ESA Contract No. 4000128320/19/NL/FF/ab)
Groups IEEC: A. Camps, E. Cardellach
Duration: 23/10/2019-30/04/2021)

KTT Contract: GNSS-R in MOSAIC

Contract with the European Space Agency to contribute to the 'Multidisciplinary drifting Observatory for the Study of Arctic Climate' expedition (MOSAiC). The contribution is a GNSS reflectometry equipment at dual linear polarization, deployed on the sea ice floe and operating during one year, drifting with the ice floe. The objective of the contract is to understand the interaction between GNSS signals and the sea ice system (snow cover, sea ice, sea water underneath), to help the geophysical retrievals of spaceborne GNSS-R measurements over sea ice.

Coordinator: Estel Cardellach
Funding Institution: ESA (RFQ 5001025474)
Duration: 05/04/2019-04/04/2021

KTT Contract: GNSS-R Grazing Altimetry Processing of Dual-Frequency Raw Data acquired by Spire Global Cubesats In-Orbit

This contract consists of processing and analyzing dedicated dual frequency GNSS reflectometry sets, acquired in 'raw mode' by Spire Global company for the purpose of this contract. The raw data sets, signals downconverted to intermediate frequency, recorded and downloaded to the ground, correspond to signals reflected in grazing angle geometry at two frequencies. The objective is to study the coherence of the signals reflected off the ocean and sea ice under these geometries, and whether the coherence is improved when combining the two frequencies ('widelane' techniques).

Coordinator: Estel Cardellach
Funding Institution: ESA (RFQ 1300054384)
Duration: 05/11/2019-04/07/2020)

KTT Contract: Development of GRASP radiative transfer code for the retrieval of aerosol microphysics vertical-profiles from space measurements and its impact in ACE mission

The overall objective of the project, linked with the goal of the last 2013 IPCC (Intergovernmental Panel on Climate Change), is to reduce uncertainties in atmospheric aerosol direct effects, particularly in the knowledge of absorption profiles. IEEC-UPC provides retrievals of aerosol microphysics from lidar alone using its advanced, multi-wavelength, dual-depolarization system. IEEC-UPC also performs estimation of the aerosol direct effect in both shortwave and longwave spectral range to validate the results from GRASP (Generalized Retrieval of Atmosphere and Surface Properties) developed in the framework of the project.

Coordinator: Michaël Sicard
Funding Institution: Commission of European Communities (H2020-778349-GRASP-ACE)
Duration: 01/03/2018-28/02/2022

KTT Contract: Contribution of SWARM data to the prompt detection of Tsunamis and other natural hazards

Contract with the European Space Agency to promote potential scientific development and applications that may emerge from ESA's Earth Explorer mission Swarm. The main objective of the project is to better characterize, understand and discover coupling processes and interaction between the ionosphere/magnetosphere, the lower atmosphere and the Earth's surface and sea level vertical displacements. The proposed research effort targets tsunamis that are the result of earthquakes, volcano eruptions or landslides. In particular, the potential detection of EarthQuakes-induced ionospheric signals from SWARM POD GNSS data (above 450 km) and COSMIC (above 800 km) are being analyzed by UPC-IonSAT group at IEEC.

Coordinator: Manuel Hernández-Pajares and Alberto Garcia-Rigo
Funding Institution: ESA (Ref: ESA Contract No. 4000126730/19/NL/IA)
Duration: 01/02/2019 - 31/01/2021

KTT Contract: Federated satellite system 6U tandem mission for sea ice and soil moisture monitoring

The FSSCat mission is an innovative concept consisting of two federated 6-Unit Cubesats, called ^{3}Cat-5/A and ^{3}Cat-5/B, in support of the Copernicus Land and Marine Environment services. These two CubeSats are the fifth generation of the ^{3}Cat spacecraft family of the laboratory. They carry a dual microwave payload (a GNSS-Reflectometer and a L-band radiometer with interference detection/mitigation), and a multi-spectral optical payload to measure soil moisture, ice extent, and ice thickness, and to detect melting ponds over ice. It also includes a technology demonstrator of an Optical Inter-Satellite Link (OISL) and a proof-of-concept of a Federated Satellite System (FSS). The FSSCat mission is the winner of the 2017 Copernicus Master ESA Small Satellite Challenge S^3 and Overall Winner. The NanoSat Lab is in charge of the development of the FMPL-2 and the FSSExp payloads. Data from ^{3}Cat-5/A will be downloaded at the IEEC/UPC Observatori Astronòmic del Montsec (OAdM) ground station.

Coordinator: Adriano Camps
Funding Institution: ESA (prime-DEIMOS)
Duration: 01/03/2018-29/02/2020

Navigation

Goal: position, navigation and timing

KTT Contract: EGNOS V3 NLES Long Loop Algorithm

Airbus Defence and Space (Airbus DS), awarded by ESA to be the prime contractor of the future EGNOS V3 system, endorsed Indra as the supplier of the NLES V3 product. The NLES product is mainly composed of:

• NLES station, which implements the main NLES mission: (1) reception and selection of CPF messages, (2) generation of SBAS messages (in C-band) to be transmitted to the Geo-stationary Earth Orbit (GEO) satellite and (3) generation of GEO steering controls.

• NLES Validation Means, to be kept at Indra facilities for AIVQ and maintenance. These means include a GEO Payload Simulator, in charge of modifying the C1/C5 signals, as it would be transmitted from the directional antenna, to account for the uplink (in C1/C5), downlink (in L1/L5), and GEO payload contributions.

In this context, Indra contracted SPCOMNAV-UAB group at IEEC as the provider for EGNOS NLES V3 Long Loop Software used for the generation of GEO steering controls.

Coordinator: José A. López-Salcedo
Funding Institution: European Space Agency with Airbus as prime contractor and Indra as the NLES subcontractor
Partners: Airbus (France, coord), Indra (Spain)
Duration: 01/07/2019 – 31/12/2020

KTT Contract: OLTBOC – Open Loop Techniques for High Sensitivity GNSS Receivers Applied to BOC Signals

The objective is to investigate the advantages of meta-signals and high-order BOC signals with respect to conventional carrier phase positioning. The focus of SPCOMNAV-UAB group at IEEC is on the development of new acquisition and tracking techniques, on the determination of the achievable performance limits, and on the analysis of the performance degradation produced by the ionosphere and the receiver front-end response.

Coordinator: José A. López-Salcedo
Funding Institution: ESA
Partners: GMV SKYSOFT (Portugal, coord)
Duration: 11/3/2019-30/6/2020

KTT Contract: HANSEL - Navigation and GNSS in Smart Cities: Testbed Concept Definition

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.

Coordinator: José A. López-Salcedo
Funding Institution: ESA
Partners: Rokubun (Spain, coord)
Duration: 15/3/2019-31/5/2020

KTT Contract: FUNTIMES2 - Future Navigation and Timing Evolved Signals 2

The objective of this project is to contribute to the design of the signals of Galileo 2nd Generation. SPCOMNAV-UAB provides consultancy on the expected evolution of the GNSS user segment technology for the timeframe 2020-2040, in such a way that, on one side, the proposed signal designs are compatible with receiver technology evolution, and on the other side, to exploit the technological progress to define signal structures that are well suited to the rise of new user needs. The focus of SPCOMNAV-UAB task is placed on potential synergies with terrestrial 5G networks, on cloud receiver implementation and on multi-antenna receivers.

Coordinator: Gonzalo Seco-Granados
Funding Institution: ESA
Partners: Airbus (Germany, coord)
Duration: 1/3/2019-28/2/2021

KTT Contract: G2GTURMM - G2G Open Service Bread-Board Emulating Mass-Market platforms

The main objective of this activity is to develop a breadboard of the future evolution of the current GNSS Mass Market Receivers implementing the Galileo Open Service evolution, and to assess their benefits in the frame of ESA G2G system level studies. The breadboard includes the hybridization of GPS and Galileo positioning with other technologies. SPCOMNAV-UAB group is in charge of processing 4G and 5G signals for range and angle-based navigation, and the group provides a generator of emulated 4G and 5G observables in realistic environments.

Coordinator: José A. López-Salcedo
Funding Institution: ESA
Partners: GMV (Coord)
Duration: 1/3/2019-28/2/2021

KTT Contract: MONITOR - Consolidation of Tools for Data Analysis from Monitor Network

The main goal of this activity is to develop a set of tools to study the scintillation phenomena and extract relevant statistics using data stored by the set of GNSS ground stations that belong to the ESA Monitor network. The work carried out by the SPCOMNAV-UAB group is focused on three objectives. First, the development of a set of routines to automate the raw data retrieval from the ESA Monitor network. Second, the development of a set of tools to detect the presence of scintillation events based on certain conditions and to identify its properties in terms of duration, time of occurrence, intensity and satellite location. Third, to statistically characterize the detected events in terms of rate of occurrence and spectral slopes, in order to facilitate a better understanding of the scintillation phenomena and their impact onto GNSS receivers.

Coordinator: José A. López-Salcedo
Funding Institution: ESA
Duration: 1/6/2019- 30/6/2020

KTT Contract: GRC/Galileo Reference Center - Development; Operations support and Hosting services

European GNSS Agency (GSA) Contract in the frame of the Galileo Reference Center (GRC). The general purpose of GRC is performing independent monitoring and assessment of Galileo service provision. The ongoing work by UPC-IonSAT is focused on supporting the Integration, Test and Validation of Ionospheric products by providing reference ionospheric products by means of UPC-IonSAT TOMION SW for the computation of Ionospheric (VTEC) and Bias products (BGD and IFB Iono). The Tomographic Ionospheric model, TOMION, is the core element in the UPC Ionospheric Analysis Centre within the International GNSS Service -IGS- since 1998. TOMION can process ground-based GNSS ionospheric data (also in real-time), GNSS LEO radio occultation data, GNSS geodetic data, dual-frequency altimeter data and ionosonde data.

Coordinator: Manuel Hernández-Pajares
Funding Institution: GSA (GMV subcontract)
Duration: 22/11/2016 - 31/12/2020

KTT Contract: MoNEWIC/eMONITOR - Evil waveform and ionospheric characterization monitoring network

European Space Agency - H2020 project for EGNOS Project Office with its main objective to monitor the different GNSS signals, extending the current capabilities of the MONITOR network, and to exploit its database to provide relevant input for the evolution of EGNOS V3. This includes monitoring and analysis of Evil Wave Forms (EWF) also known as a non-nominal signal distortions (responsibility of AIRBUS) and monitoring, analysis, and characterization of environmental effects due to ionosphere (where UPC-IonSAT is responsible of the design, implementation, test and validation of the ionospheric processors). Data analysis of ionospheric effects for SBAS will also be conducted.

Coordinator: Manuel Hernández-Pajares
Funding Institution: ESA - H2020 (Ref. ESA Contract No. 4000127903/19/NL/AS)
Duration: 01/11/2019 - 28/02/2022

Space Safety - Space Situational Awareness (SSA)

Goal: Debris mitigation and removal, Space Surveillance and Tracking - SST, Space Weather - SWE, Planetary Defense - NEOs

KTT Contract: Satellite tracking data provision

The TJO robotic telescope at the OAdM has been 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.

Coordinator: Josep Colomé
Funding Institution: CDTI (Expte4/2019Lote2-EUSST)
Duration: 05/06/2019-29/03/2021

KTT Contract: Satellite tracking data provision

Satellite tracking data provision to Deimos Space SLU in the framework of the contract EUMETSAT “ITT 17/215043 - Routine Optical Data Service for Geosynchronous Satellites. The TJO telescope participated as a backup telescope to the main system.

Coordinator: Josep Colomé
Funding Institution: DEIMOS (Expte ROPS4GEOS)
Duration: 23/01/2018-22/01/2019

KTT Contract: P3-SWE-XXVIII.1 – Ionospheric Weather Exp Service Centre

Under the ESA Space Situational Awareness (SSA) Programme a system to monitor, predict and disseminate Space Weather information and alerts is being developed. Space Weather services are being operated and made available online through ESA Space Weather Portal for any interested user. In particular, UPC-IonSAT contributes with real-time detectors of mid and strong solar flares (SISTED and SOLERA-drift -formerly GSFLAD-) and a solar EUV flux rate proxy (SOLERA -formerly GSFLAI-) by monitoring daylight ionosphere overionization by means of a global ground-based GNSS network of receivers and derived from dual-frequency carrier-phase observables.

Coordinator: Manuel Hernández-Pajares
Funding Institution: ESA (DLR Subcontract)
Duration: 11/06/2019 – 31/12/2020

Telecom

Goal: innovation in satellite telecommunications

KTT Contract: Robust Compression of Fixed Length Housekeeping Data

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 study of the definition of the forthcoming standard CCSDS 124.0-W-2, Robust Compression of Fixed-Length Housekeeping Data, whose publication is intended for May 2020.

Coordinator: Joan Serra-Sagristà
Funding Institution: Centre National d’Etudes Spatiales (CNES)
Duration: 30/10/2019-1/06/2020

KTT Contract: 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.

Coordinator: Ian Blanes
Funding Institution: Centre National d’Etudes Spatiales (CNES)
Duration: 21/02/2018- 31/12/2019

KTT Contract: High-Speed Integrated Satellite Data Systems For Leading EU Industry (Hi-SIDE)

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.

Coordinator: Joan Serra-Sagristà
Funding Institution: European Commission (Horizon 2020 research and innovation programme, grant agreement No 776151)
Partners: Airbus Defence and Space GMBH (Coordinator)

KTT Contract: Ultra-low power density uni/bi-directional IoT satellite communications, with enhanced PHY Layer Security

The activity aims to perform a security analysis of IoT protocols over satellite and to develop countermeasures, mainly at the physical layer, to identify security threats. In particular, the threats involving partial jamming or complete service unavailability shall be considered. The countermeasures should provide confidentiality and availability.

Coordinator: M. A. Vázquez-Castro (SatNEx expert)
Funding Institution: ESA (ESTEC Contract Number: 4000113177/15/NL/CLP)
Partners: CTTC (coord)
Duration: 1/3/2019-6/3/2020

Satellite & Space Technologies

Goal: technologies for space satellite manufacturing

KTT Contract: C3SatP (Catalan Cubesat Platform), a 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 telecommande, 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 it to achieve performances for which larger-sized missions would be required otherwise.
The market impact of this new multi-purpose technology is expected to be significant for New Space. The current status of the technology, the valorisation studies and Business plan carried out, the identified potential customers, as well as the ongoing projects, increase the potential of this KTT action.

Coordinator: Juan J. Ramos
Funding Institution: AGAUR-Generalitat de Catalunya (2016 PROD 00076 , including European Regional Development Funds)
Duration: 10/2017 - 01/2019

KTT Agreement: 4DCube (Debris Detection at Dawn and Dusk CubeSat)

An unprecedented approach based on small satellite technologies has been awarded in the framework of the Call to Orbit ESA programme to detect and track small-sized and composite debris with an on board optical sensor, which poses a serious risk for orbiting spacecraft. The project will allow planning and designing the mission, as well as qualify and test the designed approach with Open Cosmos SW and HW, for In-Orbit demonstration.

Coordinator: Juan J. Ramos & Jose María Gómez
Partner Institution: Open Cosmos
Ref: ESA Business Applications and ESA Space Solutions “Call to Orbit”
Duration: 01/11/2019 - 01/09/2020

KTT Contract: Consultancy service to build a constellation of nanosatellites to provide global Internet of Things (IoT) services.

IEEC consultancy contract with the SATELIOT company to provide consultancy and support in the development of a small satellite constellation for IoT applications.

Coordinator: Jose María Gómez & Juan J. Ramos
Funding Institution: SATELIOT IOT Services S.L.
Duration: 01/12/2019 - 31/07/2020

Planetary Exploration Technologies

Goal: innovation in satellite telecommunications

KTT Contract: Miniaturized sensor packages and delivery systems for in-situ exploration

MiniPINS is an ESA study led by the Finnish Meteorological Institute (FMI) to develop and prototype miniaturised surface sensors packages (SSPs) for Mars and the Moon. IEEC-UPC participates in the analysis and selection process of the different sensor systems in view of the multiple science requirements and mission constraints. IEEC-UPC will also participate in the prototyping of some of the sensor systems that will be selected for demonstration in the contract. Specific effort is made on the miniaturization of the different electronic and sensor systems. The Preliminary Mission Plan for the Mars SSP consists of 4 small penetrators (<25Kg), deployed from a Martian Orbiter, that will be stationary throughout the mission (2 years). The science program is focused on the study of Mars atmosphere, seismology, magnetic field and chemistry. The Moon SSP will be miniature systems (<5Kg) deployed on the surface by a rover. Four SSPs will be deployed on the Moon. The science objectives are focused on radiation, seismology, magnetic field and chemistry.
The output of this contract will enable ESA to prepare the technological programs required for these ambitious planetary missions.

Coordinator at IEEC-UPC (Subscontractor): Manuel Dominguez-Pumar
Funding Institution: ESA
Duration: 19/10/2019-18/4/2021

Ground-based Instruments

Goal: development of instrumentation for ground-based facilities.

KTT Contract: CTA Low noise, high bandwidth differential pre-amplifier for photomultiplier readout

The IEEC-UB team developed the PreAmplifier Circuit for CTA (PACTA) that fulfilled a set of stringent requirements in terms of bandwidth (> 400 MHz), dynamic range (> 14 bits), input signal range (> 10 mA) and low power consumption (< 200 mW). Commercial off-the-shelf electronic components do not achieve those specifications. A proprietary technology was developed by the IEEC-UB team and was protected through the Spanish patent ES 2390305 (Bl), filled on April 11, 2011 and granted on October 4, 2013, named “First front stage current-mode circuit for reading sensors and integrated circuit”, with the UB as sole applicant and with David Gascón Fora, Andreu Sanuy Charles and Lluís Garrido Beltran as inventors.
IEEC-UB delivered to Tokyo University more than 10 000 ASICs based on such technology, to be part of the cameras of 3 Large Size Telescopes of the Cherenkov Telescope Array (CTA). These ASICs (PACTA) were chosen among different prototypes to become a common component for both the Large Size Telescopes (LSTs) and the Medium Size Telescopes (MSTs). Their production, together with the quality control procedure performed by a robotic system, were done in-house and showed an excellent yield (above 99% of the ASICs fulfilled all requirements).

Coordinator: David Gascón
Funding Institution: Tokyo University (Japan)
Duration: 07/2017 - 11/2020

KTT Contract: IAC tender CTA Lote 2

Production, integration and validation of mechanical elements, electronics and programming for the construction of the cameras for the Large-Size Telescopes LST-2, LST-3 and LST-4 of the Cherenkov Telescope Array observatory in the Northern site (ORM). Contract devoted to the electronic systems and electronic integration of the three cameras. In particular, the IEEC-UB has developed an ASIC to integrate different low level trigger functionalities and will produce more than 2000 units to equip the new LST cameras.

Coordinator: David Gascón
Funding Institution: IAC (LIC-19-008-Lote2)
Partners: IFAE
Duration: 23/12/2019-31/12/2022

KTT Contract: Fabrication, assembly, testing and commissioning of the MIRADAS instrument for the Gran Telescopio Canarias

Development, implementation and test of the high-precision coordination algorithm for the twelve robotic probe-arms for the MIRADAS instrument. This instrument is one of the new generation instruments of the Gran Telescopio de Canarias.

Coordinator: Jose María Gómez
Funding Institution: University of Florida (ref. UFDSP00010995)
Duration: 2016-2020

Networks

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 2019:

- DADI/OBELICS A&A face-to-face Meeting, (WP3 and WP4 meeting), 29 - 30 January 2019, Trieste, Italy
- 5th ASTERICS DADI Technology Forum (Meeting of ASTERICS DADI partners), 26 - 28 February 2019, Strasbourg, France,
- The New Era of Multi-Messenger Astrophysics Conference, 25 - 29 March 2019, Groningen, Netherlands,
- Third ASTERICS-OBELICS International School, 08 - 12 April 2019, Annecy, France.

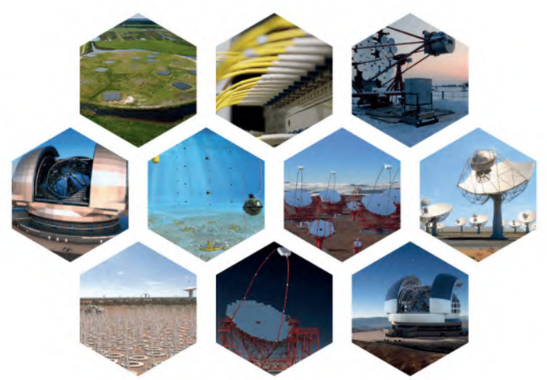

Figure 35: ASTERICS helps Europe's world-leading observatories work together to find common solutions to their Big Data challenges, their interoperability and scheduling, and their data access. Credit: ASTERICS.

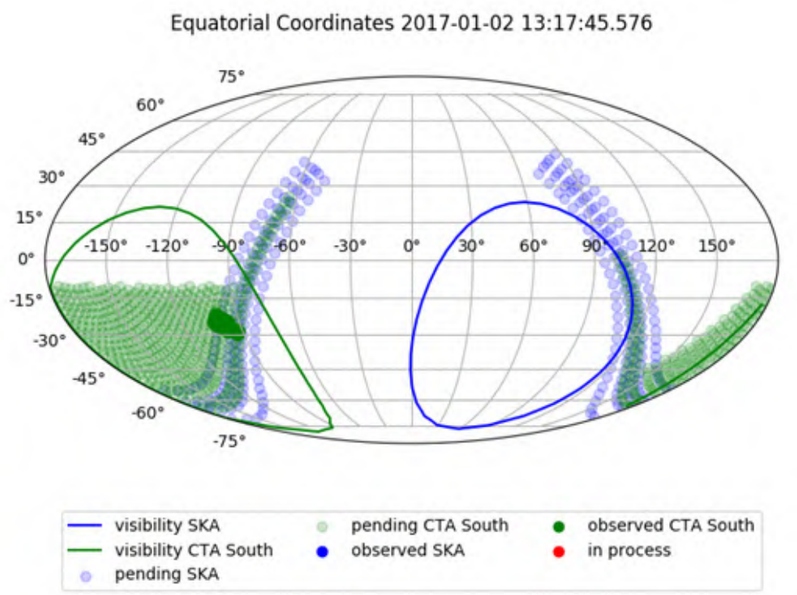

Figure 36: Example of possible schedule combining SKA and CTA South arrays. Credit: Josep Colomé (ICE) and Alan Bridger (UK Astronomy Technology Centre).

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 2019:

- PHAROS Annual Conference 2019, 22 -26 April 2019, Platja d'Aro, Spain,
- Neutron Star Theory (WG1, WG2 & WG3 meeting), , 10 - 11 October 2019, Madrid, Spain,
- Anisotropies in core-collapse supernova explosions (WG3+WG4+WG5 meeting), 21 - 23 October 2019, Palermo, Italy.

Figure 37: PHAROS community picture taken at PHAROS Conference 2019: the multi-messenger physics and astrophysics of neutron stars held near Barcelona, Spain.

MW-GAIA

MW-GAIA is a COST Action that commenced on the 14 March 2019 and will be completed by 13 March 2023. MW-GAIA provides a framework for collaboration between countries to improve the potential of the European community in the scientific exploitation of the observations of more than one billion stars with the European Space Agency's Gaia satellite, allowing it to maintain its leadership in the study of our Galaxy, its stars and planets, while allowing it to take firm steps towards the development of future space missions in astrometry.

The Action brings together key stakeholders from across Europe, to leverage expertise, and develop new techniques to fully maximise the scientific returns from Gaia's rich and complex data.

Five key challenges are addressed: The Milky Way as a Galaxy, The Life and Death of Stars; Planetary Systems Near and Far; Gaia Fundamentals: Space and Time; and Astrometry Innovation Challenge – towards sub-μas astrometry. COST enables the vital Action activities, supporting exchanges, training and meetings.

The Action will have a significant legacy, creating a dynamic and vibrant network of researchers with expertise in the study of the Milky Way, its constituents and the art of Astrometry. Participation is inclusive, with researchers accessing the Network from across Europe, irrespective of their gender or location.

The member of IEEC at ICCCUB Carme Jordi has an important role within this network since she has been elected as Action Vice Chair. From this position of vice-direction of the network, the ICCUB team is promoting a wide participation in terms of geographical, thematic and personal scope. They organized three exchange visits in 2019. In the coming years, they will continue to participate in this exchange to promote synergies between research groups, and we will organize two workshops.

Within the network, the following events were organised during 2019:

- WG1 Workshop: GAIA treasure, 3-5 September 2019, Cambridge, UK,
- WG3 Workshop: Exoplanets in the GAIA era, 18-20 November 2019, Porto, Portugal,
- WG4 Workshop: A dynamical view of the Sky, 4-6 December 2019, Nice, France.

Figure 38: Group picture of a meeting organized within the MW-GAIA network.

Highlights

IEEC Forum 2019

On 6 February 2019, IEEC held its first forum coinciding with the 23rd anniversary of the institute.

In 2019, IEEC celebrated the IEEC Forum 2019, its first forum in the history of the institution, with the aim of bringing together the members of the different scientific units. It was a 1-day event, fully promoted and organized by IEEC. Over 120 attendees gathered at the Palau Robert in Barcelona to discuss scientific and technical research in space exploration and space applications.

The morning sessions were focused on presentations by IEEC members describing some of the highlights of their research during the past year. The audience could enjoy excellent talks describing results on pulsar research, the Gaia mission, the use of Global Navigation Satellite Systems (GNSS) to monitor space weather, the prospects of exoplanet research, the Montsec Astronomical Observatory, signal processing for communications and navigation using GNSS, the first measurements from the ROHP-PAZ experiment, technology research for space missions, the final results of the LISA Pathfinder mission and the road to the LISA mission, the various applications of nanosatellites, and the development of micro-electronics components for the Cherenkov Telescope Array.

The afternoon session had the focus on better knowing the activities of the local space industry and on promoting collaboration between industry and academia. Several companies in the space business delivered short presentations highlighting their expertise and capabilities. This was followed by two presentations by Álvaro Giménez (former Director of Science of the European Space Agency) on future opportunities in the framework of ESA, as well as by Riánsares López (ACCIÓ) on the future of the space research sector within the H2020 European program. The presentations led to an open discussion, with the participation of the audience, to explore improvements in the capacities of IEEC and synergies with potential industrial partners.

The General Director of Industry of the Catalan Government, the Vice-Rector for Research from the Universitat Politècnica de Catalunya, the Vice-Rector for Research from the Universitat de Barcelona, and government officials from ACCIÓ visited the IEEC Forum 2019 at some point during the day.

At the coffee and lunch breaks there was lively conversation and discussion in what was a nice occasion for IEEC members and industry representatives to meet up and chat.

The event concluded with a beautiful and delicious cake and a hearty toast to celebrate the 23rd anniversary of the founding of IEEC, on 6 February 1996. Happy 23rd birthday, IEEC!

Figure 39: Cake of the 23rd anniversary of the foundation of the IEEC that concluded the IEEC 2019 Forum

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Highlights

Gaia DR2 bulk catalogue size shrunk by 15%

FAPEC, the professional data compressor from DAPCOM, delivers excellent performance on CSV files like those from the bulk Gaia catalogue.

In 2007, researchers from the Gaia team at IEEC, together with the Spanish software company GTD, were awarded a Technology Research Programme contract with ESA. The study, called GOCA (Gaia Optimum Compression Algorithm), pursued the design and prototyping of an optimum data compression solution for the Gaia payload. As a result of that study, a new entropy coder (PEC) was conceived. It was designed to offer good data compression efficiencies even for data severely contaminated by statistical outliers – like those caused by energetic particles impacting the imaging devices of Gaia. PEC later evolved into FAPEC, the Fully Adaptive Prediction Error Coder, which was patented in the US and led to the creation of a spin-off company, DAPCOM Data Services S.L., participated by the Technical University of Catalonia (UPC) and the University of Barcelona (UB).

DAPCOM became one of the three companies accepted in the first call of the new Business Incubation Centre of ESA in Castelldefels, near Barcelona. The incubation programme pursued the adaptation of FAPEC to non-Space applications, which led to the design and implementation of several pre-processing stages for different kinds of data. It includes images, time series, medical data, genomics, geophysics, log files, and also tabulated text data. The latter includes CSV files, as well as point clouds, where FAPEC delivers excellent performance.
Meanwhile, the Gaia Data Processing and Analysis Consortium (DPAC) was working on the preparation of the largest and most precise catalogue of our Galaxy – the second Gaia data release (or Gaia DR2). It became a reality – and a revolution – on April 25th, 2018. The catalogue was made available through an on-line platform, as well as through CSV files for bulk download.

Despite being an inefficient format for massive data storage, CSV files have been around for nearly fifty years, meaning that most data processing programs support them – as most astronomers know. They are typically compressed with standard Zip-like solutions, which provide reasonably good compression ratios, yet at a relatively slow speed. For this reason, the Gaia group at IEEC-ICCUB, in collaboration with DAPCOM, converted the whole Gaia DR2 CSV catalogue to the FAPEC format and published it. When compared to the official catalogue (compressed with gzip), it shrank from the original 554GB to 471GB – decreasing download and storage needs by 15%. Other widespread compressors like bzip2, rar, zstandard or 7-zip cannot reach this mark. Not only this, but compression and decompression speed is also faster than the mentioned solutions, especially when using the multi-threading capabilities of FAPEC. Decompression licenses can be obtained for free, to ensure accessibility to this optimized catalogue. FAPEC runs on Windows, Linux and Mac OS, and it can be invoked through the command-line, as well as programmatically from C, Python or Java.

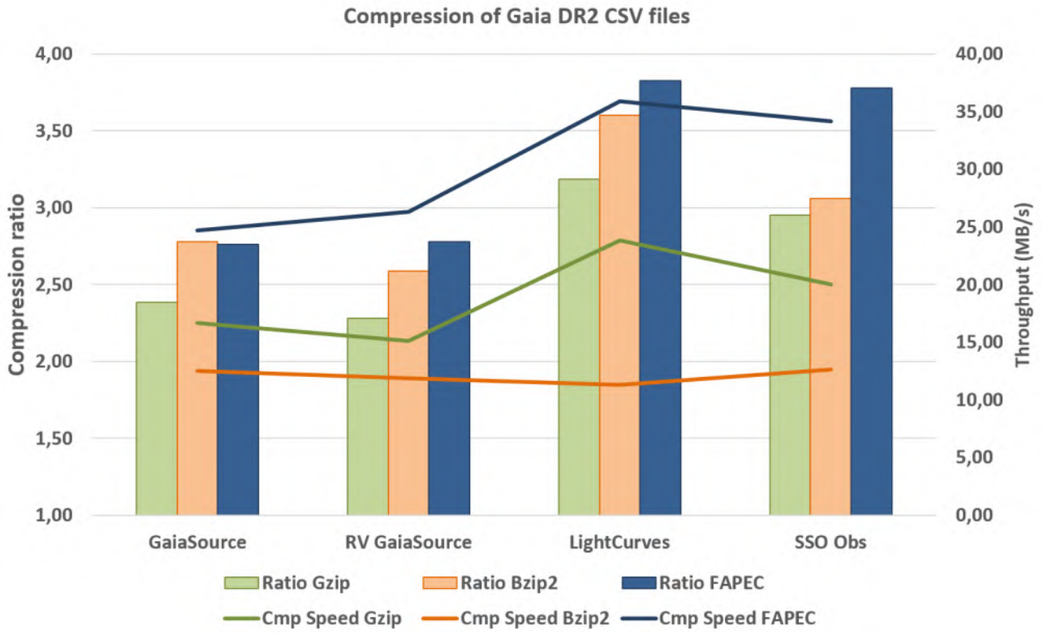

Figure 40: Comparison of FAPEC compression ratios and speeds with those achieved by historical data compressors.

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Highlights

The ATTRACT Consortium grants funding to develop a new hybrid detector

Development of a new generation of single-photon hybrid photosensors: the ATTRACT FastICPix project.

The team of engineers and researchers from the IEEC-UB section (Institute of Cosmos Sciences of the University of Barcelona, ICCUB) has been granted an ATTRACT grant to develop an integrated signal processing for a new generation of active hybrid single photon sensors. This team holds a long track record on developing photo-detectors and readout systems for science (LHCb, CTA) and medical imaging. The call addressed researchers, entrepreneurs and companies who developed breakthrough projects on pioneering imaging and sensor technologies.

The project, named FastICPix, intends to develop a new hybrid detector with a very high time resolution, close to 10 ps, even for a single photon and for large detection areas. The performance of this sensor will be at least one order of magnitude better than any existing technology. It shall bring a revolution in medical imaging by enabling reconstruction-less PET based on Time-Of-Flight (TOF) measurements. Other application areas such as transport, autonomous driving, cargo scanning, molecular imaging or particle physics experiments would also benefit from 10 ps TOF. The project will be carried out in close collaboration with CERN microelectronics and detector groups.

The ATTRACT Consortium is a research initiative born in August 2018. Funded by the European Union's Horizon 2020 and participated by several institutions, it is a pioneer initiative aimed to bring together both the European's fundamental research and the industry.

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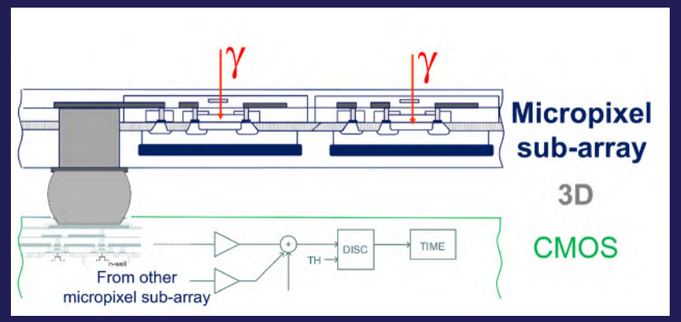

Figure 41: FastICPix: A new hybrid photo-sensr that combines actively the signal of small micropixel sub-arrays based on the fastest single photon sensor technologies with ultrafast readout electronics using 3D integration.

Highlights

Improving the sensitivity of the Virgo gravitational observatory

Virgo has detected events from 18 billion light years away in its third run.

The Virgo and LIGO gravitational observatories started their third coordinated observational run (O3) in April 2019, which will last one year. During 2019, a total of 30 candidate events were detected by Virgo, plus 12 candidate events only detected by LIGO. 20 of these seem to come from the coalescence of a binary black hole, 3 from a binary neutron star, and 2 from a neutron star merging with a black hole. Overall, Virgo has been able to detect events generated at vast distances, even reaching 5.7Gpc (18.6 billion light years away), and typically at around 1Gpc (over 3 billion light years).

The Virgo team at ICCUB is currently composed of 10 multidisciplinary experts on electronics, instrumentation, computing, software, data analysis and physics. In agreement with the Virgo Collaboration, during 2019 our team has started working on some instrumentation upgrades for the next observing run (O4), which should start in 2021.

One of these upgrades requires the design of a new high frequency data conversion and processing board, HSPRIO (High Speed RapidIO), to be used in the super-attenuators system. The main components and protocols for the board have been selected, characterized and tested. This includes the Analogue-to-Digital Converter (ADC), the Digital-to-Analogue Converter (DAC), the Field-Programmable gate array (FPGA) and the interface framework between them. We are running multiple tests for all of them, checking their specifications and performance. The latency of the total system is being experimentally estimated to see if it reaches the requirement of 3µs. The frequency response of both ADC and DAC are being tested to evaluate their noise and distortion responses. Simultaneously, the JESD204B data converter serial interface has been implemented in an FPGA and tested with both types of converters. Overall, the design of the first hardware and firmware prototypes for the board have started as scheduled.

The other upgrade where ICCUB contributes is for the frequency-dependent squeezing system aiming at the quantum noise reduction. Specifically, our team is developing new quadrant photo-detectors. We have chosen a uniform Position Sensitive Detector, contrary to the current setup of Virgo which has a gap between quadrants, meaning dead zones in the photosensitive or detection area. Remarkably, the sensors and its associated electronics components shall operate in vacuum (10–6 mbar). As can be seen in the figure, laboratory tests show that the chosen components withstand this vacuum level.

Besides instrumentation upgrades, the Virgo team at ICCUB has also contributed to computing and software engineering updates, including the migration of the main software repository of Virgo, as well as software building and deployment to modern tools aiming at a better maintainability.

Finally, in collaboration with the Virgo group at the University of Valencia, our team is working on a denoising technique, rROF, to provide cleaner data to the coherent wave burst (cWB) pipeline. It will allow detecting more events without requiring templates, effectively increasing the sensitivity of the observatory.

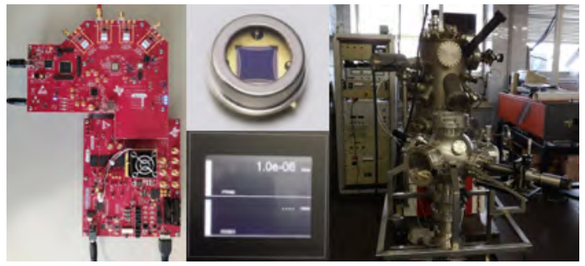

Figure 42: From left to right and from top to bottom, some of the electronics and instrumentation developments at ICCUB for the next Virgo upgrade: Digital to Analog Converter (DAC) and FPGA setup with JESD204B interface framework, 2D PSD (S2044 model from Hamamatsu), vacuum level monitoring, and vacuum test setup.

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ICCUB Virgo Team

Highlights

Astronomers discover 83 supermassive black holes in the early universe

The most distant quasars discovered ever by the Subaru HSC survey.

We know every large galaxy in the local Universe has a supermassive black hole at their centre but how they formed and evolved into the present time are still unclear. Characterising supermassive black holes identified as quasars in the early Universe would therefore provide us with important clues. Previous study detected rare, most powerful quasars at z~6 (that are also powered by most massive black holes) but this is a selection effect due to the limited survey sensitivity. A wide-area survey of the Japanese 8.2-m Subaru telescope with the sensitive wide-field camera, Hyper Suprime-Cam (HSC), goes down to a fainter flux level and has revolutionised the high-z quasar search. High-z quasar candidates selected by the multi-band HSC imaging are followed up by optical spectroscopy with Subaru and Gran Telescopio de Canarias (GTC), to confirm their identity and redshift. The number of newly discovered quasars at z > 5.7 was 93 (and counting, as the HSC survey continues), almost doubling the total number of high-z quasars, and they are populated in the luminosity range 2-3 magnitude below those previously known quasars. The discovery of the large number of low-luminosity objects enables us to construct a much more accurate luminosity function of quasars at z~6 than before and thus this places a tight limit (<10%) on the apparent quasar contribution to the re-ionization of the Universe which is supposed to complete at a similar redshift.

One of the HSC discovered quasars (HSC J1243+0100) is found to have z=7.07 which has been confirmed also by near-IR spectroscopy. Known quasars at z>7 are still few and this HSC quasar is the third most distant to date. This quasar has an order of magnitude lower luminosity than the other known z>7 quasars and its black hole mass is estimated to be ~300 million Solar masses: these properties are similar to those shared by the majority of low-z quasars.

These discoveries imply that the Subaru HSC survey started to tap the most distant (z = 6-7) counterparts of the quasar population commonly found in the low-redshift Universe, owing to the high-sensitivity survey.

The project is called Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs) associated with the Subaru HSC strategic program survey and carried out by a multi-national team, including Kazushi Iwasawa at IEEC-UB.

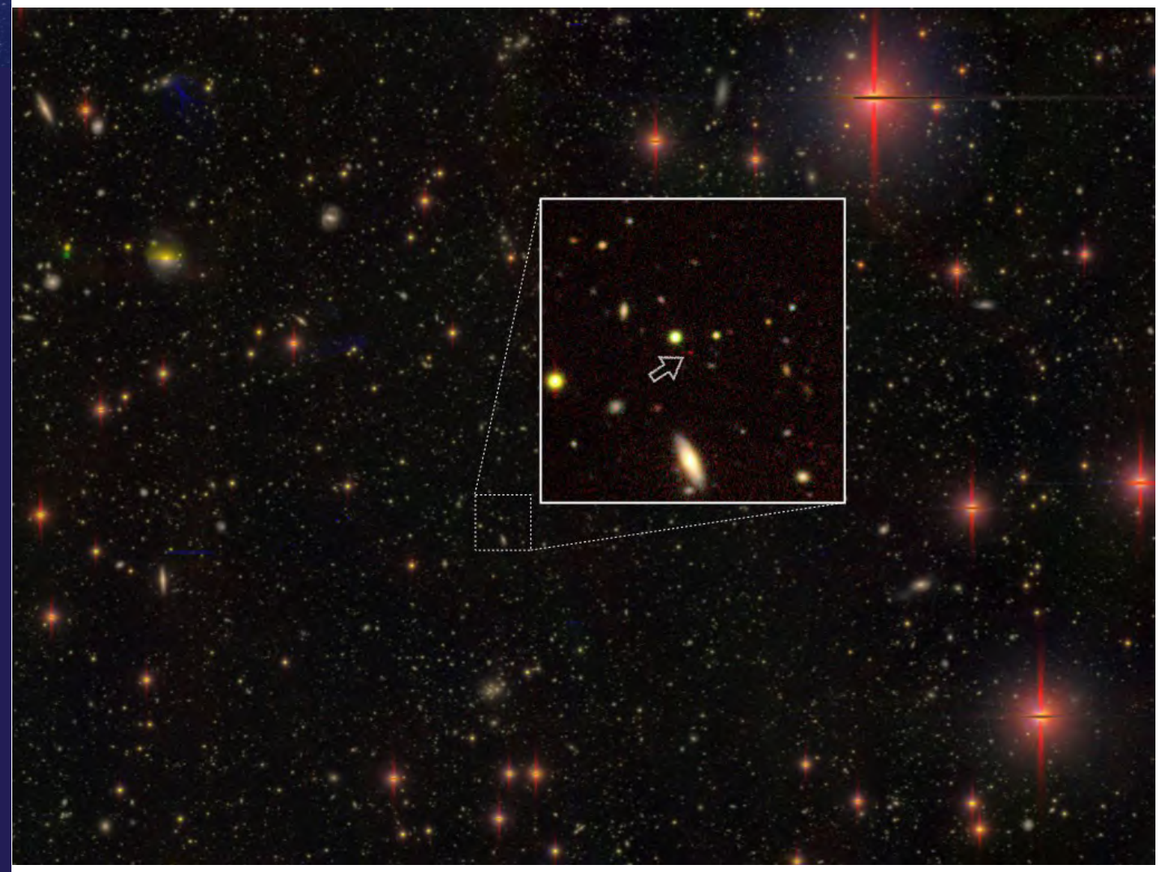

Figure 43: Subaru Hyper Suprime-Cam image of the z=7.07 quasar discovered by the SHELLQs project (credit to NAOJ).

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Highlights

Precise mass and radius determinations of one of the oldest stars in our Galaxy

Observed stellar parameters of a cool subdwarf are used to validate for the first time the theoretical relations for such stars.

At its early stages the Milky was mainly composed of hydrogen and so were the first stars born. When these stars died exploding as supernovae or by becoming white dwarfs, the interstellar medium became enriched in heavier elements. Stars born from this material display higher traces of heavy elements than primordial stars, therefore young stars are expected to have higher metallicities than older ones. Currently, we can still observe some of these very old and very low-metallicity stars, known as cool subdwarfs. However, because they are intrinsically faint and relatively rare, it has been impossible to measure both the mass and the radius for a single cool subdwarf star, leaving the theoretical relations of such stars untested.

During the process of updating the spectroscopic catalogue of white dwarf-main sequence binaries identified by the Sloan Digital Sky Survey we came up with a list of new eclipsing binaries, one of which had a very interesting spectrum. The blue part revealed the typical features of a white dwarf, the red part of the spectrum was dominated by the contribution of what seemed to be a “weird” low-mass star. We shortly realized this was a cool subdwarf star. This discovery was very exciting since we had at hand the possibility to measure the mass and the radius of a cool subdwarf for the first time, thanks to the eclipsing nature of the system.

We were awarded with director’s discretionary time at the Very Large telescope to obtain X-Shooter spectra of the cool subdwarf star from which we measured its radial velocities as well as derived its effective temperature and luminosity and estimated its metallicity (particularly the [Fe/H] abundance). We also used the Hipercam fast-speed camera mounted at the Gran Telescopio Canarias to sample the light-curves of the binary in five different band-passes. Our expectations were to sample the secondary eclipse of the binary (i.e. the transit of the white dwarf in front of the cool subdwarf; see the Figure), since this piece of information would dramatically help in deriving precise values of the mass and the radius of the cool subdwarf. Fortunately, the sensitivity of Hipercam allowed such detection.

Having obtained the stellar parameters of the cool subdwarf we compared the observed values to those expected from the theoretical relations for such stars and found excellent agreement. We thus validated for the first time the theoretical relations for low-mass low-metallicity stars. The discovery of this very interesting eclipsing binary, together with the relevance of our results, were published in Nature Astronomy in April 2019.

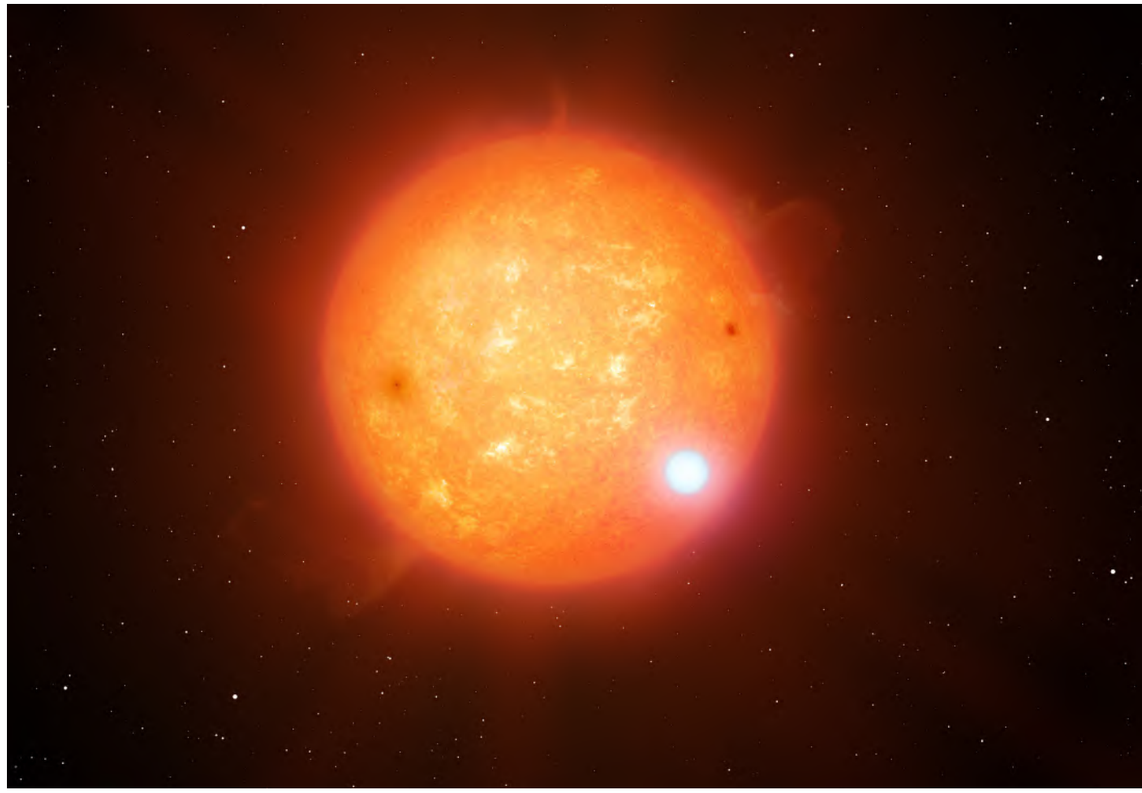

Figure 44: Artistic impression of the white dwarf transit in front of the cool subdwarf star.

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Highlights

Primordial comet fragment discovered inside meteorite gives clues to the origin of the Solar System

A fragment of an old comet discovered inside a meteorite.

In the Meteorite White Room of ICE, the Meteorites, Small Bodies and Planetary Science Group discovered a fragment of an ancient comet, right inside a meteorite from NASA's Antarctic collection.

This discovery was possible within the framework of a research project AYA2015-67175-P led by Dr. Josep M. Trigo which was just trying to find additional evidence to fill the gap in our knowledge between the nature of asteroids and comets.

Some bodies that we call transitional could be an amalgamation of both types of objects that have suffered fragmentation and regrouping over the eons. The discovery opens up clues about the materials that make up asteroids and comets.

As a result of research in this area, ICE became in 2010 the only NASA international repository of Antarctic meteorites in Spain. The discovery of this cometary fragment to the La Paz 02342 meteorite took place four years, as a result of the exhaustive study of dozens of carbonaceous chondrites that were part of this Antarctic collection.

The cometary fragment, about a hundred microns in size, is made up of an unusual mixture of organic matter, amorphous and crystalline silicates, sodium sulphates, sulphides and large presolars the latter synthesized into stars that enriched the primordial materials of our solar system. The amalgamation of materials is extremely complex, very small grain and very unbalanced chemically. Because of this, we have used, among other instruments, an ion mass spectrometer known as nano-SIMS, from the Carnegie Institution of Washington (USA).

With this instrument we have deepened the nature of each of the components of the Clastre thanks to the fact that it allows the electronic probing of the sample at a nanometric scale, both in the isotopic and elemental analysis fields. Thanks to this, we have been able to determine the unusual nature of the xenolite originating from a primeval comet and, furthermore, to specify that it contained a mantle of ice when it was incorporated into the meteorite.

The discovery was published in April in the journal Nature Astronomy.

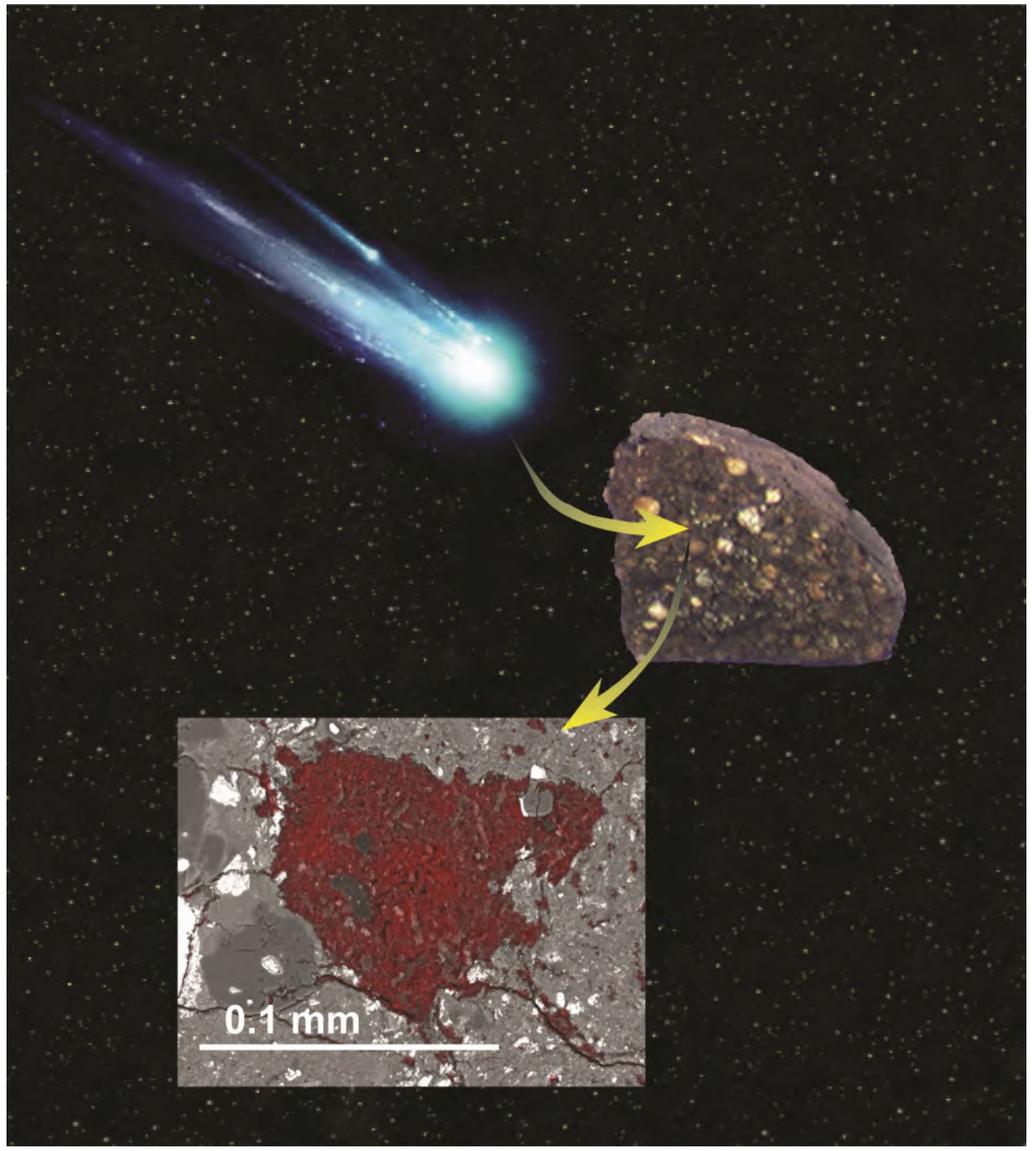

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Figure 45: Artistic impression of the primordial comet that shocked the meteorite with a section of the carbonaceous chondrite LaPaz 02342 that has been found.

Highlights

Gaia mission data reveals a re-ignition of star formation in the Milky Way's disc 5 billion years ago

The European Space Agency's Gaia satellite is opening a door into our galaxy's evolution.

It is quite accepted among the scientific community that nowadays the Milky Way makes about a Sun's worth of stars a year. However, Gaia is showing a very different behaviour of the Milky Way in the past: about five billion years ago something ignited a stellar formation episode in our Galaxy.

The Gaia mission released a high impact catalogue on 25 April 2018, measuring precise distance, motion, colors and magnitudes for more than a billion stars. To explore the Milky Way's present and past the GaiaUB team (ICCUB-IEEC) is using that splendid data set, along with some cutting-edge algorithms and a Big Data platform (GDAF-FP7-GENIUS), developed and maintained by the technological unit of the ICCUB. The results are published in Astronomy and Astrophysics and have been highlighted in the "Nature research highlights".

The researchers used the apparent brightness, color, and parallax for 2.9 million stars in the Gaia catalog. They then compare this information with a hundred thousand different simulations of the Besançon Galaxy Model, using the new BGM FASt framework (Mor et al. 2018). These simulations allow to infer the initial stellar mass function, the way those stars are distributed in the galaxy and the star formation history, which is the rate of the star formation as a function of time.

By modeling the process of star formation and evolution, the simulations can recreate a snapshot of the present of our Galaxy. Its comparison with Gaia observations provides information on the past evolution of the Milky Way.

The results (Mor et al. 2019) are stimulating and encouraging: About 10 billion years ago, our galaxy was making stars at a high rate. But its formation rate was in steady decline for the next 5 billion years. Previous studies have suggested that the Milky Way collided with another galaxy more than 10 billion years ago (e.g. Helmi et al. 2018). That merger might have stimulated a rush of star formation before eventually quashing it. Then, about 5 billion years ago another event ignited a stellar baby boom. This enhancement of the star formation lasted some 4 billion years. Maybe, the authors speculate, the Milky Way had collided again, this time with a gas-rich satellite galaxy. That would explain the re-ignition of the star formation, but maybe not the duration of this episode, which peaked 1 or 2 billion years after it started, when stars were forming at about 10 times today's rate.

The rate of new stars has been diminishing ever since. The research team's simulation ends with the present-day Milky Way making only a solar-mass worth of stars a year, in agreement with other measurements.

The plausibility of recent encounters finds support in cosmological simulations, which suggest that a Milky Way-like galaxy has a high probability of having interaction with satellite galaxies within the last 10 billion years. Additionally, studies of the kinematic structure of the Milky Way are also pointing towards recent encounters (e.g. Antoja et al. 2018) . For the more observationally minded, there's also a growing pile of studies that have been finding a sudden ramp-up in star formation 2–3 billion years ago. In this direction, J. Isern from ICE team using massive white dwarf stars i a volume of 100 pc around the Sun derived in Isern 2019 also supports a rump-up of star formation 2-3 billion years ago.

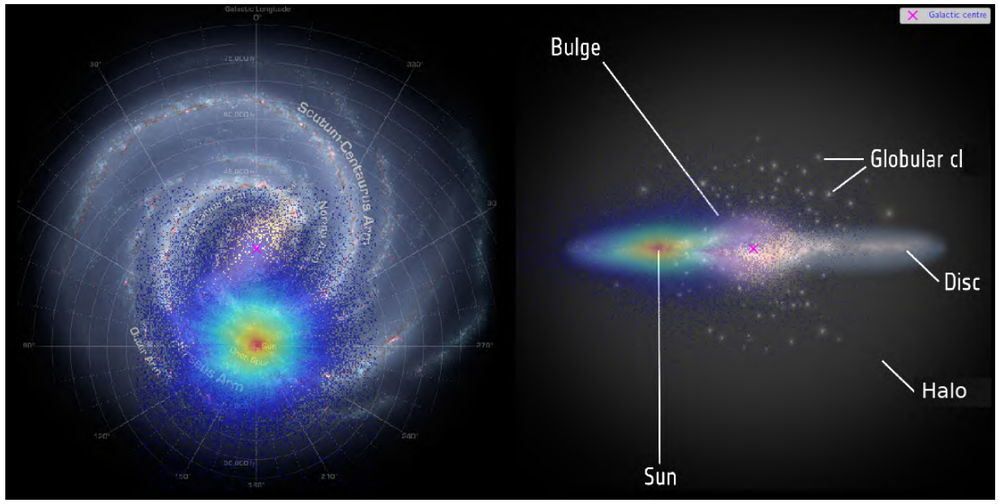

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Figure 46: Artistic impression of the Galaxy face on (left) and edge on (right). Colours are the stellar density of the Gaia sample limited in apparent magnitude G<12. Credits: NASA/JPL-Caltech; ESA/Gaia/DPAC-ESA/ATG and R. Mor.

Highlights

The analysis of a meteorite reveals secrets about the birth of the Solar System

A fragment of an old comet discovered inside a meteorite forged during the final phases of a star that disappeared a long time ago.

The study of the nuclear processes that take place in the stars is essential to understand how the key elements for the emergence of life in the cosmos are synthesized (i.e., from the oxygen we breathe to the calcium present in our bones, the iron in our blood, or the nitrogen in our DNA). When a star ejects thermonuclear-processed plasma, formation of solids begins as soon as the plasma cools down to a certain condensation temperature (about 1000 – 1500 K). Traditionally, this process has been assumed to be ruled by the carbon monoxide (CO) molecule. While most heteronuclear, diatomic molecules have dissociation energies around 3 - 5 eV, the CO molecule is characterized by a binding energy of 11.2 eV. This large value makes the CO molecule very stable. Thus, in an oxygen-rich plasma (i.e., O> C) which is gradually cooling down, all carbon atoms would get trapped in the form of CO molecules, making the subsequent formation of carbon-rich solids impossible (e.g., graphite, nanodiamonds, or silicon carbides). In contrast, in a carbon-rich plasma (C> O), all oxygen atoms would be confined into CO molecules, inhibiting the further formation of oxides, such as corundum (Al_2O_3), spinel ($MgAl_2O_4$), silicates ... Therefore, if the ratio C/O is the single criterion taken into account in the formation of solids, oxides and carbon-rich minerals could not form at the same time.

But recently, an international team, with the participation of Prof. Jordi José (IEEC-UPC), has identified for the first time a presolar meteoritic grain (known as LAP-149), a spherule older than the Solar System itself, embedded in the primitive meteorite LaPaz, with a unique chemical stratification: while its chemical abundance pattern suggests that it condensed in the plasma ejected during a nova outburst (an explosive phenomenon produced in the H-rich, accreted envelope piled up on top of a white dwarf star in a binary system), LAP-149 presents a core rich in oxides and silicates, wrapped by a thick graphite layer. The discovery, published in Nature Astronomy (2019), is the first identification of an oxide-rich sub-structure inside a graphite grain found in the lab. Analysis using multiple experimental techniques and equipment (including nanoscale secondary ion mass spectrometry [nanoSIMS], energy dispersive spectroscopy [EDS], electron energy loss spectroscopy [EELS], focused ion-beam microscopy [FIB], scanning transmission electron microscopy [STEM]...) suggests that the condensation of the carbon- and oxygen-rich layers took place simultaneously during a nova outburst, questioning the key role traditionally attributed to the CO molecule in the condensation process. At the same time, opens up new questions regarding the heterogeneous synthesis of nuclides during a nova explosion and the mixing mechanisms at play in the ejected material.

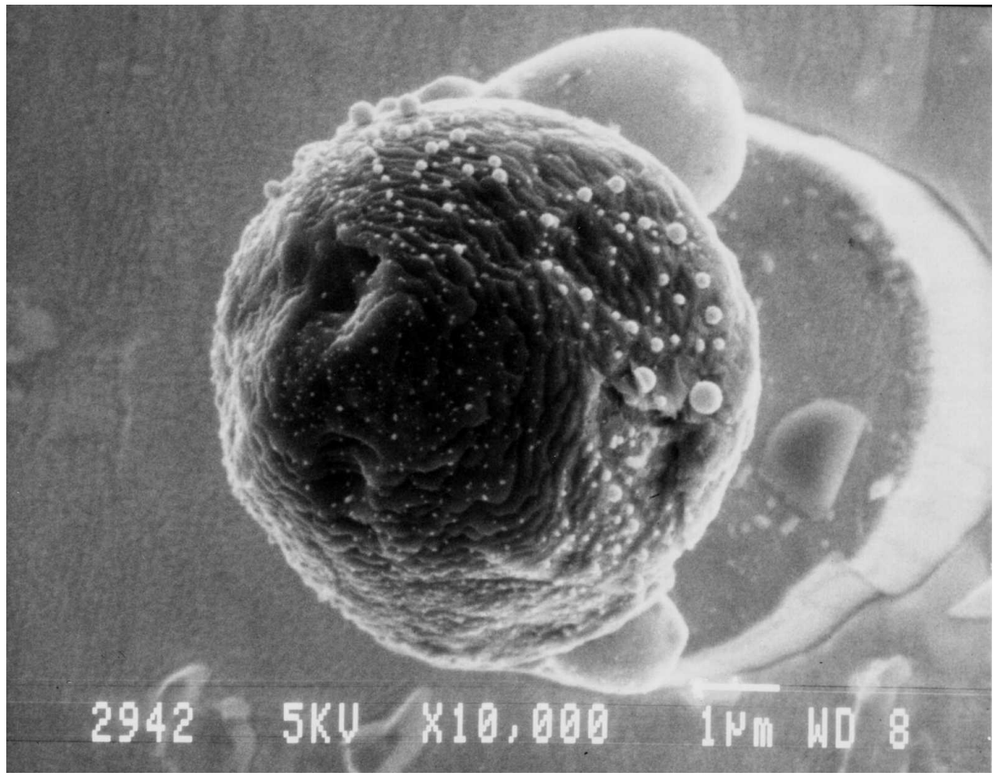

Figure 47: Secondary electron image of a graphite nova candidate grain after SIMS analysis. Credit: S. Amari, Washington University at Saint Louis

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Highlights

CARMENES finds two nearby habitable terrestrial planets

Observations taken by the CARMENES instrument, complemented with data from the TJO telescope, lead to the discovery of two small terrestrial planets around Teegarden's Star.

The CARMENES instrument started operations in 2016 at the 3.5-m telescope of the Calar Alto Observatory. It was built by a consortium of 11 institutions in Germany and Spain, including IEEC-CSIC. The main goal of the CARMENES survey was declared to be the discovery of terrestrial planets in temperate orbits around very low-mass stars. This scientific niche drove the design of the instrument, which, using two independent spectrometers, provides coverage ranging from 520 nm to 1710 nm and obtains data with spectral resolution around 90000. The most important aspect is that its temperature control and vacuum optics give it spectacular stability, so that it is possible to take Doppler spectrometry data with an accuracy of the order of 1 m s-1 for the visible channel and about 3-5 m/s for the infrared channel over very long timespans. In June of 2019 we announced the discovery of an exoplanetary system that faithfully reflects what CARMENES was built for.

At a distance of only 12.5 light years, Teegarden's Star is the 24th nearest star system to ours, and one of the smallest red dwarf stars known. Despite its proximity and due to its faintness, Teegarden's Star was only identified in 2003. The star has a mass that is about 10 times lower than the Sun's and was a prime target for the CARMENES survey. The Doppler measurements of Teegarden's Star showed the presence of at least two signals, which we reported as the two new exoplanets. Obtaining a robust detection with a new instrument required the collection of over 200 measurements since both signals have radial velocity amplitudes below 2 m/s. Photometric monitoring from the Joan Oró Telescope (OAdM) was key to determine the rotation period of the star and thus establish the planetary nature of the identified signals.

Based on the measured radial velocities, we deduce that Teegarden's Star b has a mass of 1.05±0.12 Earth masses, it orbits the star every 4.9 days at about 2.5% the Earth-Sun distance. Teegarden's Star c is also similar to the Earth in terms of mass, with 1.11±0.16 Earth masses, completes its orbit in 11.4 days and is located at 4.5% the Earth-Sun distance. Since Teegarden's Star radiates much less energy than our Sun, the temperatures on these planets should be mild and they could, in principle, hold liquid water on their surfaces, especially the outer one, Teegarden's Star c. They are among the best potentially habitable planets found so far.

Not too far in the future, technology should advance enough to be able to take direct images of these planets and study the chemical constituents and physical properties of their atmospheres. Perhaps they will move from being potentially habitable to habitable (with liquid water on the surface), and even inhabited (with a biosphere). The missions that will help us take such qualitative leap are currently being conceived, although they are not expected to be in operation until the 2040s. For now, CARMENES and other surveys are providing us with a census of nearby planets, particularly those that could have liquid water on their surfaces, that will be a treasure trove for future detailed studies.

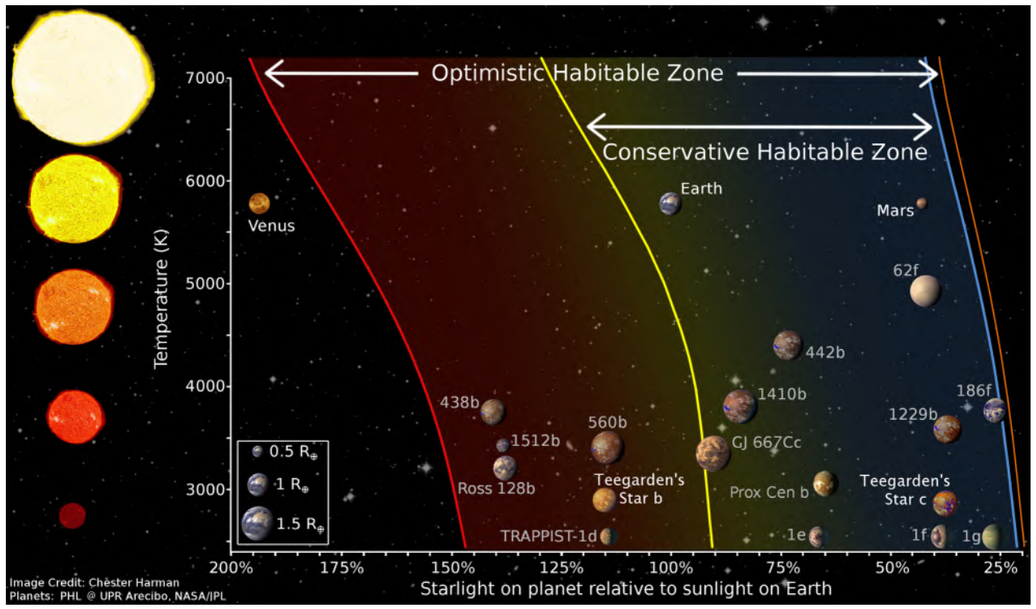

Figure 48: Diagram (planet insolation vs. stellar temperature) of the known potentially habitable exoplanets.

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Figure 49: Artistic impression of the gas giant planet GJ 3512b orbiting its red dwarf host star.

Highlights

Planetary Trio with Possibly Habitable World – TESS

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CARMENES and IEEC members leading the study on one of the first NASA/TESS systems with habitable zone planets.

The high-precision CARMENES spectrograph is now the workhorse for the Spanish community on exoplanets. The CARMENES instrument is operated by an international consortium with the same name composed by spanish and german institutions. Its project scientist is Ignasi Ribas (IEEC's director) and is participated by about a dozen other investigators at ICE. While space missions such as NASA/TESS and others lead the initial detections of planets, the actual science exploitation requires intensive follow-up with capable ground-based capabilities.

The study on the star GJ 357 is one of these cases. For this star, the team of the NASA/TESS mission reported the detection of a transiting planet in a very short period of orbit. These alerts go then to a community led collaboration which then organizes the follow-up of the most interesting targets. GJ 357 is a red dwarf star so CARMENES was in an advantageous position to perform the follow-up observations and further characterize the planet. Instead of just confirming the detection of GJ 357b, the team found out that this is actually a multi-planet system with at least three planets. The third one (GJ 357d) is a super-Earth in an orbit within the habitable zone of the star, which is the distance where a terrestrial planet could hold liquid water on its surface. Exoplanet research is a very competitive area, and the paper had to be organized and written in under a month combining tens of observations of three other spectrometers and historical ground based photometry to characterize the magnetic activity and rotation of the star. GJ 357 system is one of the first ones found by TESS with potentially habitable planets in it and the result was announced in a joint press release led by NASA. Besides the scientific relevance of the research, this work CARMENES and the participating members of IEEC in a leadership position in characterization of nearby potentially habitable planets, which is one of the most active areas in contemporary astronomy.

Highlights

Mysteriously in-sync pulsar challenges existing theories

For the first time, synchronised pulses of optical and X-ray radiation were detected from a mysterious pulsar.

Pulsars are highly magnetised, fast spinning neutron stars – the relics of massive stars. They are very dense objects, comprising up to two times the mass of the Sun within a radius of only ten km. The discovery of a mysteriously in-sync pulsar was made as part of a two-day observation campaign with X-ray satellites and optical telescopes from Earth. This combination allowed an international team of astronomers to measure with very high temporal resolution the two types of radiation coming from the ultrafast rotating pulsar.

The pulsar analysed, known as PSR J1023+0038, spins around its axis within a few thousandths of a second. Such pulsars are classed as millisecond pulsars, some of which are also sucking in matter from a companion star. Earlier studies had shown that this pulsar belongs to the rare category of so-called 'transitional millisecond pulsars' that periodically switch between two different modes of emissions – in X-rays and radio waves.

According to the leading model explaining this behaviour, the accretion of matter from the companion star gives rise to the pulsed X-ray emissions, while the radio signal is thought to result from the rotation of the pulsar's magnetic field. Further observations of PSR J1023+0038, however, revealed that an entirely different explanation might be needed to understand this class of sources. PSR J1023+0038 is the very first milisecond pulsar discovered with pulsations also in the optical band. The latest data show that the optical pulses in PSR J1023+0038 appear and disappear at exactly the same time as the X-ray ones.

Until now, it was thought that the pulsed X-ray emissions originated in a different process than the optical radiation. It was also expected these processes would take place one after the other, but this is not the case for PSR J1023+0038. The synchronised pulses are an indication that they have the same origin.

However, the new model develops a new idea: that the pulsar might be emitting a strong electromagnetic wind, which then interacts with the accretion disc around the system at a very close distance from the pulsar, giving rise to the concept of mini pulsar wind nebula.
The transitional pulsar J1023 + 0038 is one of the most interesting sources known. Its multi-frequency variability is incredibly rich, and allows us to study the relationship between the magnetic field and matter in extreme conditions.

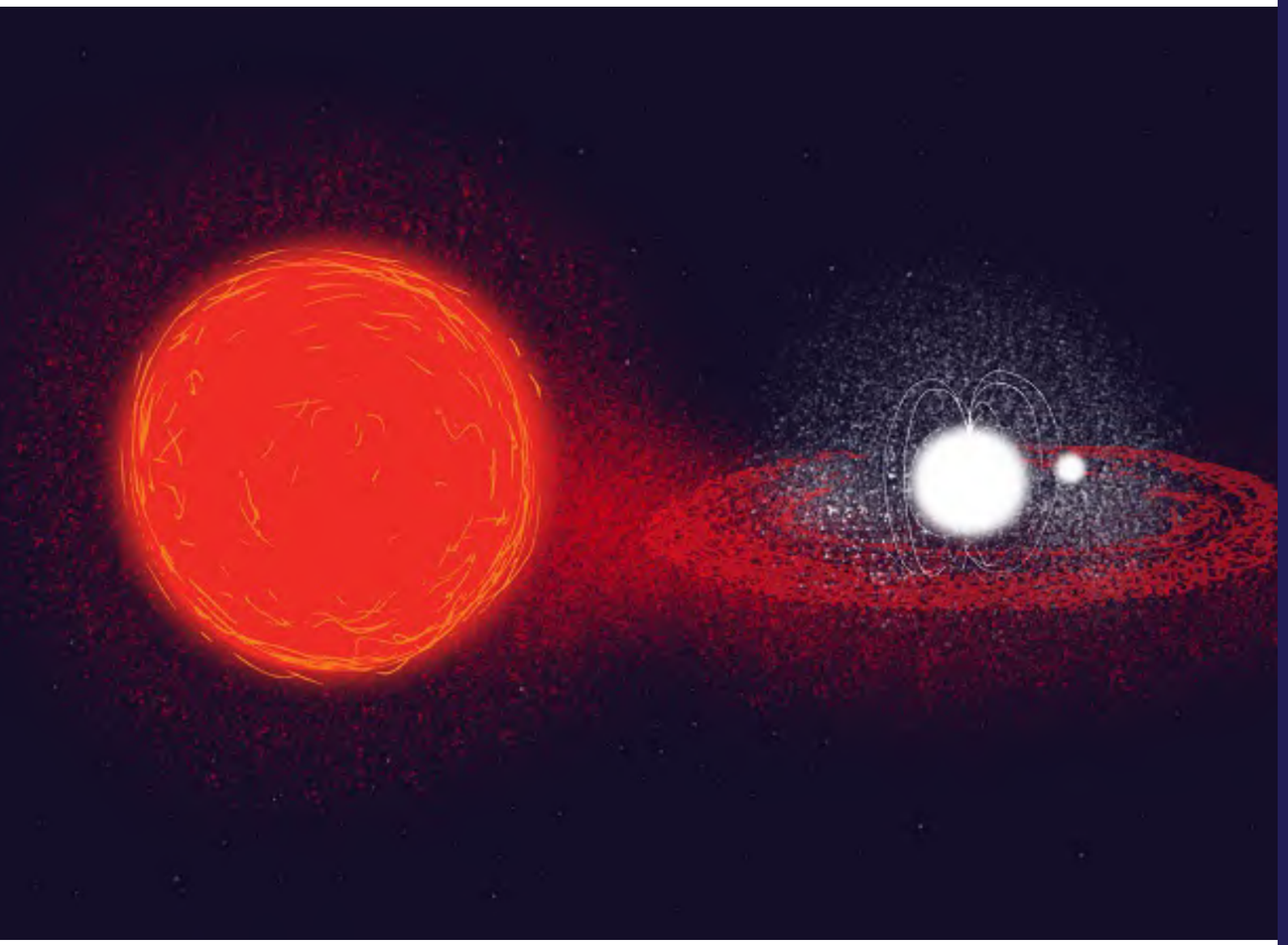

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Figure 50: The pulsar PSR J1023+0038 (in white), which is classed as a millisecond pulsar because of its fast rotation, spinning around its axis within a few thousandths of a second. The pulsar is also part of a binary stellar system, sucking in matter from its companion star (in red, on the left) via an accretion disc (also in red). The illustration is not to scale; in reality, the neutron star is much smaller than the companion star.

Highlights

Giant planet, tiny star

Low-mass stars typically host low-mass planets, but GJ 3512 b is the exception to this rule, challenging our current conception of planetary formation.

Radial velocity measurements from the CARMENES spectrograph revealed that GJ 3512, a star with only 12% the mass of the Sun, hosts a gas giant planet similar to Jupiter. Our analysis reveals that the star wobbles around the center of mass of the system with a radial velocity semi-amplitude of 71 m/s and a period of about 204 days, indicating the presence of a planet at least as massive as half Jupiter. The eccentricity of the planetary orbit also suggests that at least another planet was formed in the system and probably ejected due to dynamical interactions. Furthermore, the fits to the radial velocity data also point out the presence of a second more distant planet, whose precise properties will be determined with future observations, making GJ 3512 a multiplanetary system.

GJ 3512 b is the largest mass planet found orbiting such late-type stars by means of the radial velocity method, and the first one using a single instrument working in the near-infrared wavelength region of the spectra. It poses a major challenge to the core accretion planet formation theory, which predicts that rocky protoplanetary cores around low-mass stars do not grow sufficiently fast to form gas giant planets. This points out that this planetary system may be the first evidence proving alternative formation models such as disc instability, which predict that gas giant planets can be formed very fast from the collapse of an unstable region of the protoplanetary disc. The CARMENES survey will tell us how common this kind of system is in the Galaxy.

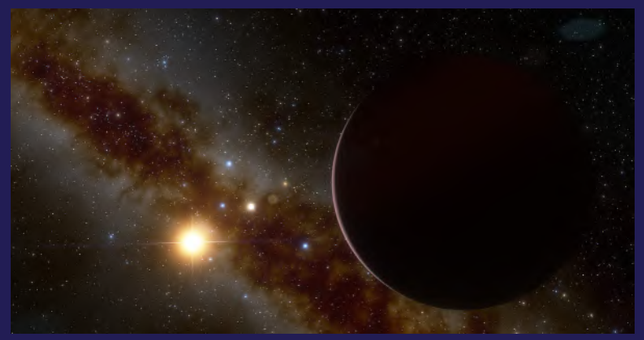

Figure 51: Artistic representation of the GJ 3512 planetary system, with a giant gaseous planet orbiting a late-type M-dwarf star. Credit: G. Anglada-Escudé.

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Highlights

Twin baby stars grow from gas streamers out of a common disk – the cosmic pretzel

High-angular resolution observations with ALMA reveals a complex network of accretion streamers nurturing two proto-stars at the centre of the circumbinary disk in the [BHB2007] 11 system.

The formation of such a binary star system has been observed for the first time with high-angular resolution using ALMA, a large array of radio (millimetre wave) antennas located at an altitude of 5000 m in the Chajnantor plateau of the Atacama desert (Chile). With these observations, an international team of astronomers, was able to identify a two-level accretion process, circum-binary disk to circumstellar disk to stars, constraining the conditions leading to formation and evolution of binary star systems. The team was led by Felipe Alves, currently at the Max Planck Institute for Extraterrestrial Physics, who did his doctoral studies at ICE, under the coordination of IEEC member Dr. Josep Miquel Girart, who is also the third author of the study.

Most stars in the universe come in the form of pairs – binaries – or even multiple star systems. The astronomers targeted the system [BHB2007] 11, the youngest member of a small cluster of young stellar objects in the Barnard 59 core in the Pipe nebula molecular cloud. While previous observations showed an accretion envelope surrounding a circumbinary disk, the new observations now also reveal its inner structure. Within the circumbinary disk there are two compact sources, that we interpret as dwarf circumstellar disks around the two young stars. The size of each of these disks is similar to the asteroid belt in our Solar System and their separation is slightly smaller than our Solar System as a whole. Both young stars are surrounded by a circumbinary disk with a total mass of about 80 Jupiter masses, which shows a complex network of dust filaments distributed in spiral shapes.

The astronomers interpret the filaments as inflow streamers from the extended circumbinary disk, where the circumstellar disk around the less massive of the two young stars receives more input, consistent with theoretical predictions. The estimated accretion rate is only about 0.01 Jupiter masses per year, which agrees with rates estimated for other proto-stellar systems. In a similar way as the circumbinary disk feeds the circumstellar disks, each circumstellar disk feeds the young star in its centre. At the disk-star level though, the accretion rate inferred from the observations is higher for the more massive object. The observation of emission from an extended radio jet for the northern object confirms this result, which is an independent indication that this star is indeed accreting more material.

The image of the “cosmic pretzel” has been considered among the first 10 most relevant images of ALMA according to the NRAO.

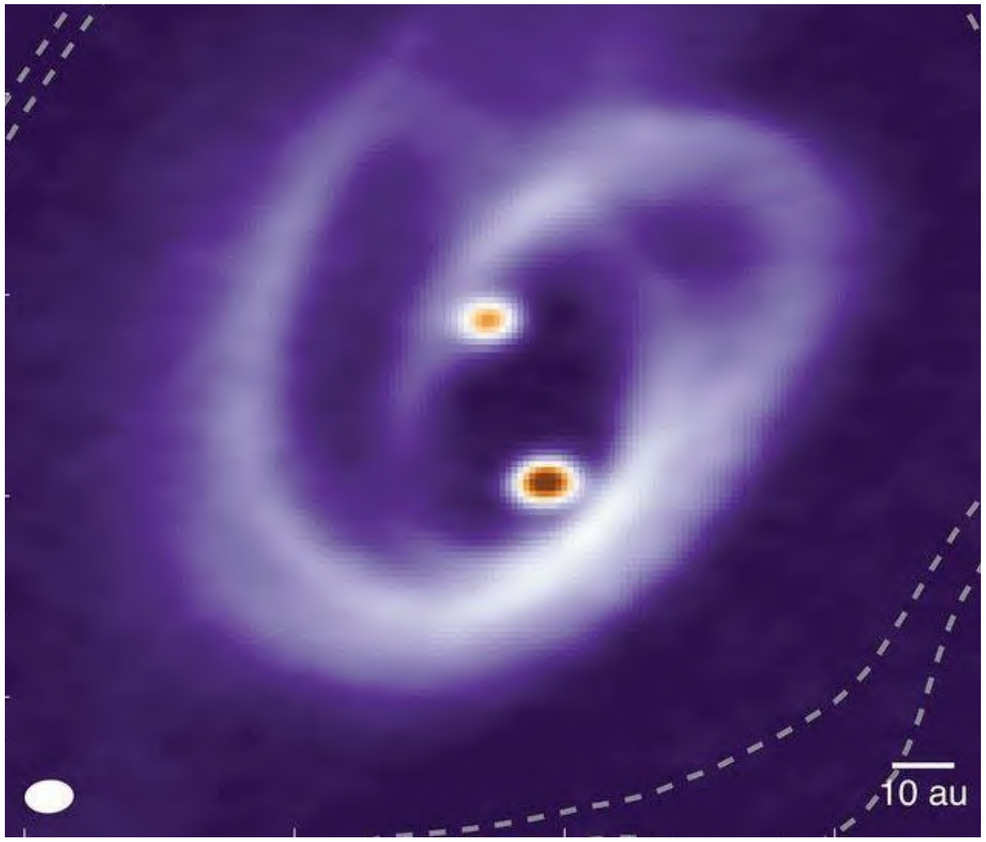

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Figure 52: Dust distribution showing a complex network of filamentary streamers around two small circumstellar disks harbouring two very young sun-like stars. Image adapted from Alves et al. 2019.

Highlights

Atmospheric data from the Spanish PAZ satellite reaches meteorological services worldwide in “near real-time” via WMO

During 2019, the radio occultation data collected aboard the PAZ satellite started short-latency dissemination to worldwide weather services, enabling their assimilation into numerical weather prediction models to improve the weather forecast

A spaceborne experiment called Radio Occultation and Heavy Precipitation aboard the Spanish PAZ satellite (ROHP-PAZ) uses GPS signals to extract information about the Earth’s atmosphere. One of the capabilities of ROHP-PAZ is to obtain vertical profiles of atmospheric temperature, pressure and water vapor parameters at high vertical resolution, well distributed across the Globe and under all types of weather conditions. This type of PAZ atmospheric products has started to reach all meteorological services around the world in 2019, through the global communications system of the World Meteorological Organisation (WMO), a specialised agency of the United Nations.

Weather forecasting requires that measurements of atmospheric parameters arrive with a maximum delay of three hours from their acquisition by the satellite, a very short latency; this is the so-called “near real-time”. The atmospheric measurements obtained by PAZ are derived from observations made with a modified GPS receiver on board. This data is temporarily stored in the on board computer until the satellite passes near a National Oceanic and Atmospheric Administration (NOAA) receiving station in Alaska. From that station, the raw data is sent to the University Corporation for Atmospheric Research (UCAR), where they are processed, controlled and sent back to NOAA for final transmission to the global weather services communication system. This entire process takes less than three hours from its acquisition on orbit. This milestone has been possible thanks to agreements between NOAA and ICE and IEEC, which are responsible for the GPS experiment on board PAZ, as well as agreements with Hisdesat, the company owning, managing and operating the satellite.

The GPS radio occultation technique was developed between the mid-1990s and early 2000s, and its data has been integrated into weather models since 2006. In June 2019, NOAA launched six satellites with this technology, covering the tropics and mid-latitudes (COSMIC-2 constellation); however, initial plans to launch six more satellites to cover the poles and high latitudes were cancelled. PAZ complements data acquired from other satellites in polar orbits by densifying these measurements in areas not covered by the COSMIC-2 constellation. This is why NOAA was interested in participating in the Spanish mission’s radio occultation experiment. Different studies have determined that this type of data significantly improves weather prediction, giving them great operational value. This means that the prediction is more accurate and, therefore, with fewer errors, when these data are integrated into the models. In addition, it functions as a self-calibrated thermometer, which helps to correct the biases of other techniques that do require calibration.

It has been proven that the quality of the atmospheric ROHP-PAZ data is equivalent to the missions also operationally processed, which has led to their worldwide distribution. The US Navy Global Environmental Model (NAVGEM) was the first model into which PAZ RO data have been operationally assimilated, since August 2019, reporting positive impacts.

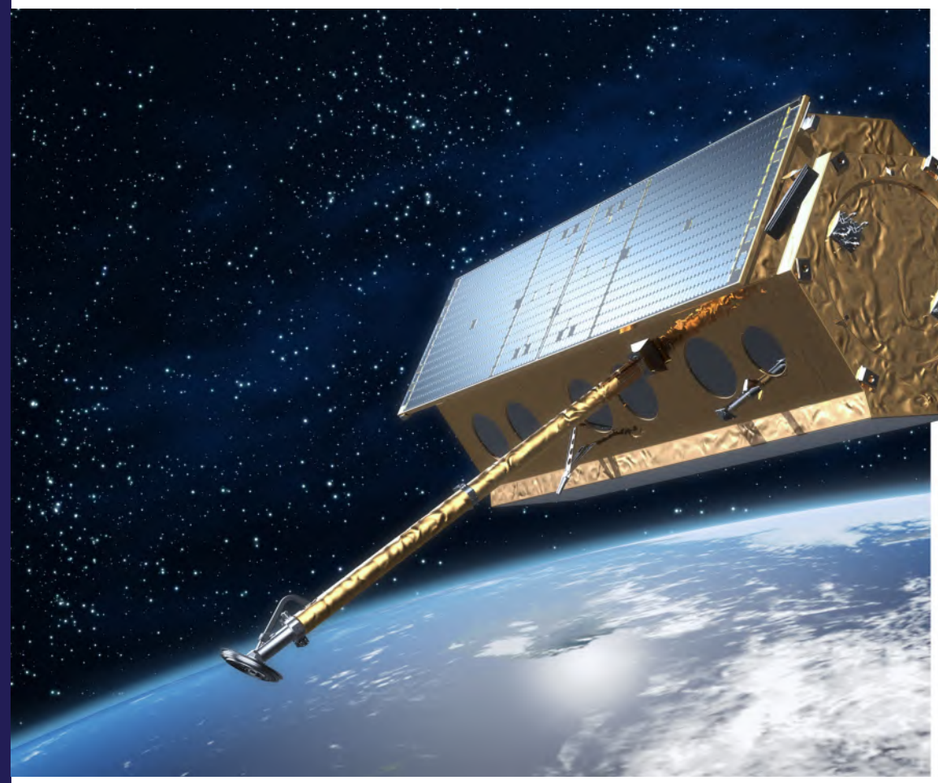

Figure 53: Artist’s impression of the PAZ satellite in orbit. Credit: Hisdesat.

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Highlights

DESI preparing to map the Universe

DESI, a new instrument to map the Universe, saw its first light in October 2019. Currently, the instrument is being commissioned to start obtaining spectra of millions of galaxies and quasars to understand the structure of the Universe.

The Dark Energy Spectroscopic Instrument (DESI) is a new instrument designed to produce a precise map of the Universe. The instrument will explore the mysterious dark energy that constitutes the 68% of the matter-density of the universe and is responsible for its accelerated expansion. For that purpose, it will carry out a survey for the next five years mapping one third of the sky obtaining the spectra of 35 million galaxies and 2.5 million quasars to determine their redshift. The instrument will start observations in 2020.

DESI is installed at the prime focus of the Mayall 4-meter telescope at the summit of Kitt Peak in Arizona, USA. DESI is a massive spectroscopic instrument providing unprecedented multi-object spectroscopy capabilities. DESI has a six-lens optical corrector that delivers a three-degree diameter field of view. The focal plane contains 5,000 robotic positioners that can be reconfigured within three minutes to collect the light of distant galaxies. Ten small cameras in the focal plane are used to ensure that the telescope is pointing accurately and the focal plane is in focus. Optical fibers are mounted in the positioners and carry the light to ten spectrographs with a spectral coverage ranging from 360 nanometers (nm) to 980 nm. The instrument control system runs the whole instrument, while the data acquisition system ensures accurate targeting and fast analysis of the large amounts of data collected.

The DESI survey will measure the positions of millions of galaxies to determine the expansion rate of the universe in the last 10 billion years. DESI will also measure the velocities of galaxies, helping to determine how gravity brings matter together. With that data set, it will be able to constrain possible models of dark energy and whether there are deviations from the theory of gravitation of general relativity.

The DESI focal plane is composed of ten petal segments, each one containing 500 positioners and one Guide, Focus and Alignment Unit (GFA). Our group at IEEC has helped IFAE in designing, producing and testing the GFAs. These are cameras located at the edge of each focal plane petal and are responsible for field acquisition and guiding and to maintain the focal plane aligned and in focus during the science exposures. We delivered twelve GFA units to Berkeley in 2019 for them to mount and integrate them in the focal plane. Ten units are now in the focal plane and the other two remain as spares.

Our group is also responsible for providing the guiding software of the instrument. We process the images taken with the GFAs and determine the telescope pointing corrections to ensure that the light from the target galaxies falls down the fibers.

DESI saw first light in October 2019 and is now being commissioned. Our team is helping in the commissioning of the GFAs and the guiding software. After commissioning, there will be a short Science Verification phase after which the survey will begin. It will run for five years and will provide very competitive cosmological constraints.

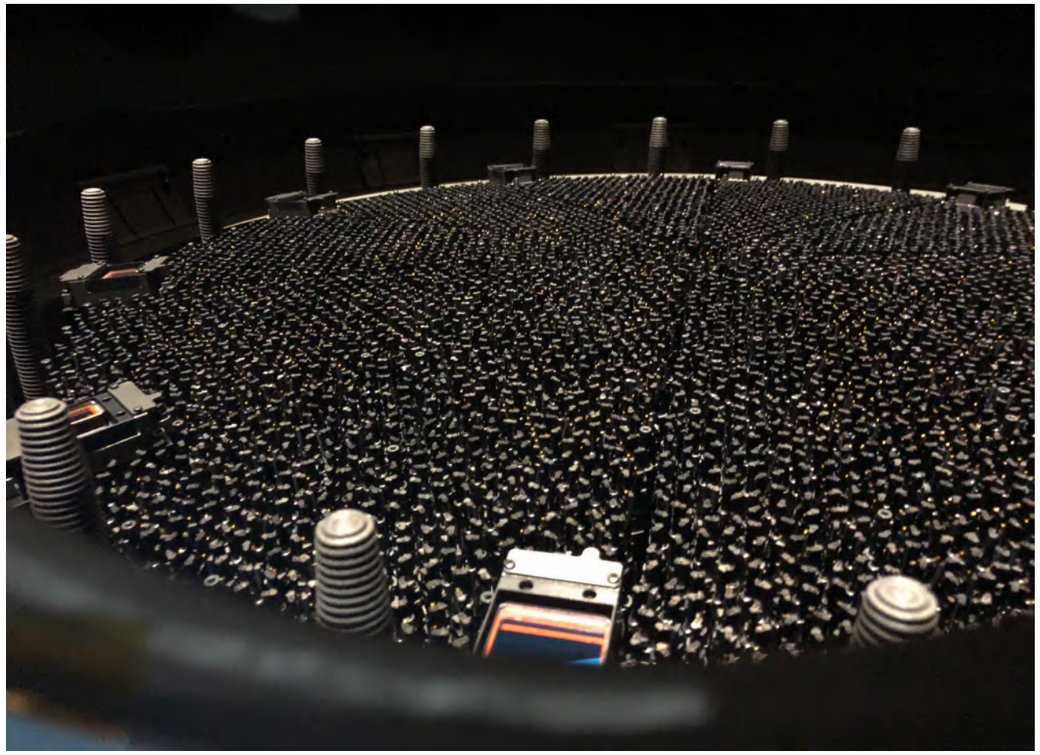

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Figure 54: Image of the focal plane showing the fiber ends of the positioners, the GFAs and the protruding protective covers of the alignment pins.

Highlights

Breaking the Limits: Discovery of the Highest-Energy Photons from a Gamma-Ray Burst

Discovery of a missing piece of the puzzle in understanding massive star collapse.

Gamma-Ray Bursts (GRBs) are brief and extremely powerful cosmic explosions, suddenly appearing in the sky about once per day. They are thought to result from the collapse of massive stars (long GRBs) or the merging of neutron stars (short GRBs) in distant galaxies. After a search that has lasted decades, observations have revealed the emission of a GRB at TeV gamma-ray energies, meaning that they are a trillion times more energetic than visible light. The detection was made using MAGIC (Major Atmospheric Gamma Imaging Cherenkov) telescopes, located in La Palma, Spain.

On 14 January 2019, a long GRB was discovered independently by two space satellites: the Neil Gehrels Swift Observatory and the Fermi Gamma-ray Space Telescope. The event was named GRB 190114C and, within 22 seconds, its coordinates in the sky were distributed as an electronic alert to astronomers worldwide, including the MAGIC Collaboration. The MAGIC telescopes observed GRB 190114C just 50 seconds after the beginning of the GRB.

The analysis of the resulting data for the first tens of seconds revealed emission of TeV photons, 100 times more intense than the brightest known steady source at TeV energies, the Crab Nebula. Together with observations at other energies, these results are the first unequivocal proof that a new emission component due to Inverse Compton processes is present in the afterglow of long GRBs. Optical observations carried afterwards revealed that the GRB took place at roughly 7 billion light-years.

After more than 50 years since GRBs were first discovered, many of their fundamental aspects remain mysterious. The wealth of new data on GRB 190114C acquired by MAGIC now offers important clues to unravel some of the mysteries concerning the physical processes at work in GRBs.

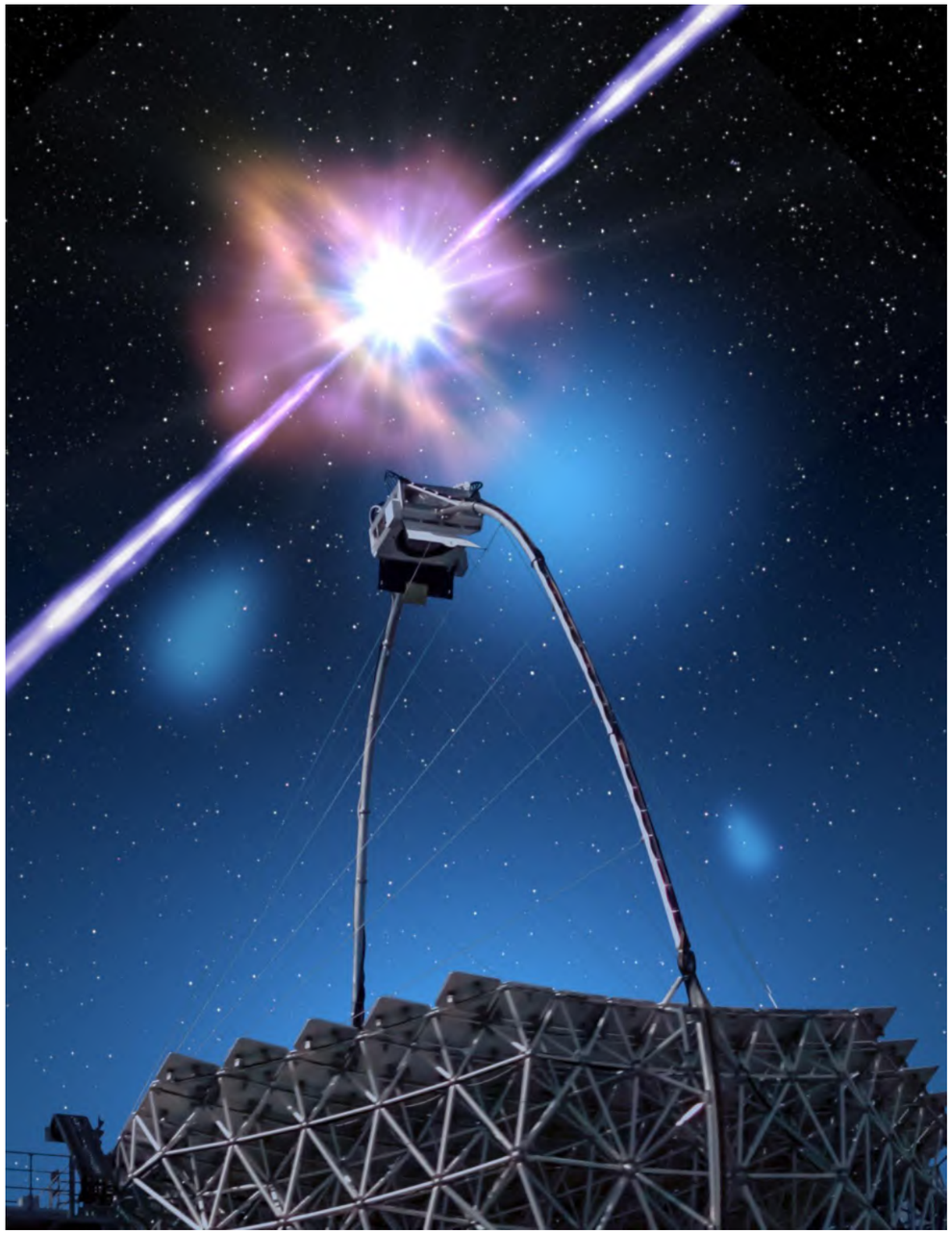

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Figure 55: Artistic view of a MAGIC telescope with a gamma-ray burst. Crédit: Gabriel Pérez Díaz/IAC.

Highlights

CHEOPS telescope is launched to space carrying drawings from Spanish children

A group of IEEC researchers, has participated in the preparation of the mission and attended the launch from French Guiana.

On Tuesday, 18 December 2019, the CHEOPS (CHaracterizing ExOplanet Satellite) mission, a space telescope from the European Space Agency (ESA) that aims to study new planets outside the solar system, was successfully launched.

The main objective of the CHEOPS space telescope is to accurately measure the radii of those exoplanets for which terrestrial spectroscopic studies have already provided estimates of their masses. Knowing both the mass and the size of the exoplanets will allow scientists to determine their density and therefore their approximate composition, i.e. whether they are gaseous worlds, such as Neptune, or rocky, such as the Earth. For this, CHEOPS will use the technique of transits through very high precision photometry, which consists of measuring the brightness of the star and detecting the decrease when the planet passes in front and hides a part of its disk.

Currently, there are more than 4000 confirmed exoplanets in about 3000 planetary systems, of which more than 650 have more than one planet. The CHEOPS space mission, part of ESA's Cosmic Vision programme, aims to refine the properties of a large sample of them. The mission is a collaboration between ESA and the Swiss Space Office. The acronym CHEOPS is a tribute to Ancient Egypt and a reference to the Cheops pyramid.

The space telescope carries onboard two plates with about 3000 drawings from European children, including 297 from Spain. The initiative was promoted by ESA in 2015, with the organization of a competition among all children between the ages of 8 and 14 in ESA member countries. The intention was to bring space development projects closer to the youngest. IEEC was one of the centres that collaborated at the state level, together with the Spanish Research Council (CSIC) and the Canary Islands Astrophysics Institute (IAC), for the collection of the drawings. More than 3000 drawings were received only from Spanish schools, being by far the country with the largest participation in the contest. The drawings were engraved in a miniaturized form, shrunk by a factor of 1000, on two titanium plates that CHEOPS is now carrying in orbit around our planet.

The launch of the CHEOPS mission, initially planned for 2017, finally took place on Wednesday, 18 December 2019, at 05:50 local time from French Guiana, and was attended by several IEEC members, such as its director Ignasi Ribas, and Josep Colomé and Kike Herrero, Technical Director and researcher at the Montsec Astronomical Observatory, respectively. In the next few months, the exoplanet research group at IEEC, led by Ignasi Ribas, will be participating in the scientific exploitation and analysis of the data from the CHEOPS telescope.

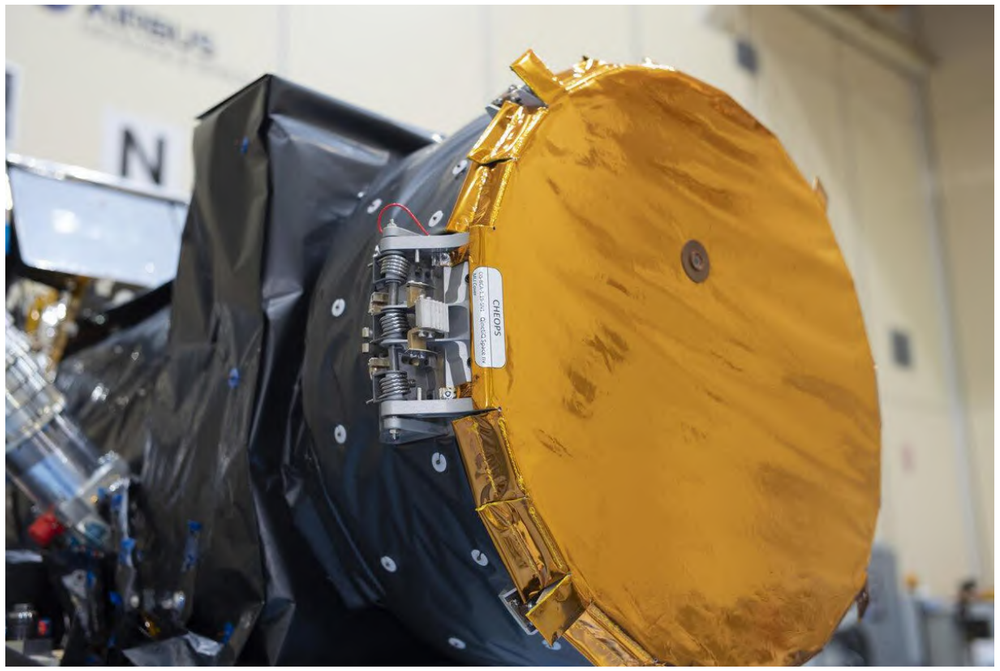

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Figure 56: The telescope baffle cover of the CHEOPS satellite, pictured here during spacecraft testing in the cleanroom at Airbus Defence and Space Spain, Madrid, protected the mission's science instrument from dust and bright light during testing, launch and the early phases of in-orbit commissioning.

Highlights

Magnetar census: the impact of highly magnetic neutron stars in the explosive and transient Universe

Magnetars, the most magnetic neutron stars, have been linked to a wide variety of explosive events.

The gravitational wave window is now open. It is then imperative to build quantitative models of neutron stars that use all the available tracers to constrain fundamental physics at the highest densities and magnetic fields. The most magnetic neutron stars, the magnetars, have been recently suggested to be powering a large variety of explosive and transient events. The enormous rotational power at birth, and the magnetic energy they can release via large flares, put the magnetars in the (yet) hand-wavy interpretations of gamma-ray bursts, the early phases of double neutron star mergers, super-luminous supernovae, hypernovae, fast radio bursts, and ultra-luminous X-ray sources.

However, despite knowing about 30 magnetars, we are lacking a census of how many we expect within the pulsar population, nor do we have robust constraints on their flaring rates. The recent discovery of transient magnetars, of magnetar-like flares from sources with measured low dipolar magnetic fields and from typical radio pulsars, clearly showed that the magnetar census in our Galaxy is largely under-estimated. This hampers our understanding not only of the pulsar and magnetar populations, but also of them as possibly related to many of Universe's explosive events.

The ERC Consolidator project MAGNESIA will infer a sound Magnetar Census via an innovative approach that will build the first Pulsar Population Synthesis model able to cope with constraints/limits from multi-band observations, and taking into account 3D magnetic field evolution models and flaring rates for neutron stars. Combining expertise in multi-band observations, numerical modelling, nuclear physics, and computation, MAGNESIA will solve the physics, the observational systematic errors, and the computational challenges that inhibited previous works, to finally constrain the spin period and magnetic field distribution at birth of the neutron star population.

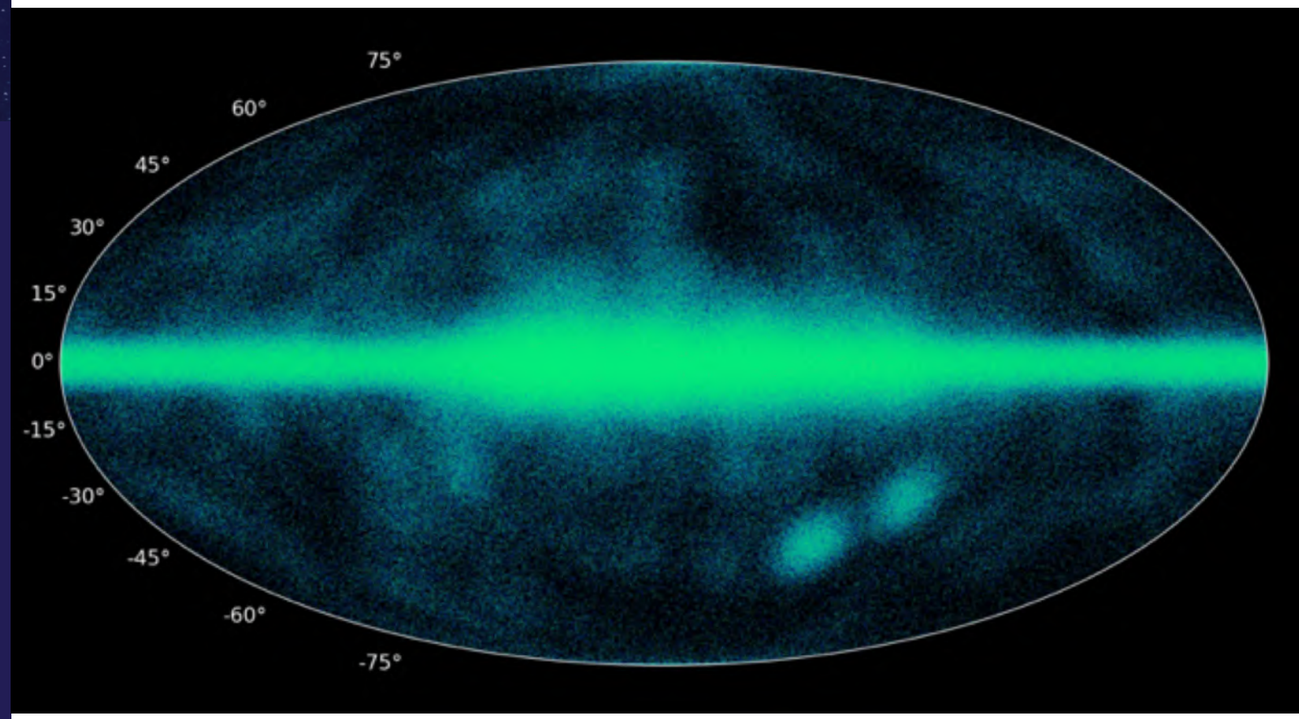

Figure 57: Simulated image of the pulsar population in our Galaxy (Credit: N. Rea/S. Serrano, ICE-CSIC, IEEC)

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Highlights

eXTP: a future X-ray space mission to study the state of matter under extreme conditions

The new X-ray space mission eXTP, a collaboration between several European countries and China, is designed to study fundamental physics topics such as the vicinity of black holes or the state of matter inside neutron stars.

The eXTP X-ray satellite (enhanced X-ray Timing and Polarimetry Mission) is envisioned to be launched in 2027, with four instruments onboard. One of them, the Wide Field Monitor (WFM), is led by Margarida Hernanz, a researcher from the IEEC at the ICE. The ICE - CSIC group will supply the whole mechanical structure of the cameras, be responsible for the mechanical and thermal design of the WFM instrument, and also for the Assembly, Integration, Verification and Test of its cameras.

The mission is designed to study the state of matter under extreme conditions of density, gravity and magnetism. The main goals are the determination of the equation of state of matter at huge densities, the probe of the gravity theory in extreme environments, as well as the study of the behaviour of light in the presence of ultra-strong magnetized stars. With these aims, the primary targets are isolated and binary neutron stars, stellar-mass and supermassive black holes and magnetars - neutron stars with huge magnetic fields - respectively.

Several scientists of IEEC at ICE-CSIC are involved in the scientific design of the eXTP X-ray satellite: in particular, Nanda Rea, Laura Tolos, Diego Torres, Francesco Coti Zelati, Alessandro Patruno, Daniele Vigano, are working in the scientific shaping of the instrument for neutron stars studies. The technical challenges about the design of the WFM instrument are in charge of engineers from ICE-CSIC and IEEC, in particular José Luis Gálvez, Lluís Gesa, Mikel Lamensans and Eduard Mirabet.

The WFM instrument will be composed of a set of 3 pairs of coded mask cameras, equipped with silicon drift detectors, covering a wide Field of View. Its mission will be to scan for and catch rare events, for which it will then be able to emit triggers, so that the other instruments onboard the satellite, that have a narrower field of view, could make more precise spectral and timing observations. The idea of this mission, dedicated to study the state of matter under extreme conditions by using X-rays, stems from an older European Space Agency (ESA) mission proposal, called LOFT (Large Observatory For X-ray Timing). The feasibility study, financed by ESA, was completed in 2013 with an excellent evaluation. Even though LOFT was not selected for launch, the idea was continued by a collaboration between China and Italy, Spain, Germany, Denmark, France, Netherlands, Poland, Czech Republic and Switzerland, who are now actively participating in the development of eXTP.

Figure 58:
Simulated image of the pulsar population in our Galaxy (Credit: N. Rea/S. Serrano, ICE-CSIC, IEEC)

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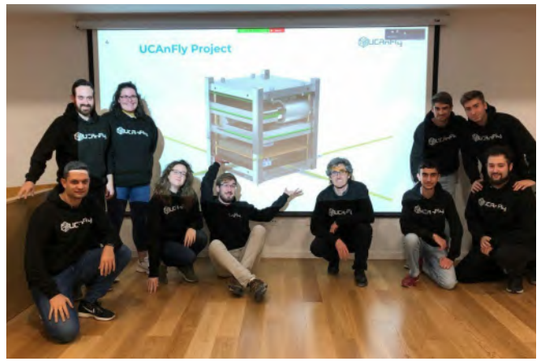
Short News

Located in the Autonomous University of Barcelona, ESA's Micro-Ecological Life Support System Alternative (MELiSSA) pilot plant, which was initiated as part of a research programme on life support technologies, celebrated its 10th anniversary.

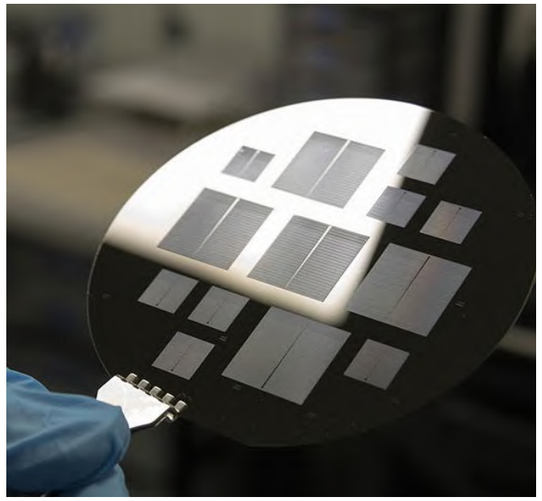
Nanda Rea (IEEC and ICE-CSIC) won the Royal Academy of Sciences Foundation for Young Women Scientific Talent prize, awarded by the Royal Academy of Sciences of Spain in the Physics and Chemistry category.

IEEC's director, Ignasi Ribas, and ICC researcher, Licia Verde, at the opening of the 24th Science Week in Catalonia with a debate about the frontiers of science.



With technology developed at IEEC, the nanosatellite UCAnFly, from the Superior School of Engineering of the University of Cadiz, has been selected by ESA for its programme "Fly Your Satellite!".

Juan Carlos Morales (IEEC and ICE-CSIC) awarded with the Premi Ciutat de Barcelona 2019 Experimental Sciences and Technology prize for having led a study that found a giant exoplanet around a dwarf star.



IEEC members at UPC's Dept. of Electronic Engineering have participated in the design, manufacture and calibration of the wind sensor for the MEDA instrument, which will travel to Mars on NASA's 'Mars2020' mission.

Collaboration with the organisation of professional meetings

The “Modified Gravity and Cosmology Workshop” took place from 8 to 10 May 2019 and it was organized and hosted at ICE. The workshop aimed to topics related to cosmology and theoretical physics, such as cosmological models: modified gravities, f(R) theories and the like, non-local models; quantum gravity; quantum cosmology and loop quantum cosmology; quantum vacuum and the Casimir effect; or the cosmological constant problem.

On May 2019, from the 20 to the 24, ICE organized the workshop “Polarization in Protoplanetary Disks and Jets”. It was held at the “Casa de la Cultura de Sant Cugat del Vallès” with the main goal of bringing together observers and theoreticians interested in the study of magnetic fields in protoplanetary disks and protostellar jets as well as polarization mechanisms to review the current state of the research and explore effective means to probe magnetic fields.

This meeting is part of the “Fòrum de Sant Cugat” that the IEEC organizes biannually and for which it has signed an agreement with the City Council.

Figure 59: Group photo of the attendees to the Polarization in Protoplanetary Disks and Jets workshop.

The “High Energy Phenomena in Relativistic Outflows (HEPRO VII)” meeting was hosted by ICC. The workshop took place at the Faculty of Physics in the Aula Magna Enric Casassas from 9 to 12 July 2019. The High Energy Phenomena in Relativistic Outflows (HEPRO) conference series are devoted to the discussion of the latest and more relevant observational, phenomenological, and theoretical developments in the field of high-energy astrophysics related to systems displaying relativistic winds and jets.

Figure 60: Prof. Josep Maria Paredes (ICC) at the inauguration event of the HEPRO VII Meeting.

Also, from 4 to 6 September 2019 the 5th edition of the “Variable Galactic Gamma-Ray Sources V (VGGRS V)” workshop was held at the premises of ICC. The main topics of the workshop were high-energy processes in compact sources, variable non-thermal emission in galactic sources and numerical simulations. It focused on the study of gamma-ray binaries as well as on the potential of CTA in advancing our understanding of these systems.

Collaboration with the organisation of Summer Schools

From 1 to 5 July 2019, ICE organized its 3rd Institute of Space Sciences Summer School. In this edition, it was linked to the 1st IEEE Geoscience and Remote Sensing Society (GRSS) Instrumentation and Future Technologies (IFT) Remote Sensing Summer School (IFT-R3S). The objective of the 1st Summer School on Instrumentation and Future Technologies for Remote Sensing was to promote future research in remote sensing, to connect future PhD students to research topics under the IEEE GRSS IFT Technical Committee, and to highlight the educational activities of the GRSS society. This IFT-R3S was meant to be the first of an itinerant series (annual or biannual) of IFT-R3S editions, moving to different towns and continents and hosted by other Instrumentation and Future Technologies Technical Committee (IFT-TC) groups. There were 42 participants at Master, PhD and young professionals and postdocs level from 21 different countries. As an institution committed to gender equality, the participants were gender balanced (54.8% male and 45.2% female).

Figure 61: A group photo of the participants of the IFT-R3S.

The 4th Barcelona TechnoWeek was organised by ICCUB in collaboration with IEEC from 17 to 21 June 2019. The Barcelona TechnoWeek is a series of meeting point events around a technological topic of interest for both academia and industry. This 4th edition was devoted to the emerging field of nanosatellites. It was an intensive 5-day “bootcamp”, providing a comprehensive introduction to the basic concepts of nanosatellite design and construction.

Figure 62: Image of one of the TechnoWeek lectures.

Meetings, Schools & Training

PHD Theses

Author: David Roma Dollase
Department/Institute: Universitat Politècnica de Catalunya. Departament de Física
Title: Global ionospheric maps : estimation and assessment in post-processing and real-time
Date: 9 April 2019
Director: José María Gómez Cama and Manuel Hernández Pajares

Author: Daniel Pacheco Mateo
Department/Institute: University of Barcelona. Departament de Física Quàntica i Astrofísica
Title: Analysis and modelling of the solar energetic particle radiation environment in the inner heliosphere in preparation for Solar Orbiter
Date: 30 April 2019
Director: Neus Àgueda Costafreda and Àngels Aran Sensat

Author: Rubén Barragan Cuesta
Department/Institute: Universitat Politècnica de Catalunya. Departament de Teoria del Senyal i Comunicacions
Title: Lidar remote sensing and co-operative observations: Processing methods and aerosol radiative transfer
Date: 5 May 2019
Director: Francisco Rocadenbosch Burillo and Michaël Sicard

Author: Roger Mor Crespo
Department/Institute: University of Barcelona. Departament de Física Quàntica i Astrofísica
Title: The star formation history and the stellar initial mass function of the Milky Way disc. The population synthesis Besançon Galaxy Model in the Gaia era
Date: 18 June 2019
Director: Francesca Figueras Siñol and Annie Robin

Author: Sergi Locubiche-Serra
Department/Institute: Autonomous University of Barcelona. Departament de Telecomunicació i Enginyeria de Sistemes
Title: Robust Carrier Tracking Techniques for GNSS Receivers Affected by Ionospheric Scintillation
Date: 18 July 2019
Director: José Antonio López Salcedo and Gonzalo Seco Granados

Author: **José Luís Bernal**
Department/Institute: **U**niversity of Barcelona. Departament de Física Quàntica i Astrofísica
Title: Cosmology on the edge of A-Cold Dark Matter
Date: 13 September 2019
Director: Licia Verde

Author: **Àlex Alarcon González**
Department/Institute: Autonomous University of Barcelona. Departament de Física
Title: Cosmology with Galaxy Surveys
Date: 2 October 2019
Director: Enrique Gaztañaga

Author: **Núria Torres Albà**
Department/Institute: University of Barcelona. Departament de Física Quàntica i Astrofísica
Title: High Energy Processes in Active Galaxies
Date: 14 October 2019
Director: Kazushi Iwasawa and Valentí Bosch Ramon

Author: **Marius Oltean**
Department/Institute: Autonomous University of Barcelona.
Title: Study of the Relativistic Dynamics of Extreme-Mass-Ratio Inspirals
Date: 24 October 2019
Director: Carlos Sopuerta and Alessandro Spallicci

Author: **Francisco Rivas García**
Department/Institute: Autonomous University of Barcelona. Departament de Física
Title: Thermo-elastic contributions to the acceleration noise on-board LISA Pathfinder
Date: 29 October 2019
Director: Miquel Nofrarias Serra and Carlos Sopuerta

Author: **Anna Maria Porredón Díez de Tejada**
Department/Institute: Autonomous University of Barcelona. Departament de Física
Title: Modeling galaxy clustering for precision cosmology
Date: 31 October 2019
Director: Martin Crocce and Pablo Fosalba Vela

Outreach

The Montsec Astronomical Observatory opens its doors to the public

Located at 1570 elevation, in one of the most suitable areas on the European continent for astronomical observation, the Montsec Astronomical Observatory (OAdM) is a cutting-edge scientific infrastructure managed by IEEC and used by scientists. However, for a few days per year, the facility can be visited by members of the general public. The open doors took place one Sunday per month from May to September.

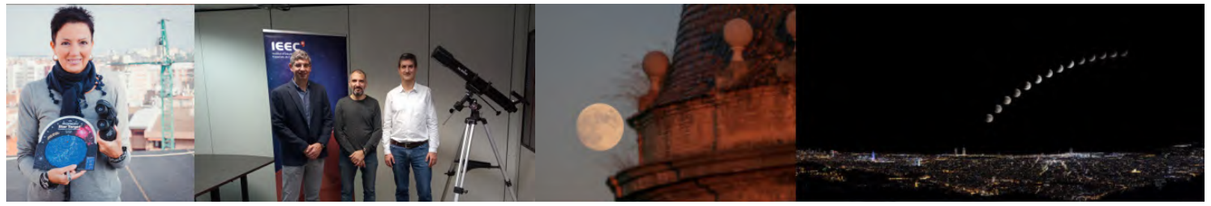
A visit to the observatory consists of a guided tour of the three robotic telescopes — the Joan Oró telescope, the Fabre-ROA Montsec telescope and the XO-Montsec telescope — the automatic station of the Meteorological Service of Catalonia (SMC) and the environmental quality measurement station of the XVPCA network (IDAEA), and several antennas for low orbit satellites' communications installed and managed by the Universitat Politècnica de Catalunya and IEEC. The guide astronomers explain how the scientific instruments work and what kind of research is done at the OAdM.

A total of about 170 people visited the OAdM in 2019.

IEEC organizes the “Capture the Moon” social media competition

On the occasion of the 50th anniversary since the first humans set foot on the Moon, IEEC launched the “Capture the Moon” social media campaign. Users were invited to share pictures of the moon snapped with a phone or camera on their Facebook or Twitter account and tag IEEC’s accounts.

From the 10 most-liked images received, two overall winners were selected, judging by the creativity and quality of the photos. The first prize was a refracting telescope 90/900 EQ2 SkyWatcher and the second prize a binocular starter kit ORION 10x50. For his wonderful photo sequence of the lunar eclipse, as seen on the night sky above Barcelona, Francesc Masip was awarded first prize. The second prize was received by Anabel Pérez, who entered the contest with a picture showing the view of the Moon from Zaragoza.



Collaboration of IEEC with the Splashdown Festival

IEEC collaborated in the organisation of the IV edition of the SPLASHDOWN Festival, that took place on 5, 6 and 7 July 2019. For the first time ever, the festival of the cosmos and space exploration arrived in Barcelona, at the Centre de Cultura Contemporània de Barcelona (CCCB). The SPLASHDOWN Festival is dedicated exclusively to space exploration. The three days of the festival were full of conferences, workshops, music, cinema, live radio, interactive shows and activities for children. Participants had the opportunity to dive into subjects such as: the Moon missions, searching for exoplanets, asteroids, pulsar stars, measuring distances in astronomy and Mars exploration among many others.

SPLASHDOWN Festival is organised by a team part of the LANIAKEA Association, formed by professionals in astronomy dissemination, engineering, scientific research, project coordination, editing and graphic design, and scientific tourism. The event has a scientific council made of research and engineers in the areas of astronomy, astrobiology, aeronautics and more. IEEC supported the festival with promotion and ideas for content, while several IEEC members delivered some of programme activities: Enrique Herrero, Xavier Luri, Nanda Rea and Josep Maria Trigo.

IEEC promotes and participates in an event of the Women In Aerospace Europe Association in Barcelona

On 4 October, the local chapter of Women in Aerospace Europe (WiA-E) in Barcelona was inaugurated. WiA-E is an association created over 10 years ago with the main aim of promoting, and giving visibility to the participation of women in the aerospace industry. This is done through various activities and open to the general public. Barcelona’s participation in WiA-E was promoted by the Barcelona City Council, IEEC and GTD System & Software Engineering.

On this occasion, leaders from the private and academic sectors -through IEEC- participated in a roundtable to discuss the role of women in the field of space science and technology.

Open doors for World Space Week

From 4 to 10 October it was celebrated in Barcelona and all around the world the World Space Week (WSW) – an international celebration of science and technology, and their contribution to the betterment of the human condition. Three locations where members of IEEC work opened their doors to the general public on this occasion: the Montsec Astronomical Observatory (6 October), the UPC Clean Room (7 October) and the MELiSSA pilot plant (10 October).

The United Nations General Assembly declared in 1999 that World Space Week will be held each year on the same exact dates: from 4 to 10 October. These dates commemorate two events: the launch of the first human-made Earth satellite, Sputnik 1, thus opening the way for space exploration, on 4 October 1957 and the signing of the Treaty on Principles Governing the Activities of States in the Exploration and Peaceful Uses of Outer Space, including the Moon and Other Celestial Bodies, on 10 October 1957.

Maker Faire

This year, IEEC participated again in the Maker Faire Barcelona held in the Nau Bostic, on the 5 and 6 October 2019, promoting the activity carried out at IEEC on Nanosatellites. The Maker Faire Barcelona brings together the local and international Maker Community that unites researchers and practitioners of the Maker movement that includes Universities and Research Centers and Socially Innovative Companies. The meeting between makers, technologists, scientists and companies wants to promote the interaction between different initiatives and a great diversity of proposals, favoring the transmission of knowledge and practice among the general public.

IEEC joins Panoramic festival to celebrate how space inspires art

IEEC joined the third edition of Festival Panoràmic, the festival of photography, cinema and new media, that focused on celebrating 50 years since humans stepped on the Moon. The event took place in Granollers, between 17 – 20 October 2019.

In the inaugural evening of the festival, on 17 October, IEEC researcher at ICE-CSIC Guillem Anglada-Escudé delivered, together with the director of the festival, Joan Fontcuberta, the conference “Ultima Thule, the colonisation of space”.

Ultima Thule is a Greco-Latin term describing a place beyond the known world and it is the nickname of the most primitive and most distant object ever identified in the Solar System. Discovered on 26 June 2014 by astronomer Marc Buie using the NASA/ESA Hubble Space Telescope, (486958) 2014 MU69, nicknamed Ultima Thule, is also a trans-Neptunian object located in the Kuiper belt. Ultima Thule was chosen as a slogan for this edition of the festival as a metaphor and a way to give perspective to the programme.

The festival included exhibitions, documentaries and film projections by some of the most celebrated visual artists nowadays, as Martin Parr, Cristina de Middel, Marcel·lí Antúnez or Rubén Torras.

Up: Ultima Thule movie screen and Poster
bottom left: Martin Parr, space dogs collection

IEEC participates at the Barcelona Science Festival, 26 – 27 October 2019

IEEC participated at the 13th edition of the Science Festival, that took place in Barcelona, ion 26 and 27 October 2019. The event consisted of 190 activities on science, technology, knowledge and culture, distributed in 26 spaces, with the goal to bring the research done in Barcelona and its area of influence closer to citizens.

IEEC participated in the festival with two events: a workshop, and a debate. The workshop, entitled “Les escales espacials i temporals de la nostra galàxia” and conducted by researcher Teresa Antoja (ICC), engaged the participants to learn interesting facts such as how far away the Sun is from the centre of the Milky Way or when a collision between our Galaxy and the neighbouring Andromeda galaxy will take place. In the debate, entitled “Vida a altres planetes”, researchers Francesc Vilardell (IEEC) and Josep Manuel Carrasco (ICC) discussed the possibility of life existing in other parts of the Universe and what type of research is being conducted to discover and study exoplanets that may or may not host life.

GAIA and ICC on the cover of the Spanish magazine Astronomía

The article about the GAIA mission signed by the researchers from IEEC at ICC Mercè Romero, Lola Balaguer and Jordi Portell appeared on the November cover of the Spanish magazine Astronomía.

First published in 1985, it was the first Spanish magazine to go on sale at newsstands and which was entirely dedicated to the dissemination of astronomy, astrophysics and space sciences. In November 2016, the magazine received the Special Jury Prize of the 29th edition of the Prisma Awards, the most prestigious and veteran guard of those awarded in the dissemination field in Spain. The jury’s minutes highlighted “the trajectory of this reference publication as well as its adaptation to new communicative contexts, knowing how to maintain the interest of the public during the last three decades”.

IEEC joins the celebrations of Science Week with a debate about artificial intelligence

Within the activities held on the occasion of the 24th edition of Science Week (Setmana de la Ciència) in Catalonia, on 13 November 2019, IEEC together with ICE and the Artificial Intelligence Research Institute (IIIA-CSIC) organised a debate on artificial intelligence and space exploration.

Entitled “Artificial intelligence and space exploration: from the Moon to Mars”, the dialogue between the IEEC researcher at ICE, Dr. Jordi Isern, and the IIIA-CSIC researcher, Dr. Ramón López de Mántaras, dealt with topics as current as the impact of artificial intelligence on interplanetary human spaceflight, as well as the ethical boundaries and implications for human beings. Moderated by journalist Núria Jar, the conversation took place at the Centre de Cultura Contemporània de Barcelona (CCCB).

Figure 63: Snapshot of the dialogue between Dr. Jordi Isern and Dr. Ramón López de Mántaras.

The dialogue, designed for both a specialised and a general public, was attended by around fifty people, who showed great interest in the subject and made very positive comments.

The dialogue was part of the activities taken place within the Science Week in Catalonia.

Organised by the Fundació per a la Recerca i la Innovació (FCRi) and the Generalitat de Catalunya, the 24th edition of Science Week in Catalonia took place on 8-17 November 2019 and hosted a range of activities dedicated to scientific dissemination: open days, exhibitions, talks, games and scientific workshops.

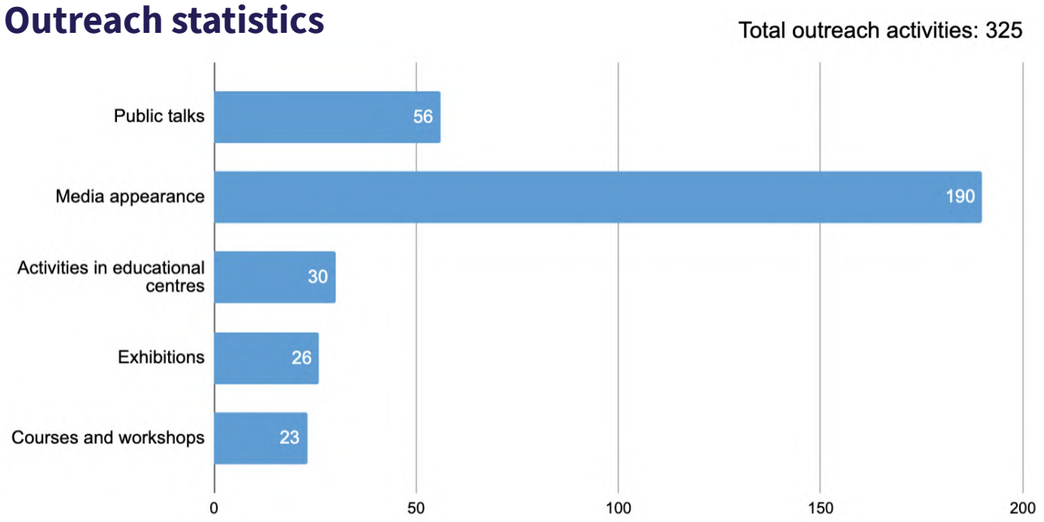
Live webcast of the Transit of Mercury

On 11 November 2019, a rare astronomical event took place: the transit of Mercury. IEEC’s research unit ICC conducted a live broadcast of the event. For this event, ICC had prepared a series of outreach events. Aside from the webcast, pre-registered groups and individuals were able to observe the transit with telescopes placed at Palau Reial, Diagonal Avenue, while Physics students were invited to observe the event on the roof of the faculty.

Among all planets in the solar system, only Mercury and Venus, as they are closer to the Sun than Earth, can transit in front of the Sun from our point of view. Although it is not as spectacular as an eclipse, planetary transits have been very important during the history of astronomy, as they were used to determine the distance to the Sun for the first time. From Earth’s perspective, Mercury crosses in front of the Sun only 13 times during a century. The next transit will happen on 13 November 2032.

Figure 64: Students observing the Transit of Mercury with the telescopes placed at Palau Reial.

Outreach statistics



Bubble Nebula (NGC 7635)

IEEC

In memoriam Jordi Torra Roca, professor at UB, researcher at ICCUB and IEEC Director from 2015 to 2017, passed away on 26 February 2019. He led with excellence the leadership of the Spanish group involved in the Gaia mission. His work was recognized by the City of Barcelona with its prize in the field of Science and Technology (2013) and by the Government of Catalonia with the Narcís Monturiol Medal (2018).
Rest in peace, Jordi.

IEEC

Hubble's 28th birthday picture: The Lagoon Nebula • Credit: NASA, ESA, STScI

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