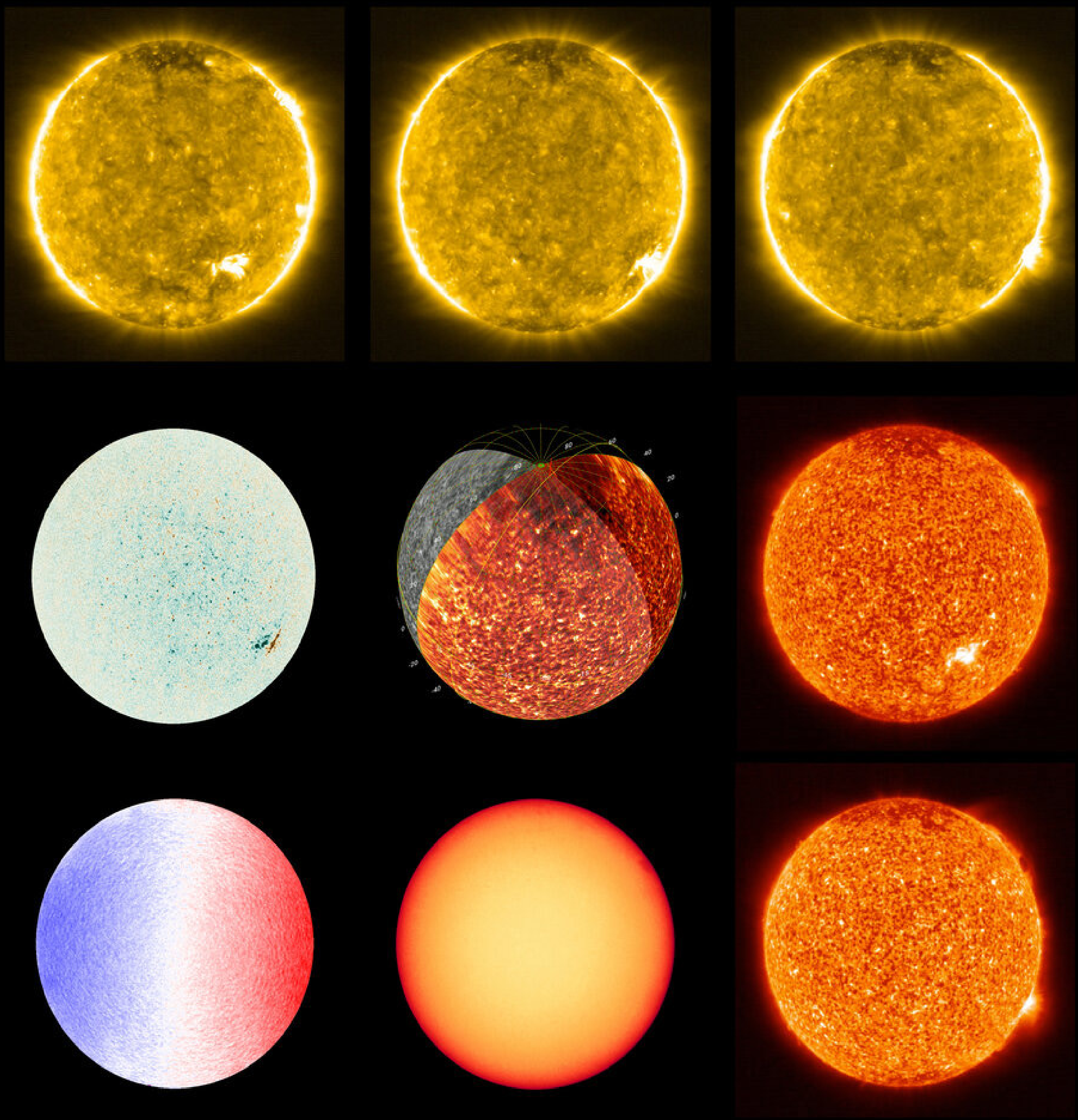
IEEC
Institut d'Estudis
Espacials de Catalunya

Annual Report 2020



Cover image: ESA's Solar Orbiter is revealing the many faces of the Sun. The Extreme Ultraviolet Imager (EUI) Full Sun Imager (FSI) took the images in the top row and far right column across the week following 30 May 2020, and contributed to the central image.

The yellow images, taken at the extreme ultraviolet wavelength of 17 nanometres, show the Sun's outer atmosphere, the corona, which exists at a temperature of around one million degrees. The red images, taken at a slightly longer wavelength of 30 nanometres, show the Sun's transition region, which is an interface between the lower and upper layers of the solar atmosphere. In this region, which is only about 100 km thick, the temperature increases by a factor of up to 100 to reach the one million degrees of the corona.

Solar Orbiter will travel around the Sun and out of the ecliptic plane, which loosely defines where the planets orbit. So, EUI will be able to image the far side of the Sun as well as the solar poles. The middle image shows projected, simultaneous solar images from EUI FSI (red) at Solar Orbiter's position during its first perihelion, the closest point in its orbit to the Sun, and the NASA Solar Dynamic Observatory mission (gray) in Earth orbit.

The image in the middle of the first column was taken by the Polarimetric and Helioseismic Imager (PHI) instrument on 18 June 2020. It shows a 'magnetic map of the Sun' that reveals the magnetic field strengths on the solar surface. The blue, white and red image at bottom left is a tachogram of the Sun, again taken with PHI. It shows the line of sight velocity of the Sun, with the blue side turning to us and the red side turning away. Next to this image, is a view of the Sun in visible light, taken by PHI on 18 June 2020. There are no sunspots because there is very little magnetic activity.

Solar Orbiter is a space mission of international collaboration between ESA and NASA.

Credit: Solar Orbiter/EUI Team; PHI Team/ESA & NASA

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Foreword

Year 2020 will surely be remembered for decades to come as the year of the COVID-19 pandemic. From March onwards we all had to adapt to a new life environment, with lockdowns, restrictions and social distancing. The new situation severely affected everyone's routines regarding both personal and professional life. For most of 2020, our workplaces have been devoid of the usual hustle and bustle and all activity has shifted into solitary work from home, only interacting with colleagues through videocalls and offline messaging. Casual conversations and social bonding have come to a minimum and this has certainly taken its toll on the emergence of new ideas and projects. However, in spite of the grim landscape, 2020 has been a very productive year for IEEC, with an all-time record number of publications and also many new contracts with industry.

But before dwelling into the results from 2020, we shall pay tribute to Lluís Gesa, who passed away on May 29. Lluís was a very esteemed colleague, with a leading role in many engineering projects within IEEC. He was looked up to by younger engineers, who approached him for advice and guidance. Lluis' sad and untimely passing leaves a profound void on all who had the fortune of crossing paths with him. His kindness and bonhomie will be remembered.

IEEC outputs during 2020 have been impressive. Our researchers have produced over 410 refereed papers, nearly 90% of them in journals belonging to the first quartile in terms of impact factor. Furthermore, over 90% of the publications have been made available through different forms of open access, in line with what should be the norm for publicly-funded research. A selection of research highlights resulting from the publications and also from other technical activities can be found in this volume, where you will see that they cover many of the areas of expertise of IEEC members: dark energy, the Sun, meteorites, asteroids, comets, evolved stars, binary stars, galactic astronomy, galactic dynamics, exoplanet discoveries, pulsars, black holes, gravitational waves, star formation, GRBs at TeV, Gaia mission exploitation, asteroseismology, Earth observation,... Importantly, collaboration between the units has further 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. IEEC inputs have also been quite substantial. While competitive projects from various calls have stayed quite constant with respect to previous years, contracts with industry and agencies have significantly increased. Furthermore, European funds now represent nearly one quarter of all funds managed by IEEC, which is in line with our strategy to push participation in European programmes.

The various facilities at Montsec Observatory have been keeping up their very high standard in terms of efficiency and productivity. A vigorous program of scientific observations from the Joan Oró Telescope, stemming from open calls every semester, has produced numerous high-impact results on a variety of research topics. This is in part because the number of users has increased by 25% since last year. Also, two instruments are now the workhorses at the telescope: the LAIA imager and the ARES spectrograph. Furthermore, Montsec has become a ground station for nanosatellite communications with the formal agreement between the UPC and IEEC for the joint operation of the UHF/VHF and S-band antennas. The Montsec Observatory has also been very active in outreach, with talks and events, joint activities with the GeoParc Conca de Tremp, and media appearances.

A program that has truly exploded at IEEC during 2020 is that related to New Space activities. Firstly, the UPC-IEEC group at the NanoSat Lab successfully launched the FSSCAT mission in September and the two 6U cubesats are already producing valuable data. On the technology development front, there have been intensive efforts to finalize the C3SatP platform on time for a possible flight opportunity in 2022. This has been the work of some 15 scientists and engineers from IEEC that have been working in close collaboration. But a major step forward is the funding received by IEEC from the Catalan Government to develop and exploit two nanosatellite missions. One of them is a 3U cubesat for telecommunications (Internet of Things) and the other one is a 6U cubesat for Earth observation (hyperspectral camera). The public tendering occurred during 2020 and the missions are expected to be launched in 2021 and 2022. This is just the start of a much more ambitious programme extending out to 2023 that comprises many more activities and several more space missions. This is certainly a flourishing area for IEEC!

IEEC members participate (and have leadership roles) in a wide variety of scientific 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 2020.

The Cherenkov Telescope Array (CTA), one of IEEC's key projects, has been subject to significantly activity from our members, including the definition of the key science projects, manufacturing of electronic components for the cameras, construction and commissioning of the telescopes, and the weather monitoring system. The latter included the successful commissioning of a Raman LIDAR prototype. The LISA mission, another IEEC key project, continued its definition work with participation of an extended team of researchers from three of the units. Also, the IEEC group participated in the LISA Data Challenges, which will help define the necessary analysis tools in preparation for the flood of data from the mission. Finally, Ariel, the third IEEC key project, achieved a very important milestone in November, with the formal adoption by ESA. The mission is due to become a reality! In 2020 the Ariel IEEC team has been busy preparing the System Readiness Review and also defining the Ariel scheduling software to make sure that the mission requirements in terms of number of targets observed can be fulfilled. Regarding science for Ariel, our researchers have made significant progress in implementing measures to correct planetary spectra for the pernicious effects of stellar activity. A full report of the main developments by these key projects during 2020 is provided here, together with an account of other mission and project milestones in highlight format.

Innovation results have been plentiful in 2020, with an increasing number of contracts with industry and space agencies (European Commission, ESA, CNES, Sener, CDTI,...) to deliver hardware and software products, algorithms, and data. This report includes an account of a number of success cases. 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. Another of IEEC's offices, the Communication Office, with the support from company Science Wave, has expanded in 2020 by incorporating Ana Montaner to the team. Among the tasks of the communications team 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, including the hackathon Act in Space, Women4Space events, Maker's Faire Girona, Science Week, etc. Internal communication is also very important and, just before the pandemic lockdown drew all planned social activities to a halt, we managed to celebrate the 2nd IEEC Forum on February 6, marking the 24th anniversary of the foundation of the institute. This time the event took place at the Barcelona Centre for Contemporaneous Culture (CCCB), where over 100 IEEC members and invited participants gathered to share one full day of interesting talks, debates and informal conversations. We also had the pleasure to hear a talk by one of the authors of the M87 supermassive black hole image, which was a major scientific breakthrough of 2019.

Year 2020 has been successful in recognizing IEEC researchers for their achievements. Nanda Rea was awarded with the 4th Fundació Banc Sabadell Prize for Science and Engineering, Héctor Gil-Marín obtained the Young Researcher Prize in Theoretical Physics of the Spanish Royal Physics Society, and Enrique Gaztañaga received the First Prize in Scientific Short Film Ciencia en Acción 2020. Congratulations to them! Finally, this annual report volume also includes an account of professional meetings that received IEEC support during 2020, and training activities such as Summer schools and PhD theses.

I would like to close this preamble by warmly welcoming the new members that have joined IEEC during 2020 and by wishing you all a year 2021 full of joy and successes! And hoping that all the pandemic restrictions will slowly die away and we will be able to come back (at least partially) to our workplaces and regain our social life.

Contact person
Ignasi Ribas, Director
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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 twenty-five 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 Universitat de Barcelona (UB), the Universitat Autònoma de Barcelona (UAB), the Universitat Politècnica de Catalunya (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 of the Universitat de Barcelona - ICCUB
- 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.

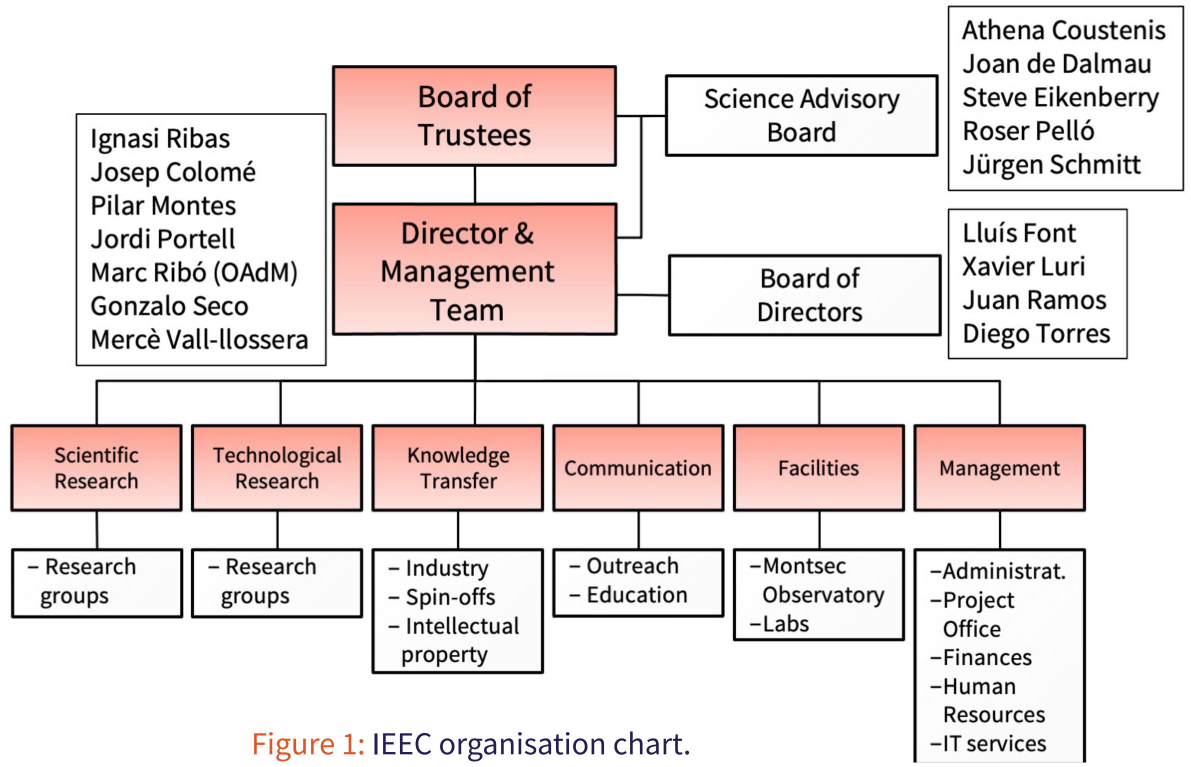


Figure 1: IEEC organisation chart.

Personnel

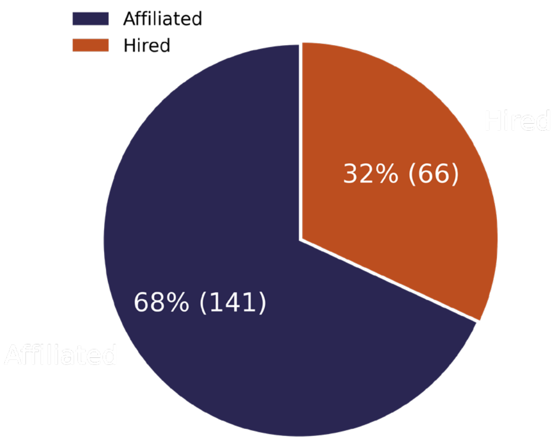
The statistics, tables and graphs illustrate the distribution of IEEC's personnel according to their work situation, gender, scientific unit and role.

Total personnel: **207**	Male: **164 (79%)**	Female: **43 (21%)**
	Hired: **66 (32%)**	Affiliated: **141 (68%)**

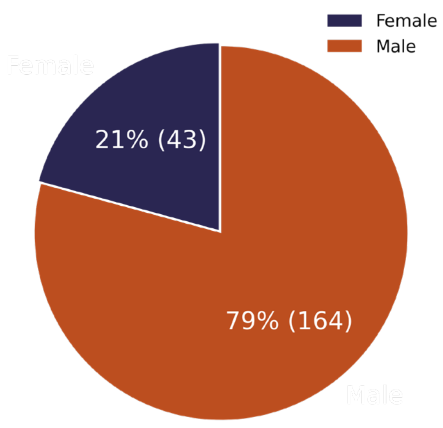
	IEEC	ICE	CERES	ICCUB	CTE	TOTAL
	Core Staff					
Administration & IT & PO	8					8
	Affiliated members					
Administration				1		1
Research & engineers (faculty)		26 (18)	13 (8)	46 (22)	25 (21)	110(69)
PhD Students		3	3	18	6	30
	IEEC contracts					
Administration & services		3		2		5
Researchers & en-gineers (facultuy)	5 (0)	16 (4)	1 (0)	16 (1)	1 (0)	39 (5)
PhD Students	1	8	0	5	0	14
	TOTAL					
	14	56	17	88	32	207

Personnel

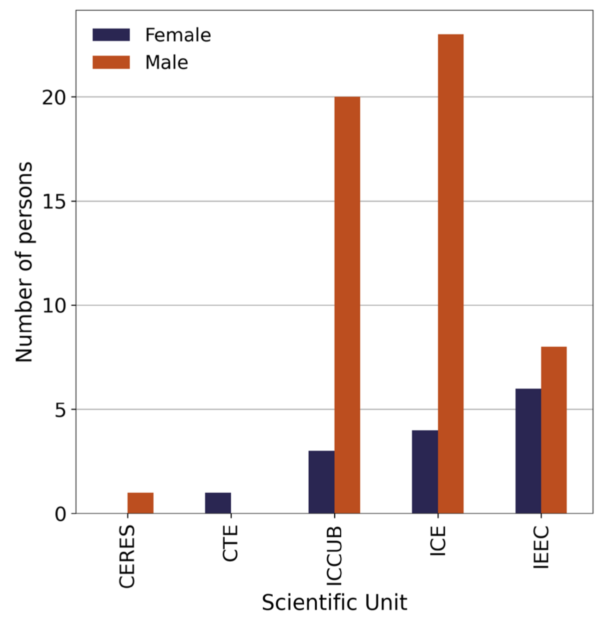
Personnel



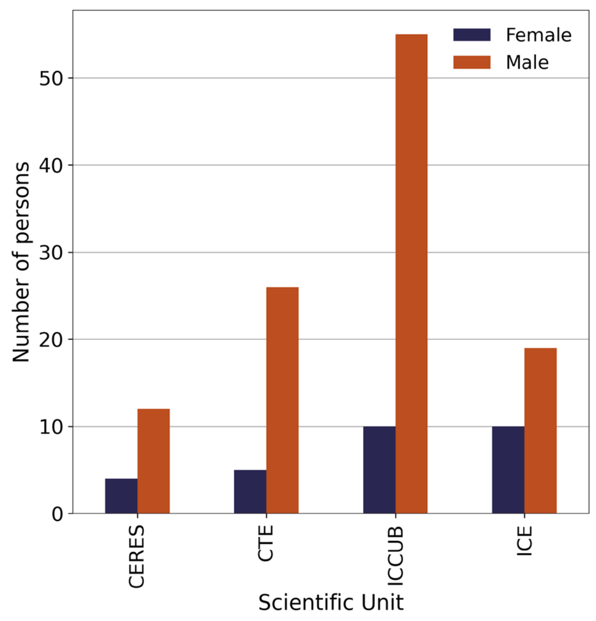
Personnel per work situation



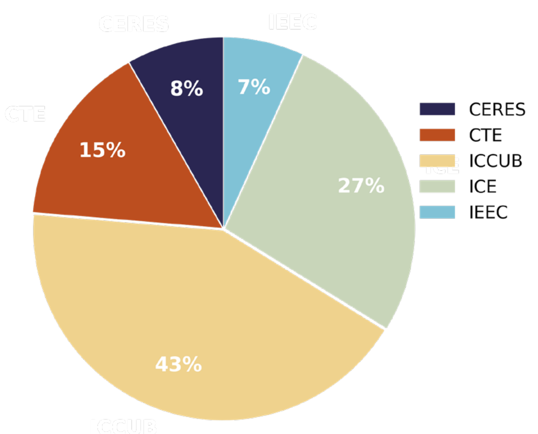
Personnel per gender



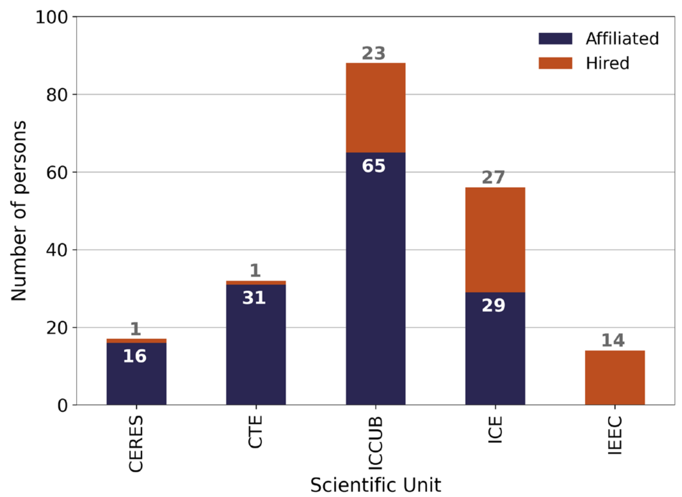
Hired personnel per scientific unit and gender



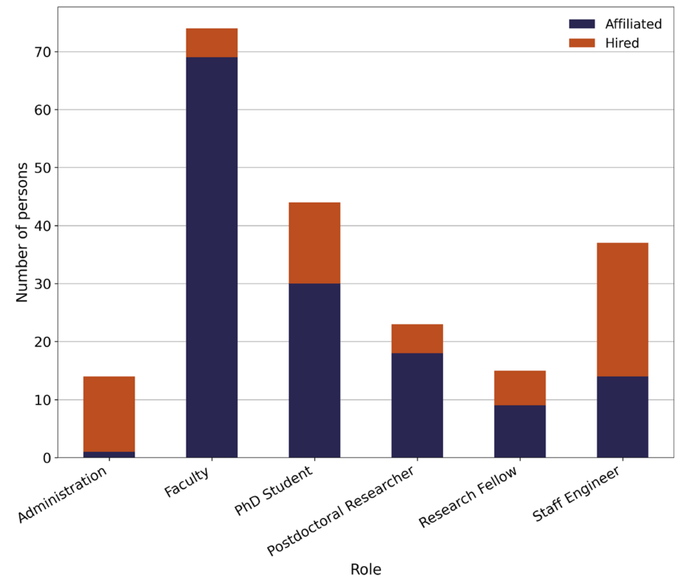
Affiliated personnel per scientific unit and gender



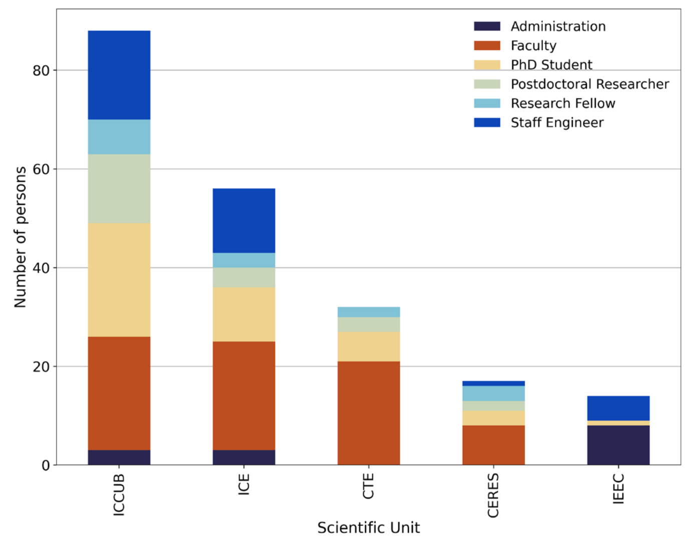
Personnel per scientific unit



Personnel per work situation and scientific unit

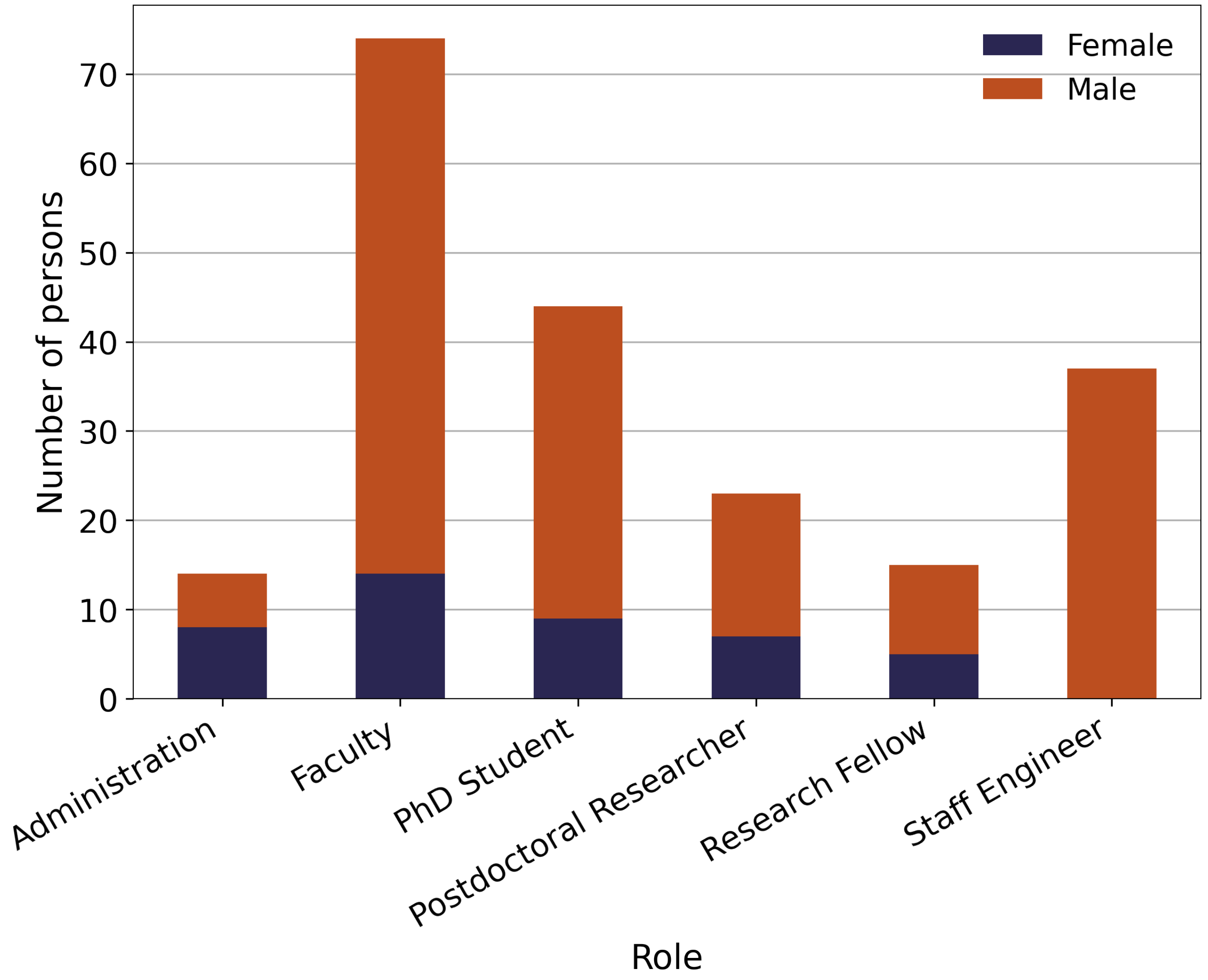


Personnel per work situation and role



Personnel per role and scientific unit

Personnel

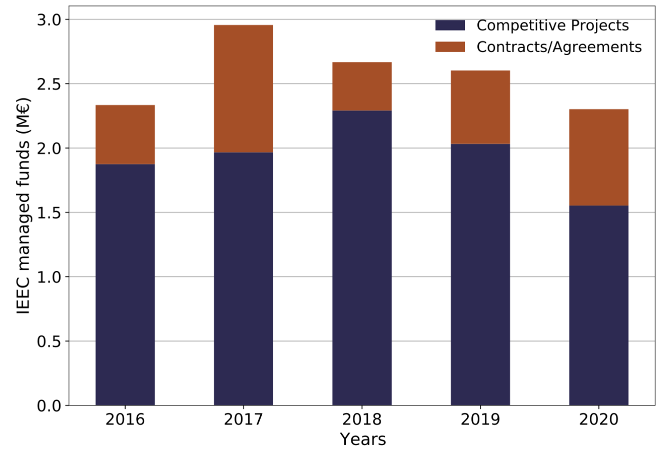


Personnel per role and gender

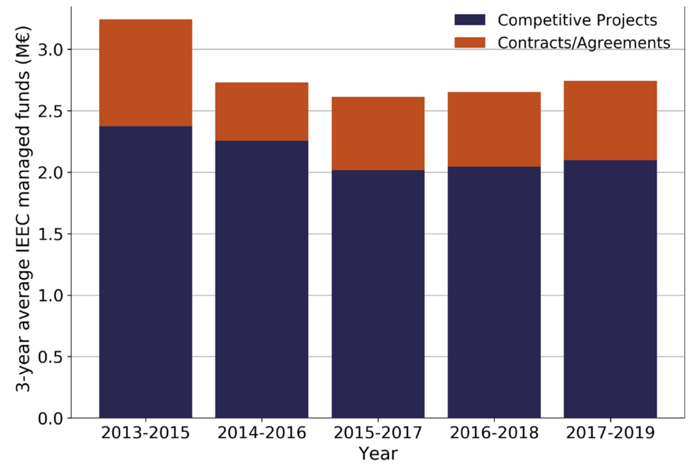
Projects

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.

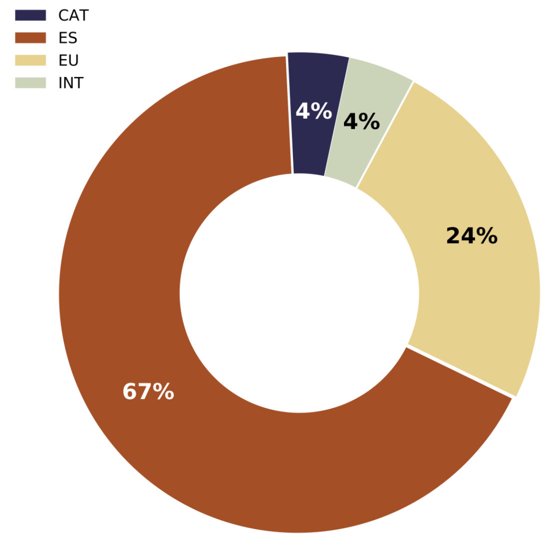
*** Provisional economical data pending closure of the 2020 financial year.**



Incomes per year and project class



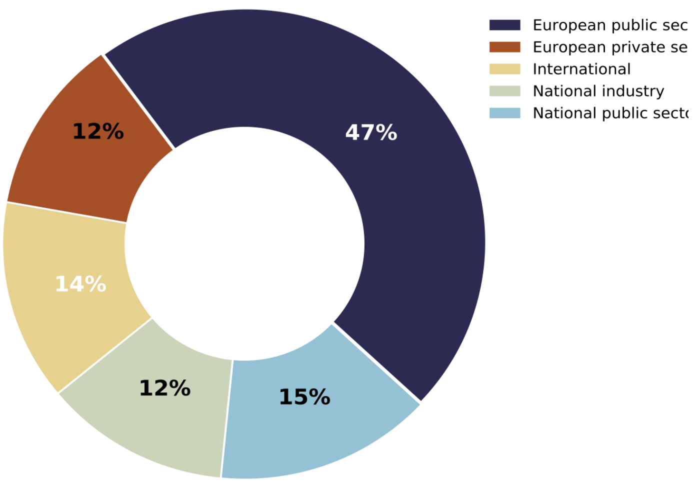
Triennial mean incomes per year and project class



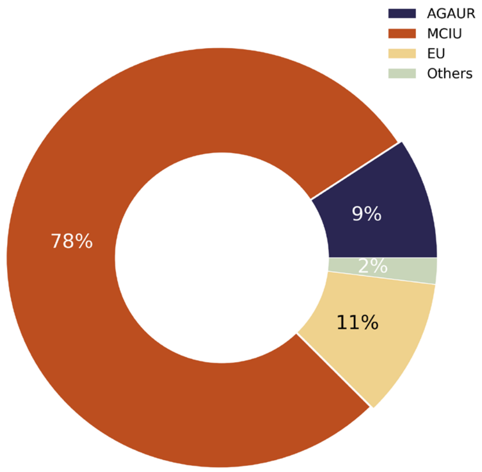
Incomes per geographical area

Contracts/Agreements	Incomes (k€)
European public sector	352.1
European private sector	90.4
National industry	93.3
National public sector	109.7
International (noneuropean)	103.4

Competitive Projects	Incomes (k€)
AGAUR	90.3
MCIU	1340.0
EU	118.2
Others	4.4



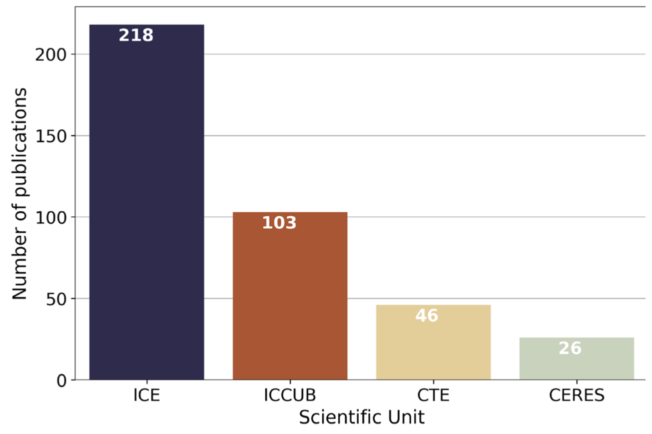
Incomes from contracts/agreements



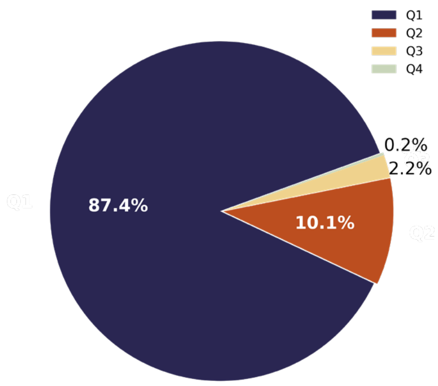
Incomes from competitive projects

Publications

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

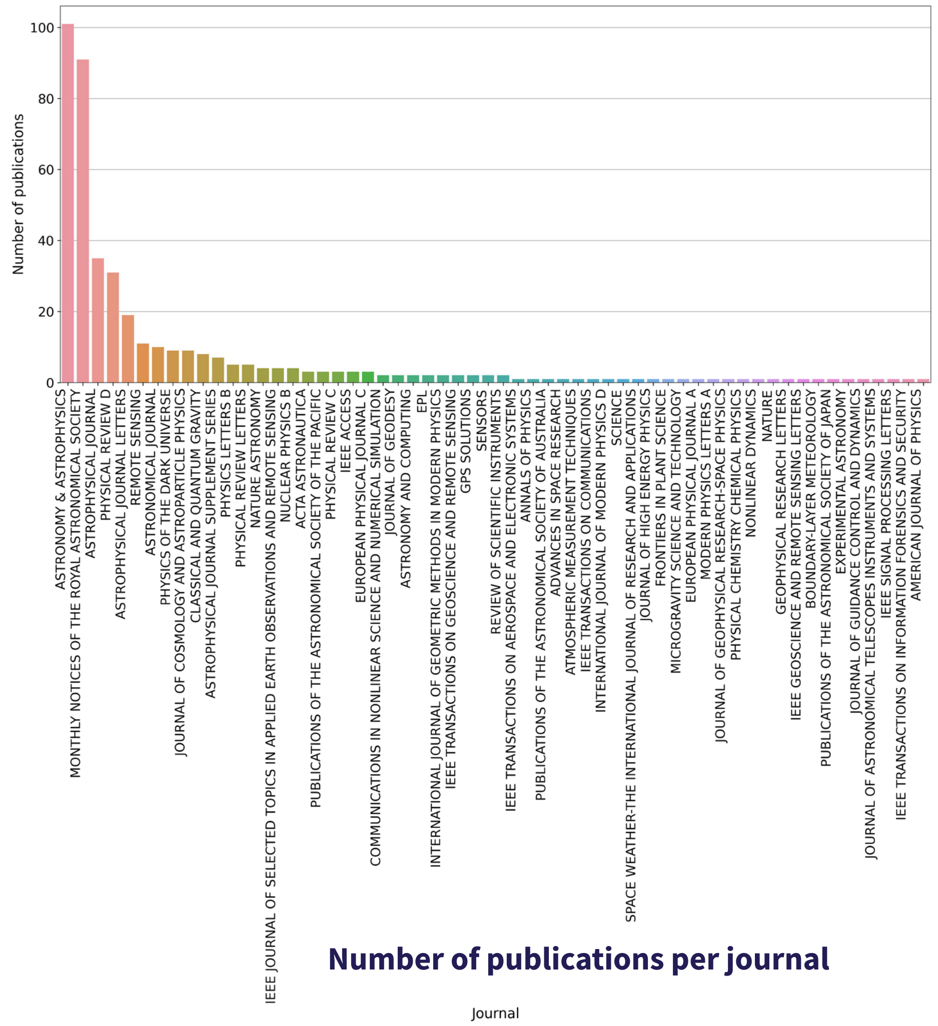


Number of publications per scientific unit

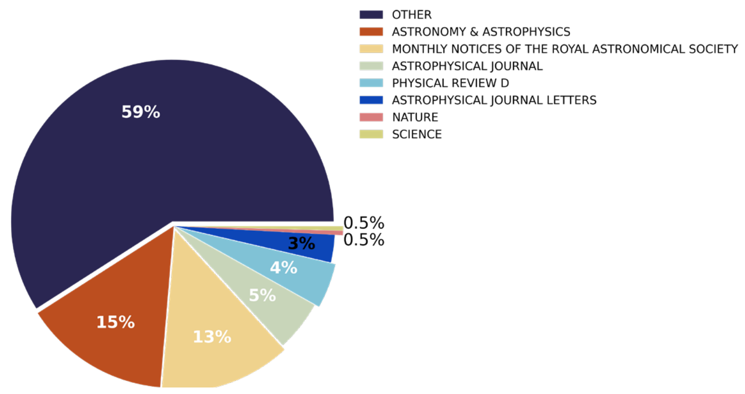


Number of publications per journal quartile

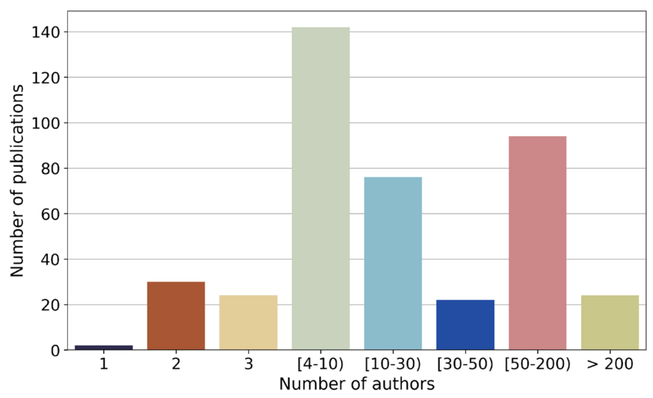
The total number of publications include the 21 publications done by authors at Universitat de les Illes Balears (UIB).



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:

- ICE + ICCUB = 7 publications
- CERES + ICCUB = 20 publications
- CTE + ICCUB = 5 publications
- ICE + IEEC = 9 publications
- CTE + IEEC = 2 publications
- ICCUB + UIB = 4 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 three facilities for research in astronomy, among others. The astronomical equipment consists of two robotic telescopes: Telescopi Joan Oró (TJO, managed by IEEC-Generalitat de Catalunya) and Telescopi Fabra-ROA Montsec (Reial Acadèmia de Ciències i Arts de Barcelona and Real Observatorio de la Armada). In the past, the OAdM also hosted the robotic telescope XO-Montsec (IEEC). In addition, it houses a camera for the detection of fireballs and hazardous near-Earth asteroids (AllSky Camera, IEEC). The OAdM also hosts the Satellite Ground Station Montsec (SGSMontsec), formed by several antennas for low orbit satellites' communications designed, implemented and installed by the NanoSat Lab of the Universitat Politècnica de Catalunya (UPC) and managed by UPC and IEEC. Moreover, the Observatory 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 two wide-field video surveillance cameras of the firefighters to survey a very wide area around Montsec.

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, 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 incidents 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 2020, despite the pandemic situation, IEEC achieved different milestones at OAdM. Below we make a summary of them.

Figure 1: View of OAdM displaying the TJO (right) and the TFRM (left) with a clear night sky in the background.

OAdM infrastructures

During 2020 there have been different improvements of the OAdM infrastructures. An evaluation to upgrade the computers needed to allow a secure communication with OAdM, and in particular with TJO, and their maintenance has been performed. Some of the computers have been replaced, while others will be in the future. The main entrance door of the fence was replaced with a new one that incorporates a digital locker that allows for a better control of the access of users. Three new video security cameras were installed at OAdM to provide a better panoramic view (see Figure 2) and improved sensitivity in the infrared to have more visibility at night. As already mentioned above, the OAdM now hosts two wide-field video surveillance cameras of the firefighters, which have been installed in the communication mast (see Figure 3), to allow for a better coverage of the Montsec area and beyond, thus improving the security of a very wide region surrounding the OAdM.

Figure 2: View of OAdM after a snowstorm displaying the TJO (center), the TFRM (left) and the roof of the environmental quality measurement station of the XVPCA network (right) with the belt of Venus in the background.

Figure 3: : Left: Mast with meteorological and communication instrumentation. Right: Upper part of the mast displaying the two wide-field video surveillance cameras of the firefighters installed in June 2020.

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) 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. During 2020 ISROCS has been modified to allow a better handling of the proposal priorities, of the already executed observations during the semester and of the possibility to schedule the remaining ones during the observable windows requested by the users, which significantly improve the efficiency of the TJO operations.
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 4: Building and open dome of the Joan Oró Telescope (TJO), visible inside.

The ARES spectrograph is composed of 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 continued in 2020, allowing us to improve the quality of the obtained spectra by limiting the exposure time of the arc lamps used for wavelength calibration, and showing interesting results (see below). 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 (SVO). In 2020, the SVO was updated to include all the public raw images of the TJO with a total amount of over 400.000 images, obtained during 2000 different nights. 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 2020 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 (TAC) 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. In 2020, the TJO SST software was further improved to provide satellite tracking data in real time.

At the end of 2020, OAdM had 157 registered users at MUR, 63 of them from IEEC, 31 from other Spanish institutions, and 63 from international institutions. This represents about a 25% increase in the number of registered users compared to 2019 (which was already a 25% higher than in 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 within international collaborations such as MAGIC or CTA. This scheme, together with the new instrumentation, increased the number of proposals received, from 9 per year during 2016-2018 to 30 adding the two calls issued in 2020

(18 in the spring one, 12 in the autumn one, with most of the last ones being resubmissions of the first semester). This also increased the telescope pressure time, with a fraction of requested over available scientific time of about 1.3. In addition, TJO also received two 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 is also important to point out here that there has been a significant increase in the number of different principal investigators of the proposals and in the different scientific topics to be addressed.

It must be noted that the useful time decreased around 5% compared to 2019 because of the worse weather we had in 2020. The production and duty cycle decreased slightly but within acceptable margins (statistical fluctuations).

Observation statistics

- Useful time (night-time hours with good weather conditions): 2012 h (63.6% of total night time)
- Time acquiring data (regardless of quality): 1792h (89.2% of total night-time with good weather)
- Time acquiring useful data: 1666h (82.8% of total night-time with good weather) → Duty cycle

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 (TAC).

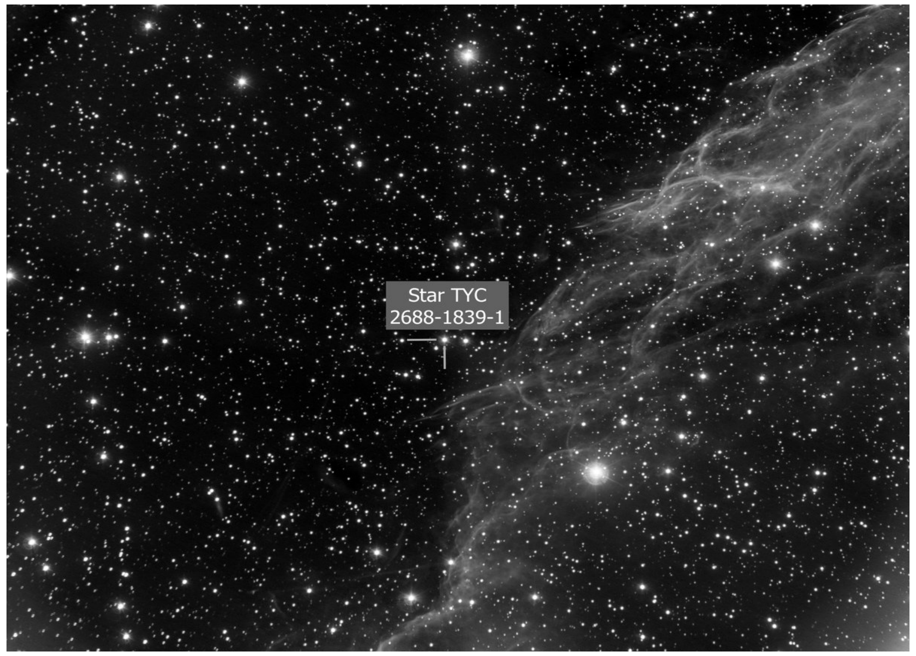


Figure 5: Image of the star TYC 2688-1839-1, which shows transits from the exoplanet KELT-16 b, obtained with the TJO with the Veil nebula in the background.

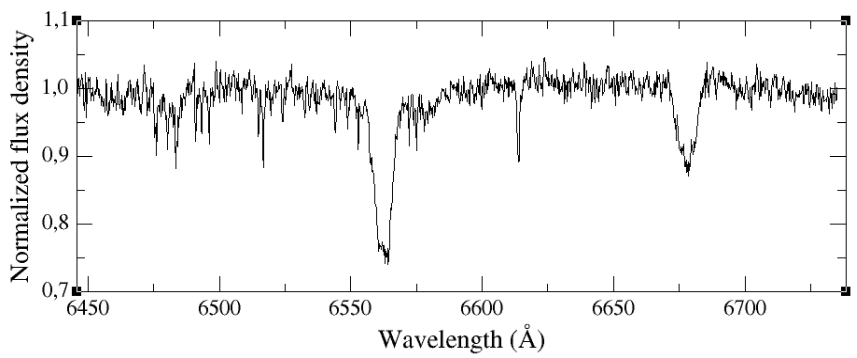


Figure 6: Spectrum of the V=8.6 magnitude star HD 3191 obtained with a 30-min exposure with ARES. The spectral lines of Halpha (6563 A), He I (6678) and the interstellar one at 6613 A are clearly visible.

Montsec Astronomical Observatory

During 2020, the TJO participated in different scientific projects, including the study of Solar System objects, monitoring of exoplanet transits, characterisation of M dwarf stellar activity, studies of RR Lyrae stars, monitoring of novae or different types of pulsars in binary systems, detailed studies of white dwarfs or newly discovered black hole X-ray binaries, radial velocity studies of high-mass X-ray binaries, spectroscopy of blue stragglers, light curves of type Ia supernovae and Gaia transients, such as the ones producing microlensing events, astrometric studies for a better definition of reference frames or monitoring of faint blazars.

It is important to stress here that thanks to its robotic control system, capable of fully unattended operations, the TJO could provide uninterrupted observations for the science and SST programs ongoing during the first semester of 2020, despite the global pandemic situation and the lockdown preventing regular maintenance visits to the OAdM.

In 2020 the number of science images decreased significantly compared to 2018-2019, but this is in part due to the worse weather commented above and to longer science images because of the use of the ARES spectrograph, with longer exposure times, in some scientific projects. The number of refereed publications has remained high, as it was already for 2019.

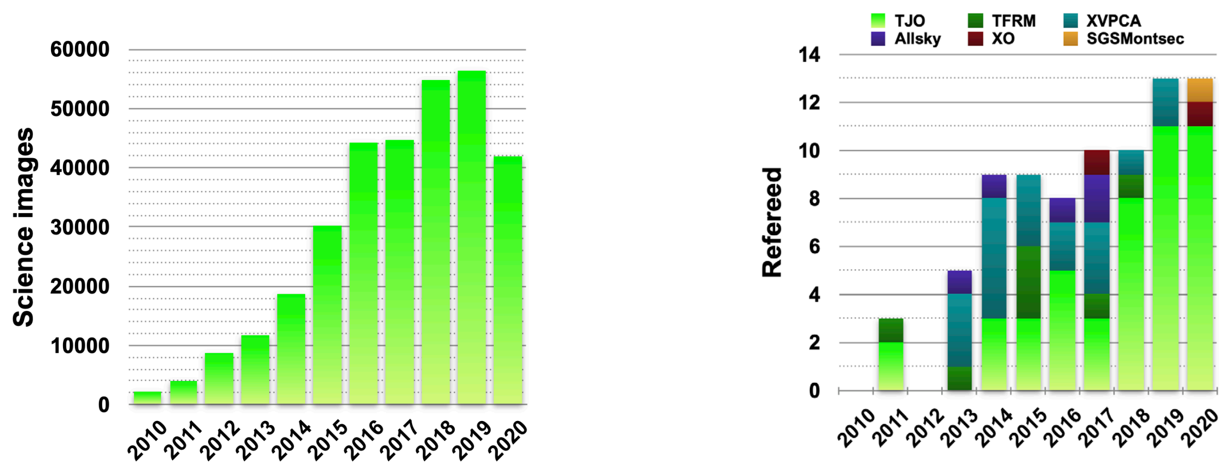


Figure 7: Left: Number of scientific images obtained with the TJO as a function of time. Right: Refereed publications with OAdM facilities.

In summary, with an efficient use of the LAIA camera and the continuation of shared-risk scientific observations with the ARES spectrograph, 2020 has been a very productive year for the TJO.

Satellite Ground Station Montsec

During the last few years there has been a significant effort towards building a ground station for communication with low-Earth orbit (LEO) satellites that has finally crystallized as the Satellite Ground Station Montsec (SGSMontsec). This station has been installed and is managed by the UPC NanoSat Lab in collaboration with IEEC.

The privileged location of the OAdM free of obstacles in the horizon and a clean electromagnetic environment makes SGSMontsec 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.

In 2020 the SGSMontsec has been used to operate nanosatellites such as the ones of FSSCAT. Also in 2020, there have been works at OAdM to condition a room closer to the S-band antenna to allow moving the computing services there in the future. In addition, there have been negotiations between IEEC and UPC to reach a formal agreement of collaboration to operate the SGSMontsec. Finally, in 2020 we are glad to include publications from the SGSMontsec for the first time in the OAdM output.

Figure 8: Panoramic view of OAdM displaying the TJO (left) the S-band antenna (right) with the Milky Way in the background. Credit: Kike Herrero (IEEC).

Outreach

During 2020, the pandemic situation prevented the organization of the usual monthly visits from May to September. However, in collaboration with Sant Esteve de la Sarga, an observation of the night sky was conducted following all recommendations by health authorities at Serra d'Estorm on 21 August. In addition, a virtual visit of the OAdM was conducted by Kike Herrero through the IEEC Youtube Channel on 18 November in the framework of the Science Week 2020, with more than 100 connections in real time.

Regarding social networks, in April 2020 TJO made observations of the BepiColombo flyby of the Earth on its way to Mercury that were shared via Twitter. Also, a picture displaying several OAdM facilities was used as a IEEC Picture of the Month in June, while another one of the TJO with a background of stars was used as a IEEC Picture of the Month in August.

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Facilities And Key Projects

NewSpace

The NewSpace represents a new use of the space with small satellites and a fast development with an emphasis on lower costs, operational agility and the reliance on private capital. This new technology allowed creating a new set of digital services and a new economy with a growing fortress. This new ecosystem assumes a paradigm change for the space sector and can contribute to a better management of the territory, measure the effects of climate change and provide coverage of Internet of Things (IoT) and 5G in a homogeneous way and in remote areas of the territory.

What is NewSpace?

Space science research has spawned revolutionary technologies that have expanded humanity's knowledge. Until recent years, the exploration and use of space have been synonymous with state public investment and government policies, in which the high cost and associated risk posed by this sector makes it difficult to access by private entities.

A great technological development and a very significant reduction in costs have removed the entry barriers to the space, generating a global movement within the sector. This is what is known as NewSpace, a term that has clearly meant a paradigm shift since 2000, the year it was first used.

The NewSpace represents a new economy based on the democratization of access to space and the aerospace industry. New private actors have appeared recently seeking new opportunities in the exploration of space. It is a growing sector that will achieve its mature phase in the next few years. It is estimated that in the period 2020-2025 there will be around 3,500 new launches of CubeSats. These figures show more than 600% growth with respect to the launches that have been completed in the last few years.

The NewSpace provides opportunities for the use and exploitation of space platforms for a wide variety of applications, including scientific research, development and qualification of space technology, Earth Observation, and telecommunications, such as the 5G network and the internet of Things (IoT). While the first revolution has taken place in the field of Earth Observation, it is in the field of telecommunications that a more disruptive change with the greatest potential to establish a new market can be seen.

Nanosatellites, and in particular CubeSats, have become the ideal platforms for balancing the performance and capabilities of satellites with the cost of production, launch and maintenance. These satellites are usually launched into low-altitude orbits, known as low Earth orbits (LEOs).

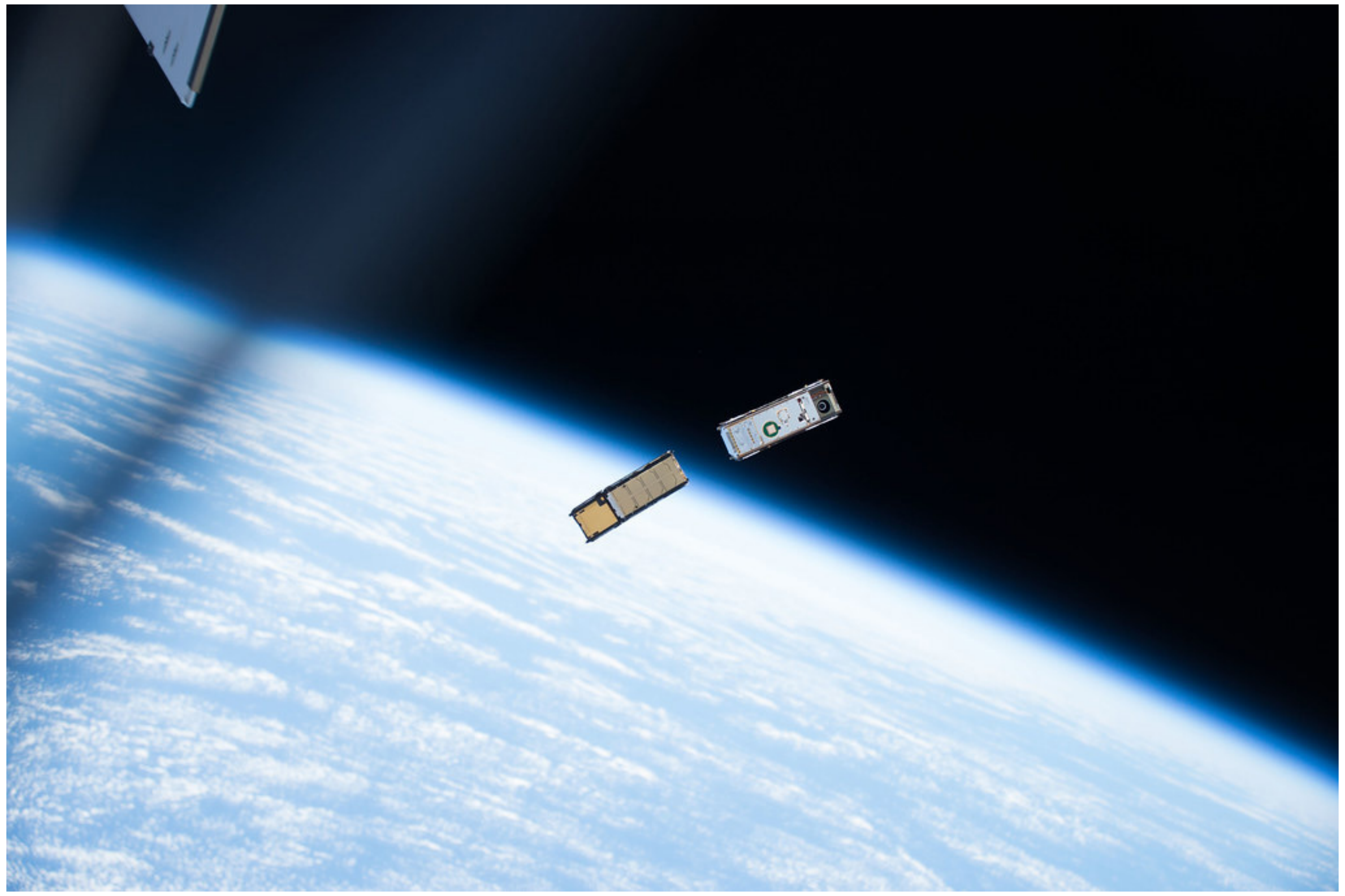

Figure 9: CubeSats. Credit: NASA's Marshall Space Flight Center is licensed under CC BY-NC 2.0.

The current commitment decided by the NewSpace sector to develop a new market and a new technological fabric will have a tractor and unifying effect of other technologies, such as 3D printing, artificial intelligence, advanced electronics for sensors and computers and secure communications. In addition, the transversality of the space will allow generating a great diversity of applications, partly thanks to the interrelation between sectors.

NewSpace

NewSpace at IEEC

IEEC has a number of capabilities that make it a reference in the space sector. In the field of NewSpace, the following projects stand out:

Space missions: IoT and EO nanosatellite services

Within the framework of NewSpace in Catalonia, IEEC is launching two missions that will provide data services on two different topics:

• Earth observation (EO): a 6U nanosatellite (six units, according to the cubesat standard), and a payload for obtaining images of the Earth from space in different spectral bands for the 'study of the territory.
• Internet of Things (IoT): a 3U nanosatellite and payload that must provide wireless communication between terrestrial devices and satellites to offer connectivity in parts of the territory that are difficult to access or without coverage by conventional terrestrial networks.

These services are in line with the research and innovation activity of IEEC with regard to the implementation of missions based on space technologies and aim to promote the space sector in Catalonia from high value-added applications, based on digital technologies, strongly aligned with the strategic sectors of the Generalitat de Catalunya (specifically, the NewSpace Strategy).

The satellite services will be provided to IEEC, and this will collaborate with other R&D centers, departments and bodies of the Generalitat de Catalunya, for the study of different cases of use and its possible applications.
These services are ultimately aimed at creating an ecosystem that encourages the growth and consolidation of the NewSpace sector based on digital technologies.

Montsec Satellite Earth Station

A key part of each space mission lies in the ability of the ground segment (GS) to contact the satellite to transmit remote controls and receive the results of scientific measurements or telemetry data that the system has acquired. The Montsec Satellite Ground Station (SGSMontsec), located in the OAdM-IEEC and managed by IEEC in conjunction with the NanoSat Lab of the UPC, operates an UHF/VHF, and an S-Band GS.

Figure 10: S-band antenna of the SGSMontsec (with the AllSky Camera visible to its left).

Multipurpose platform (C3SatP)

The C3SatP project was born to develop a versatile platform for nanosatellites. This development includes an OBC (On Board Computer), an OBDH (On Board Data Handler, for high-performance calculations and operations) and an SDR (Software Defined Radio, dedicated to communications), financed with a grant Product of the Generalitat. Once the first phase was completed, the project has continued to evolve, adapting it to particular applications, such as the 4DCube mission. This mission was selected with 46 other ideas by the ESA for The Open Space Innovation Platform. The main goal of this mission is to detect space debris smaller than 10 cm that cannot be detected by optical or radar techniques. Other applications of the platform are those needed by Earth Observation missions that require processing images on board the same satellite, with the use of Artificial Intelligence algorithms.

Finally, the C3SatP platform will be used in the EO nanosatellite mission that will be launched in 2022 in the framework of the IEEC satellite service contracts. The platform will be an on-board secondary payload for technology demonstration and will gain the required flight heritage to be used as a main payload in future missions.

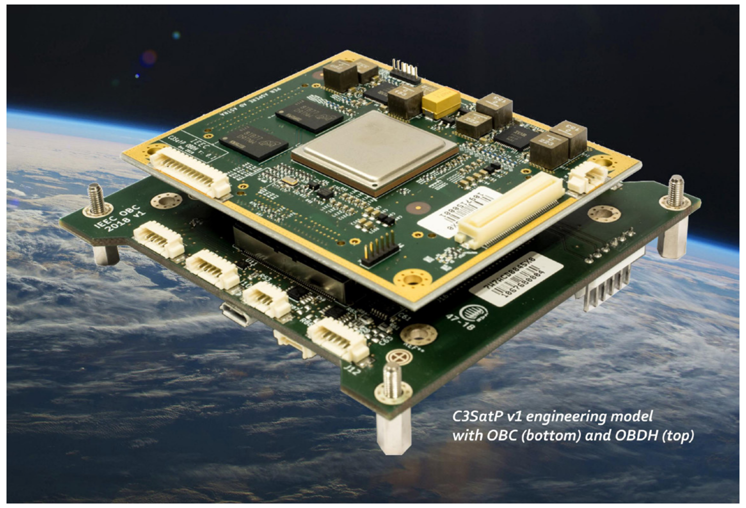

Figure 11: Recreation of the C3SatP model with OBC and OBDH. Credit: IEEC.

Earth Observation Missions

IEEC is actively collaborating with the NanoSat Lab of the UPC and other institutes linked to Earth Observation missions. We highlight the following:

^{3}Cat Series ("CubeCats")

^{3}Cat-1 was the first satellite developed in Catalonia and the first in a series of nanosatellite missions designed and developed in the NanoSat Lab of the UPC. The ^{3}Cat-2 included a secondary payload developed at IEEC to validate the technology of a high-resolution magnetometer for its future application in the ESA LISA mission . The 3Cat-3 was an Earth Observation mission, in which IEEC worked in collaboration with the Cartographic and Geological Institute of Catalonia (ICGC), that includes a camera with multispectral sensor, a passive radiometer and a receiver GNSS-R for soil moisture studies.

Based on the experience gained with the ³Cat-1 and the 3Cat-2 that were launched in 2018 and 2016, respectively, the UPC NanoSat Lab designed the ³Cat-4 with only one unit (1U). This mission was designed to demonstrate the suitability of this type of platform for performing Earth Observation applications with passive instruments. The ³Cat-4 has a GNSS-R (Global Navigation Satellite System - Reflectometry) instrument capable of measuring various meteorological phenomena, geographical features and oceanic parameters, detecting and analyzing the reflected signals from the constellations of satellite navigation systems. The ³Cat-4 mission was accepted and takes part in the "Fly Your Satellite!" program (second edition) of the European Space Agency (ESA) Academy and it has an expected launch date in 2021.

FSSCAT mission

The FSSCat mission has been developed in the NanoSat Lab of the UPC and was launched on 9 September 2020. It is a mission of two 6U cubesats (³Cat-5/A and ³Cat-5/B) flying together for monitoring polar ice and measuring soil moisture, using state-of-the-art two-sensor fusion technology, one combining a GNSS Reflectometer and a Microwave Radiometer (developed by UPC), and another consisting of a Hyperspectral camera (developed by Cosine) that operates in the visible, near-infrared and thermal spectrum. The two satellites also have onboard an inter-satellite communication system, which uses frequencies in the optical and radio domain (developed by Golbriak).

Key infrastructures for NewSpace in Catalonia

IEEC supports the construction and maintenance of key laboratories and infrastructures in Catalonia for research in space sciences, and does so by collaborating with the patron institutions through the respective research units. Examples are: the NanoSat Lab of the UPC, the IEEC-UPC clean room of the Department of Electronic Engineering, the IEEC-CSIC laboratories (clean rooms, radiation laboratory authorized by the Nuclear Safety Council - CSN, optical laboratory, etc.), and the laboratories and facilities of ICCUB of the UB and its Science Park, as well as those of the CERES, located on the campus of the UAB.

IEEC also manages the operations of the Montsec Astronomical Observatory (OAdM-IEEC), located in Sant Esteve de la Sarga (Pallars Jussà, Lleida). The Observatory is in a privileged position, it has an obstacle-free horizon that allows optimal visibility in all directions allowing a continuous coverage of all satellite passes practically from the horizon. The Observatory participates in satellite surveillance and tracking and satellite communication programmes thanks to these privileged conditions.

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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 Imaging Atmospheric Cherenkov Telescopes (IACTs). 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, very 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

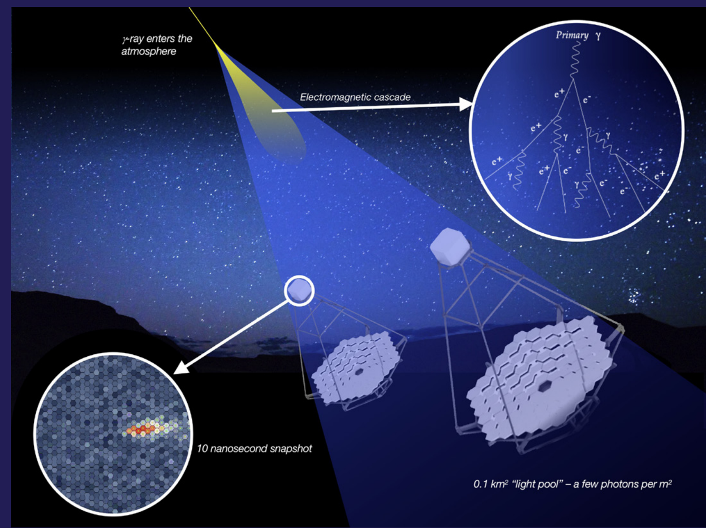

Figure 12: How IACTs indirectly detect a VHE gamma ray. Source: CTA Consortium.

IACTs image the very short (between 5 and 20 ns long) and faint flash of Cherenkov radiation generated by cascades of relativistic charged particles, known as Extensive Air Showers (EAS), produced when a very-high-energy gamma ray strikes the atmosphere (see Figure 12). The total area on 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.

Three classes of telescope types are required to cover the full CTA energy range. For its core energy range (100 GeV to 10 TeV), CTA is planning 40 12m-diameter Medium-Sized Telescopes (MSTs). Eight 23m-diameter Large-Sized Telescopes (LSTs) and 70 4m-diameter Small-Sized Telescopes (SSTs) are planned to extend the energy range below 100 GeV and above 10 TeV, respectively. The MSTs and LSTs will be installed on both sites, while the SSTs will only be installed on the southern hemisphere site.

The Cherenkov Telescope Array

The northern hemisphere array is being constructed at the Roque de los Muchachos Observatory (ORM) on the Canary Island of La Palma, while the southern hemisphere array will be located at less than 10 km south-east of the European Southern Observatory's (ESO's) existing Paranal Observatory in the Atacama desert 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 define the future of the field. According to the current schedule, the CTAO preconstruction phase will finish with the establishment of the CTAO European Research Infrastructure Consortium (ERIC), the legal entity with governments as shareholders that will be charged with starting of the construction phase. The ERIC will be established no later than 2022, and the construction phase should last five years from then (up to 2027). Following the end of the construction phase, the Operation & Enhancement phase will take place towards the full scope configuration.

Data with prototype telescopes and early configuration phases can initiate already during the construction phase. Today more than 1,500 project participants from more than 200 institutes in 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 the CTAO gGmbH. The CTAO gGmbH is the current interim legal entity, charged with preparing the design and the implementation of the Observatory and will give way to the CTAO ERIC.

The more than 200 VHE gamma-ray sources detected by the current generation of IACTs (HESS, MAGIC and VERITAS) and the wide range of high impact scientific results suggest that extreme particle acceleration is more common in nature than previously expected. VHE gamma-ray emitters include pulsars, pulsar wind nebulae, binary systems, starbust galàxies, active galactic nuclei and gamma ray bursts, among others. With the improvement in sensitivity, a thousand source detections over the lifetime of the observatory are 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 (exploring the nature of Dark Matter, search for axion-like particles, 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 the 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 in helping the Spanish CTA 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 2020 are described below.

Physics prospects for CTA

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

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. A first prototype of the MST-NectarCAM was tested in Berlin and front end boards with ACTA and L0-trigger ASICs were produced to fully equip the complete MST1 camera in 2019. 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 was studied in cooperation with the University of Geneva in order to be used for future upgrades of LST and MST cameras.

During 2020, IEEC members managed the ASICs production for the MST-NectarCAM 2-9 (PACTA, ACTA and L0-trigger) but the reception of these units was delayed to 2021 due to the COVID-10 pandemic situation. Also, a modification of the ACTA amplifier was done, to include a pulse-injection functionality (production and validation will take place in 2021). The IEEC engineers, in collaboration with the Microelectronics section of the Electronics Systems for the Experiments group (ESE-ME) at CERN, designed an 8-channels ASIC for the SiPM readout, referred to as FASTIC, capable of performing an active summation in two groups of 4 channels. This ASIC also provides a linear Time over Threshold response for energy measurements that can be sent to an FPGA for digitization. This ASIC, which will be validated in 2021, will be studied for future upgrades of the LSTs.

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 (Figure 13). LST1 includes developments by IEEC, in particular camera electronics. The commissioning phase is expected to finish in 2021. The first gamma-ray signal was detected on 23 November 2019 coming from the Crab Nebula , which is considered the standard candle in very high energy astronomy. Pulsations from the Crab Pulsars were detected in 11.4 h of observations conducted in January-February 2020, validating the timestamping system and the low-energy performance of the telescope (Figure 14).

Figure 13: The Large Size Telescope 1 at Observatorio del Roque de los Muchachos (La Palma, Canary Islands, Spain).

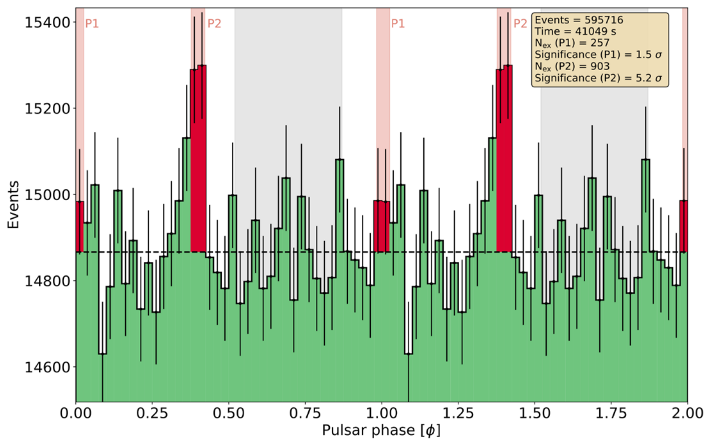

Figure 14: Phasogram of Crab Pulsar as measured by the LST1. Pulsars are known to emit pulses of gamma rays during phases P1 and P2. The shown significance is calculated considering source emission from those phases (in red) and background events from phases in grey. Credit: LST collaboration.

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 where, during 2020, the two first deliverables (documentation delivery and 90 L0-trigger units delivery) have been completed.

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 behaviour ensuring the correct instrument operation. The tendering process finished in mid-2020 and the IEEC offer was selected. The specific purpose of this contract is the development of the GUI for the camera calibration and data visualization and the GUI for weather monitoring data visualization. The activities carried out are the requirements analysis and the preliminary design of the software, and a prototype GUI has been developed.

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 was signed to provide CTAO with services such as assistance with observatory systems engineering, the CTAO costbook, and participation in system reviews.

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. The weather station has been installed at the LST1 site in July 2020 and intensively characterized since then.

Commissioning of CTA Barcelona Raman LIDAR prototype

As a part of the Atmospheric Characterization project of CTA, an advanced Raman LIDAR optimised to fulfil the requirements of CTA was commissioned at the UAB campus. Such optimisation led to the inclusion of innovative elements that are not present in commercial LIDARs, such as a large 1.8m diameter parabolic mirror, separate near-range optics and a powerful 100 mJ laser. The Raman LIDAR is a key instrument to obtain, in less than one minute, 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 telescopes' reflector surfaces and to keep down the systematics in the estimation of both gamma-ray flux and energy. In 2019 the prototype was recognised by CTAO as the first official CTA pathfinder instrument. In December 2020, the Raman LIDAR was sent to the LST1 site to start an on-site one-year commissioning phase that will allow to review the chosen solutions and establish the performance of the final version of the Raman LIDAR (Figure 15). The CTA Barcelona Raman LIDAR prototype is a joint effort of IEEC members from CERES, the IFAE group of CTA, the University of Nova Gorica (Slovenia) and CTA members from INFN Padova (Italy).

Figure 15: The Barcelona Raman LIDAR prototype and its transport to the Barcelona harbour on the way to La Palma (Canary Islands, Spain).

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.

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. The Short-term Scheduler (STS) is one of the high-level sub-systems of ACADA and is under the responsibility of the ICE. An initial release of the ACADA software, including the STS package, was published in 2020. It was devoted to the implementation of a minimum set of features to basically test the integration of all software packages. The STS implemented the reception of the planning, the Scheduling Block validation and the execution management. The scheduling algorithm that is based on Artificial Intelligence technologies evolved to cover the increased number of constraints and is going to be industrialized following quality standards in further releases.

On the other hand, the Long-Term Scheduler (LTS) is included in the SUSS (Science User Support System) WP and it is also under the responsibility of the IEEC. The LTS scheduling algorithm is under development and it is being used in simulation mode to check its performance.

Both STS and LTS scheduling algorithms are based on the IEEC scheduling software package called STARS (Scheduling Technologies for Autonomous Robotic Systems). STARS is being used in production in several ground-based telescopes and is also being adapted for space missions (i.e., Ariel ESA mission).

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Facilities And Key Projects

LISA

Space-borne gravitational wave detection

On 15 September 2019, the Laser Interferometer Gravitational-wave Observatory (LIGO, United States of America) detected gravitational waves for the first time in history, confirming the last prediction of Einstein's General Relativity. This first detection was also revolutionary in the sense that it consisted in gravitational waves coming from the coalescence and final merger of two Black Holes, the first time we have observational evidence of such a system. The Nobel Prize in Physics 2017 was awarded to this discovery that inaugurated the new area of Gravitational Wave Astronomy. Nowadays, LIGO, Virgo (a gravitational-wave European detector located in Italy), and KAGRA (Japan) are routinely making detections of binary compact systems that emit gravitational waves. LIGO and Virgo are ground-based detectors that cover the high-frequency band of the gravitational wave spectrum (between 10-104 Hz). As it happens with the electromagnetic spectrum, there are other parts of the gravitational-wave spectrum that are also very interesting from the scientific point of view. In particular, by looking at the low-frequency band (between 10-5-1 Hz) we can access very massive systems, as for instance the coalescence of a supermassive binary black hole system, which are not accessible to ground detectors due to seismic and Newtonian gravity gradient noises.

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 Figure 16). The main objective of LISA is to carry out the scientific program that was presented in the document "The Gravitational Universe", approved by ESA in October 2013 as a scientific case for the L3 mission, by detecting 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 1,050 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).

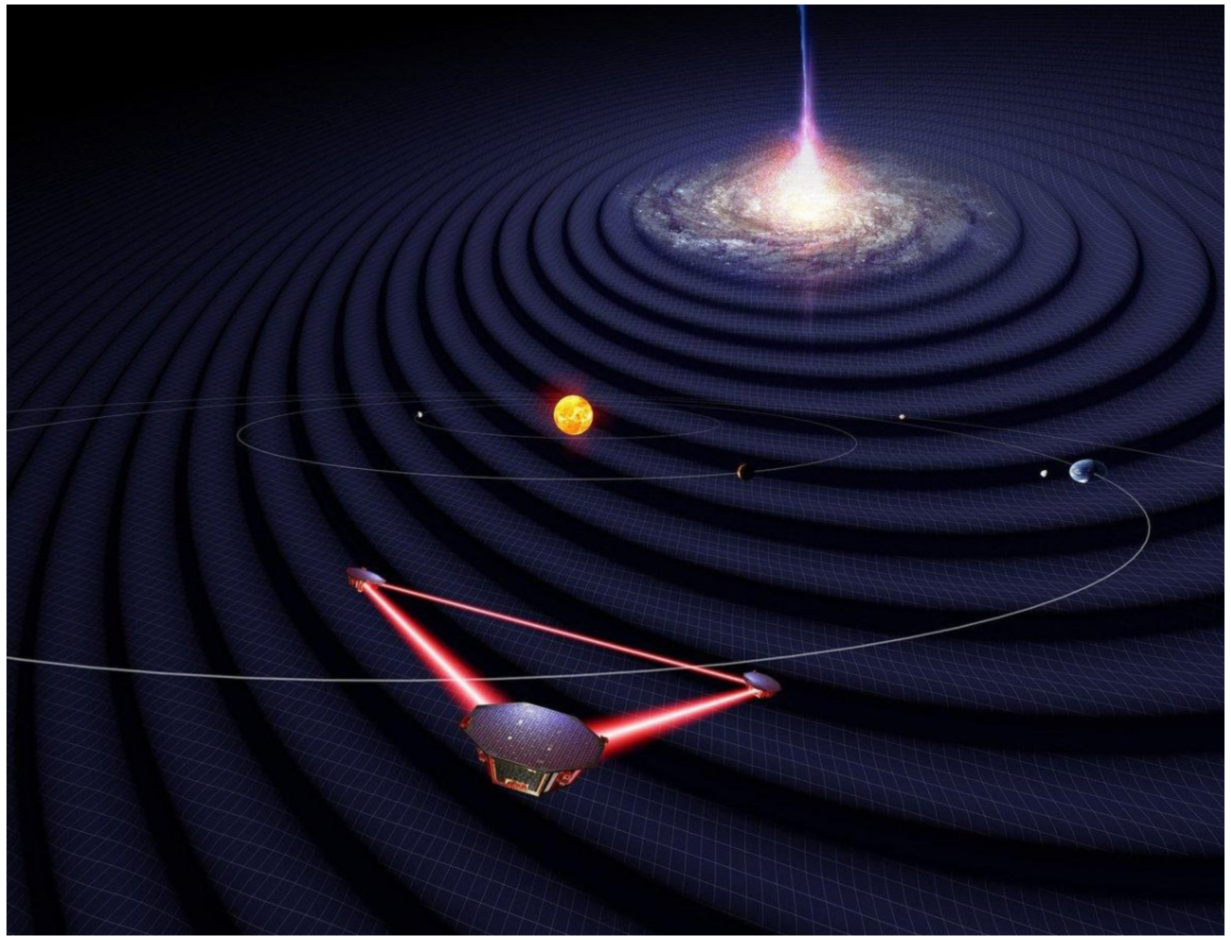

Figure 16: Artistic representation of LISA (the ESA-L3 mission). The constellation of three spacecraft is seen following a heliocentric orbit around the Sun following the Earth. In the background, a representation of the emission of gravitational waves by a binary system of supermassive black holes.

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 (ultra compact 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 Figure 17 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.

LISA

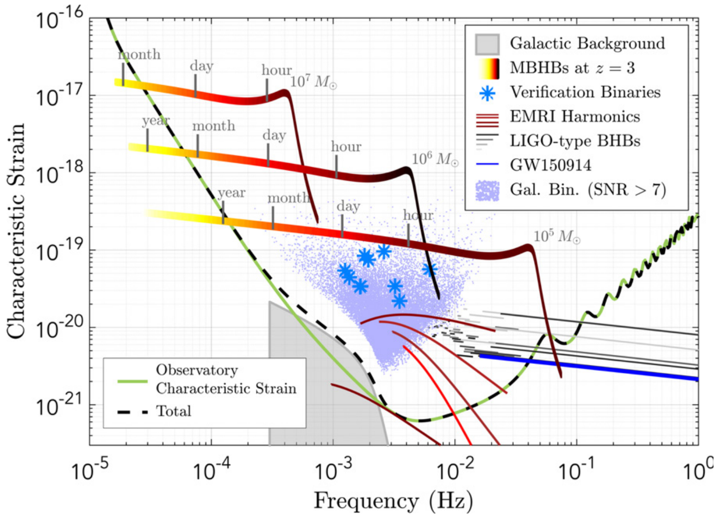

Figure 17: Examples of gravitational-wave sources in the frequency range of LISA, compared with its sensitivity for a 3-arm configuration. The data are plotted in terms of dimensionless 'characteristic strain amplitude'. The tracks of three equal mass black hole binaries, located at z = 3, are shown. 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 selection of LISA was in part a consequence of the LIGO discovery, but above all, of the great success of the ESA LISA Pathfinder mission, that successfully demonstrated the main technology for LISA. LISA Pathfinder was launched on 3 December 2015 from the Kourou spaceport in French Guiana. It started scientific operations on 1 March 2016 through 30 June 2017. On 18 July 2017 the last telecommand was sent to the spacecraft, permanently disconnecting it after 16 successful months of scientific measures. LISA Pathfinder tested the fundamental concept of gravitational wave sensing in flight (see Figure 18): 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. On 7 June 2016, the LISA Pathfinder collaboration announced at the European Space Astronomy Center (ESAC, near Madrid) the success of the LISA Pathfinder mission by showing 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 Figure 19). These results were published in article entitled "Beyond the required LISA free-fall performance: New LISA Pathfinder results down to 20 micro-Hz" in the prestigious journal Physical Review Letters, and show that the results are much better than the initial requirement for LISA Pathfinder and better than the requirement for LISA.

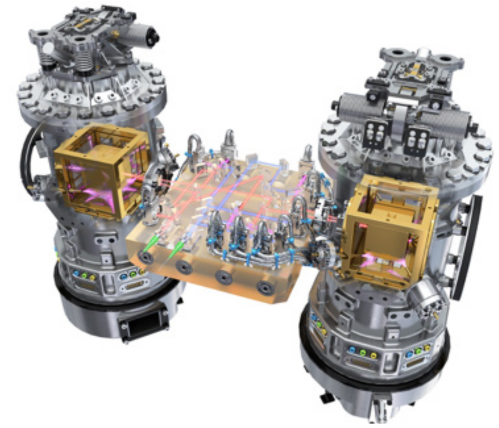

Figure 18: ESA's LISA Pathfinder payload, the "LISA Technology Package" (LTP), where all of the mission's science experiments were performed. Credit: ESA.

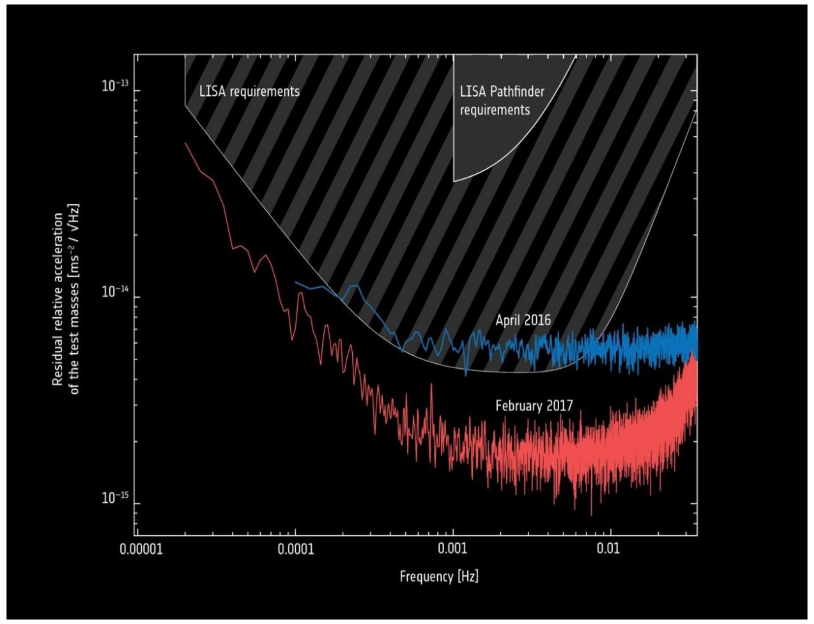

Figure 19: Parasitic differential acceleration of LISA Pathfinder test masses as a function of the frequency. The data refers to a ~13 day long run taken at a temperature of 11 °C. Data is compared with LISA Pathfinder requirements and with LISA requirements. Fulfilling requirements implies that the noise must be below the corresponding shaded area at all frequencies.

The Gravitational Astronomy Group

The Gravitational Astronomy Group at ICE conducts its research primarily in the area of Gravitational Wave Astronomy. The group leads the Spanish contribution to the LISA mission (in collaboration with the IEEC groups at UPC and UB) and has led the Spanish contribution to LISA Pathfinder (in collaboration with the IEEC groups at UPC and UAB). To understand the relevance of the group to the LISA mission, it is important to mention that Carlos F. Sopuerta (ICE, CSIC) 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 (ICE, CSIC) 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 (ICE, CSIC) acts as the Spanish LISA National Project Manager.

LISA

The main activities of the group in these two missions have been carried out thanks to research grants from the National Plan of the Ministry for Space Research (currently PID2019-106515GB-I00) and also to be a Generalitat de Catalunya funded quality group (SGR-1469). The expected 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).

Thanks to the expertise acquired with the LISA Pathfinder mission, the Gravitational Astronomy Group at IEEC is currently leading the ESA contract 'LISA Enhanced Temperature Subsystem' (LETS) to develop a first prototype (TRL4) of the future LISA temperature subsystem, together with DLR-Bremen and SENER Aeroespacial. This includes technological improvements in the read-out and an ultra-stable test bench to be installed at the ICE premises. Figure 20 shows the current setup under testing at ICE. IEEC researcher at ICE M. Nofrarias is leading IEEC in this international effort together with the German Space Agency (DLR) and SENER Aeroespacial.

LISA is currently finishing the phase A of design and developments and the Gravitational Astronomy-LISA group (ICE, CSIC and IEEC), in collaboration with the UPC-IEEC and UB-IEEC groups, is currently supporting ESA in the phase A studies to define a baseline design for the mission. Our role in this phase is to work in collaboration with the two primes (Airbus, Thales) running parallel design studies, providing recommendations on the Data and Diagnostics Subsystem definition. We are also developing compact magnetometers based on resistive technologies for their potential use in LISA.

On the LISA Pathfinder front, we are currently carrying on investigations with the data collected during the LISA Pathfinder experiments. The group has recently led two papers in the LISA Pathfinder collaboration, one on the thermal environment around the test masses and another one on the magnetic environment. New work by our group on the LISA Pathfinder thermal and magnetic environment is underway as well as other investigations by other members of the collaboration in which we participate. In particular on the Optical Measurement System.

On the other hand, our group has participated in the first round of LISA Data Challenges that aim at developing the necessary Data Analysis Tools for the future scientific exploitation of the mission and the development of the ground segment of the mission. We also participate in several Working Groups of the LISA Consortium and we have recently participated in most of the LISA Science White Papers that will appear in the near future. 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.
is leading from IEEC this international effort together with the German Space Agency (DLR) and SENER Aerospacial.

Figure 20: LETS test bench. The vacuum chamber includes a series of active and passive thermal shields to isolate the sensors inside from external temperature fluctuations.

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Facilities And Key Projects

ARIEL

Ariel (Atmospheric Remote-sensing Exoplanet Large-survey) is an exciting mission that will allow us to understand what exoplanets and their atmospheres are made of. Thanks to its ability to observe hundreds of transiting planets, we will obtain an extensive and varied sample of observations that should reveal the most important chemical compounds in planetary atmospheres, as well as their structure. Questions such as 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 will be addressed by Ariel. This revolution will be key to boost our knowledge of the planetary systems in the universe, including our own…

Ariel was selected in March 2018 by the European Space Agency (ESA) for its M4 medium-class science mission. In November 2020 the mission was formally adopted so that implementation can start, with a target launch date in 2029. The instrument 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 (see Figure X for an artist's rendering of the spacecraft). 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, which has a stable environment and an uninterrupted view of the sky. This will maximise its options for observing exoplanets discovered previously by other missions.

Ariel is conceived to observe for at least 4 years a large number (~1000) 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. 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.

The Ariel mission concept is developed by a consortium of more than 70 institutes from 17 countries. IEEC is one of the co-PI institutes (co-PI: I. Ribas) and leads the Spanish contribution (PI: I. Ribas; National Project Manager: J. Colomé), which also includes the Instituto de Astrofísica de Canarias (IAC) and the Universidad Politécnica de Madrid (UPM). IEEC, through groups at CSIC and Universitat de Barcelona (UB), participates in various aspects of the mission, as shown in Figure 21, which illustrates the technical involvement.

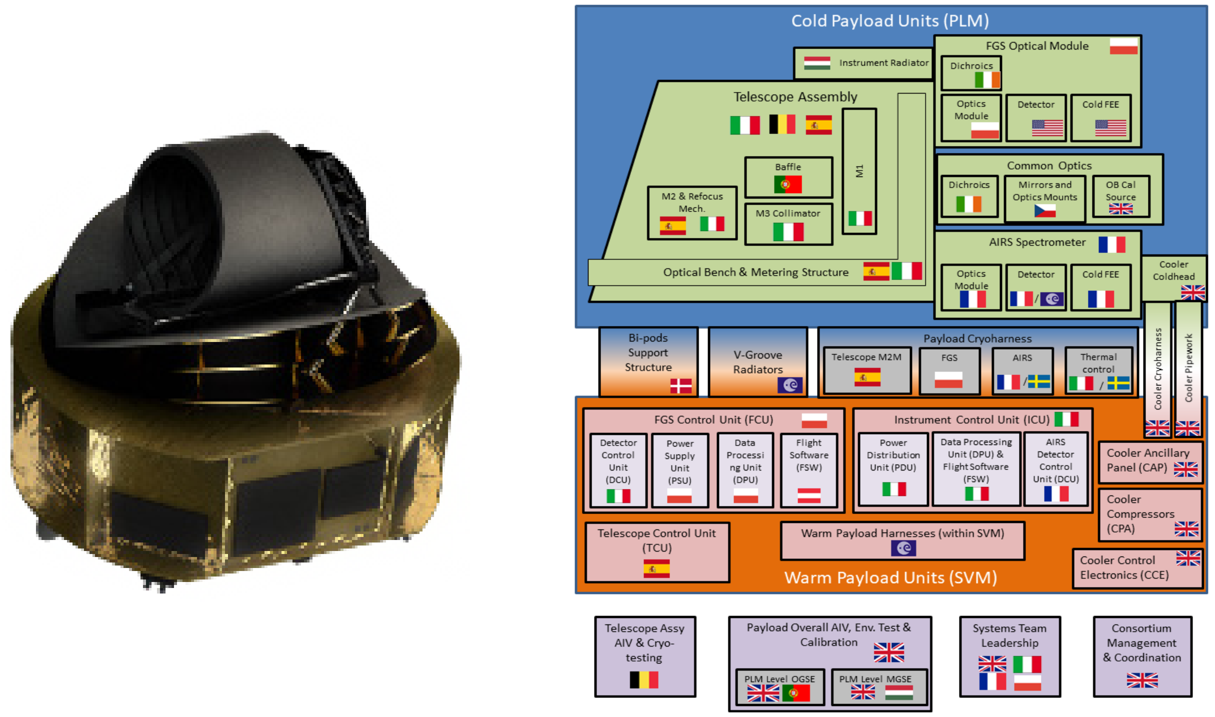

Figure 21: Left: Artist's rendering of the Ariel spacecraft. Right: Ariel Payload Hardware block diagram.

IEEC's participation in Ariel has two aspects, one eminently scientific and the other of technological nature. Regarding the science part, our work basically consists in studying the effects of stellar intrinsic variations, known as stellar activity, on the spectra of planetary atmospheres. Stars, like the Sun, are often covered by dark and bright spots that alter the depth of the planetary transit and therefore the spectrum of the planet's atmosphere being measured. We are developing methods to correct out such variability and thus keep Ariel's data free of any bias.

With regard to technology, IEEC is responsible for the design, implementation, assembly and verification of the Telescope Control Unit (TCU; diagram in Figure 22). 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. It also implements command handling, data formatting and communication with the spacecraft. The TCU is a standalone unit and a sub-system of the telescope assembly, jointly with the M2M. IEEC is using the expertise gained in previous missions (Solar Orbiter and LISA Pathfinder) for the development of flight electronics and software. IEEC is responsible as well for the design and manufacture of the mechanisms of the secondary mirror (M2M) refocusing system, which is devised to ensure that the telescope is in best focus and meets wave-front error requirements when in operation. IEEC therefore holds responsibility on a critical part of the Ariel payload, from the electro-mechanics to the software logics. Furthermore, IEEC leads the mission planning system by using our expertise on scheduling techniques using Artificial Intelligence (AI) algorithms to ensure that observing time is fully optimised. This is a key building block of the Science Ground Segment of the mission.

The technical activity during 2020 has been focused on preparing the System Readiness Review (SRR), which has culminated with the adoption of the mission by the ESA Space Program Committee. The team has worked to increase the Technology Readiness Level (TRL) of the different subsystems. The objective is to reach TRL 6 in 2021 for all subsystems, with special emphasis on the M2M device, as it is considered one of the most critical elements of the telescope. Work has been done to develop the new design of the On-Board Calibration Unit Driver (OBCUD), as it includes not only a tungsten filament, but also LED emitters (Figure 23). The stability required is remarkable, and jointly with the M2M device are the most challenging aspects of the TCU. The currently achieved results and the corresponding analysis are quite promising, and a thorough test process for the TCU will be carried out during 2021 to determine the performance of the different subsystems. In parallel, the Instrument SRR for the TCU will be performed.

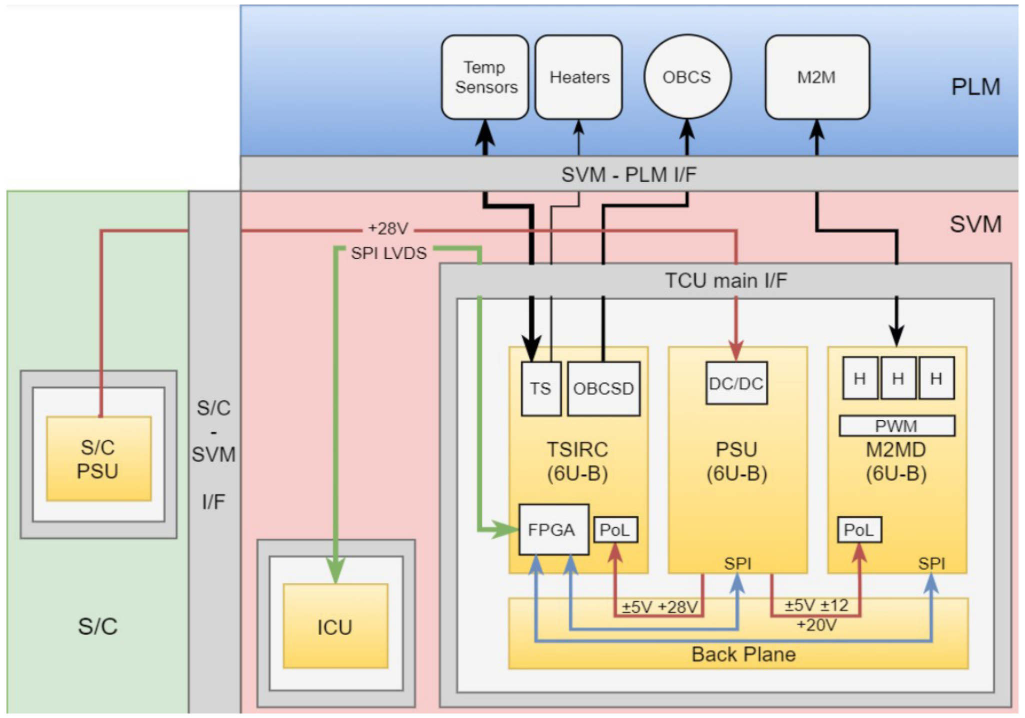

Figure 22: Ariel TCU system block diagram.

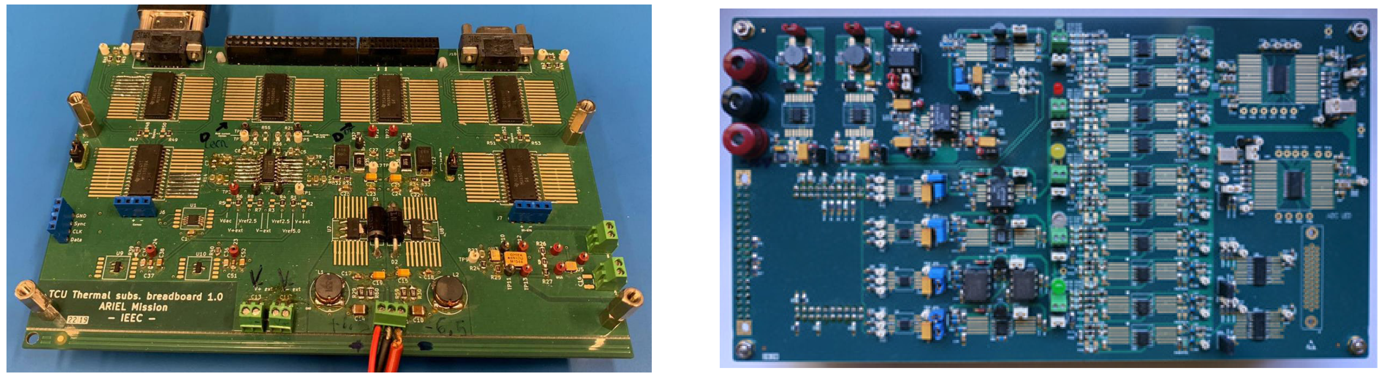

Figure 23: Thermal control (left) and On-Board Calibration Unit Drive (right).

The M2M development was focused on the definition of the system requirements in the framework of the SRR that lead to the mission adoption by ESA. In this sense, the characteristics of both M2M and its cryogenic harness have been defined in great detail, providing a mature definition of the characteristics of these systems. In addition, the ESA Core Technology Program (CTP) activity, started in 2019 to increase the TRL of M2M, was completed during 2020. All the required functional, vibrational and thermal tests for one of the M2M actuators (Figure 24) were conducted and the required documentation was delivered to both ESA and the Ariel Mission Consortium. These tests, performed at the facilities of Sener Aeroespacial, were an essential part of the M2M development. Their main goal was to test the improvements required in the original M2M design, inherited from the Euclid mission, to fulfill the Ariel mission requirements. The results of these tests will be used in the future development of the M2M design during 2021.

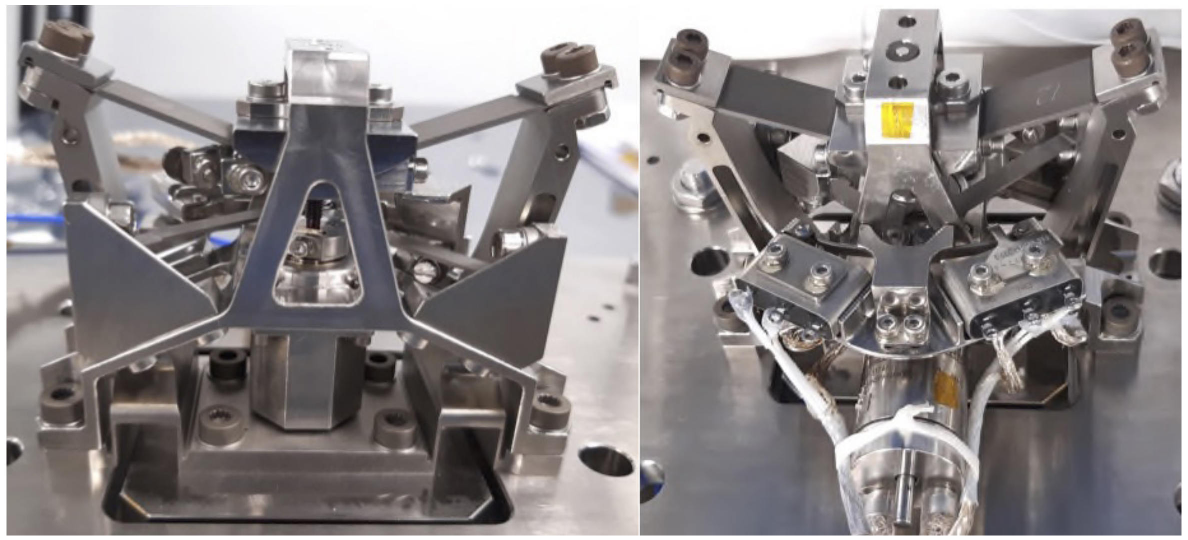

Figure 24: M2M actuator used during the tests completed in 2020 as part of the CTP activity. M2M will have three of these actuators to allow the fine positioning of the Ariel secondary mirror.

We are also developing the scheduling software that will be used for the planning of the Ariel observations. A total of about 1,000 exoplanets will be studied, distributed in three tiers depending on the level of precision needed for the study of their atmospheres. They are labeled as Tier 1, 2, and 3 from lower to higher precision, respectively. For each planet, from one to several transits or eclipses will be combined in order to reach sufficient signal-to-noise ratio. The large amount of possible combinations and the fact that transit and occultations are time-constrained events complicate the calculation of optimized plans. For this reason, we are developing a scheduling software based on AI techniques that have demonstrated to be very efficient for this kind of problem. During 2020, we have been investigating different AI optimization algorithms with the goal of improving the performance of the code. We have upgraded the code introducing Particle Swarm Optimization techniques and we have studied the plans resulting from the scheduling of the Ariel mission reference sample. The results show that the new algorithm provides efficient solutions while reducing the computation time with respect to previous versions of the code. Also, they demonstrate that the goal of characterizing about 1,000 planets is feasible within the Ariel mission nominal lifetime, being even possible to increase the precision for several planets or the number of surveyed systems (see Figure 25). We have additionally studied the use of part of the mission time that is difficult to assign to exoplanet time-constrained events for ancillary science observations. A technical note with the description of the results was presented to the Ariel Consortium, and our scheduling solution was adopted for the mission. We finally submitted a manuscript for publication in the Experimental Astronomy journal.

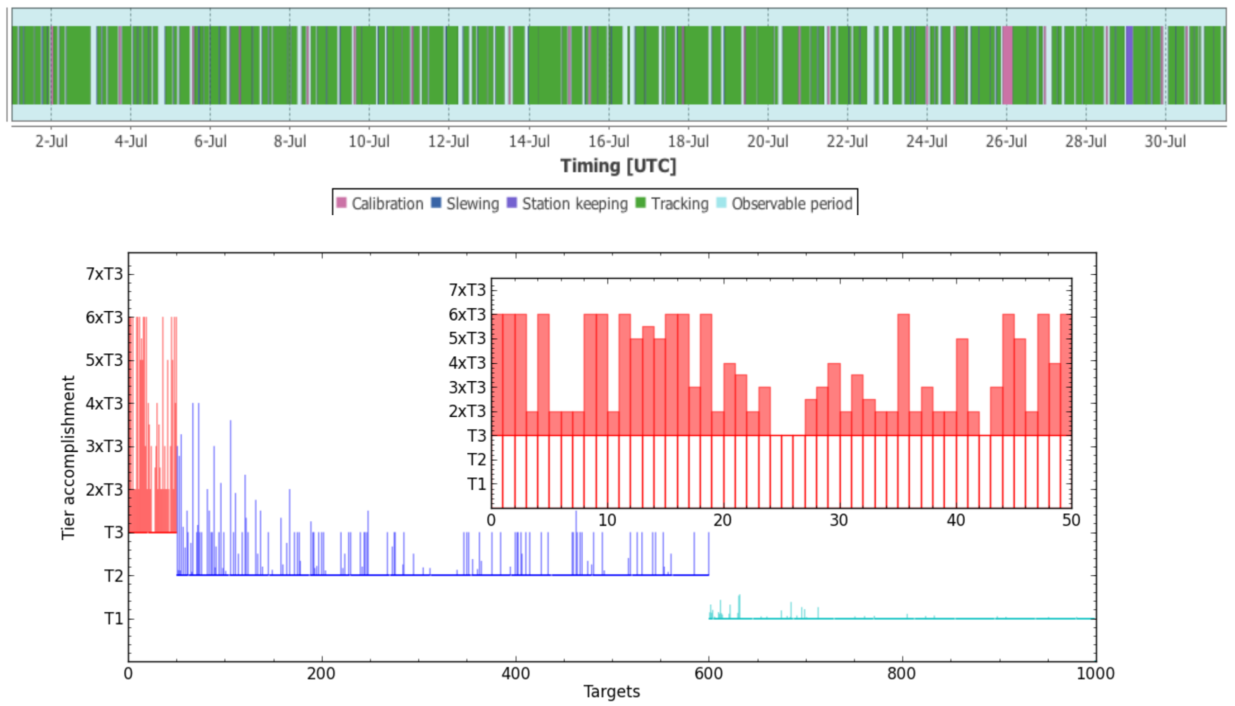

Figure 25: Top: example of the first month plan obtained with our algorithm using the Ariel mission reference sample of targets. Different colors indicate different operations: target observations (green), telescope slewing (blue), calibration observations (magenta), and housekeeping maneuvers (violet). Bottom: goal accomplishment for each target in the Ariel mission reference sample. Red bars correspond to Tier 3 planets that will be observed at the maximum precision. The inset plot shows that all of these targets can be observed at the requested precision and it is even possible to increase the number of observations by a factor of 6 for many of them. Blue bars illustrate the case for Tier 2 targets. For several of them, it is possible to reach Tier 3 precision. Finally, cyan bars correspond to Tier 1 targets.

ARIEL

As part of our scientific contribution to Ariel, we are leading the Stellar Activity WP, as well as participating in the Ephemeris WP and in the selection of the target sample. The highlight of our science activities in 2020 has been the publication (Rosich et al. 2020) of a method to derive the surface distribution and properties of stellar active regions by modelling multi-wavelength time-series observables. Our StarSim code has the capability to solve the inverse problem and derive the properties of the stars and their active regions by fitting photometric data. As a test case, we analyzed ~600 days of BVRI multi-band photometry of the K2 V exoplanet host star WASP-52. We were able to determine the relevant activity parameters and reconstruct the time-evolving longitudinal map of active regions (see Figure 26). The star shows a heterogeneous surface composed of dark spots with a mean temperature of 575 ± 150 K lower than the photospheric value, with filling factors ranging from 3 to 14%. We used the results to study the chromatic effects on the depth of exoplanet transits obtained at different epochs and corresponding to different stellar spot distributions. From peak-to-peak photometric variations of ~7% in the visible, the residual effects of unocculted dark spots on the measured transit depth of the giant planet WASP-52 b are about 10−4 at 550 nm and 3×10−5 at 6 µm. Our findings demonstrate that it is possible to reconstruct the parameters and distribution of active regions over time by using contemporaneous ground-based multi-band photometry of an active star. This makes it possible to quantify the effects from unocculted star spots on the planetary radius measured from transit spectroscopy and mitigate them by about an order of magnitude, thus helping Ariel to fulfill its science goals.

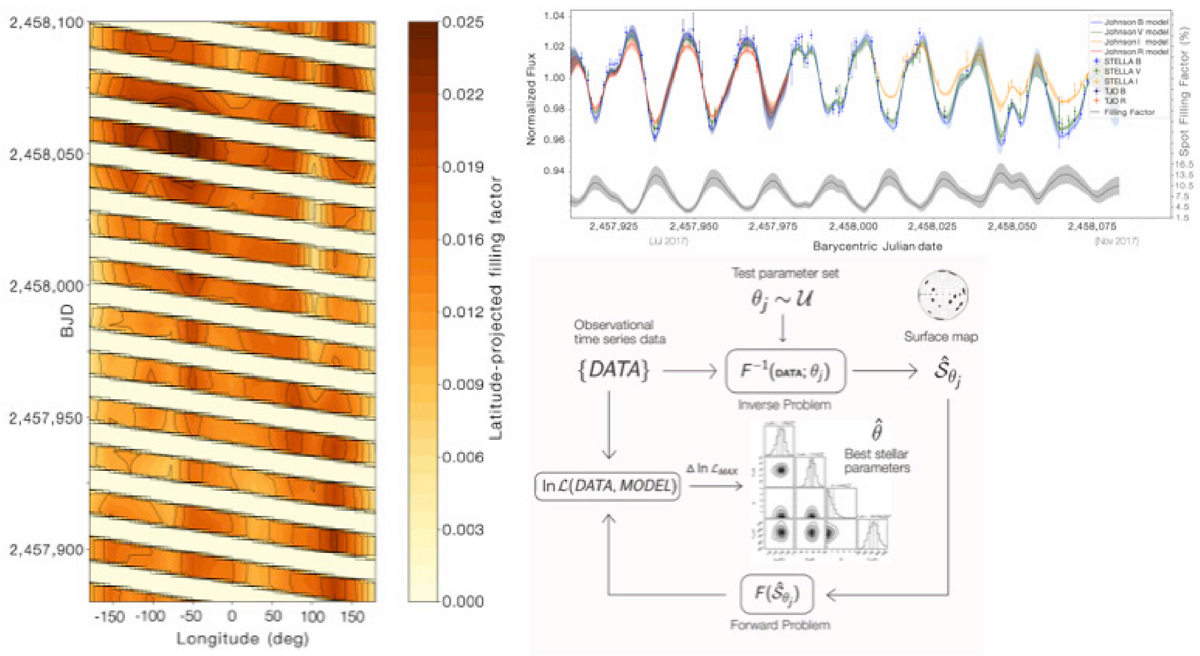

Figure 26: Bottom-centre: Flow chart of the parameter inference approach. Top: Application of the inversion procedure to multi-band photometry of WASP-52 with model fits and total projected spot filling factor. Left: Time-series of the reconstructed WASP-52 surface map (latitude-projected filling factor).

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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 four scientific-technological units able to raise challenges in the knowledge frontier, and led by a highly competitive team in space science and instrumentation with a high degree of internationalisation. This great complementarity between the scientific and technological fields is based on the fact that space is not just a research object in itself, but also a means to pave the way for new methodologies and technologies to generate knowledge. Research in the space science field has historically – especially over the last few decades – caused a transformation of the world we live in.

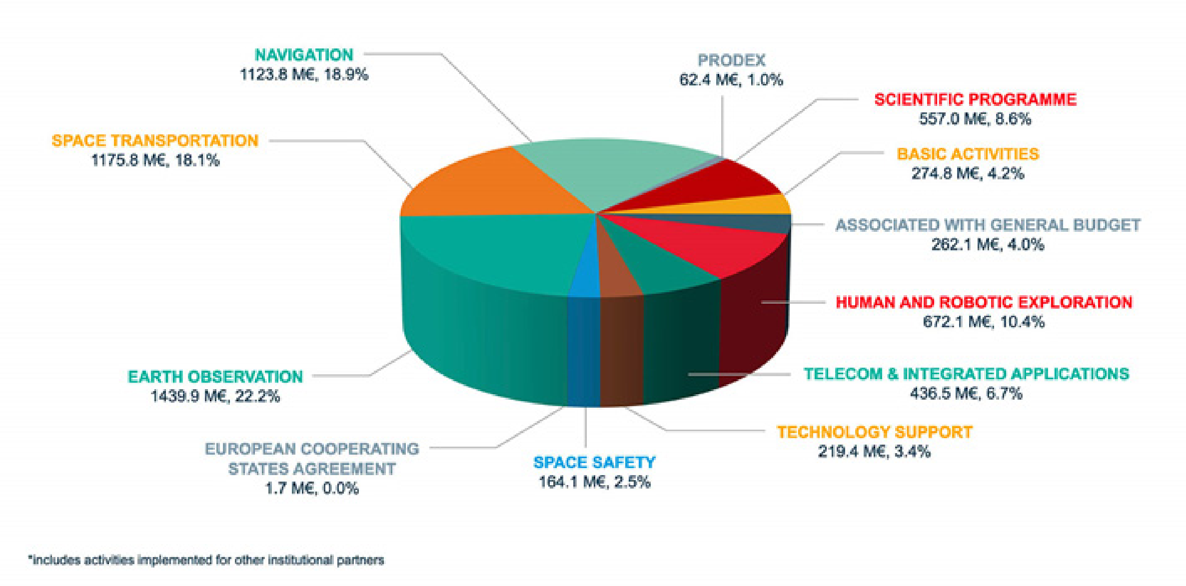
Collaboration with the space industry, especially that of the so-called Traditional Space and, to a lesser extent, with that of the New Space, are mainly performed through industrial contracts funded by state-level projects (Spanish Plan Estatal de I+D+i) aimed at the construction of large scientific 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 Catalan New Space Strategy approved in October 2020, and in technology demonstration programs of the ESA. It is also important to mention the commitment to develop capacities of the ground segment or downstream, with the Satellite Ground Station developed by the UPC at the Montsec Observatory and devoted to satellite communications, 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 2020 include the satellite tracking services at the Montsec Observatory, GNSS receivers and studies on the positioning performance of 5G technologies, navigation systems for on-board positioning based on pulsar stars, space weather applications on navigation and space safety, AI scheduling technologies for ground-based telescopes and space mission planning, 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 27: ESA budget for 2021 distributed by domain.

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 Figure 27 that illustrates the ESA budget distributed by domain for 2021- 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: LISA Phase A Instrument Study for a Gravitational Wave Observatory

IEEC contributes to the ESA contract 'LISA Phase A Instrument Study for a Gravitational Wave Observatory', together with the rest of European main hardware providers to LISA, i.e. Max Planck Institut for Gravitational Physics (Germany), CNRS (France), and University of Trento (Italy). The objective of the contract is to provide support to ESA at System Engineering level. This contract excludes any development or studies associated with the national contributions, which are funded through national funds.

Coordinator: Miquel Nofrarias
Funding Institution: ESA (Contract No. 4000128647/12/NL/BW)
Duration: 14/2/2020-28/2/2021

Earth Observation

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

KTT Contract: BEEPS-IOM, Biomass end-to-end performance simulator – Ionospheric Module

ESA's BIOMASS Earth Explorer mission aims at providing global aboveground forest biomass. Its payload is a UHF synthetic aperture radar. At UHF ionospheric effects, notably the group delay and phase advance, the Faraday rotation, and the intensity and phase scintillations (or rapid fluctuations) are significant and have to be properly modelled to be compensated, to understand the limitations of the proposed technique, and to select the optimum observation conditions. In this project the ionospheric module of the BIOMASS end-to-end performance simulator (BEEPS-IOM) is implemented. IEEC is in charge for the algorithm development and prototyping in Matlab, and RDA (CH) to convert them into C++, complying with all ESA quality standards.

Coordinator: Adriano Camps
Funding Institution: ESA
Partners: RDA (CH)
Duration: 30/1/2020-30/12/2022

KTT Contract: SIMIONO, Ionosphere Impact and Corrections for Low Frequency Radars

The objective of this project is to consolidate the understanding, assessment and correction of ionospheric effects on space-borne low-frequency radar observations, including several modes of P & L-bands SAR (monostatic, bistatic, polarimetric, interferometric), as well as VHF/UHF radar sounders, and GNSS-Reflectometers for scatterometry and altimetry. A correct and fine representation of the ionosphere layers (models, data), considering both the mean values and the inhomogeneities causing spatial and temporal fluctuations of the electron density at different scales are considered, and an API is implementing these models for use in future ESA end-to-end performance simulators. The project is coordinated by ONERA (FR), who is in charge of the algorithm prototyping of SAR sensors. IEEC is in charge of the algorithm prototyping of low-frequency radars sounders and GNSS-R instruments, and RDA (CH) is in charge of converting these algorithms into C++, complying with all ESA quality standards.

Coordinator: Adriano Camps
Funding Institution: ESA
Partners: ONERA (Fr), RDA (CH)
Duration: 30/1/2020-30/12/2022

KTT Contract: OSIP Open Channel Early Technology Development Activities Evaluation Session 2020-05 – Widelane Grazing Angle Carrier Phase Altimetry with GNSS Reflected Signals: exploring beyond the PRETTY mission

IEEC leads an experimental campaign, funded under the ESA's Open Space Innovation Platform (OSIP), to understand the performance of GNSS sea surface altimetry using carrier phase delay observations at grazing angles of observation at two frequencies. This new technique can be applied when the scattering off the sea waves presents a strong coherent component, i.e., when the surface is effectively smooth with respect to the electromagnetic wavelength and geometry. The chances of coherent scattering increase at grazing angles of observation. The smart use of the dual frequency system are also investigated. The experiment uses IEEC developed hardware installed on top of Puig Major (Serra de Tramuntana, Mallorca) at over 1400 m altitude close to the sea. An oceanographic buoy located at the observational area provides in-situ wind and waves information.

Coordinator: Estel Cardellach
Funding Institution: ESA, Contract Number: 4000133252/20/NL/GLC
Partners: IEEC, IMEDEA-CSIC, SOCIB, DLR
Duration: 26/11/2020-31/1/2022

KTT Contract: Scout Mission Concepts and System Consolidation Studies: HydroGNSS

As a result of the proposal submitted to ESA's Scout Missions, the HydroGNSS concept was selected for further studies together with three other missions. These studies were intended to Consolidate and refine the proposals and prepare the missions for the final competition. The proposal and consolidation studies were led by Surrey Satellite Technology Ltd. (SSTL, UK), main contractor. IEEC contributions are mostly focused on novel aspects of the 'coherent channel', a new mode of the GNSS-R receiver onboard.

Coordinator: Estel Cardellach
Funding Institution: ESA. Main contract ESA-SSTL Ref.4000129140/19/NL/CT, SSTL-IEEC subcontract MS000397
Partners: Surrey Satellite Technology Ltd. (SSTL) main contractors, IEEC, La Sapienza University (Italy), Finnish Meteorological Institute (Finland), University of Nottingham (UK), National Oceanography Centre (UK)
Duration: 1/4/2020-31/7/2020

KTT Contract: Analysis of Water Relations in the Soil-Plant Continuum Using Microwave-Lidar Synergy

The project exploits L-band passive and active microwave missions, as well as Lidar vegetation height measurements, in order to disentangle the water component from the signal of the passive microwave attenuation variable, the vegetation optical depth (VOD). The VOD contains information on biomass, vegetation structure, and vegetation water content. In this project, VOD-derived vegetation moisture maps are produced and are applied as a keystone variable to model the water flux in the soil-plant-atmosphere continuum (SPAC). This new, multi-sensor approach provides more detailed models of the SPAC, which is an essential component in the water and carbon cycles. Therefore, the project provides future models on carbon uptake and climate scenarios, is used to monitor vegetation hydric stress, and provides a more accurate understanding of a key ecophysiological process.

Coordinator: David Chaparro
Funding Institution: Fundació "La Caixa"
Partners: MIT (USA), DLR (Germany), Universitat de València, Université Catholique de Louvain (Belgium)
Duration: 1/1/2020 – 31/8/2022

Navigation

Goal: position, navigation and timing

KTT Contract: PODIUM, Pulsar Orbit Determination for Interplanetary Unaided Missions - Pulsar Navigation for Science Missions

The aim of the PODIUM activity is to perform a preliminary design and sizing of a hardware navigation unit that, once mounted on a spacecraft, will acquire and process measurements to enable autonomous on-board positioning in the Solar System. The unit design and performances are assessed for two reference scenarios, well known by the proposal team: EnVision and L2 observatory. The PODIUM Pulsar Navigation System relies on pulsars for these measurements. The IEEC team at ICE-CSIC contributes with the pulsar signal timing algorithm software that is used for selected sizing cases based on the analytic approach to refine the error budget assessment. And it also contributes with the expertise in the design and test of X-ray optics that is very relevant for the concept study of the PODIUM sensor.

Coordinator: Nanda Rea & Margarida Hernanz
Funding Institution: European Space Agency (ESA)
Partners: Sener Aeroespacial, Elecnor Deimos
Duration: 29/12/2020 – 31/3/2022

KTT Contract: INNUENDO – Enhanced GNSS Signals in Space and User Receiver Processing

The objective of this project is to investigate alternative approaches to the classic MEO-based GNSS positioning, navigation and timing. Emphasis is placed on the potential use of LEO satellites as well as on innovative techniques and signal designs to improve resilience and performance. SPCOMNAV-UAB contribution is focused on the analysis of chirp spread spectrum for positioning with LEO satellites, as a way to achieve faster acquisition with lower complexity while preserving a good trade-off in terms of multiple access interference and multipath rejection.

Coordinator: Gonzalo Seco-Granados
Funding institution: European Space Agency (ESA)
Partners: LINKS Foundation (Italy, coord)
Duration: 20/02/2020–30/03/2021

KTT Contract: GIMAD – GNSS Interference Monitoring and Detection System

The objective of this project is to develop an interference detection station capable of permanently detecting potential interference sources that may hinder the safety and integrity of GNSS users. SPCOMNAV-UAB contributes to this activity by developing signal processing techniques for interference detection using measurements from a single antenna in the GNSS band, from an antenna array in the GNSS band and from a single antenna out of the GNSS band.

Coordinator: Gonzalo Seco-Granados
Funding institution: European Space Agency (ESA)
Partners: Indra (Spain, coord)
Duration: 08/07/2020–31/12/2021

KTT Contract: GNSSW-HS – Earth-Moon Navigation / System Study and Development of a Highly-Sensitive Spaceborne Receiver Prototype

The objective of this project is to study the use of multi-constellation GNSS for Earth-Moon navigation and to develop a prototype of a GNSS spaceborne receiver that might be used in future Lunar missions. SPCOMNAV-UAB contributes to this project by developing a software emulator providing realistic pseudorange and velocity/phase observables as obtained at the output of both the acquisition and tracking stages of a GNSS spaceborne receiver.

Coordinator: José A. López-Salcedo
Funding institution: European Space Agency (ESA)
Partners: GMV NSL (UK, coord)
Duration: 01/06/2020–30/11/2020

KTT Contract: OSNMA+ – Enhanced GNSS Receiver/User Terminal

The objective of this project is to design, develop, test and demonstrate a close-to-market enhanced GNSS receiver fully compatible with the latest Galileo Open Service Signal In Space Interface Control Document (SIS-ICD), including I/NAV improvements and the use of the Open Service Navigation Message Authentication (OSNMA).

Coordinator: José A. López-Salcedo
Funding institution: European GNSS Agency (GSA)
Partners: Qascom (Italy, coord)
Duration: 02/11/2020–01/11/2022

KTT Contract: RF-SESMS – GNSS Reference Station Environment Monitoring Unit

The objective of this project is to develop an RF site environment survey and monitoring system in order to monitor, characterize and model the RF environment affecting GNSS ground sensor stations. SPCOMNV-UAB is providing support on multipath characterization and modeling in the GNSS band.

Coordinator: Gonzalo Seco-Granados
Funding institution: European Space Agency (ESA)
Partners: Indra (Spain, coord)
Duration: 01/09/2020–28/02/20221

KTT Contract: ESGR – Edge Snapshot GNSS Receiver

ESGR is a technology transfer project between SPCOMNAV-UAB and Loctio, a Location as a Service (LaaS) startup company targeting positioning for the Internet of Things (IoT). The ultimate goal of the project is to reduce the energy per position fix incurred by conventional IoT devices, which mostly rely on embedded GNSS chipsets. Instead, the project aimed at exploiting the new paradigm of processing GNSS signals in the cloud/edge, thus offloading most of the computational load out of the IoT device and enabling ultra-low power positioning.

Coordinator: José A. López-Salcedo
Funding institution: European Commission (H2020-ICT-04-2017)
Partners: Loctio
Duration: 16/08/2020–14/02/2021

KTT Contract: Forecasting Space Weather Impacts on Navigation Systems in the Arctic - Greenland Area (FORSWAR

Prototype a new advanced space weather forecasting model for the satellite-based Positioning, Navigation and Timing (PNT) users in the Greenland area. New techniques for space weather forecasting are being developed (in particular, forecasting ionospheric scintillations) and their advantage over existing models will be analyzed. The new model aims at providing a readable map over Greenland indicating weak, moderate and severe disturbances in the PNT applications for general users.

Coordinator: Manuel Hernández-Pajares
Funding institution: ESA-ESTEC (Contract Number: 4000131555/20/NL/AS)
Partners: University of Oslo, DLR
Duration: 10/09/2020-10/12/2021

KTT Contract: Analysis and characterization of total electron content derived from global ionospheric maps in the polar regions (PolarGIMs)

Determine the main VTEC climatology in both polar ionospheres in a realistic way. Ionospheric GIMs suitability to show the VTEC footprint of different phenomena of polar ionosphere, in terms of up to six case studies: tongues of ionization, trough and dawnside drifting structure, flux transfer event, theta-aurora SP VTEC observation, ionospheric convection patterns, and SED during infrequent major geomagnetic storms. Development of a tool that allows a general analysis of polar climatology: the unsupervised clustering of the normalized VTEC maps in both the south and north polar regions, provided by a LVQ neural network.

Coordinator: Manuel Hernández-Pajares
Funding institution: European Commission Joint Research Centre (JRC)
Duration: 10/2018-11/2020

Space Safety - Space Situational Awareness (SSA)

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

KTT Contract: Space Weather User Needs for the Mediterranean Region (SWEMED)

The project aims to identify how the SSA SWE segment customer requirements baseline needs to be enhanced and tailored to best meet the needs of end users operating in the Mediterranean region. To achieve this, a user consultation exercise has been performed including workshops in five countries of the Mediterranean region: France, Greece, Italy, Portugal, and Spain. The targeted sectors include communication and navigation, offshore resource exploration/exploitation, power system operation, pipeline operation, railway operation, aviation, shipping, logistics, space surveillance and insurance.

Coordinator: Manuel Hernández-Pajares
Funding institution: ESA-ESOC (SSA P3-SWE-XXIII.1)
Partners: Universidad de Alcalá, GMV, Deimos, NKUA
Duration: 06/2019-05/2021

Ground-based Instruments

Goal: development of instrumentation for ground-based facilities.

KTT Contract: STARS scheduling software for the COLIBRI Telescope

The STARS (Scheduling Technologies for Autonomous Robotic Systems) software framework developed by the IEEC for telescope time scheduling purposes was adapted and delivered to the Laboratoire d'Astrophysique de Marseille (LAM) for its specific use at the COLIBRI telescope. The framework is complemented with two graphical interfaces: the Management for Users in the Robotic Observatory Control System (MUR) for proposal management (or planning) purposes; and the Analysis Tool for Planning (ATP) that is used for an expert performance analysis of the obtained schedules. COLIBRI telescope is located in Mexico and is devoted to carry out automatic follow-up observations of the SVOM (Space based multi-band Variable Object Monitor) satellite, a French and Chinese mission for GRB detection to be launched by the end of 2021.

Coordinator: Francesc Vilardell & Josep Colomé
Funding Institution: CNRS – LAM (France)
Duration: 05/2020 - 05/2021

KTT Contract: IAC tender CTA Lote 3

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 Camera Control Software that allows the data acquisition of the Cherenkov radiation with the camera detector and the calibration light, and uses weather sensors to provide a high-logic behavior ensuring the correct instrument operation.

Coordinator: Josep Colomé
Funding Institution: IAC (LIC-19-008-Lote3)
Duration: 8/6/2020-23/12/2022

KTT Contract: Consultancy service for Discrete Optimization Methods for Sensor (Telescope) Planning

The consultancy service was devoted to assessing Artificial Technologies for telescope time scheduling and it was based on the experience at the IEEC in providing scheduling solutions for a wide range of different projects. The challenges found, the algorithms developed and the final solutions reached have provided IEEC a strong expertise in the field. The consultancy was mainly focused on the technical solutions found to solve the scheduling problem from single telescope to multi-observatory coordinated operations. The latter was analysed to explore the challenges to schedule a network of ground-based telescopes for satellite tracking purposes.

Coordinator: Josep Colomé
Funding Institution: DEIMOS
Duration: 05/2020 - 11/2020

KTT Contract: Collaboration on calibration and environmental monitoring for preparing the implementation of the Cherenkov Telescope Array Observatory

The purpose of the contract is to establish and carry out a Research and Development Collaboration for preparing the implementation of the Cherenkov Telescope Array Observatory. In particular, IEEC provides support from Dr. Markus Gaug, who coordinates the Array Calibration, the Environmental monitoring and the Atmospheric characterization projects of CTAO.

Coordinator: Lluís Font
Funding Institution: CTAO GmbH
Duration: 1/03/2020 – 28/02/2021

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Networks

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 400 scientists 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 working 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.

Due to the COVID-19 pandemic situation, there was not possible to organize any event during 2020, but we produced an outreach project focused on building a virtual reality tour within the Milky Way, passing through the thousands of different pulsars systems hosted in our Galaxy.

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MW-GAIA

MW-GAIA is a COST Action that started on 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. Currently, it encompasses 29 COST countries plus some neighbour and international partner countries.

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.

Due to the COVID-19 pandemic situation, the activities of the network during 2020 were limited to the first months: one workshop, one school and few exchange visits. The school "Milky Way size galaxy formation and high performance computing", held on 14-17 Jan 2020, was organized and hosted by ICCUB. The other scheduled activities were postponed to 2021.

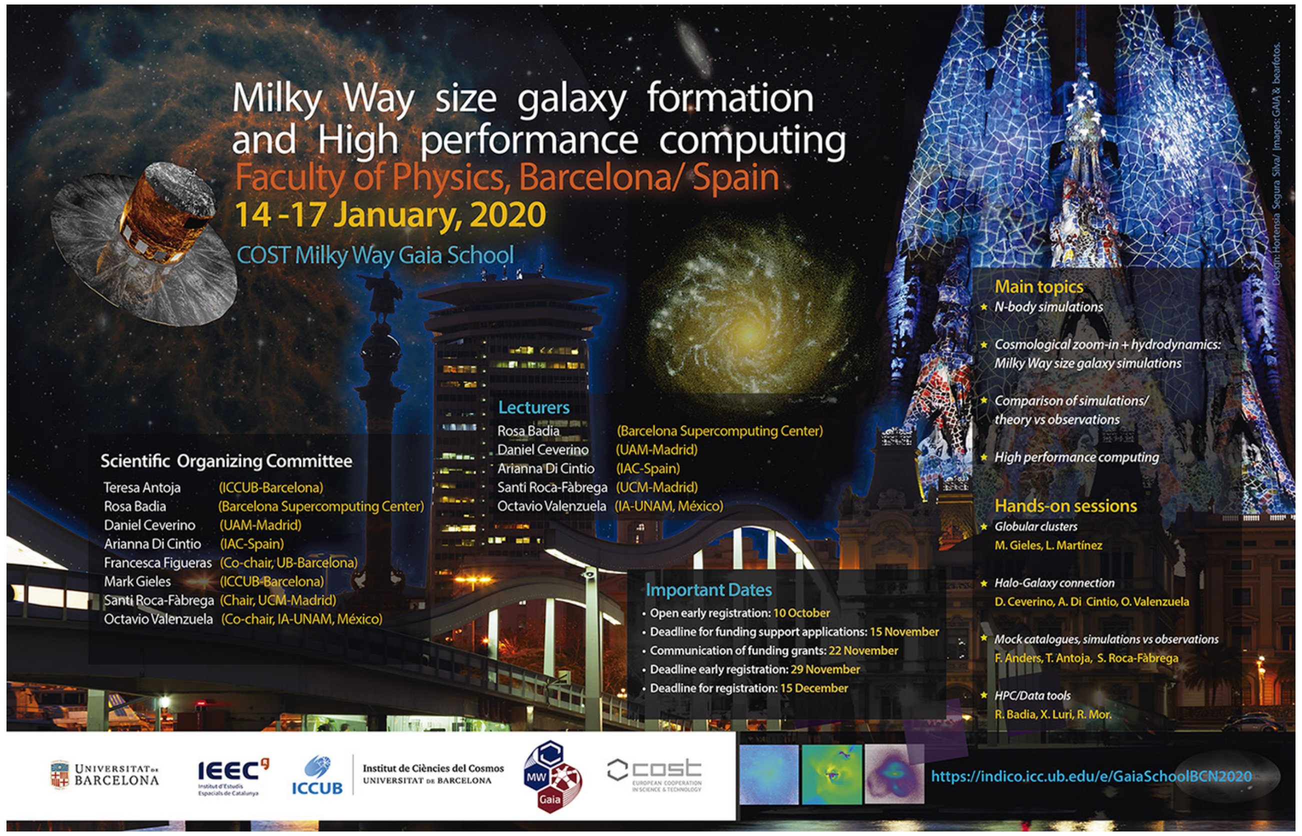

Figure 28: Group picture of the school organized and held by ICCUB within the MW-GAIA network.

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SCIENTIFIC HIGHLIGHTS

The Milky Way and Gaia-Enceladus galactic collision dated by observing stellar tiny flickering

The motion of ν Indi in our Galaxy — an old Milky Way Halo star — reveals a tumultuous past, the result of the collision between Gaia-Enceladus and the Milky Way. Now, small variations in its brightness are used to determine its age.

A single bright star, situated in the constellation of Indus — visible from the southern hemisphere — has revealed new insights on an ancient collision that the Milky Way underwent with another smaller galaxy, called Gaia-Enceladus, early in its history.

The work, led by the University of Birmingham and in which the ICE researcher Aldo M. Serenelli has participated, has used the characterisation of a single ancient, bright star, called ν Indi, to study the history of the Milky Way. Stars carry "fossilized records" of their histories and, hence, the environments in which they formed. The team used data from spatial and ground-based telescopes to unlock this information from the star ν Indi.

The star was aged using its natural oscillations (asteroseismology), detected in data collected by NASA's Transiting Exoplanet Survey Satellite (TESS). Launched in 2018, TESS is surveying stars across most of the sky to search for planets orbiting the stars and to study the stars themselves. When combined with data from the European Space Agency's Gaia Mission, TESS data have revealed that ν Indi was born early in the history of the Milky Way, 11.5 billion years ago, and later the Gaia-Enceladus collision altered its motion in our Galaxy.

The motion of ν Indi in the Galaxy has been affected by the Gaia-Enceladus collision, which therefore took place after the star was born. In this way, asteroseismically-determined age has allowed to place new limits on when the intergalactic collision took place.

The presence in our galaxy of many stars belonging to Gaia-Enceladus indicates that its collision with the Milky Way had and has had a large impact on the evolution of our Galaxy. Understanding this is a hot topic in astronomy, and this study is an important step in determining exactly when this collision occurred.

The work also demonstrates the potential of asteroseismology made with TESS, and the possibilities that arise when it is possible to combine observations with state-of-the-art instruments, even in the case of a single bright star.

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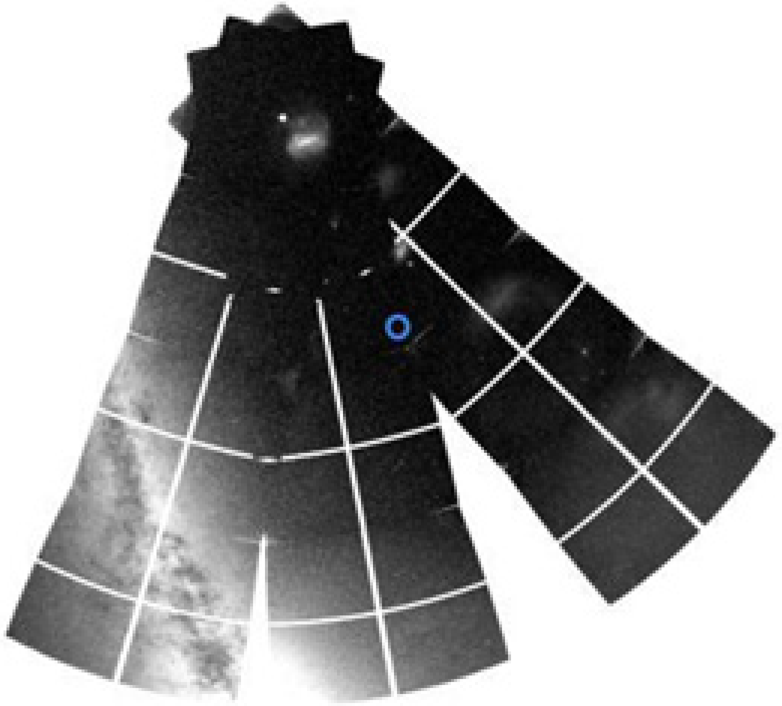

Figure 29: TESS mosaic of Sectors 1, 12 and 13.
Credit: T. Mackereth - University of Birmingham.

Highlights

Proxima Centauri amazes us again: a possible second low-mass planet is found orbiting the nearest star to the Sun

A deeper exploration of the nearest planetary system shows evidence of radio emission from star-planet interactions.

Following up the 2016 discovery of Proxima b, a terrestrial exoplanet in a temperate orbit around the nearest star to the Sun (Proxima Centauri, at a distance of 4.2 light-year), IEEC researchers, led by the ICE researcher Guillem Anglada-Escudé, coordinated a series of follow-up observations, which made it possible to reveal the presence of a candidate low-mass planet orbiting the star at a distance 1.5 times greater than that separating the Earth from the Sun. The whole scientific community was invited to participate in the analyses in an open science experiment as a part of the Red Dots initiative.

The re-analyses led by Fabio del Sordo and Mario Damasso allowed the detection of a significant second signal in a rather long orbital period, which would correspond to a second planet in a much colder orbit. Despite the detection being not as robust as Proxima b, there have been hints of a possible object hinted at in similar orbital periods using direct imaging methods.

In addition to this, the results of an intensive observational campaign led by researchers at Instituto de Astrofísca de Andalucía (IAA, CSIC), with participation of IEEC researchers, revealed that Proxima is emitting in radio frequencies consistent with the interaction of Proxima b´s and the star's magnetic field in a scaled up version of the emission seen in Jupiter and its moons.

On-going world-wide observations are being pursued in this deeper and more detailed exploration of our nearest stellar neighbour.

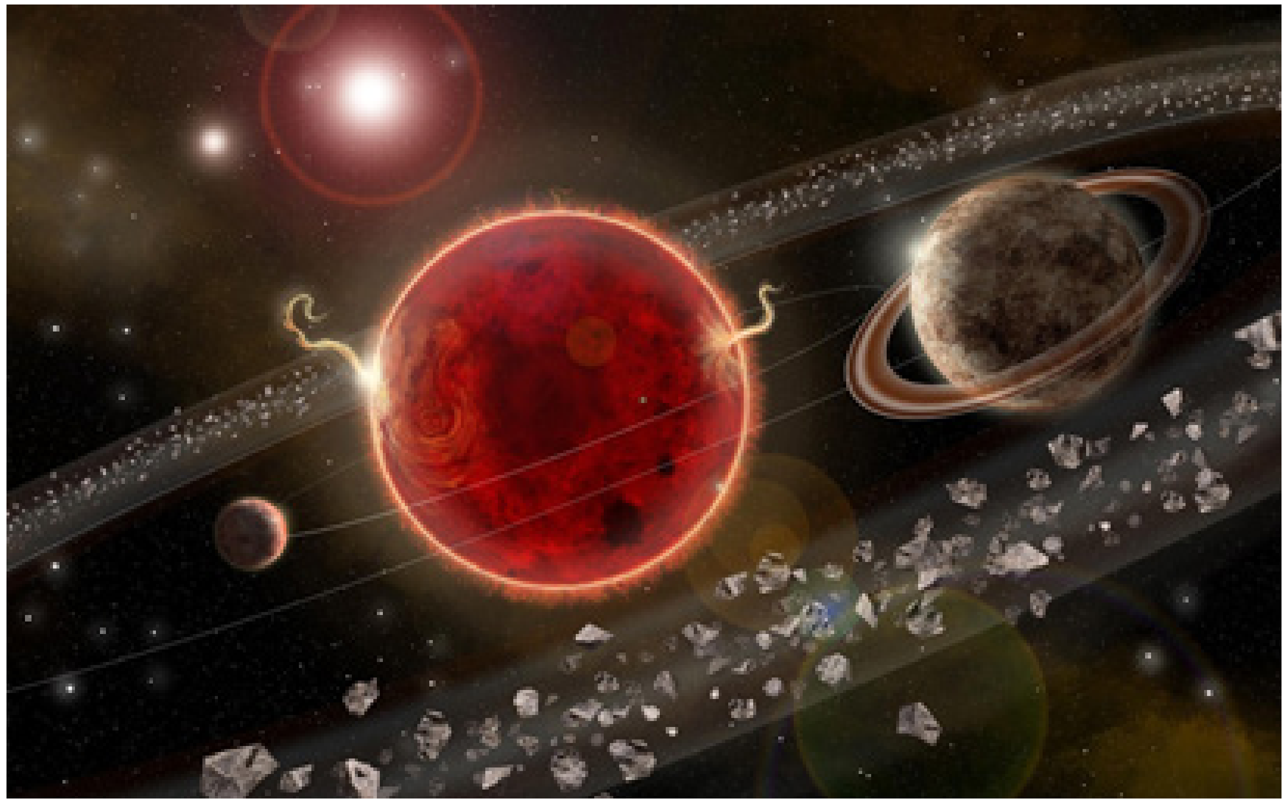

Figure 30: Artistic recreation of Proxima Centauri and its planets.

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Highlights

eXTP: matter under extreme conditions of density, gravity and magnetism to be revealed by a future X-ray space mission

The future X-ray satellite eXTP, a collaboration between China and Europe, will study fundamental physics topics related to matter in the vicinity of black holes and inside neutron stars, where either gravity, density or magnetism reach their highest possible values.

The eXTP (enhanced X-ray Timing and Polarimetry Mission) is an X-ray satellite planned by China and Europe, with European Space Agency (ESA) supervision and collaboration, expected to be launched at the end of 2027. It will include four instruments onboard, two led by China and two, by Europe; the Principal Investigator (PI) of one of the two European instruments — the Wide Field Monitor (WFM) — is the researcher from ICE Margarida Hernanz. The contribution of IEEC at the ICE group is the whole mechanical structure of the cameras of the WFM, as well as their assembly, integration and tests before sending them to the prime contractor of the satellite in China. The LAD (Large Area Detector), SFA (Spectral Focusing Array) and PFA (Polarimetry Focusing Array) are the three other instruments onboard eXTP, with the LAD led by Italy and SFA and PFA by China.

The WFM instrument includes 6 coded mask cameras, grouped in 3 camera pairs, covering a wide Field of View. Its unprecedented combination of Field of View and imaging capability, will make it a discovery machine of the variable and transient X-ray sky. The goal of the WFM is thus to detect transient phenomena, called outbursts, occurring in binary stars where either a black hole or a neutron star is accreting — swallowing, capturing — matter from a companion star. Also isolated extremely magnetic neutron stars called magnetars experiencing dramatic outbursts will be detected by the WFM. All these cosmic phenomena feature extremely fast temporal variability. Once detected and localised by the WFM, the eXTP satellite will repoint to the particular source in the sky, so that the LAD, SFA and PFA, that have a narrower Field of View but an excellent spectral and timing accuracy, will be able to take long exposures of such sources. Information about strong gravity in the vicinity of black holes, high density in the interior of neutron stars and huge magnetic fields in neutron stars will be obtained, as never before, thanks to the combination of the LAD, SFA and PFA instruments of eXTP.

The other European countries participating in the eXTP instrumentation development in addition to Spain (WFM PI) are Italy (LAD PI), Germany, France, Netherlands, Denmark, Poland, Czech Republic, and Switzerland. ESA is giving advice and is expected to provide funding through a MoO (Mission of Opportunity).

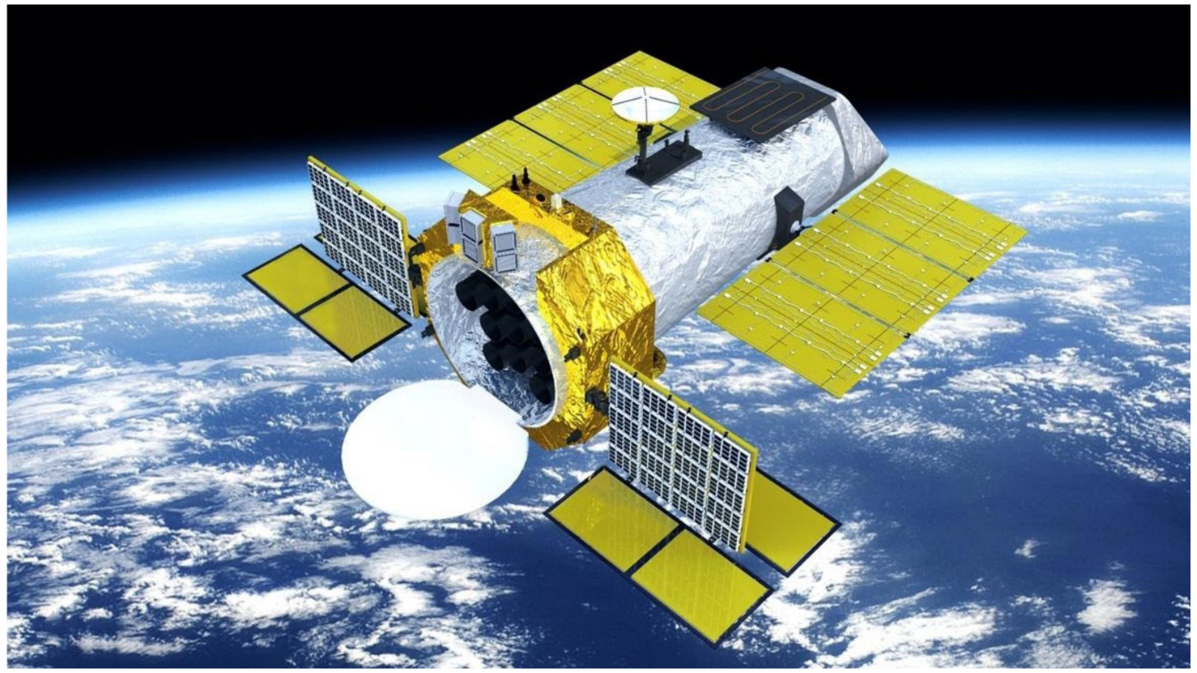

Figure 31: Artist impression of the eXTP satellite. Credit: eXTP website.

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Highlights

Gaia16aye: A microlensing event of a binary system

A 500-day global observation campaign spearheaded more than three years ago by the ESA's galaxy-mapping project Gaia has provided unprecedented insights into the binary system of stars that caused an unusual brightening of an even more distant star.

While ESA's mission Gaia scans the sky multiple times, it provides near-real-time photometric data, which can be used to detect unexpected changes in the brightness or appearance of new objects from all over the sky. This is dealt with by the Gaia Science Alerts system, which processes daily portions of the spacecraft data and produces alerts on potentially interesting transients.

The main purpose of the publication of the alerts from Gaia is to enable the astronomical community to study the unexpected and temporary events. Photometric follow-up is necessary in particular in the case of microlensing events in order to fill the gaps between Gaia observations and subsequently construct a densely sampled light curve, sensitive to short-lived anomalies and deviations to the standard microlensing evolution.

Gaia16aye was found during the regular examination of the photometric data collected by the Gaia mission. Gaia16aye was identified as an alert on 5 August 2016, processed by the Gaia Science Alerts pipeline (AlertPipe), and published on Gaia Science Alerts. The alert was triggered by a significant change in brightness (reaching G=14.27 mag) of an otherwise constant-brightness star with G = 15.51 mag. Gaia16aye (l=65°, b=3.8°) is located well in the northern part of the Galactic Plane towards the Cygnus constellation.

The follow-up observations started immediately after the announcement of the alert. In total, more than 25,000 photometric and more than 20 spectroscopic observations were taken over the period of about two years from more than 50 observatories. One of the telescopes used in this follow-up programme was the Joan Oró Telescope (TJO), located at Sant Esteve de la Sarga (Lleida, Spain), contributing with about 2,000 observations, representing the 9% of the observations obtained by all the collaboration.

The data showed a curious evolution in its light curve exhibiting five distinct brightening episodes, reaching up to I = 12 mag, compatible with a microlensing event due to a binary system. Using a full Keplerian binary orbit microlensing model combined with the motion of Earth and Gaia around the Sun fitting the photometric data, the set of orbital parameters of the binary lensing system could be determined. Using this approach, the lensing system was found to be composed of two main-sequence stars with masses 0.57 and 0.36 solar masses located at 780 pc, with an orbital period of 2.88 years and an eccentricity of 0.30.

Events such as Gaia16aye indicate the potential for the microlensing method of probing the mass function of dark objects, including black holes, in directions other than that of the Galactic bulge. This case also emphasises the importance of long-term time-domain coordinated observations that can be made with a network of heterogeneous telescopes. The TJO has contributed to this programme since 2015 and is currently the third observatory in the collaboration with more observations submitted (more than 18,000) and has observed more than 70 Gaia alerts.

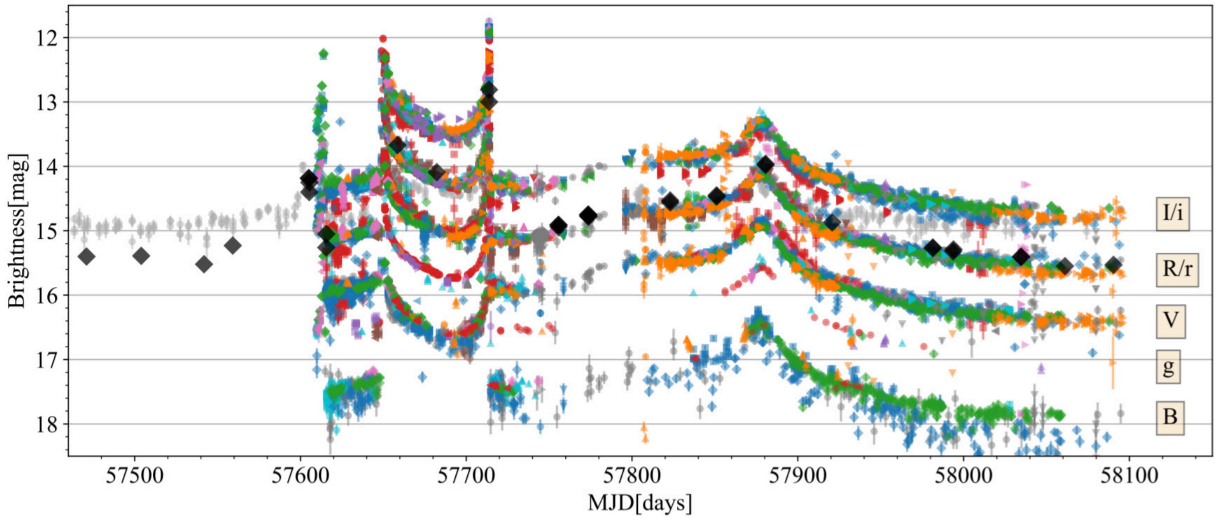

Figure 32: Gaia16aye light curve extracted from Wyrzykowski et al (2020). Gaia satellite observations (black diamonds) are not able to densely study this light curve and ground-based observations are needed from different observatories (in colour) and with different photometric passbands (see labels at the right side) to study this event. Data points obtained from TJO observatory are marked as green diamonds.

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Highlights

Solar Orbiter, a mission with IEEC contribution

A team from IEEC at ICCUB has worked on one of the ten instruments that the satellite will carry on board.

On 10 February 2020, the Solar Orbiter probe was launched from Cape Canaveral (Florida). The objective of the mission is the study of the Sun in detail thanks to a suite of scientific instruments and an ideal orbit around it. The probe will approach the Sun up to a distance of 42 million kilometres, meaning that the isolated parts of the probe will be exposed to temperatures over 500°C, while the parts remaining in the shadow will be at around -180 °C. During this mission, the orbit will increase its inclination towards the ecliptic up to 30 degrees, which will make it possible for researchers to obtain high resolution images of the solar poles.

IEEC researchers at ICCUB have contributed to two instruments: the Energetic Particle Detector (EPD) and the Polarimetric and Helioseismic Imager (PHI). The instruments have passed the commissioning phase, providing unprecedented data. SO/PHI will provide high precision measures of the magnetic field of the solar photosphere.

On one hand, researchers from the Heliospheric Physics and Space Weather Group (HPSWG) at ICCUB provided scientific support to the team of the EPD instrument. The members of HPSWG, experts in data analysis and modelling of solar particles, developed models to predict the environment of particle radiation Solar Orbiter will find and are working on tools to facilitate the analysis of the particles it will detect.

On the other hand, other researchers at IEEC-ICCUB team took care of the development and implementation of an Image Stabilization System (ISS) of the PHI instrument, which will enable the balance of the probe movements to acquire images of high quality. Solar Orbiter is the most complete solar mission from an instrumental point of view. The probe has ten instruments weighing a total of 209 kilograms. This weight limitation has arisen as a challenge when designing the PHI instrument, which has a mass of about 30 kg. Four of these instruments, which allow the detection of the solar wind (plasma and magnetic field), radiation and emitted particles, work in situ, while the other six do it remotely and allow imaging at different wavelengths and spectroscopy of the solar photosphere and the corona.

Figure 33: The United Launch Alliance Atlas V rocket, carrying the Solar Orbiter, lifts off Space Launch Complex 41 at Cape Canaveral Air Force Station in Florida, on 9 February 2020.

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Highlights

A highly detailed shape model of asteroid (2) Pallas from VLT adaptive optics observations

For the first time, resolved images revealing the surface of large asteroids have been obtained. This incredible achievement was possible by using the Very Large Telescope (VLT) and the Spectro-Polarimetric High-contrast Exoplanet REsearch (SPHERE) instrument.

Studying the surface of asteroids has been possible only with the help of dedicated (and expensive) space missions. An international team of astronomers has obtained resolved images of the larger asteroids, revealing not only their contour but also their surface details. Results have been presented in the journal Nature Astronomy for one of the largest objects in the Solar System, the asteroid (2) Pallas.

The team, led by principal investigator Pierre Vernazza from the Laboratoire d'Astrophysique de Marseille in France, obtained images of Pallas using the SPHERE instrument at the European Southern Observatory's Very Large Telescope (VLT), an array of four telescopes, each with an 8-meter-wide mirror, situated in the mountains of Chile.

The team obtained 11 series of images over two observing runs, catching Pallas from different angles as it rotated. After compiling the images, the researchers generated a 3D reconstruction of the shape of the asteroid, along with a crater map of its poles, and parts of its equatorial region.

The ICCUB researcher Toni Santana-Ros coordinated the photometric follow-up of Pallas during the project's first year. The team processed the light-curve data, which was then used by another group to build a 3D model of the asteroid. Combining both adaptive optics and the 3D shape model provides information about certain areas of the object that might remain non-visible in the optical images. Furthermore, using the model together with the images allows making an enlargement of the object, and then we can measure certain aspects such as its radius or density. For instance, we have obtained an accurate value for Pallas' density, which was still under debate.

In all, the research identified 36 craters larger than 30 kilometers in diameter — about one-fifth the diameter of Earth's Chicxulub crater, the original impact of which likely killed off the dinosaurs 65 million years ago —. Pallas' craters appear to cover at least 10 percent of the asteroid's surface, which is "suggestive of a violent collisional history," as the researchers state in their paper.

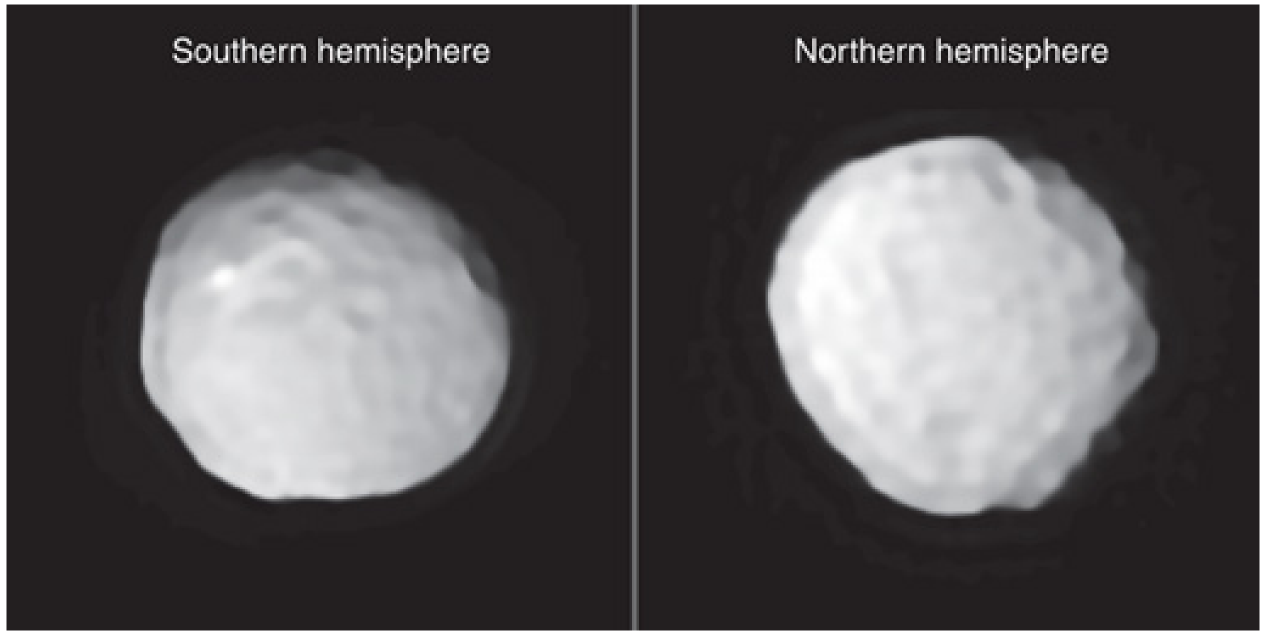

Figure 34: The two hemispheres of (2) Pallas as seen by VLT/SPHERE Images taken on 28 October 2017 ut (southern hemisphere) and 15 March 2019 ut (northern hemisphere).

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Highlights

First release of the PAZ polarimetric radio occultation data for precipitation characterization

The experiment, led by IEEC researchers, released the first set of polarimetric navigation radio occultation data in April 2020. These signals have the unique combined sensitivity to thermodynamic and precipitation parameters.

A team of researchers at ICE first released the data obtained by the experiment with GPS signals on board the Spanish Earth observation satellite PAZ on 22 April 2020. These data sets are the only GPS signals acquired at two polarizations from a spaceborne satellite, a new technique called Polarimetric Radio Occultations (PRO). The researchers had previously confirmed that the recorded polarimetric signals are sensitive to heavy rainfall and other hydrometeors, a hypothesis tested in the GPS experiment aboard PAZ.

The Radio Occultation is a technique to observe the atmosphere of a planet using two elements: one that transmits radio or microwave signals (in this case, the GPS satellites) and another element that receives them (here, a device installed aboard the PAZ satellite). The peculiarity of this technique is that, if the transistor and receiver elements are joined in a straight line, it crosses the Earth, i.e. the elements are hidden by the Earth. However, the signal continues to be received because the GPS beam bends. This bending of the rays can be measured and related to the vertical structure of the atmosphere. As a result, vertical profiles of temperature, pressure and moist are typically inferred from GPS radio occultation data.

The novelty of the Radio Occultation and Heavy Precipitation experiment aboard PAZ (ROHP-PAZ), launched in February 2018 and activated in May 2018, is its capability to quantify the effects suffered by the signals induced by large rain droplets (intense rain) and frozen particles (cloud ice, snow, graupel…). These features are captured through the vertical and horizontal components of the GPS signal, the so-called 'polarimetric observations', measured for the first time from space. The other spaceborne sensors measuring rain and cloud ice look at the rainy scenarios from above, in the form of vertical 'slices', while the PRO technique provides horizontal 'slices' of the precipitation at reasonable vertical intervals, a side-look that complements the rest of measurements. The experiment is also the only one able to jointly sense precipitation and its thermodynamic properties, important pieces of information to understand the conditions underlying intense precipitation.

After a process of accurate data calibration, the set was made publicly available and it is regularly expanded as the PAZ satellite continues its data acquisition, at a rate of approximately 200 new vertical profiles per day. The data are accessible through the ROHP-PAZ website, which also contains outreach information.

The ROHP-PAZ experiment is an experiment funded by the Spanish Ministry of Science and Innovation, and led by ICE. In addition to NASA JPL, the experiment is possible through collaborations with the PAZ satellite owner, operator and exploiter, Hisdesat, the National Oceanic and Atmospheric Administration (NOAA) and the University Corporation for Atmospheric Research (UCAR).

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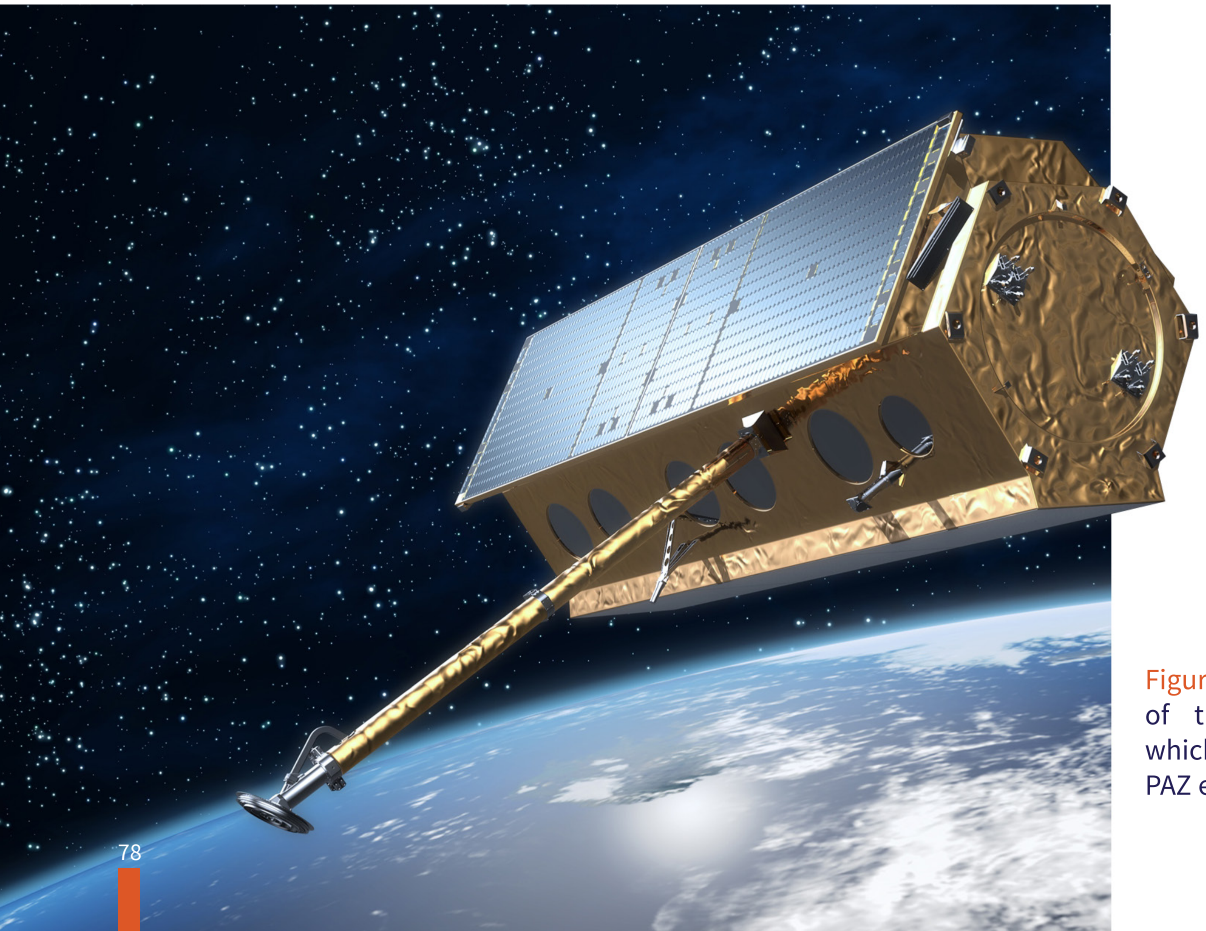

Figure 35: Artistic view of the PAZ satellite, which hosts the ROHP-PAZ experiment. Credit: Hisdesat.

Highlights

BepiColombo's Earth fly-by monitored with the Telescopi Joan Oró (TJO)

Optical observations of the BepiColombo spacecraft during its fly-by with the Earth allowed the scientist to validate the methods used to monitor hazardous Near-Earth Objects (NEOs). The TJO participated in an international campaign aiming to measure the fast fly-by of BepiColombo on 10 April 2020.

BepiColombo is a spacecraft which resulted from the collaboration between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). This probe is currently on its way to Mercury, where it will arrive on 5 December 2025 after a series of complicated flybys with the inner planets. One of these flybys was planned with the Earth, occurring on 10 April 2020.

ESA's Planetary Defence Office (PDO) has, as a main mission, the evaluation and monitoring of Near-Earth Objects (NEOs) which can become a hazard for our planet. With this purpose, the PDO has access to a worldwide network of mid-size telescopes located in five different continents. These telescopes are regularly used to monitor asteroids which might represent a hazard for the Earth due to their non-zero impact probability. One of the telescopes of this network is the Joan Oró Telescope (TJO) owned by IEEC.

The fly-by of BepiColombo represented an unique opportunity to observe an object which orbit is actively monitored by radio, but at the same time, has a very similar characteristics of a NEO having an encounter with the Earth. By comparing the optical observations with the ground-truth provided by the probe's telemetry, the scientists could validate the methods commonly used to monitor dangerous NEOs.

For this reason, the PDO organized an international campaign in order to follow BepiColombo's Earth fly-by with optical telescopes. Images of this event were gathered with telescopes located in Chile, Australia and the Catalan TJO. Although the spacecraft was very bright during its encounter with the Earth (~8 magnitude), it still was a very challenging target due to its high angular speed (2 deg/min), much faster than typically observed NEOs.

Despite the difficulties, the TJO managed to gather a set of 98 images which, together with the other data sets, allowed the PDO team to reconstruct the orbit of BepiColombo with an amazing high accuracy: the fly-by distance and the time of closest approach were calculated with an agreement better than 1σ compared to telemetry.

This excellent agreement allowed the team to validate their methods and confirms that NEO orbits determined with purely optical measurements are extremely reliable, at sub-kilometer and sub-second levels.

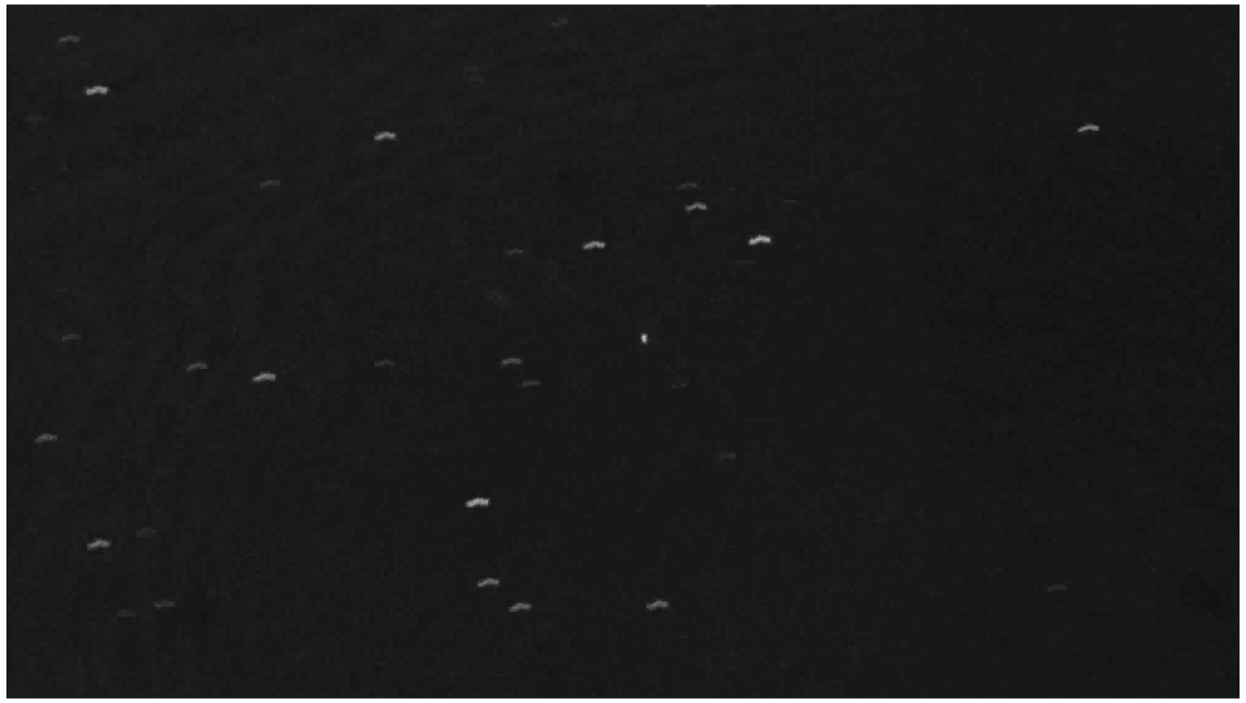

Figure 36: One of the frames obtained with the Joan Oró Telescope (TJO) on 10 April 2020 during the fly-by of BepiColombo's spacecraft (roundish-like body in the center of the image).

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Highlights

Youngest baby pulsar ever found could help understand the most powerful explosions in the Universe

The pulsar is located 15,000 light years away and it contains remnants of an ancient massive star. It is also a magnetar, with a magnetic field a thousand billion times stronger than that of the Earth.

Pulsars are some of the most exotic objects in the Universe. They form as massive stars end their lives via powerful supernova explosions and leave extreme stellar remnants behind: hot, dense and highly magnetised. Sometimes pulsars also undergo periods of greatly enhanced activity, in which they throw off enormous amounts of energetic radiation on timescales from milliseconds to years.

Smaller bursts often mark the onset of a more enhanced 'outburst', when X-ray emission can become a thousand times more intense. A multi-instrument campaign with the ESA XMM-Newton, NASA NuSTAR and Swift has now captured such an outburst emanating from the youngest baby pulsar ever spotted: Swift J1818.0−1607.

Not only is this pulsar the youngest of the 3000 known in our Milky Way galaxy, but it also belongs to a very rare category of pulsars: magnetars, the cosmic objects with the strongest magnetic fields ever measured in the Universe. It lies around 15,000 light-years away, within the Milky Way and it is only 240 years young. People on Earth would have been able to see the supernova explosion that formed this baby magnetar, right when Beethoven was writing his masterpieces.

This magnetar is also of the fastest-spinning such objects known, whirling around once every 1.36 seconds — despite containing the mass of two Suns within a stellar remnant measuring just 25 kilometres across —. To infer this magnetar's age, high-resolution long-term measurements of both the rate at which it is spinning and of how this spin is changing over time were crucial.

While interesting in their own right, magnetars are relevant on a far wider scale: they might play a key role in driving a whole host of transient events we see in the Universe. These events are thought to be somehow connected to magnetars either during their birth, or in the very early stages of their lives, making this discovery especially exciting. Examples of transient events include gamma-ray bursts, super-luminous supernova explosions, and the mysterious fast radio bursts. These energetic events are potentially linked to the formation and existence of young, strongly magnetised objects, like Swift J1818.0−1607.

This kind of research is hugely important in understanding more about the stellar content of the Milky Way, and revealing the intricacies of phenomena occurring throughout the wider Universe.

The massive observational campaign that led to the discovery of this young pulsar was carried out by members of IEEC at ICE, published in the Astrophysical Journal Letters, and led to several Press Releases from NASA and ESA.

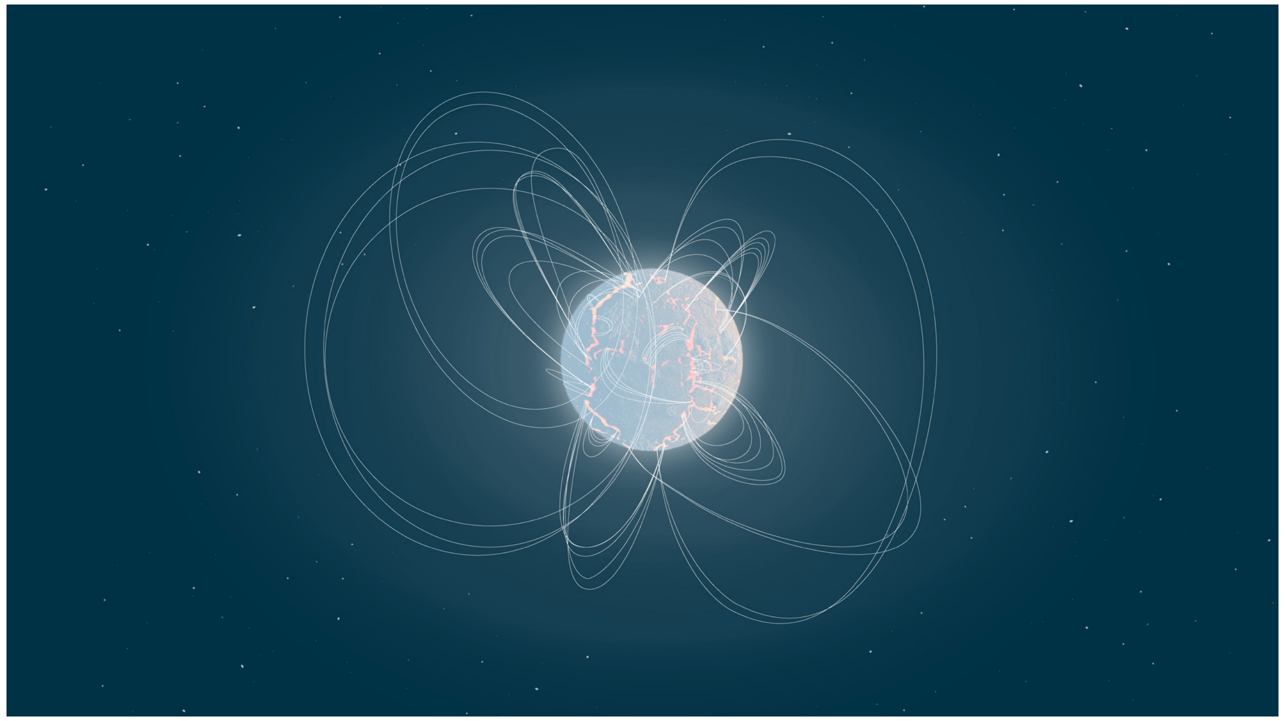

Figure 37: Magnetars are the cosmic objects with the strongest magnetic fields ever measured in the Universe. They are extremely magnetised pulsars — the hot and dense remnants of massive stars that throw off energetic radiation that appears to pulse on timescales from milliseconds to years —.

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Highlights

More Exotic planetary systems in the Solar neighborhood: the nearest compact multiplanet system, and the nearest exoplanet in a young star

A compact multiplanet system with two or more super-Earth was found around the 10th nearest star system to the Sun, the star Gliese 887, which is also the brighter M-dwarf as seen from Earth. Moreover, NASA's TESS and Spitzer Missions, with the contribution from an IEEC researcher, reported the discovery of a planet around a nearby star

The systematic exploration of the immediate Solar System neighbours has been bringing additional exciting discoveries. Among them is the planetary system reported in 'Science' journal around GJ 887, a red dwarf star at only 3 parsecs from us (about 7 light years) which puts it as the 10th nearest star system to the Solar system. The planetary system is composed by, at least, two super-Earth mass planets in warm orbits, but there is tantalizing evidence for more. Since it is very nearby, and the star is relatively bright and quiet, it may be possible to characterize this planetary system with NASA's James Webb Space Telescope (scheduled to be launched by 2021).

This discovery was possible thanks to the Red Dots collaboration, co-lead by IEEC's researcher Guillem Anglada-Escudé and the participation of several other scientists from IEEC at ICE.

During the same period, the same researchers scored another high impact result in the journal Nature, reporting the nearest exoplanet orbiting a young star (the well-known star AU Microscopii, or AU Mic). The star system is quite young (about 25 Million years, compared to the 4.8 Billion years of the Sun), which indicates that the planet is still in its final phases of formation. The fact that it is transiting, enables future characterization studies of its atmosphere, which are unique keys to the same processes of planet formation that build our solar system.

This discovery was made possible thanks to the NASA TESS space photometry mission combined with a decade-long ground-based spectroscopic monitoring of the star. As this is an important and picturesque system — the star is very active, and has vast debris disks signposts of an incipient planetary system — NASA issued a special feature poster on this star.

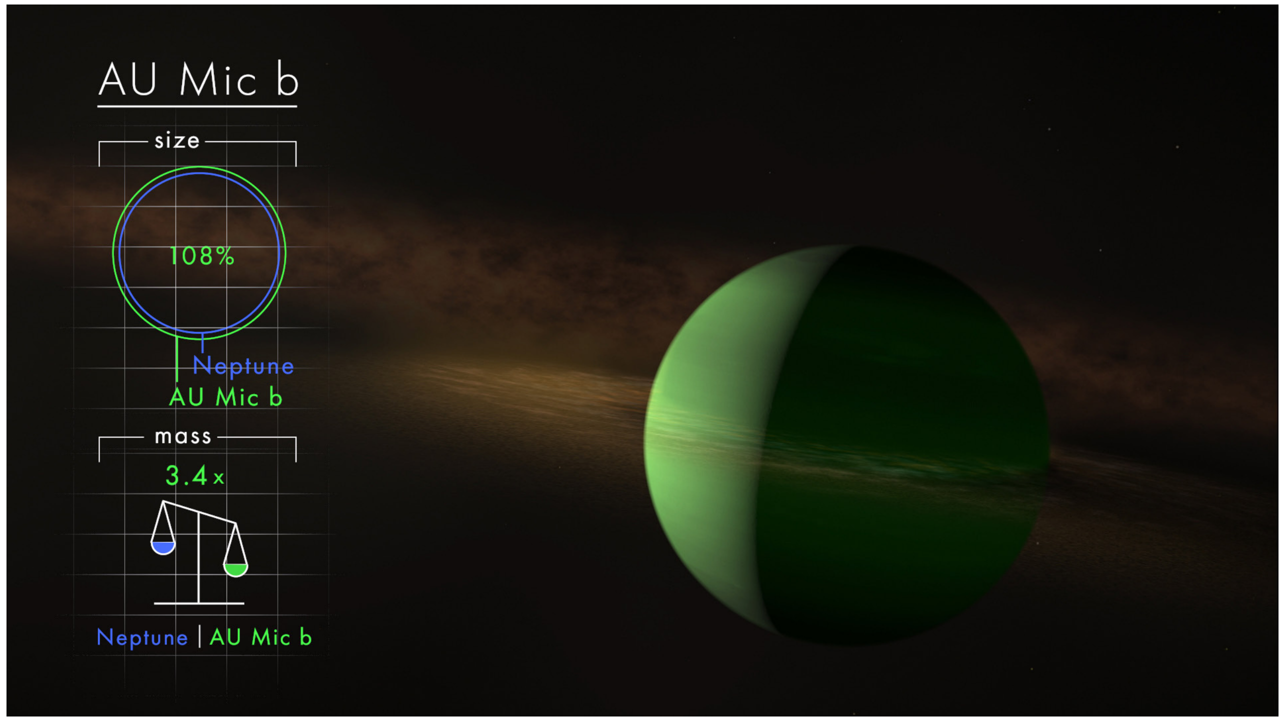

Figure 38: Illustration of the size of AU Mic b. Credit: NASA's Goddard Space Flight Center/Chris Smith (USRA).

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Highlights

Euclid space telescope's Near-Infrared instrument ready to draw a 3-D map of galaxies of the distant Universe

The Euclid satellite is now being assembled, integrated and tested once the instruments have been delivered by the Euclid Consortium. The launch date expected for 2022 is getting closer.

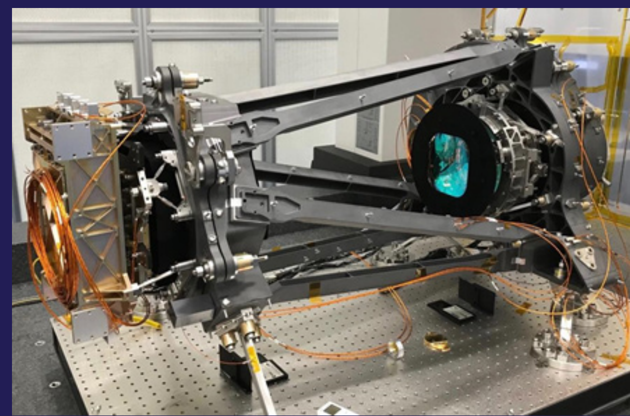
Euclid is an ESA medium that aims at understanding why the expansion of the Universe is accelerating and what is the nature of the source responsible for this acceleration that physicists refer to as dark energy. Dark energy represents around 70 % of the energy content of the Universe today, and together with dark matter it dominates the Universe matter-energy content. Both are mysterious and of unknown nature but control the past, present and future evolution of the Universe.

Euclid consists of a 1.2 m telescope that mounts two instruments: a visible imager (VIS) to take wide field sharp images and a near-infrared spectrophotometer (NISP) that can image and take slitless spectroscopy in the near-infrared. Both instruments have been constructed by the Euclid Consortium and delivered during 2020.

Now that the instruments have been delivered to ESA, Thales Alenia Space and Airbus Defence and Space, they will be integrated first with the telescope and then with the rest of the payload module and the satellite, which will take several months to ensure that everything is precisely aligned and the electronics work properly.

It has been a long journey to get this far. Euclid was selected for implementation in 2011, after undergoing nearly five years of studies. While there is still a lot of hard work and testing ahead, the delivery of the instruments and telescope means that the spacecraft is really starting to come together and ready for its launch planned for September 2022.

Figure 39: NISP (cold part) before thermal Multi Layer installation. The NISP detector system with its 16 near-infrared detectors is on the left. The filter and grism wheels are inside the box on the far right in front of the optical assembly.



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Highlights

The SDSS-eBOSS collaboration releases the largest 3D map of the Universe

The eBOSS collaboration has reconstructed the expansion history of the Universe over the last 11,000 million years, providing clues to understand the nature of Dark Energy, the geometry of the Universe and its expansion rate today.

In July 2020, researchers from the Sloan Digital Sky Survey collaboration (SDSS) released the final results of the extended Baryon Oscillation Spectroscopic Survey (eBOSS): a 3-dimensional map with positions of nearby bright galaxies, luminous red galaxies, emission line galaxies, quasars and neutral hydrogen clouds from redshift 0.15 up to 3.5. In total, 2.5 million of objects have been mapped and their spectra measured with an unprecedented precision. Such high-quality spectra has allowed the precise determination of their radial velocity and distance.

One of the key science goals of eBOSS has been the measurement of the Baryon Acoustic Oscillations (BAO) signal in spectroscopic galaxy samples covering a wide range of epochs.

The BAO are pressure waves travelling in the photon-baryon plasma during the early epochs of the Universe. These waves are frozen at a very specific moment, when the temperature of the Universe drops below a certain threshold and the photon-baryon medium disappears. This process sets a characteristic distance-pattern given by the velocity and time that such waves have been travelling through the plasma. This distance is known as the sound horizon scale and represents one of the most robust standard rulers in cosmology today. The sound horizon scale feature gets imprinted in the matter distribution — through the density of baryons — as well as in the latter distribution of galaxies formed on the peaks of baryon density regions. This feature imprints a peak-signature in the correlation function of galaxies at the sound horizon scale separation in comoving distance. Measuring the BAO peak in the correlation function of the galaxy samples at different epochs (see right panels of Fig. 40), has provided eBOSS researchers a ruler to calibrate the distance measurements to these samples and allowed us to understand how the Universe has been expanding along these epochs.

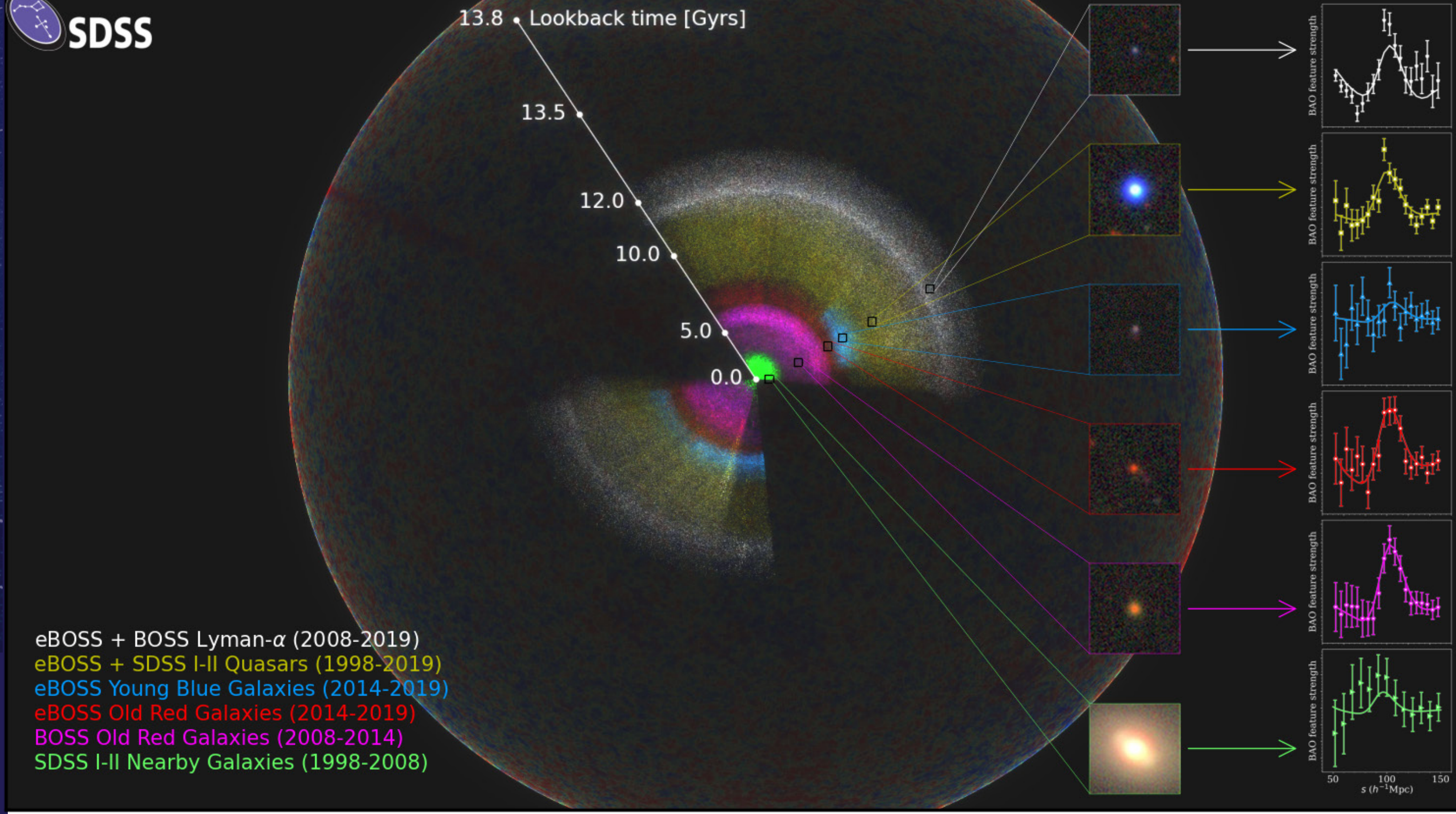

Figure 40: The SDSS map is shown as a rainbow of colors, located within the observable Universe. We are located at the center of this map. The inset for each color-coded section of the map includes an image of a typical galaxy or quasar from that section, and also the BAO signal of the pattern that the eBOSS team measures there. Credit: Anand Raichoor (EPFL), Ashley Ross (Ohio State University) and SDSS.

The results presented by the eBOSS collaboration certify that the expansion of the Universe has been accelerating over the last 6,000 million years, and confirms by its own the presence of Dark Energy at 8-sigma significance. When the eBOSS results are combined with other datasets, such the analysis of the Cosmic Microwave Background anisotropies by the Planck satellite, we find that the preferred model is a flat-Lambda Cold Dark Matter, with 69 % of Dark Energy, 26 % of Dark Matter and 5 % of baryonic matter.

The eBOSS results have also contributed to the recent debate about the expansion rate of the Universe today, the Hubble constant, H0. The BAO technique cannot determine H0 on its own, as it needs an absolute determination of the sound horizon scale. Such value can be inferred using abundances of primordial elements, such as hydrogen and helium. With such calibration, eBOSS determines that H0 =67.3 ± 1.9 km/s/Mpc (at 2-sigma confidence level). Such value is highly consistent with CMB measurements by Planck, H0 =67.4 ± 1.0 km/s/Mpc, and in high tension with direct measurements based on nearby galaxies by the SH0ES collaboration, 74.0 ± 2.8 km/s/Mpc.

In the forthcoming years, new instruments such as the space satellite EUCLID and DESI (Dark Energy Spectroscopic Instrument) will deliver larger 3D galaxy catalogues, observing one order of magnitude more objects than SDSS. These maps will allow more precise determination of the properties of Dark Matter and Dark Energy.

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Highlights

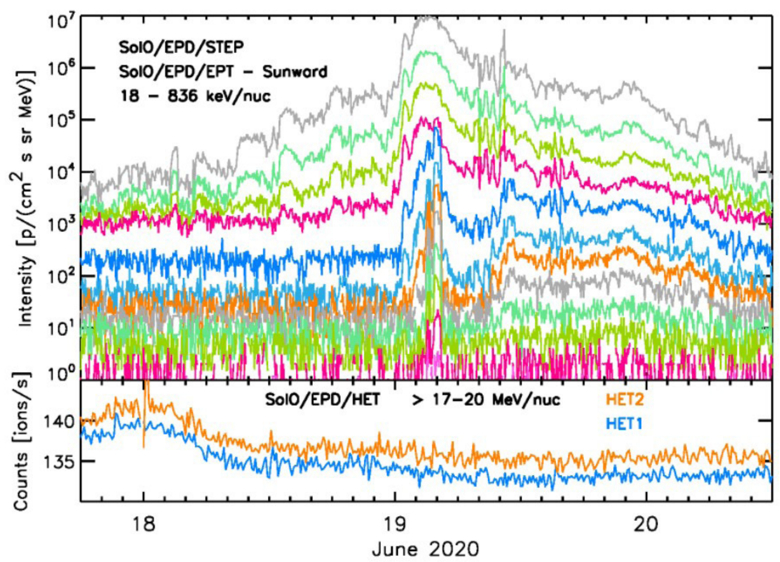
First data and magnetic field images of the Sun, obtained by instruments co-developed by IEEC for Solar Orbiter team

The first public release of Solar Orbiter data was done at the end of September 2020 and, since then, charged particle measurements, solar wind plasma and magnetic field in-situ data as well as extreme ultraviolet and radio remote-sensing data have been published.

The combination and the high-quality data of the various instruments of Solar Orbiter is providing detailed information from the inner regions of our solar system. The current solar activity cycle is expected to peak in July 2025 and, hence, significant solar eruptive phenomena will occur more often allowing us to gain insights on the physics at the basis of space weather. In the meantime, the relative quietness of the Sun has allowed the study small solar and interplanetary driven events. These events give us a huge opportunity to deepen in the understanding of charged particle acceleration mechanisms thanks to the combination of the in-situ and remote sensing observations.

First results were presented last December 2020 at the annual American Geophysical Union Fall Meeting (AGUFM). Several studies have been already performed and published as letters to the Editor in Astronomy & Astrophysics and others are under development. As an example of the latter, it was presented at AGUFM the study of a low-energy ion event (shown on top of Figure XX) observed by Solar Orbiter after its first perihelion, when the spacecraft was located at half the distance of the Earth from the Sun, and about 60 degrees eastward from the Earth and at a similar latitude. The use of data from the different instruments suggests an interplanetary origin for the detected low-energy particles.

On the other hand, the Polarimetric and Helioseismic Imager (SolO/PHI) instrument also provided its firsts magnetograms (shown on bottom of Figure 41) and Line of Sight velocity images. The images on the lower side make use of the Image Stabilization System (ISS) developed by IEEC-UB members. The ISS makes use of the granules (orange patterns) shown in the lower center figure to track the evolution of the Sun and compensate for the platform jitter. The top row of the accompanying image shows an image of the Sun with the SolO/PHI whole disk telescope at the centre. The image on the left shows a solar magnetic field map where the green and brown colors represent the two polarities (North and South) of the magnetic field. The velocity map obtained with the same telescope is shown on the right, where red areas indicate downward movements, while blue areas indicate ascending solar plasma. On the bottom row we can see a detail (i) of the solar surface taken with the SolO/PHI high-resolution telescope (centre); (ii) of the solar magnetic field with the high-resolution telescope (left) and finally, (ii) of the velocity map of the solar surface with the same telescope (right).



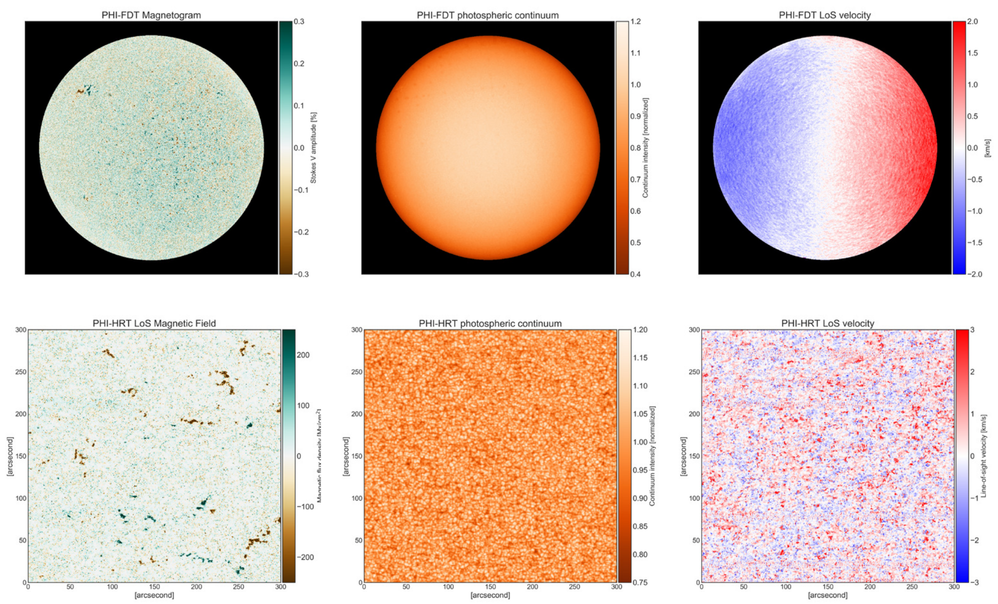


Figure 41: Top: 18-20 June 2020 particle event: low-energy ion (top panel) and high-energy ion (bottom panel) particle measurements from different detectors of the Energetic Particle Detector suite of Solar Orbiter. Credit: A. Aran (ICCUB, IEEC). Bottom: Examples of the images taken by the PHI instrument during the commissioning phase. Credit: SOLAR ORBITER/PH/ESA/NASA.

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Highlights

Hidden AGN in dwarf galaxies revealed by MaNGA: light echoes, off-nuclear wanderers, and a new broad-line AGN

Most active galactic nucleus (AGN) are suspected to feature supermassive black holes at their centers and to be found at the centre of massive galaxies. But, in the past decade, hundreds of AGN that harbor lower mass black holes have also been found in dwarf galaxies.

An active galactic nucleus (AGN) is a compact area at the centre of a galaxy that emits energy in its central region, usually generated by a massive black hole, among other elements. Previous studies of AGN in dwarf galaxies primarily relied upon single-fiber (3 arcsecond aperture) spectroscopic measurements taken at the galactic center (i.e. the Sloan Digital Sky Survey, SDSS). Prominent emission lines are identified in these spectra and their flux ratios plotted in a "Baldwin, Phillips & Terlevich" (BPT) diagram. Depending on a galaxy's location on a BPT diagram, the primary emission source for each galaxy is classified as star formation, AGN, Low-Ionization Nuclear Emission-Line Regions (LINERs; emission that can originate from AGN and hot old stars), or a composite of multiple ionization mechanisms. However, these single-fiber measurements are often biased towards central AGN and can fail at AGN identification if there is abundant star formation in the center of a galaxy. Moreover, strong host galaxy light can diminish AGN signatures.

Alternatively, spatially resolved spectroscopic measurements can provide more definitive evidence of AGN activity. In particular, integral field unit (IFU) spectroscopy can trace emission line features from varying physical regions of a galaxy (Figure 42).

The SDSS / Mapping Nearby Galaxies at APO (MaNGA) survey is a critical step forward in this direction. This survey will provide IFU data for nearly 10,000 galaxies, which will make it the largest such catalog. The ICE researchers Mar Mezcua and Helena Domínguez Sánchez leveraged MaNGA and conducted the largest dedicated study of dwarf galaxies that host AGN within the survey.

Of the 4,718 sources they investigate, the researchers categorized 1,609 sources as dwarf galaxies after imposing an upper mass cutoff of 3 billion solar masses. Subsequently, they examine a spectrum of each spatial pixel, or spaxel, for each dwarf galaxy to conduct a spatially resolved BPT analysis. As shown in Figure 42, the BPT diagram plots the [OIII]λ5007/Hα flux ratio against the [NII]λ6583/Hβ flux ratio. The location of each spaxel on the diagram determines the primary emission mechanism (i.e. star-forming, AGN, LINER, or composite) at each galactic position. To resolve the fact that LINERs are not exclusively linked to AGN activity, the authors utilize the WHAN diagram (which identifies sources with Hα equivalent widths < 3 Å, the traditional threshold for AGN detection) to further eliminate non-AGN from their sample. The final catalog that results from this step nets 37 dwarf galaxies that host an AGN within MaNGA.

Of the 37 dwarf galaxies which host AGN, the authors analyzed 35 with available SDSS single fiber spectra. They reported only 12 AGN of the 35 that were classified as such from the single fiber spectra; the IFU measurements thus reveal 23 additional AGN that were either labeled as star-forming, composite, or quiescent with the single fiber method — a true testament to the benefit of spatially resolved spectra.

So why did these single fiber measurements fail? It is likely that the missing AGN are either off-nuclear or currently inactive. Using the spatially resolved BPT diagrams, the authors analyze the non-central AGN spaxels and find diffuse, elongated, and generally symmetric emission. These characteristics are consistent with light echoes — the ghostly remnants of previously active AGN. Yet, they cannot rule out the possibility that these are signatures of active off-nuclear AGN. To resolve this confidently, the authors express their intention to conduct follow up observations with high-resolution radio and X-ray wavelengths using FIRST and Chandra.

Finally, the investigators computed the masses of the AGN black holes in their sample and initially determined 14 intermediate-mass black holes. The remaining black holes are deemed SMBHs. These results suggest that dwarf galaxies with AGN can host many types of black holes and that the fundamental nature of these galaxies requires further investigation.

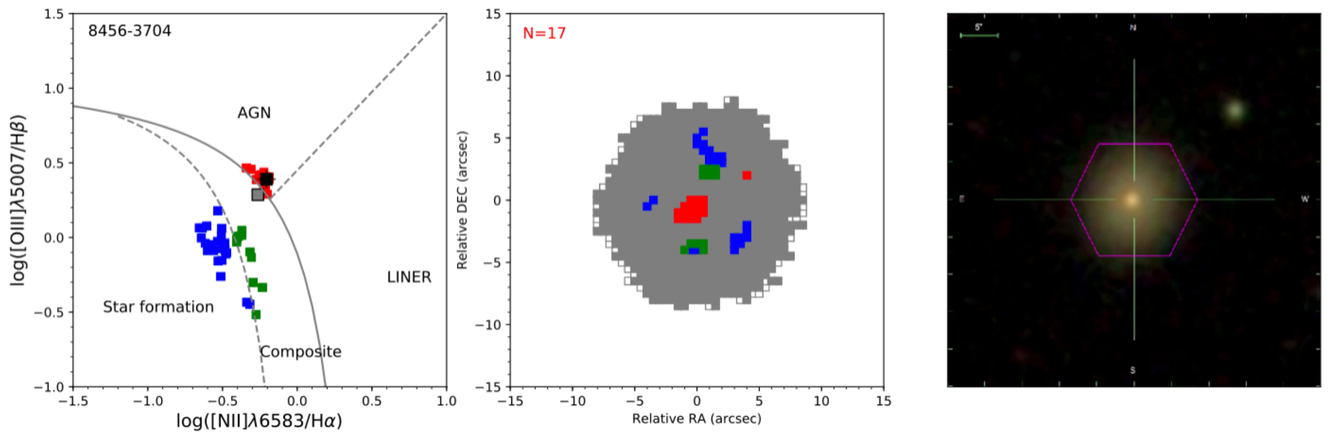

Figure 42: Left: BPT diagram showcasing emission line classifications (i.e. star-forming, AGN, LINER, or composite) for each spaxel for a sample dwarf galaxy (8456-3704). The black square represents the median BPT location of the spaxels that are classified as AGN/ LINER. The gray square marks the SDSS single fiber location. Middle: physical distribution of BPT spaxels. Empty squares trace the IFU coverage and gray squares indicate spaxels with a continuum signal-to-noise ratio greater than 1. Right: SDSS composite image. The pink hexagon shows the IFU coverage.

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Figure 43: Artistic view of SS 433 and the cosmic gas cloud. The microquasar SS 433 and its sway jet with helical structures are shown in the middle of the figure. In the foreground, the glowing of a molecular cloud represents the gamma-ray source revealed in this study. The concentric circles represent the gamma-ray heartbeat found, in synchrony with the SS 433 sway period. Credit: Konrad Rappaport, Susane Landis (Scicomlab for DESY), under advice by Jian Li (DESY), Diego F. Torres (ICREA/ICE, IEEC/CSIC).

Highlights

The heart of darkness: scientists detect a mysterious gamma-ray heartbeat coming from a cosmic gas cloud

An inconspicuous cloud in the constellation Aquila is beating with the rhythm of a nearby precessing black hole, indicating a connection between the two objects, as the research team reported in the journal Nature Astronomy.

A research team composed of international scientists from Germany, Spain, China and America and led by DESY scientist Jian Li and ICREA Professor Diego F. Torres from ICE, rigorously analysed more than ten years of data from NASA's Fermi space telescope, looking at a so-called microquasar. The system catalogued as SS 433 is located some 15,000 lightyears away and consists of a giant star with about 30 times the mass of our sun and a black hole with about 10 to 20 solar masses. The two objects are orbiting each other for a period of 13 days, while the black hole sucks matter from the giant star, generating jets.

The high-speed particles and the ultra-strong magnetic fields in the jet produce X-rays and gamma rays. The accretion disc does not lie exactly in the plane of the orbit of the two objects. It precesses, or sways, like a spinning top that has been set up slanted on a table. As a consequence, the two jets spiral into the surrounding space, rather than just forming a straight line. The precession of the black hole's jets has a period of about 162 days.

Meticulous analysis revealed one gamma-ray signal with the same period from a position located relatively far from the microquasar's jets. It is located at the position of a gas cloud. The found timing signal provides an unambiguous connection between the microquasar and the cloud, separated by about 100 light years. This is as amazing as is intriguing, opening questions regarding how the black hole powers the cloud's heartbeat thus far.

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Highlights

FSSCAT mission

Providing the first maps of Sea Ice Concentration and Thickness, and Soil Moisture using CubeSats.

On 3 September 2020 at 3:51 a.m. CEST (Central European Summer Time), the Vega SSMS rocket of the European Space Agency (ESA) launched two small satellites of the UPC NanoSat Lab into space from the European spaceport in Kourou, French Guiana. The two nanosatellites form the mission called 'FSSCat: Federated Satellite System 6U tandem mission for sea ice and soil moisture monitoring', which was the 2017 winner of ESA's "Sentinel Small Satellite (S^3) Challenge Award" and the "Copernicus Masters Competition".

The main goal of the mission is to monitor polar ice and soil moisture, while also testing communication systems between nanosatellites, in order to create a future network of federated satellites. The mission carries on board the PhiSat-1 project — the first in orbit system to experiment the use of artificial intelligence (AI) in space —, promoted by the ESA Phi-Lab. The project will detect the presence of clouds in the images created by the satellites and discard those that do not have good enough quality.

The increase in temperature at the North Pole has a major impact on the entire planet, both from an ecological and economical point of view. It is therefore of paramount importance to record and analyze the effects of climate change on the thickness of snow and layers of ice.

FSSCAT consists of two small CubeSat satellites, named ^{3}Cat-5/A and ^{3}Cat-5/B. ^{3}Cat-5/A carries onboard the FMPL-2 microwave radiometer/GNSS-reflectometer scientific payload, to measure the soil moisture — a crucial variable for agriculture, desertification studies or for calculating fire risk indices — as well as the sea ice concentration, extent and thickness in the polar regions, which are fundamental parameters for maritime navigation and for monitoring the evolution of climate change. ^{3}Cat-5/B carries an hyperspectral optical payload called Hyperscout-2 that captures and processes information in the visible, near-infrared and thermal infrared bands of the electromagnetic spectrum. High-resolution hyperspectral and thermal imaging can be used to estimate effects such as urban heat islands, detect oil spills, monitor fires or water quality and, combined with FMPL-2, to obtain higher-resolution land-surface moisture maps.

The reception of the data recorded by ^{3}Cat-5/A will be done twice a day by means of the monitoring station that UPC has at the Montsec Observatory (OAdM) managed by IEEC, in Sant Esteve de la Sarga (Lleida, Catalonia).

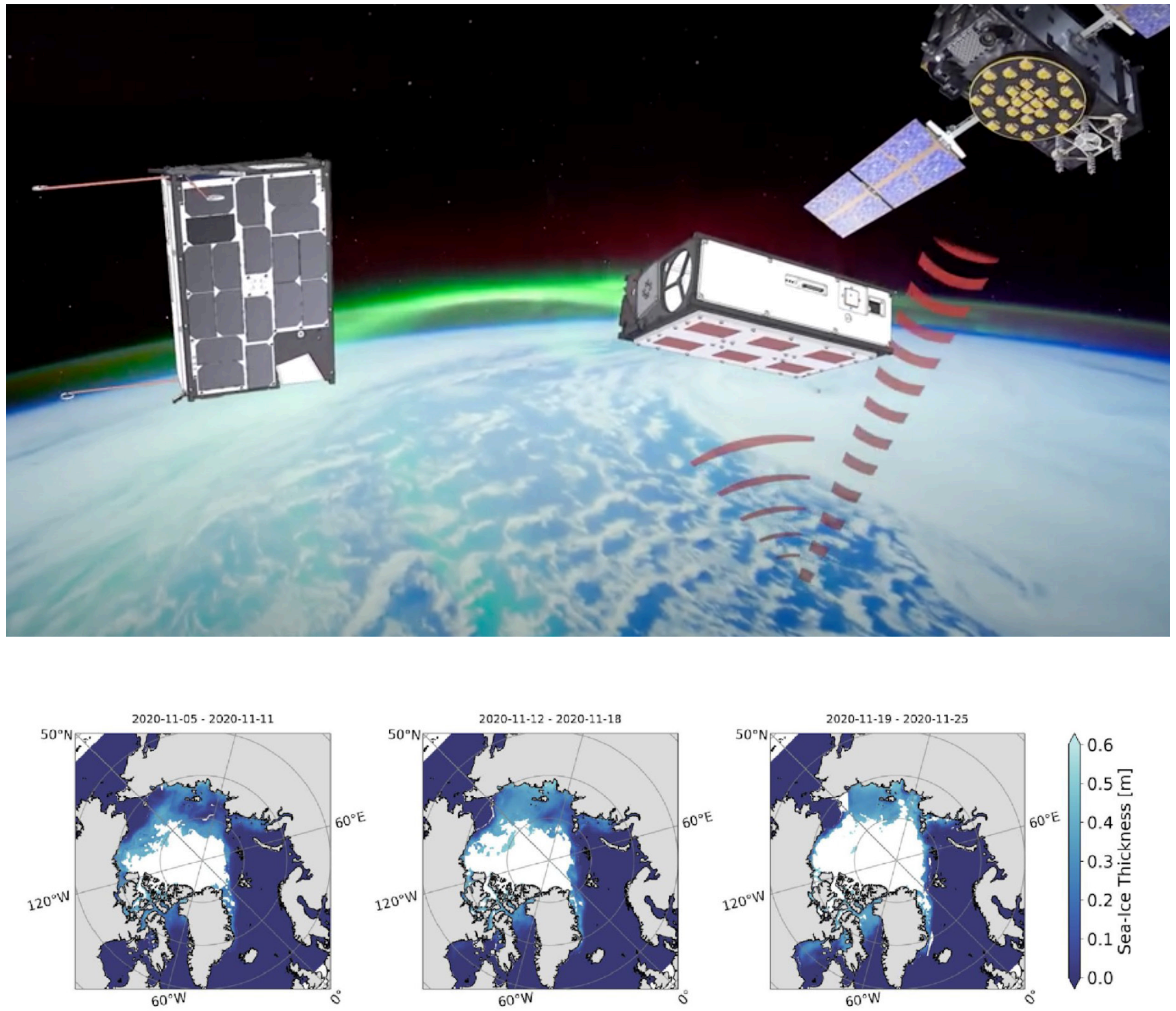

Figure 44: Artistic representation of the spatial view of FSSCAT taking measurements (upper panel) and the Sea Ice Thickness measured lower panel).

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Highlights

Proposal for the Einstein Telescope observatory: an infrastructure of the future

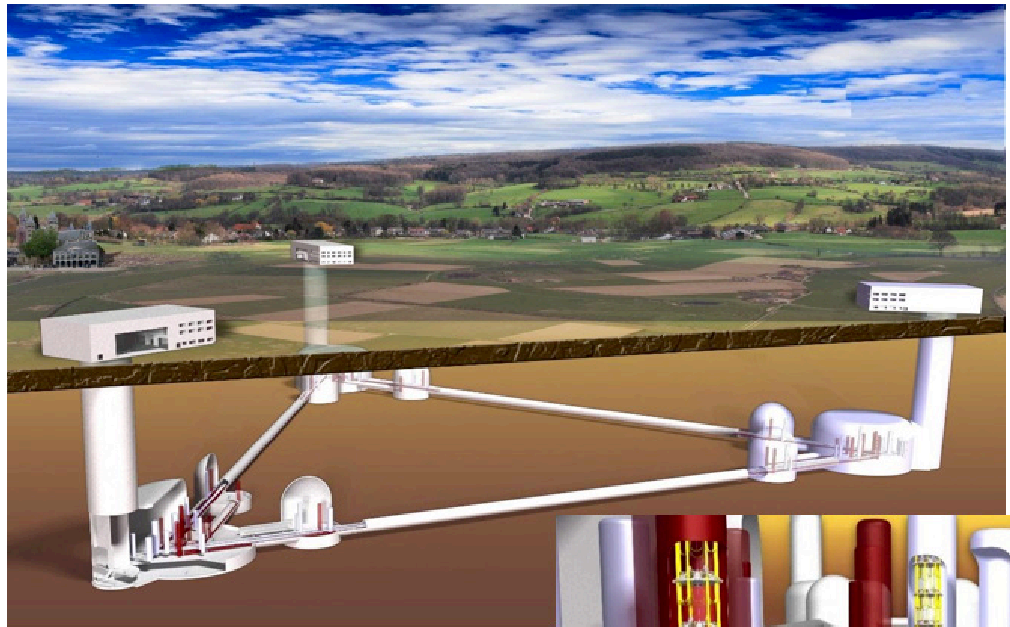
ET will be a third-generation underground observatory for Gravitational Waves. An international consortium has submitted its proposal to the ESFRI roadmap.

The outstanding scientific achievements of Advanced Virgo (in Europe) and Advanced LIGO (in the USA) during the last few years initiated the era of Gravitational Waves (GW) astronomy. The adventure began with the first direct GW detection in September 2015 and continued in August 2017 when both observatories detected GWs emitted by two merging neutron stars. Simultaneously, signals of this event were observed by a variety of telescopes –on Earth and in Space– over a wide range of the electromagnetic spectrum, marking the beginning of the era of multi-messenger astronomy.

Now, scientists and technology experts propose the creation of a new observatory capable of observing GWs with a sensitivity at least one order of magnitude better than the current second-generation detectors. The Einstein Telescope (ET) will be located in a new physical infrastructure and will apply technologies that are dramatically improved over the current ones. It will enable scientists to detect nearly any merge of two intermediate-mass black holes in the entire Universe, thus contributing to the understanding of its evolution. This will shed new light on the Dark Universe and will clarify the roles of dark energy and dark matter in the structure of the Cosmos. ET will explore the physics of black holes and will detect thousands of coalescences of neutron stars, improving our understanding of the behaviour of matter under such extreme conditions of density and pressure. We will also have a chance to explore the nuclear physics of supernovae.

ET is the most ambitious project for a future underground observatory for gravitational waves. The conceptual design of this pioneering third-generation observatory has been supported by a grant of the European Commission, and now an international consortium has officially submitted the proposal for the realisation of such an infrastructure in the 2021 update of the European Strategic Forum for Research Infrastructures (ESFRI) roadmap. The consortium is formed by 40 research institutions and universities all across Europe, led by Italy with the political support of The Netherlands, Belgium, Poland and Spain. Its transnational headquarters are currently established at the European Gravitational Observatory (EGO) in Italy.

ET has arisen great interest in the Spanish scientific community involved in GWs, which includes all the centres that currently participate in ground-based and space programs: LIGO, Virgo, KAGRA, IPTA and LISA. Spanish researchers have significantly contributed to the development of the ET physics program, as well as to the preparation of its technical design report. IEEC researchers participate in most of these GW programs. The ICCUB and ICE-CSIC are amongst the Spanish institutions that supported the ET ESFRI initiative.
Two sites are currently being evaluated for ET: The Euregio Meuse-Rhine, at the borders of Belgium, Germany and the Netherlands, and Sardinia, in Italy. A companion project in the US, Cosmic Explorer, is expected to follow. With a successful ESFRI proposal, the project will enter its preparatory phase, which foresees the beginning of construction in 2026 intending to start observations in 2035.



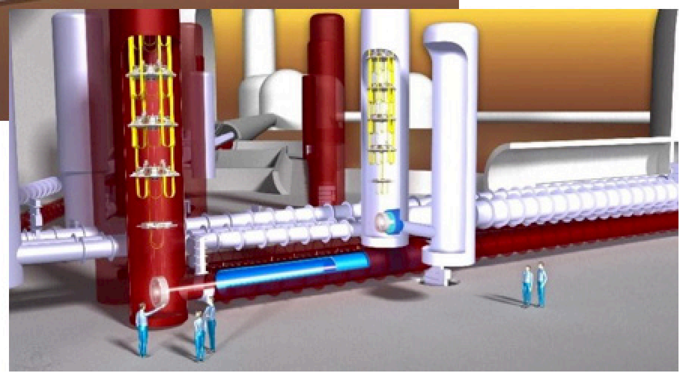


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Figure 45: Top: Artistic view of the ET observatory. Bottom: A closer view of the suspension system. Credit: The Einstein Telescope.

Highlights

The Nüwa concept: a sustainable city on Mars

A team led by IEEC researchers provides the keys to a future city for a million inhabitants on the red planet

Nüwa is the result of a concept study on what a city of one million inhabitants on Mars would look like. Moving beyond the classic engineering exercise of building a planetary settlement and supplying it from Earth, Nüwa's design explores ways to sustain itself and its own growth using in situ resources in a sustainable way. The project was presented in the Mars City State Design competition (Mars Society) and was selected by an international jury among the 10 finalists from over 175 submitted proposals.

Nüwa's design project was developed by SONet (the Sustainable Off-world Network), which is a community of international professionals and researchers interested in multidisciplinary approaches to sustainable exploration of space. The project was led by researchers from IEEC, belonging to ICE and the UPC. The architectural & urban planning design was led by the ABIBOO studio. Participants from other countries include researchers and professionals from the United Kingdom, Germany, Austria, USA, Venezuela and Argentina.

The concept study included not only technical aspects but also the Earth-Mars transportation system and the main characteristics of Nüwa's society. Its economic model consists of postulating that the growth rate is always proportional to the number of inhabitants, and then estimating how many resources are needed to add an additional citizen to the infrastructure. This model predicts an exponential growth from one thousand to one million inhabitants in fifty years. The resources needed to ensure this growth were estimated through an iterative method implying the city systems, the availability of energy and the existing resources. For example, energy is needed to fabricate new solar panels, which also requires mineral resources, machines to collect those resources, that need metals and manufacturing infrastructure to produce them, which in turn consume energy.

Apart from machines and infrastructure, the city requires motivated citizens eager to travel from the Earth and work towards communal and self-improvement. Therefore, a system of value decoupled from Earth, but based on Martian physical assets, is also needed together with a system of rules, laws and dedicated governance bodies to implement it. The result of the exercise is that, while the model seems technologically viable, especially with the aid of automation and artificial intelligence, it requires much more energy per inhabitant compared to the one required by a person on Earth.

At the end of the day, Nüwa is a reflection of how much our own planet is giving us for free, and how far we need to work towards minimizing our footprint and preserving our own world. That is why SONet members are doing their bit to advance through a sustainable and human centered approach to the exploration of space.

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Figure 46: Nüwa is placed in a Martian cliff in Tempe Mensa. Residential and work areas are placed in big cylindrical galleries inside the cliff walls (left side of the image). Big communal areas are placed at the valley (lower part of the image), whereas energy and food production areas are placed at the upper mesa (not shown in the image). Render by ABIBOO Studio/SONet (Gonzalo Rojas).

Highlights

New research on subsecond optical flashes in the night sky will help reduce their impact on astronomical discoveries

The Evryscopes first-time measure flashes population, often mistaken for stars, reflecting off satellites and space trash in Earth's orbit.

Quick flashes of light in the night sky have been linked to the growing mass of satellites and debris zipping around Earth's orbit. Astronomical surveys have seen occasional reflected light glints from satellites. Those flashes can cause false alarms in surveys looking for new events in the sky.

A team lead by astronomers at the University of North Carolina at Chapel Hill (UNC-CH, USA), that includes Octavi Fors, IEEC researcher at ICCUB, systematically measured for the first time subsecond, star-like optical flashes, often mistaken for stars, reflecting off satellites and space trash orbiting Earth.

With six months of all-sky data, the authors measured more than 100,000 flashes, with an event rate of ~1,800 sky−1hr−1, peaking at g=13.0 mag. Of these, ~340 sky−1hr−1 were bright enough to be visible to the naked eye in typical suburban skies with a visual limiting magnitude of V~ 4.

As a result, these orbital flashes event rates turn out to be orders of magnitude higher than the public alerts provided by all active all-sky, fast-timescale transient surveys. Therefore, orbital flashes are the dominating foreground when searching untriggered fast transients with optical wide-field surveys. However, for well-localized (arcminute-scale) events, such as FRBs surveys, the probability of coincidence between an orbital flash and an astrophysical event is low enough (~10-5) for the optical surveys to place constraints on their potential counterparts.

These measurements were conducted by the Evryscopes. They are two innovative telescopes, constructed and funded by the US National Science Foundation, that acquire an image of the whole observable sky every two minutes. They allow us to continuously monitor the brightness of millions of stars with an unprecedented combination of time resolution and sky coverage. The Evryscope South was deployed in May 2015 at Cerro Tololo Inter-American Observatory (CTIO, Chile). The Evryscope North was deployed in October 2018 at Mount Laguna Observatory (California, USA), in collaboration with San Diego State University. The combined observation of these two Evryscopes allows all-sky monitoring every two minutes.

The Evryscope Fast Transient Engine (EFTE) is an image-subtraction pipeline for candidate detection developed for low-latency discovery of fast astrophysical transients, including bright flares from cool dwarfs, early phases of optical counterparts to gravitational wave events, and the hypothesized optical counterparts to FRBs.

Reflections from Earth satellites can take two forms: short duration flashes that can lead to mistaken astrophysical events and streaks associated with fast-moving or slowly rotating satellites. In the latter, although the number of satellites launched by companies like SpaceX Starlink is highly increasing, the authors conclude that these constellations are unlikely to contribute significantly to the subsecond flashes rates.

The potential impact on the astronomical community by bright streaks caused by sun-illuminated satellites moving across an image are a separate class of events that needs to be studied.

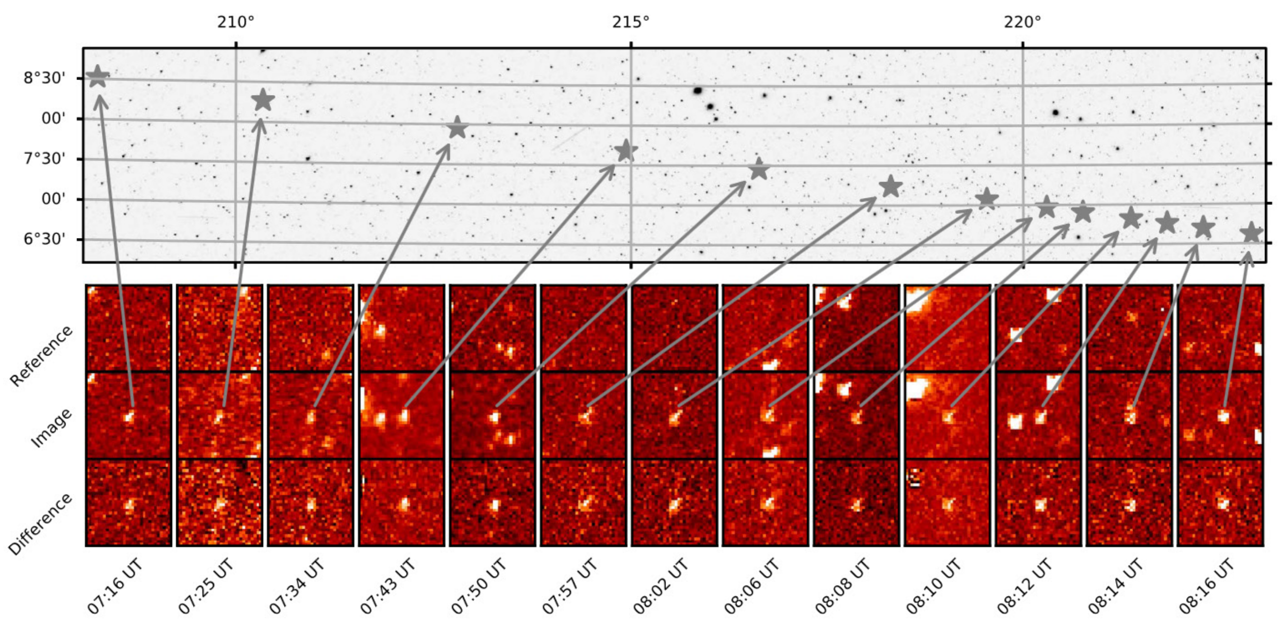

Figure 47:
Top: Example of a typical flash-producing trajectory seen by EFTE, followed over a single Evryscope pointing. Bottom: Postage stamp 6.'6x6.'6-sized cutouts of the reference, science, and discovery images, demonstrating point-like morphology. Credit: Corbett et al.

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Highlights

Disk, planet and star of the same system seen growing together

An international team, including a former and a present member of IEEC, have found a young star surrounded by a giant-planet forming disk that is still accreting material from the parent cloud.

Stellar systems, like our own, form inside interstellar clouds of gas and dust that collapse producing young stars surrounded by protoplanetary disks. For the first time an international team (which includes a former and a present IEEC member), has observed a protoplanetary disk with a large gap being fed by the surrounding cloud via large accretion filaments, suggesting that a planet may be forming in tandem with the parent star while the disk around them is still growing. The observations were done with the Atacama Large Millimeter/submillimeter Array (ALMA) and the Very Large Array (VLA).

The observed star, [BHB2007] 1, is very young (1 million years old) and it is located at the tip of the Pipe Nebula molecular cloud at a distance of 163 pc (530 light years). The young star is surrounded by a disk of molecular gas and dust particles with a radius of 160 au (1 au is the distance between the Earth and the Sun). The disk, as seen by ALMA, exhibits an enormous gap, void of large dust particles, that starts at 20 au (the Uranus orbit) from the star and extends for about 70 au. Nevertheless, this gap still contains a large amount of molecular gas (mostly molecular hydrogen, but also other molecules such as carbon monoxide). The gap properties indicate the presence of a young giant planet or a brown dwarf located in the gap. Indeed, by modelling the disk properties, the team estimates that an object with a mass between 4 and 70 Jupiter masses is needed to produce the observed gap in the disk. There is some other evidence of the presence of the putative giant. Thus, there is a compact radio source in the southern part of the gap and localized molecular gas heating near the radio source. The radio source was detected with the VLA, and it is an indication that the planet accretes material from the disk, it heats up the gas and possibly powers strong ionized winds.

The disk is surrounded by large filaments of gas around this disk. The filaments are probably accretion streamers feeding the disk with material extracted from the ambient cloud. The disk reprocesses the accreted material, delivering it to the young star.

This study has been done by an international team led by the former IEEC member, Dr. Felipe Alves (now at the Center for Astrochemical Studies from the Max Planck Institute for Extraterrestrial Physics, MPE) with the active participation of the ICE researcher Josep Miquel Girart.

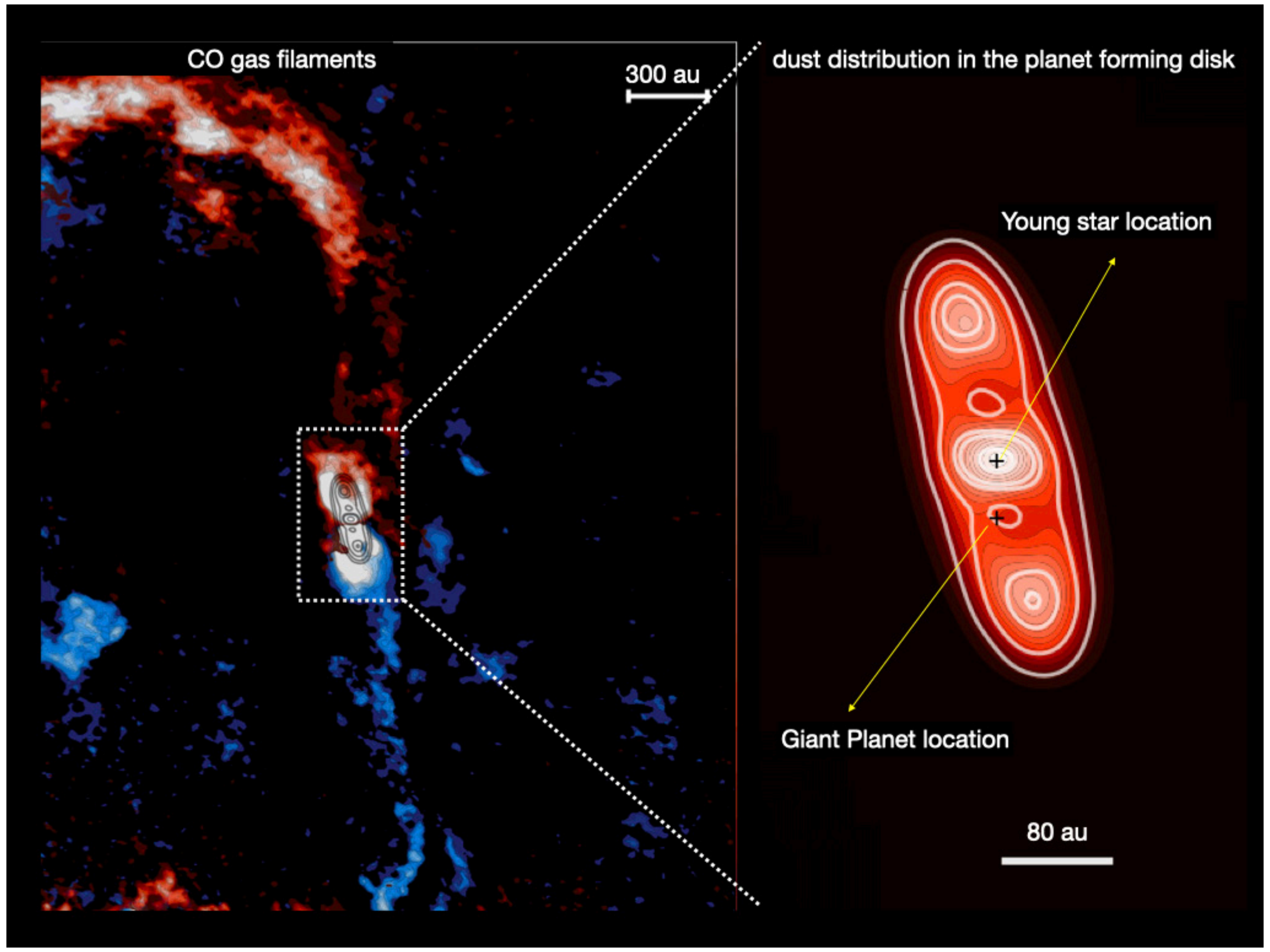

Figure 48:
False-colour image showing the filaments of accretion falling into the protoplanetary disk (seen in the inset) around the protostar [BHB2007] 1. Credit: MPE.

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Highlights

A cosmic cataclysm allows to test the quantum structure of space-time

Researchers from IEEC participated in a sensitive test of Einstein's theory of general relativity using the strong signal observed by the MAGIC collaboration from a distant gamma-ray burst.

Einstein's theory of Relativity postulates that the speed of light in vacuum is constant, independent of the energy of photons. In a study published in the journal Physical Review Letters, the MAGIC collaboration, including authors of IEEC, tested this postulate using observations of a gamma-ray burst (GRB) detected in January 2019 by the two MAGIC telescopes from La Palma.

The attempt was based on the fact that Einstein's theory describes gravity as a result of the interaction of mass with space-time. His predictions have been confirmed by many experiments. Despite this, physicists suspect that there is a more fundamental theory of gravity, of a quantum nature, and still unknown. Several quantum gravity theories consider that the speed at which photons travel in vacuum depends on their energy. This hypothetical phenomenon is called Lorentz invariance violation (LIV). It is believed that, if it existed, this speed difference would be too tiny to be measured, unless its effect accumulates over long periods of time or over long distances, such as it is the case of the emissions that occur in GRBs and are detected on Earth.

GRBs are brief flashes of very high-energy photons (or gamma rays) emitted by distant cosmic explosions. The photons produced by GRBs travel for billions of years before reaching Earth, which could make the effect of the hypothetical differences in their speed measurable. Furthermore, quantum gravity theories predict that the higher the energy of the photons, the greater the difference. Therefore, very high-energy gamma-ray telescopes, such as MAGIC, are expected to be especially efficient in the search for LIV effects.

GRBs occur at unpredictable times and places in the sky. There are GRB detectors on the board of satellites in Earth's orbit that have a very wide field of view, allowing them to detect and locate GRBs almost instantaneously as they occur, and send alarms to telescopes around the world, including MAGIC. On January 14, 2019, after receiving an alert from the Swift satellite's GRB detector, MAGIC made the first detection of a GRB in the very high-energy gamma-ray band, thus completing a search that has lasted more than 15 years. The so-called GRB190114C could be detected due to the fact that MAGIC began its observation just 50 seconds after it occurred.

The careful analysis of the data found no significant difference in the speed of gamma rays of different energy. This does not mean that the effort was useless, since the MAGIC scientists managed to set limits on possible theories of quantum gravity. The limits to quantum gravity that have been obtained from this work agree with those that already existed, and they are the first ones to be obtained by observing the highest energy emission that occurs in a GRB.

With this groundbreaking study, the MAGIC team has established a starting point for future research in search of measurable effects of the quantum nature of space-time.

Figure 49:
Artistic representation of a GRB observed by MAGIC telescopes.

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Short News

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Release of the Newsletter

In February 2020, IEEC proudly presented the first edition of the new IEEC Newsletter, a quarterly report of events, activities, developments, announcements and highlights relating to IEEC members and day-to-day life at the institution.

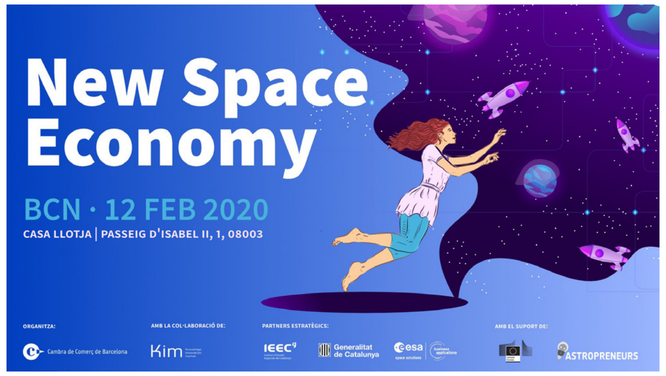
Juan Carlos Morales awarded Premi Ciutat de Barcelona 2019 in Experimental Sciences and Technology

The ICE researcher Juan Carlos Morales was awarded this prestigious prize for having led a study that found a giant exoplanet around a dwarf star. This discovery challenges conventional theories of planetary formation accepted to date.

Successful celebration of 2nd IEEC Forum

On 6 February 2020, IEEC celebrated its annual forum, coinciding with the 24th anniversary of its foundation. The event took place at the Centre de Cultura Contemporània de Barcelona (CCCB) and gathered about 120 attendees, including members of the institute, Catalan government officials and representatives from industry related to the space sector.

IEEC, strategic partner and participant at the NewSpace Economy meeting

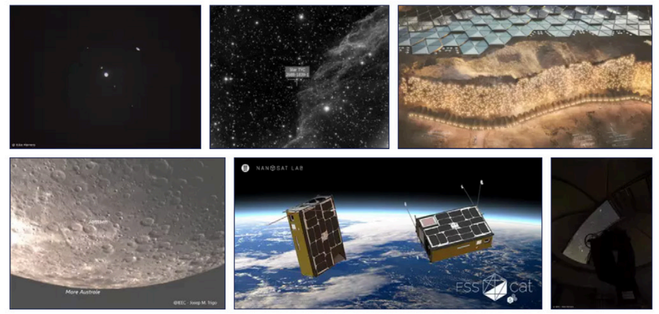


Together with the Chamber of Commerce of Barcelona, in collaboration with the Knowledge Innovation Market Bcn Foundation (KIM-Bcn), IEEC participated as a strategic partner in the organisation of a meeting with the organisations, institutions, companies and researchers that finance, promote and develop projects related to the NewSpace.

UPC selected by ESA to host the 4th Symposium on Space Educational Activities

UPC was selected to organise the 4th Symposium on Space Educational Activities, which, due to the COVID-19 pandemic situation, has been postponed to 2022. IEEC and ICCUB will also support the event. This will be the first time that this symposium will be held in our country.

Publication of Picture of the Month



IEEC officially welcomed back the Picture of the Month section. It has featured spectacular pictures as diverse as images from Montsec Observatory (OAdM), a snapshot of the comet NEOWISE or an artist's view of two CubeSat FSSCat-mission nanosatellites in orbit.

IEEC becomes a Galileo Masters 2020 regional partner providing technological mentoring

IEEC became a regional partner of the Galileo Masters 2020 contest, by providing technological mentoring to all the participants of the Galileo Prize Catalonia/Spain. IEEC is a pioneer in proposing this figure of mentors who accompany and give feedback to the participants throughout the competition.

Nanda Rea wins the 4th Fundació Banc Sabadell Prize for Science and Engineering

The ICE researcher Nanda Rea won the 4th Fundació Banc Sabadell Prize for Science and Engineering for her study of a class of neutron stars with extremely intense magnetic fields: magnetars, a particular type of pulsar. The prize aims to recognise the achievements of young researchers.

ICCUB is awarded with the Maria de Maeztu Excellence Distinction (2020-2023)

ICCUB was one of the six Maria de Maeztu Excellence Units accredited by the Spanish Ministry of Science and Innovation. This is the second time that ICCUB receives this award, which distinguishes organizations with highly competitive research programs that are among the best in the world in their respective scientific areas.

IEEC is now a Member of the European Astronomical Society

IEEC joined the European Astronomical Society (EAS) as Organisational Member. As an institution, IEEC will receive several benefits, such as discounts for exhibition space at the yearly EAS annual meeting and job advertisements in the community.

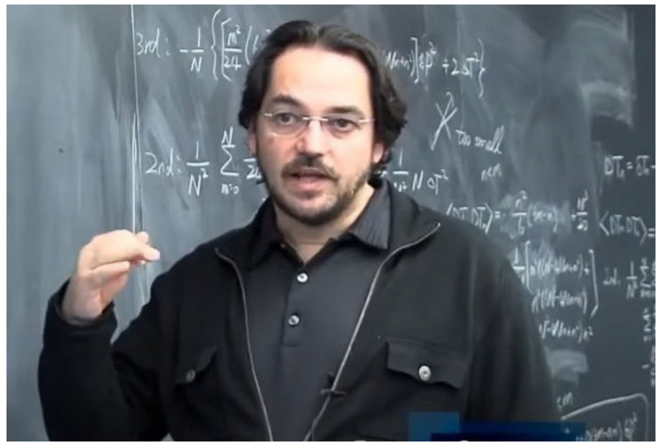
Héctor Gil-Marín wins the Young Researcher Prize in Theoretical Physics awarded by the Spanish Royal Physics Society

The postdoctoral Junior Leader 'La Caixa' Fellow at ICCUB, Héctor Gil-Marín, was rewarded with the Young Researcher Award in Theoretical Physics of the Spanish Royal Physics Society ("Real Sociedad Española de Física") - Fundación BBVA 2020 Physics Prizes.

Presentation of the NewSpace strategy for Catalonia

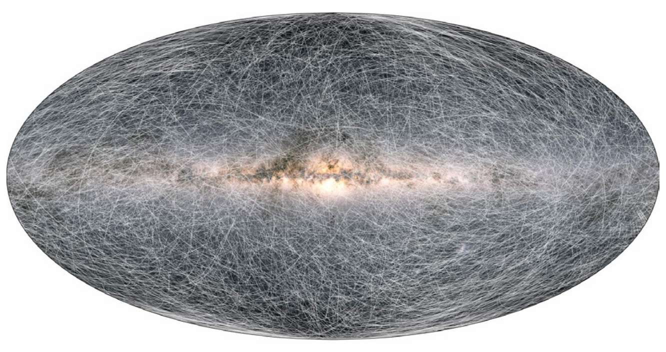
In October 2020, the Catalan Government (Generalitat de Catalunya) approved the NewSpace Strategy for Catalonia, which will deploy a programme of specific actions to strengthen the ecosystem of the Catalan NewSpace. IEEC has significantly contributed to the definition of the strategic plan.

First shared prize for the Scientific Short Film of the researcher Enrique Gaztañaga in Ciencia en Acción 2020



The ICE researcher Enrique Gaztañaga was awarded the first prize ex-aequo in the Ciencia en Acción 2020 competition, in the modality Scientific Shorts, with the work entitled "2019 The Accelerating Cosmos Part I Cap. III". This award was shared with Álex Muntada and Jaume Benet, both from the Universitat Ramon Llull.

Early Data Release 3 of Gaia data



The early third delivery of the Gaia mission data was made public on 3 December 2020. Coinciding with the early publication of this groundbreaking catalog, the ICCUB organised an educational talk and a colloquium aimed at the scientific community.

Meetings, Schools & Training

Barcelona-Valencia Meeting on Gravitational Waves and Virgo

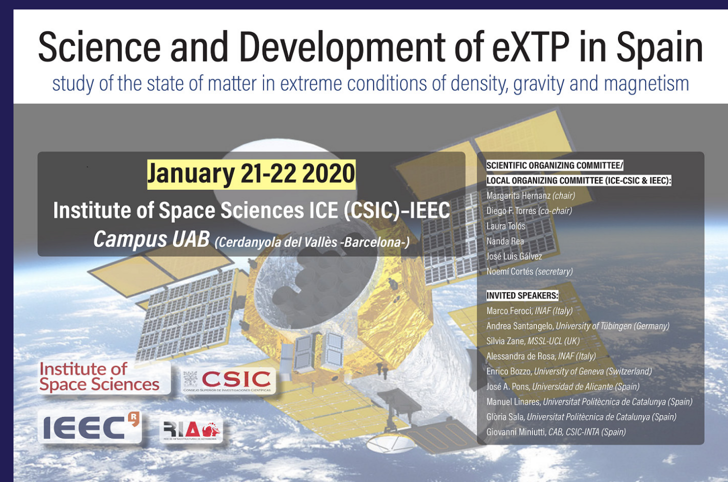
On 20 and 21 January 2020, the Barcelona-Valencia Meeting on Gravitational Waves and Virgo was held at ICCUB premises. The meeting included talks and presentations regarding several aspects of gravitational wave events, methodology and data processing.

MAGIC Collaboration AGN Working Group Meeting

From 20 to 24 January 2020, the 2020 meeting of the MAGIC Collaboration AGN Working Group took place at ICCUB. During the workshop, talks and lectures about the study of the gamma-ray emission from Active Galactic Nuclei (AGN) were presented.

Science and development of eXTP in Spain

The RIA meeting Science and Development of eXTP in Spain, held at ICE on 21 and 22 January 2020, was intended to publicize the science and possibilities that eXTP is offering to the Spanish astronomical community. The large involvement of Spain in eXTP offers a unique opportunity to get the most out of this mission, thanks to the detailed knowledge of the instrumentation.



ICCUB Winter meeting

A new edition of the series of the ICCUB Winter Meeting took place on 3-4 February 2020. The idea of this meeting is to gather as many people as possible, and give the opportunity to young researchers working in the research areas of the Institute (i.e., Astrophysics, Particle Physics, Cosmology, Gravitation and Nuclear Physics) to present their work in a way as didactic and entertaining as possible.

Gaia-RIA workshop. Expanding the Gaia legacy: the role of Spanish ground-based facilities

The meeting, held on 17-19 February 2020 in Barcelona, aimed to present and discuss current and future projects that use or complement Gaia data. The Gaia team analyzed the contributions already made by the Spanish Singular Scientific and Technical Infrastructures and the international research infrastructures, its involvement in large ongoing and future photometric and spectroscopic surveys, as well as the prospects for new instrumentation in a European and international framework. The meeting also intended to pay tribute to Jordi Torra, whose pioneering work in the preparation of the Hipparcos mission in the 1980s in Spain laid the foundations for the subsequent Spanish participation in the Gaia mission, leading some of its most important aspects.

1st PAZ Polarimetric Radio Occultations User Workshop

The 1st PAZ Polarimetric Radio Occultations (RO) User Workshop, which was held on-line due to the pandemic situation, targeted scientists working on observational or modelling aspects of precipitation, convection, extreme events, microphysics schemes, model evaluation (climate, NWP), and RO data assimilation that might benefit from this expanded RO capability. The objectives of the workshop were, among others, to provide potential users with an understanding of the data, their geophysical content, possibilities and limitations as well as to enable data providers better understanding of the needs of scientific users.

Euclid Meeting 2020 remotely

Due to the Covid-19 pandemic situation, the face-to-face Euclid Meeting 2020 that should have been held in Sitges from 4 to 8 May 2020 was cancelled. However, around 500 people participated from home on the on-line version of it. Five plenary sessions and 17 splitted ones were joined during those days by the Euclid researchers.

Meetings, Schools & Training

PHD Theses

Author: **Nicola Bellomo**
Department/Institute: Universitat de Barcelona (UB). Departament de Física Quàntica i Astrofísica
Title: Exploring Signatures of New Physics in Cosmology
Date: 4 January 2020
Director: Licia Verde

Author: **Raúl Onrubia Ibáñez**
Department/Institute: Universitat Politècnica de Catalunya (UPC). Departament de Teoria del Senyal i Comunicacions
Title: Advanced GNSS-R instruments for altimetric and scatterometric applications
Date: 13 March 2020
Director: Adriano Camps Carmona & Hyuk Park

Author: **Pau Ramos Ramírez**
Department/Institute: Universitat de Barcelona (UB). Departament de Física Quàntica i Astrofísica
Title: Substructure in the phase-space of the Galaxy with Gaia
Date: 25 September 2020
Director: M. Teresa Antoja Castelltort

Author: **Juan Adrián Ruiz De Azúa Ortega**
Department/Institute: Universitat Politècnica de Catalunya (UPC). Departament d'Enginyeria Telemàtica
Title: Contribution to the Development of Autonomous Satellite Communications Networks - The Internet of Satellites
Date: 9 November 2020
Director: Adriano Camps Carmona & Ana M. Calveras Auge

Author: **Juan Pedro López-Zaragoza**
Department/Institute: Universitat Autònoma de Barcelona (UAB). Departament de Física
Title: Magnetic environment and magnetic-induced forces in LISA Pathfinder
Date: 9 November 2020
Director: Miquel Nofrarias

Author: **Safoura Tanbakouei**
Department/Institute: Universitat Autònoma de Barcelona (UAB). Departament de Física
Title: Reflectance properties and mineralogy of asteroids and comets by using carbonaceous chondrites
Date: 14 November 2020
Director: José María Trigo-Rodríguez

Author: **Haixia Lyu**
Department/Institute: Universitat Politècnica de Catalunya (UPC). Departament de Física
Title: Contributions to ionospheric modeling with GNSS in mapping function, tomography and polar electron
Date: 17 November 2020
Director: Manuel Hernandez Pajares

Author: **Marina Lafarga Magro**
Department/Institute: Universitat Autònoma de Barcelona (UAB). Departament de Física
Title: Stellar activity and exoplanets of M dwarfs from CARMENES visible to near-infrared spectroscopy
Date: 10 December 2020
Director: Ignasi Ribas

Author: **Tingting Lin**
Department/Institute: Universitat Autònoma de Barcelona (UAB). Departament de Física
Title: Models of pulsar wind nebulae
Date: 15 December 2020
Director: Diego E. Torres

Author: **Daniel Pascual Biosca**
Department/Institute: Universitat Politècnica de Catalunya (UPC). Departament de Teoria del Senyal i Comunicacions
Title: Design and performance analysis of advanced GNSS-R instruments back-end
Date: 21 December 2020
Director: Adriano Camps Carmona & Hyuk Park

Author: **Andrea Pocino**
Department/Institute: Universitat Autònoma de Barcelona (UAB). Departament de Física
Title: Cosmology with narrowband photometric redshifts
Date: 22 December 2020
Director: Francisco Castander

Outreach

IEEC promotes Women4Space, a series of talks organised by UPC and Women In Aerospace Europe in Barcelona

On 13 and 14 November 2020, the Hackathon Act in Space 2020 took place. The event is an international innovation competition promoted by the French National Centre for Space Studies (CNES) and supported by the European Space Agency (ESA), the ESA Business Incubation Centre Barcelona network (ESA BIC Barcelona) and the ESA brokers. Leading organisations proposed more than 90 technological challenges related to their activity in order to solve them through the application of space technologies. Participants from all over the world must work on creating business prospects for the proposed challenges by using

patents, technologies and satellite data made available by CNES, ESA, Airbus and all Act In Space partners to create new companies. The national edition of this event was organised by the Chamber of Commerce of Barcelona, with the support of the KIMbcn Foundation and the institutional support of the Department of Digital Policies and Public Administration of the Catalan Government (Generalitat de Catalunya), and was held in virtual format. IEEC collaborated as a partner and its director, Dr. Ignasi Ribas, participated as a member of the jury for the evaluation of the projects.

IEEC promotes Women4Space, a series of talks organised by UPC and Women In Aerospace Europe in Barcelona

The local division of the Women in Aerospace Europe (WIA-E) association in Barcelona presented in 2020 the first edition of Women4Space, a series of talks that aims to give visibility to outstanding women in the space sector. The first of the series of talks, "Gaia: Revealing the history of the Milky Way by measuring 2 billion stars", took place on the same opening day 26 November by Dr. Carme Jordi, professor in the Department of Quantum Physics and Astrophysics of the University of Barcelona and ICCUB researcher, who talked about the Gaia project and her personal and professional career experiences. This initiative was promoted by IEEC and GTD System & Software Engineering, and it was held within the agenda of the activities carried out by the Universitat Politècnica de Catalunya (UPC) during the 2020 - 2021 school year to celebrate its 50th anniversary.

IEEC participates in the Science Week 2020 in Catalonia

From 14 to 29 November 2020, the 25th edition of the Science Week in Catalonia (Setmana de la Ciència - SC'20) was held. One more year, IEEC participated in the Science Week by organizing several online talks and virtual visits in research centers. On 18 November 2020, Kike Herrero, support and operations astronomer at the Montsec Astronomical Observatory (OAdM), performed a virtual visit to the facility. That same day, Josep Maria Trigo, astrophysicist and researcher at ICE gave a talk entitled "Evolution of the atmosphere and climate change". On the following day, on 19 November 2020, Francesc Gòdia, professor of Chemical Engineering at the School of Engineering of Universitat Autònoma de Barcelona (UAB), conducted a virtual visit to the MELiSSA Pilot Plant, while Mar Mezcua, researcher at ICE, talked about "Supermassive black holes: the most powerful motors of the Universe". On the other side, on 26 November 2020, Carme Jordi, professor in the Department of Quantum Physics and Astrophysics at ICCUB gave what was the First talk of the Women4Space conference cycle, "GAIA: revealing the history of the milky way by measuring 2 billion stars".

Participation of IEEC to the Maker Faire Girona

On 4 December 2020, the MakerFaire was held in Girona. The Maker Faire Barcelona is a digital creativity event that, since 2014, has been held annually in different districts of the city of Barcelona. In 2020, however, it was organised with the desire and enthusiasm to expand his horizons, while maintaining his own personality. The result was Maker Faire Girona, dialogues on the frontiers of Arts, Science and Technology. In the event, two researchers of IEEC participated in the conversation framed in the space subject about Space technologies for a better future on Earth. The researcher of ICE Guillem Anglada talked about "Can we create a human economy independent of the Earth?", while the director of IEEC Ignasi Ribas touched the topic of "Space research to address the goals of sustainable development".

Outreach statistics

Contact
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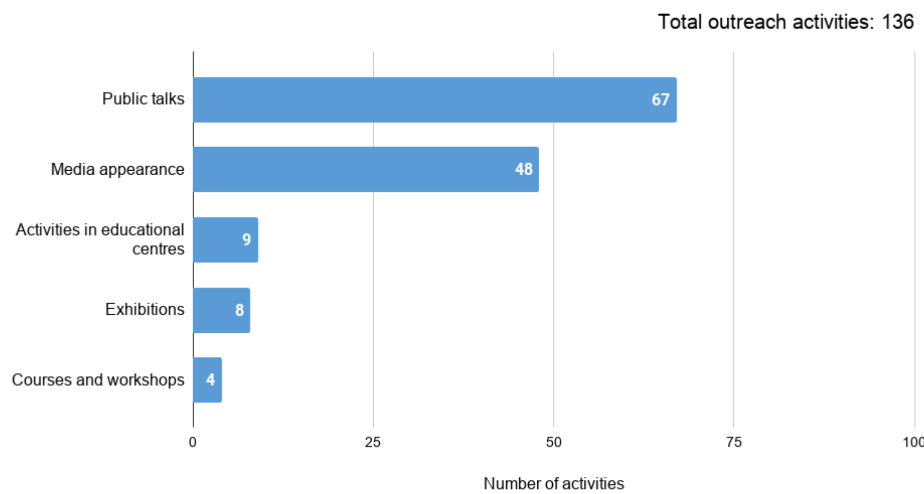
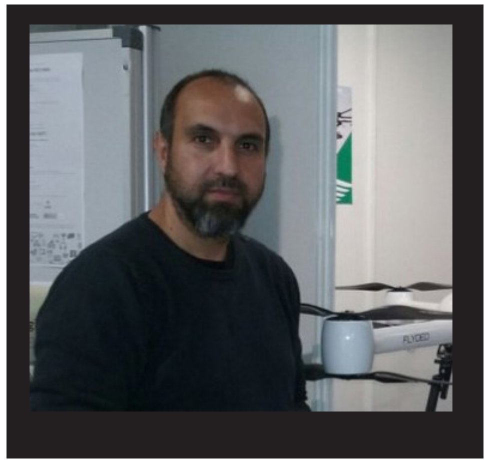
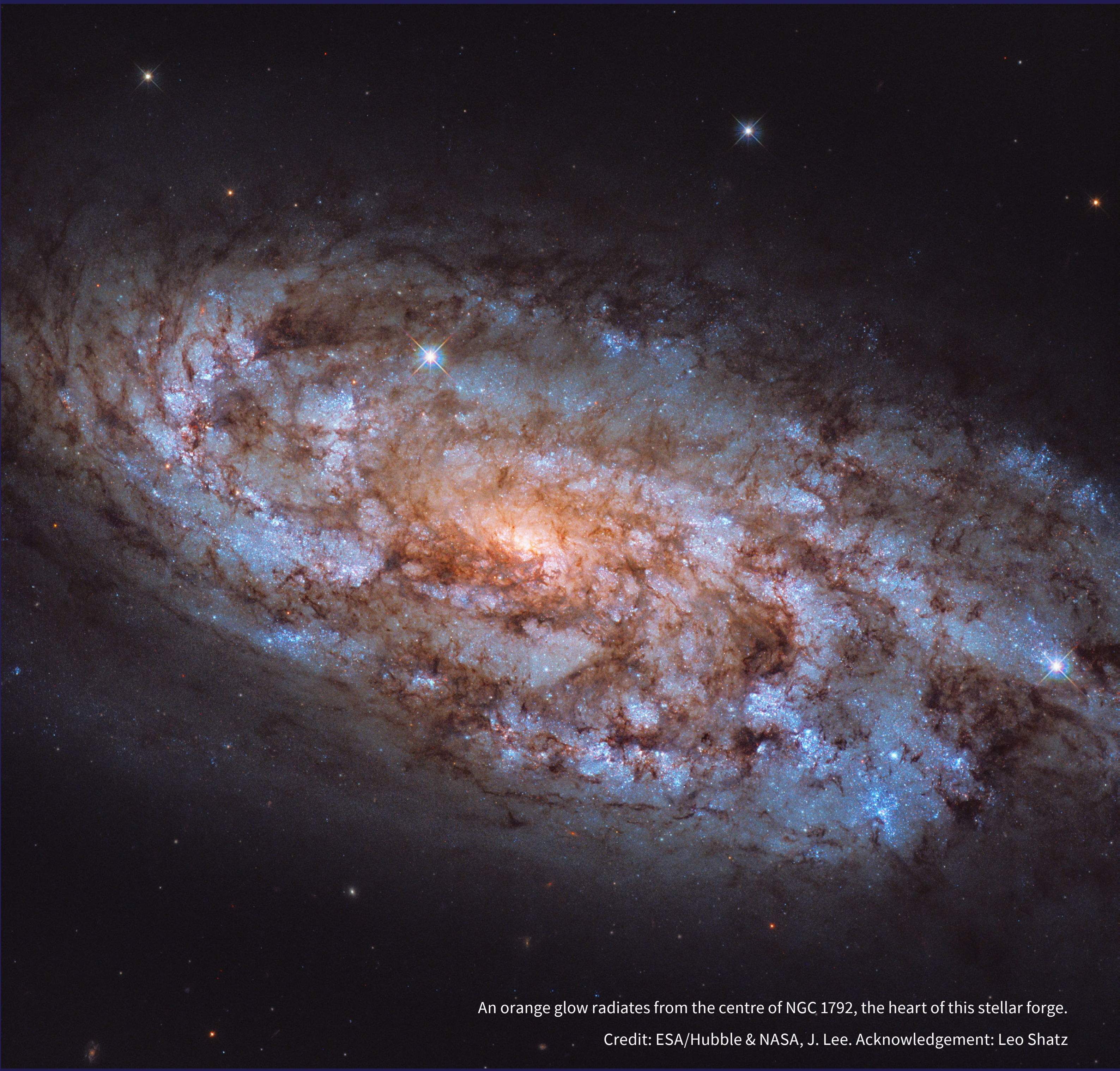
comunicacio@ieec.cat





In memoriam Lluís Gesa Boté, computer engineer, lecturer at the UAB Engineering School and researcher at the Institute of Space Sciences (ICE, CSIC) and IEEC. He was a senior engineer who worked for projects such as LISA Pathfinder, CARMENES, CTA, Ariel, PLATO and eXTP. Lluís was a very esteemed colleague, who was always keen on sharing his passion, knowledge and generosity with those around him. He will be deeply missed.
Ad Astra, Lluís.



An orange glow radiates from the centre of NGC 1792, the heart of this stellar forge.

Credit: ESA/Hubble & NASA, J. Lee. Acknowledgement: Leo Shatz

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