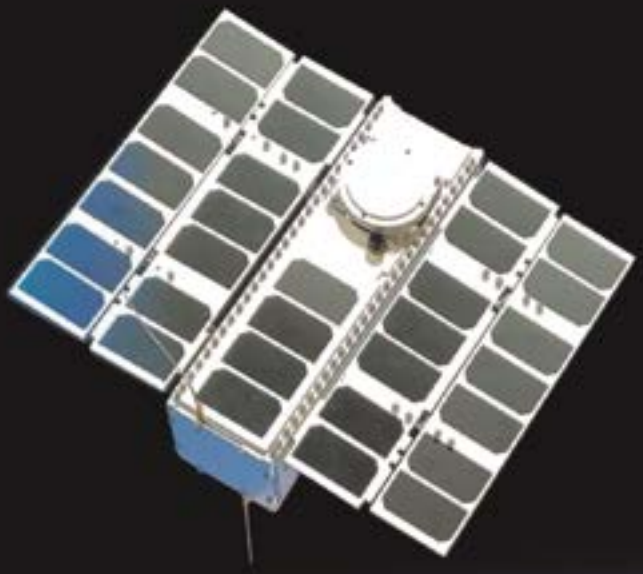
IEEC
Institut d'Estudis
Espacials de Catalunya

Annual Report 2021



Cover image: Artistic recreation of the nanosatellite *Enxaneta* flying over the Earth.

Enxaneta is the first of several nanosatellites that the Catalan Government will put into orbit in the framework of the NewSpace Strategy for Catalonia, approved in October 2020.

It was successfully launched by the Russian company GK Launch Services on 22 March 2021, aboard a Soyuz 2 rocket. The aim of the nanosatellite is to provide global Internet of Things (IoT) connectivity services with 5G coverage.

The nanosatellite is a 3-unit CubeSat, about the size of a shoe box and weighing about 10 kg. It travels at a speed of about 7 km per second at 550 km of altitude and makes a full orbit around the Earth every 90 minutes. It passes over Catalonia twice a day. Named *Enxaneta* by the children of Catalonia, the nanosatellite was developed by the Catalan companies Sateliot and Open Cosmos through a contract tendered by the IEEC.

Enxaneta is transmitting all the collected data to the Satellite Ground Station of the Montsec Observatory (OdM-IEEC), made up of several antennas for communication with low-orbit satellites which were conceived and installed by the NanoSat Lab of the Universitat Politècnica de Catalunya · BarcelonaTech (UPC).

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Foreword

2021 has been a very special year for the IEEC. It marks the 25th anniversary of its foundation, on 6 February 1996. Of course, we would have liked to celebrate this landmark under more favourable circumstances. We all hoped that the COVID-19 pandemic would be long gone, but this has not been the case. Successive waves of contagion have hampered day-to-day life and, of course, the normal development of professional and social activities. Activity at our workplaces has been variable and the few face-to-face events held have not taken place in the best conditions. Many of us have grown weary of sitting in front of our computers, engaging in video conference after video conference. Fortunately, we managed to find a quiet interval between pandemic waves to hold the IEEC Forum 2021 and this was certainly a highlight of the year. After nearly a year and a half of work in semi-isolation, and thanks to the high vaccination rate, many people were able to gather at the Centre de Cultura Contemporània de Barcelona (CCCB) for an afternoon of talks, lively exchanges, long-missed social interaction, and… celebrate the 25th anniversary of the IEEC! In addition to this gathering, we also commemorated our anniversary by producing a variety of materials (videos, brochures) and organising numerous (virtual) events for all of us to enjoy. You can find an account of these activities in this Annual Report.

In spite of the adverse context, 2021 has been extraordinarily productive. If an all-time record number of publications was set in 2020, with 410 refereed papers, this year the number has further increased to an impressive 461. Furthermore, most of these articles have appeared in top-notch journals (87% in the first quartile of impact factor), and following our open science policy, they have largely been made available through different forms of open access. You can enjoy a taste of the science results published by IEEC researchers in the highlights section, covering topics within astrophysics, cosmology, Earth observation and navigation.

If last year we saw the arrival of new programmes at the IEEC within the framework of the Catalan Government's NewSpace Strategy, 2021 has confirmed that this facet of our activity is here to stay. On 21 March 2021, the first nanosatellite (3U cubesat) of this strategy, dubbed *Enxaneta*, was successfully launched from Baikonur (Kazakhstan). *Enxaneta* is a telecommunication satellite, providing Internet of Things (IoT) connectivity, and it is being used to test integration with ground 5G networks. It is operated in collaboration with the private company Sateliot. A second nanosatellite (6U cubesat) is being manufactured by the private company Open Cosmos and has its launch scheduled for 2022. The focus of this second mission will be to provide multi-spectral imagery of the Earth's surface (particularly Catalonia) with a resolution of about 5 m. The images will have multiple applications in combination with data from the EU Copernicus programme. Importantly, the 6U cubesat will fly IEEC technology. The high-performance C3SatP platform will be put into orbit as a hosted payload and therefore reach full maturity in terms of technology readiness. During 2021, a team of engineers from the IEEC have been working tirelessly to make this project a success. There is no doubt that this will be the case. You will find many more details of the New Space strategy and the associated IEEC activities as you read on.

The various facilities at Montsec Observatory (OdM) have been maintaining their very high standards of efficiency and productivity. The scientific observations from the Joan Oró Telescope, which are conducted via open calls, have led to numerous high-impact results on a variety of research topics (asteroids, exoplanets, supernovae, optical counterparts, binary stars…). Furthermore, the number of users this year has increased by a further 15%, reaching nearly 200, with an approximate 3-way split between IEEC, Spanish and international users. In addition to astronomy, the Montsec Observatory is expanding its infrastructures to other areas. For example, the formal agreement signed in 2021 between the Universitat Politècnica de Catalunya · BarcelonaTech (UPC) and the IEEC to exploit S-band and UHF/VHF antennas for nanosatellite communication will be the seed of the future teleport that will continue growing as part of the NewSpace Strategy.

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. A subset of these are considered "Key Projects" within the IEEC, because they are of special relevance for several reasons, most importantly because they involve participants from several research units. During 2021, Key Projects were the Cherenkov Telescope Array (CTA), the LISA mission and the Ariel mission, the latter two being part of the European Space Agency (ESA) programme. Specific articles in the present report describe these projects and provide updated information on their status and main activities throughout 2021. Suffice it to say here that activity has been frenetic on every front and that all milestones are being successfully reached.

Knowledge transfer and innovation is an essential activity at the IEEC. We are very conscious of the importance of innovating and transferring knowledge to industry for its exploitation. Our Knowledge Transfer Office (KTO) has set up direct contracts and agreements with industry, agencies and government entities, and with European consortia as part of the H2020 programme. Notable examples are satellite tracking services at the OdM; 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. Knowledge transfer to the general public is also an integral part of the IEEC's mission. Our Communication Office has organised many outreach activities throughout 2021. Collaboration with the CCCB with the Mars exhibit, fostering the initiatives of women scientists and engineers, and the *Enxaneta* launch campaign are just three select examples of the many more described below. Furthermore, a quarterly newsletter edited by the Communication Office is distributed by e-mail to all IEEC members and keeps us all informed on the latest events and developments.

In addition, this annual report contains articles about the COST networks that we manage, as well as accounts of professional meetings that received IEEC support during 2021, training activities such as Summer schools, and PhD theses. We also include a short note explaining that the IEEC was officially admitted as a member of the International Astronautical Federation (IAF) during its General Assembly in October 2021 in Dubai.

Before I close this foreword, I would like to wholeheartedly congratulate the IEEC members and research units that have received awards and recognitions during 2021. This is a perfect tribute to the excellence of the work performed. Finally, I would like to warmly welcome the new members who have joined the IEEC during 2021 and I wish you all a joyful 2022 with even greater success!

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Presentation

The Institute of Space Studies of Catalonia

The Institute of Space Studies of Catalonia (IEEC - Institut d'Estudis Espacials de Catalunya) is a centre that promotes the development of activities related to space in Catalonia in its aspects of research, innovation and training. The IEEC collaborates and participates in the planning, execution, dissemination and transfer of knowledge of all kinds of initiatives, studies and projects related to space scientific research and technology.

The IEEC is a non-profit foundation that was established in February 1996. It has a Board of Trustees composed of the Generalitat de Catalunya, Universitat de Barcelona (UB), Universitat Autònoma de Barcelona (UAB), Universitat Politècnica de Catalunya · BarcelonaTech (UPC), and the Spanish Research Council (CSIC). The IEEC is also a CERCA centre.

The research structure consists of four units, each belonging to one of the Trustee institutions, and they constitute the core of the R&D activity. The Research Units are:

- Institute of Cosmos Sciences of the Universitat de Barcelona - ICCUB
- Centre for Space Studies and Research - CERES (UAB)
- Research Group in Space Sciences and Technologies - CTE (UPC)
- Institute of Space Sciences - ICE-CSIC

Scientists and technicians from the Research Units can simultaneously act as members of their institutions and as members of the IEEC. All senior scientific personnel at the IEEC are affiliated staff members from one of the Research Units.

The IEEC organisation chart is shown in Figure 1, as approved in November 2021. The Board of Trustees is the highest governing body of the IEEC. They appoint 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 appointed by the Board of Trustees with the mandate to evaluate the quality of the scientific and technical output and advise on the strategic planning of the IEEC, as well as on the overall organisation.

Over the past year, the IEEC has taken a leading role in the implementation of the NewSpace Strategy of the Catalan Government. Therefore, a new managerial and advisory structure has been established to fulfil the new responsibilities. In particular, the Space Advisory Board (SpAB) and the Strategic Board for the Promotion of the Space Sector will provide monitoring and guidance, and will constitute an interface with the industrial ecosystem in Catalonia. The IEEC management structure has also increased significantly during 2021, and is organised into 3 general Areas and 13 Offices with clearly defined roles and responsibilities. Figure 1 shows the organisation chart with the functional dependencies and relationships of the Areas and Offices.

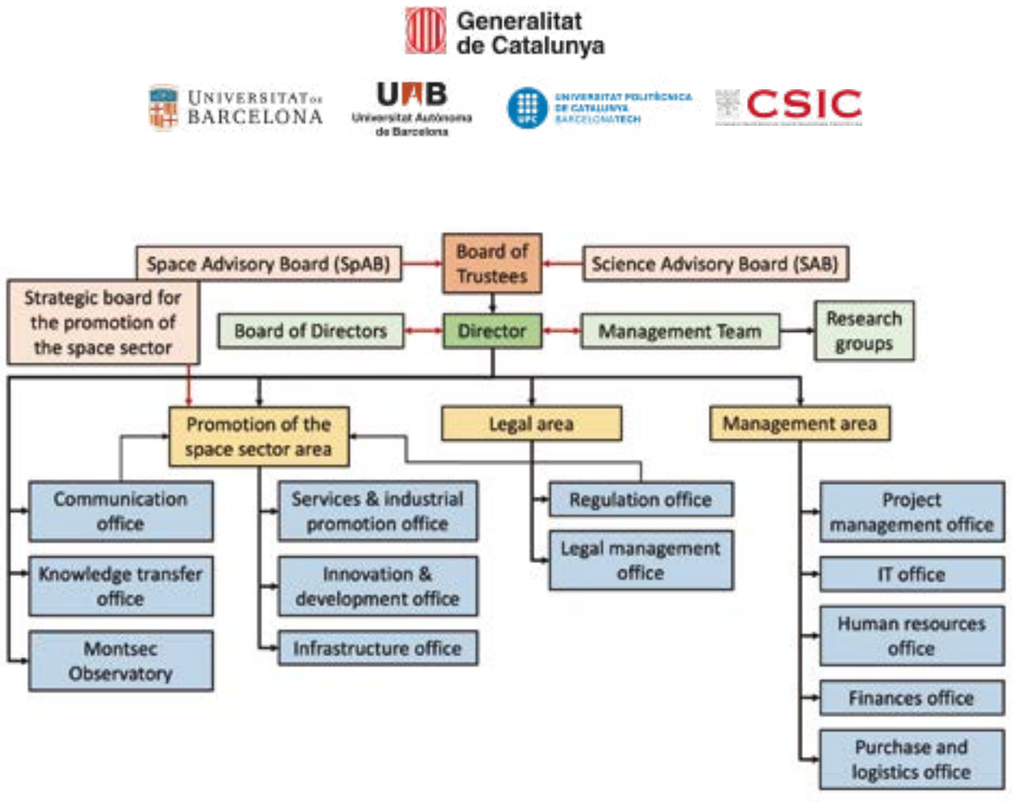


Figure 1: IEEC organisation chart.

The IEEC focuses its efforts on the study of the Cosmos and the Earth as a planet, through a powerful programme for research, development and technological innovation within the framework of scientific missions and projects. The Institute participates and has high-level responsibilities in multiple space missions and ground instrumentation facilities, as can be seen in Figure 2. The research lines developed by the IEEC belong to three different fields.

Astrophysics and Cosmology

The IEEC conducts cutting-edge research in the fields of Astrophysics and Cosmology through the use and development of advanced technologies such as instrumentation for ground-based telescopes and space missions, as well as tools for analysing large volumes of data. It also establishes strong multidisciplinary connections with various areas that include particle physics, geology, biology and mathematics. The main areas are: determination of the large-scale structure of the Universe; detection and measurement of gravitational waves; analysis of the most energetic astrophysical phenomena; understanding how stars form, evolve and die, as well as the resulting compact objects; study of the physics of the Sun and its relationship with the Earth; characterisation of the formation, evolution and architecture of our galaxy and other galaxies; the search for new exoplanets with potentially habitable conditions; Mars exploration; interpretation of the role played by the interplanetary environment; and tracking and study of the asteroids, comets and meteorites that surround us.

Earth Observation and Navigation

The IEEC develops new concepts of remote sensing for Earth Observation and optimisation of Global Navigation Satellite Systems (GNSS). The main areas of activity are: Earth Observation instrumentation; measurement of the Earth's surface and atmosphere, and monitoring of natural hazards through reflectometry, radio occultations with sources of opportunity, and GNSS data; combination of GNSS and wireless communications (including 5G) for smart cities and intelligent vehicles; advanced radiometric and hyperspectral data acquisition and processing technologies; and the synergy and fusion with other Earth Observation products and technologies, through the optimal exploitation of aerospace infrastructures.

Space Technology

The IEEC is a leading centre in the construction of space instrumentation in different areas of scientific and technological research on national and international programmes. The Institute leads technological development projects for ground- and space-based instrumentation in technologies for telecommunications sensors and subsystems, electronic systems and control and processing software, platforms for nanosatellites, robotics and artificial intelligence, and Big Data tools for data management, analysis and exploitation, among others. In addition, the IEEC participates in the European and international networks that define the roadmaps of the agencies and organisations for future missions.

Space missions

GRAVITATIONAL WAVES

GAMMA

X-RAYS

VISIBLE

VISIBLE-INFRARED

INFRARED

Solar Orbiter

LISA

LISA Pathfinder

Fermi

eXTP

PLATO

Cheops

Gaia

Euclid

Ariel

DATA SERVICE

GNSS

MetOp/ROM-SAF

Geross-ISS

ROHP-PAZ

SMOS

Nanosatellites

Ground Instrumentation

Joan Oró telescope (TJO)

CARMENES

Cherenkov Telescope Array (CTA)

W1m (WGT)

MIRADAS

PAU

MAGIC

DES

Rubin observatory

DESI

SDSS-III

Figure 2: Main space missions and ground-based instruments with IEEC participation.

Personnel

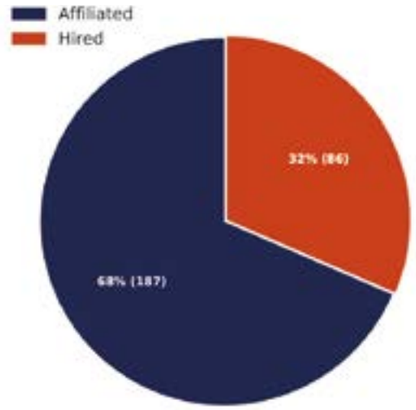
The statistics, tables and graphs illustrate the distribution of IEEC's personnel according to their work situation, gender, Research Unit, and role.

Total personnel: **273**	Male: **222 (81%)**	Female: **51 (19%)**
	Hired: **86 (32%)**	Affiliated: **187 (68%)**

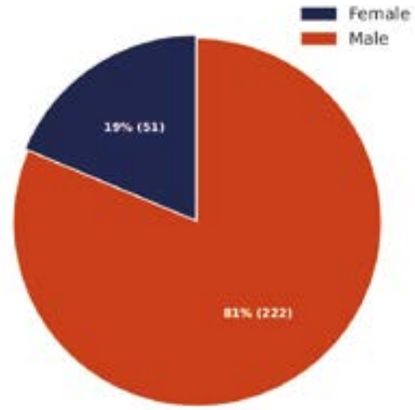
	Administration & IT & PO	Researchers & engineers	TOTAL
IEEC Core Staff	10	12	22

	ICE-CSIC	CERES	ICCUB	CTE	TOTAL
	IEEC contracts				
Administration & services	3	-	-	-	3
Faculty	1	1	1	-	3
Researchers & engineers	20	1	15	2	38
PhD Students	10	2	7	1	20
Total	34	4	23	3	64
	Affiliated members				
Administration & services	-	-	5	-	5
Faculty	18	8	32	23	81
Researchers & engineers	20	5	27	6	58
PhD Students	5	3	31	4	43
Total	43	16	95	33	187

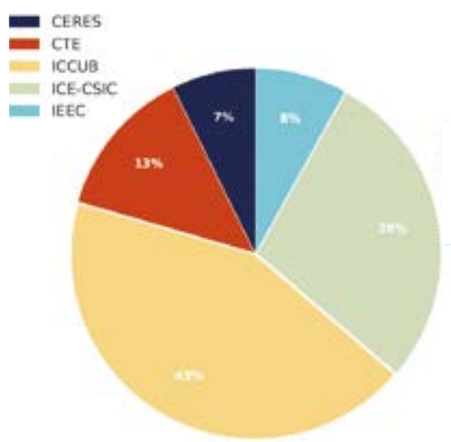
IEEC Core Staff	IEEC contracts	Affiliated members	TOTAL
22	64	187	273



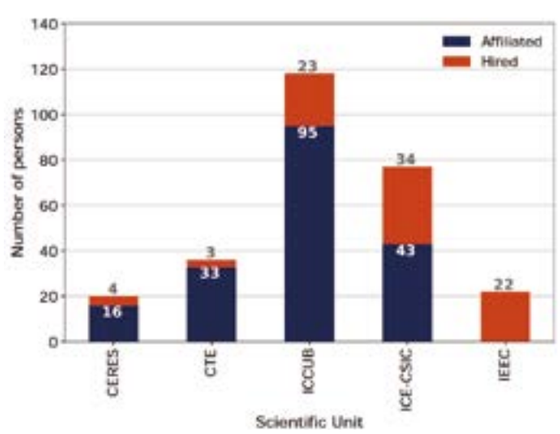
1. Personnel according to work situation



2. Personnel by gender

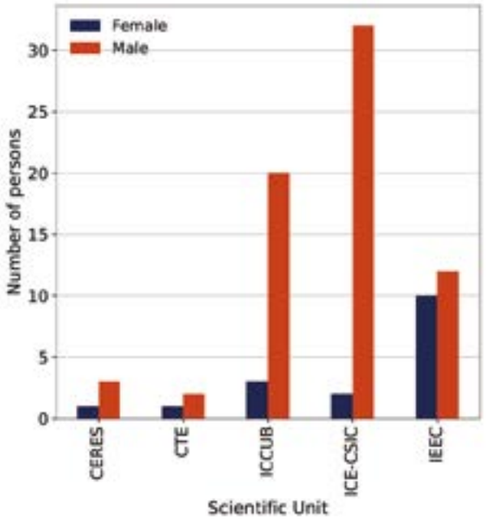


3. Personnel by Research Unit

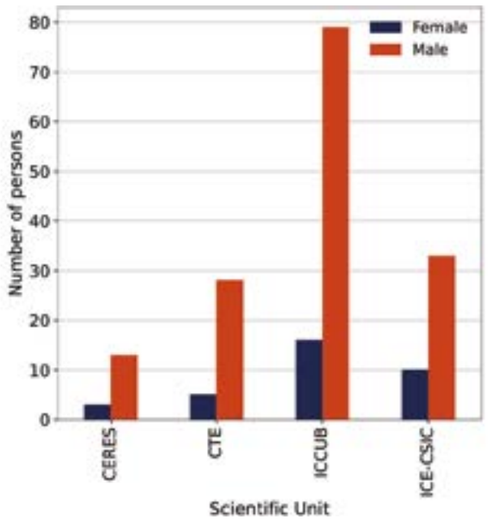


4. Personnel by work situation and Research Unit

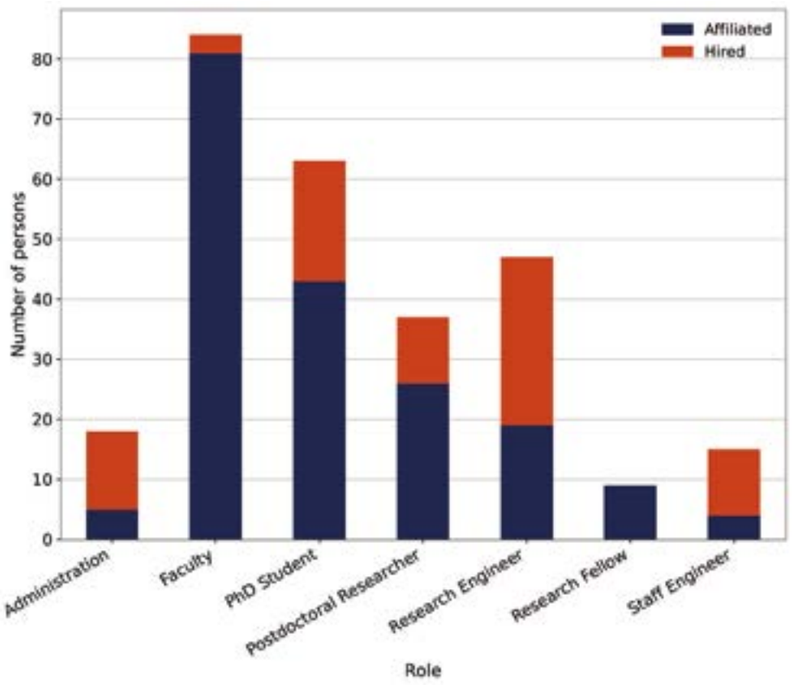
Personnel



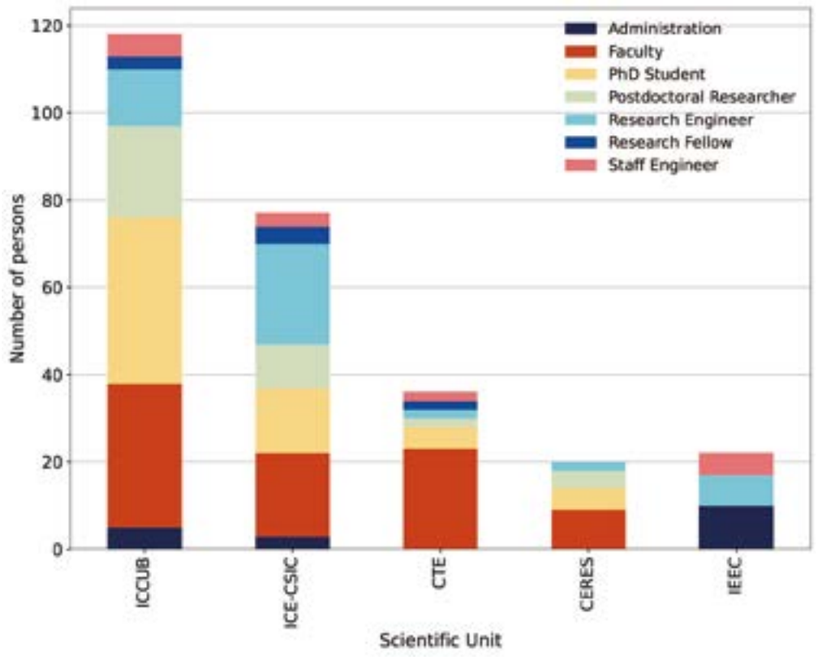
5. Hired personnel by Research Unit and gender



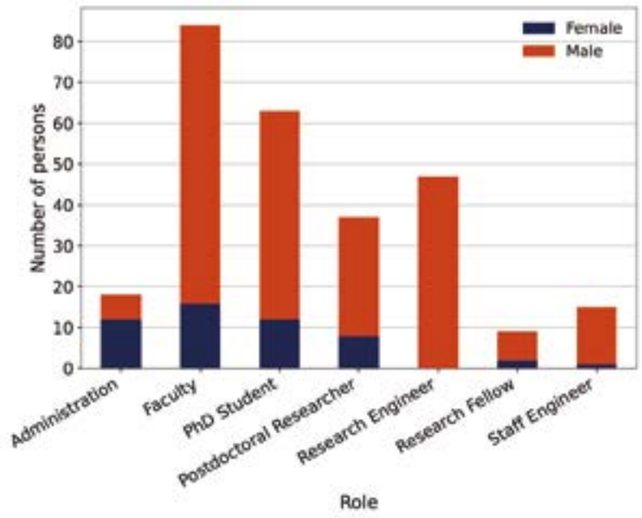
6. Affiliated personnel by Research Unit and gender



7. Personnel by work situation and role



8. Personnel by role and Research Unit



9. Personnel by role and gender

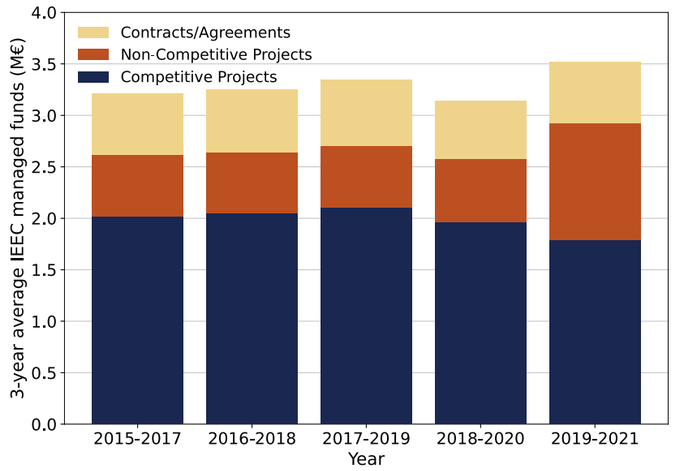
Projects

The charts and graphs below show the funding secured and managed by the IEEC, including base funding from the competitive projects, non-competitive projects, and contracts/agreements with industry*. Data for several years are shown to illustrate the time evolution.
*** Provisional economic data pending closure of the 2021 financial year.**

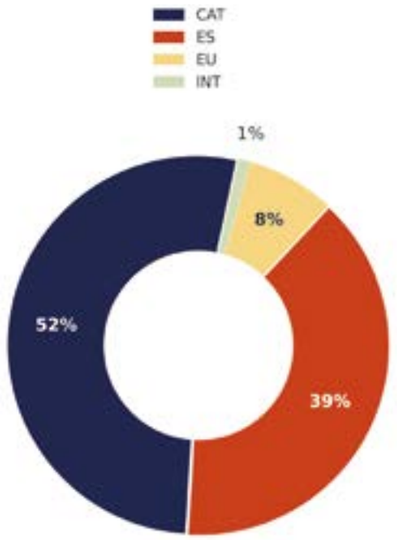
Contracts/Agreements	Income (k€)
European public sector	151.8
European private sector	51.1
National industry	80.6
National public sector	130.0
International (non-European)	46.6

Subsidies	Income (k€)
Competitive projects	
AGAUR	56.2
MCIU	1,507.0
EU	131.2
Non-competitive projects	
NewSpace strategy	1,352.1
Programme contract	832.2
Others	65.3

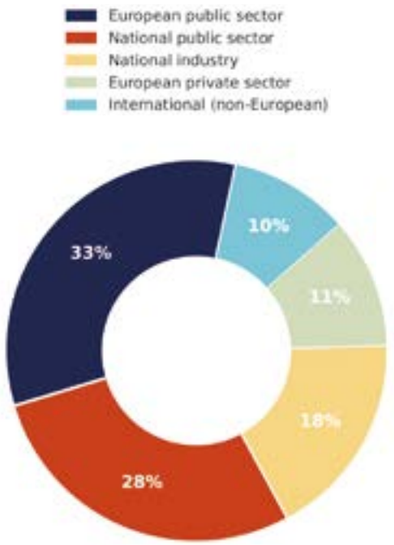
10. Income by year and type of project



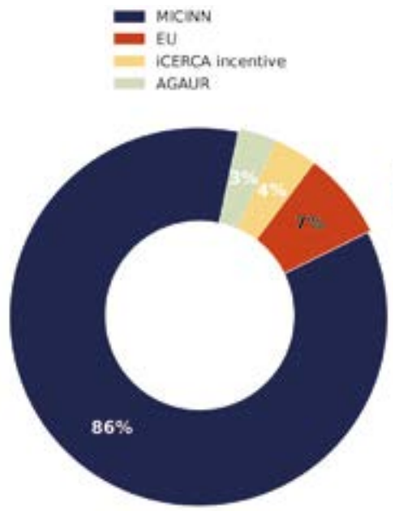
11. Mean triennial income by year and type of project



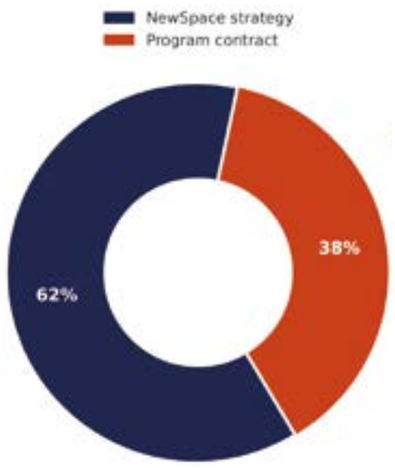
12. Income by geographical area



13. Income from contracts/agreements



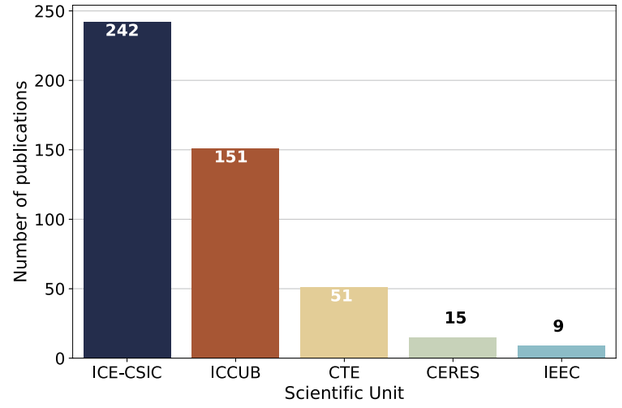
14. Income from competitive projects



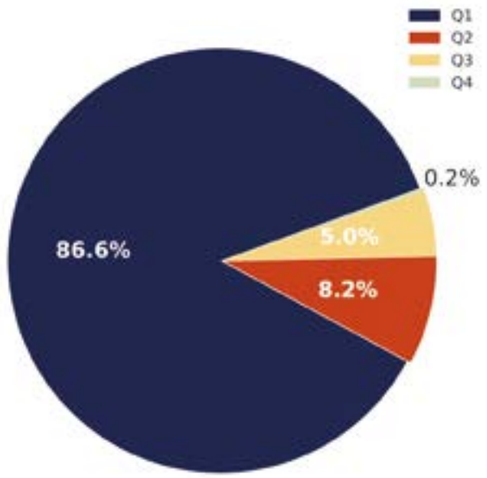
15. Income from non-competitive projects

Publications

The total number of publications authored by the IEEC members is 461. Hereby there is a graphical summary of the total scientific and technical publications carried out by the IEEC members according to the Research Unit, journal quartile, journal, scientific subject, and author.



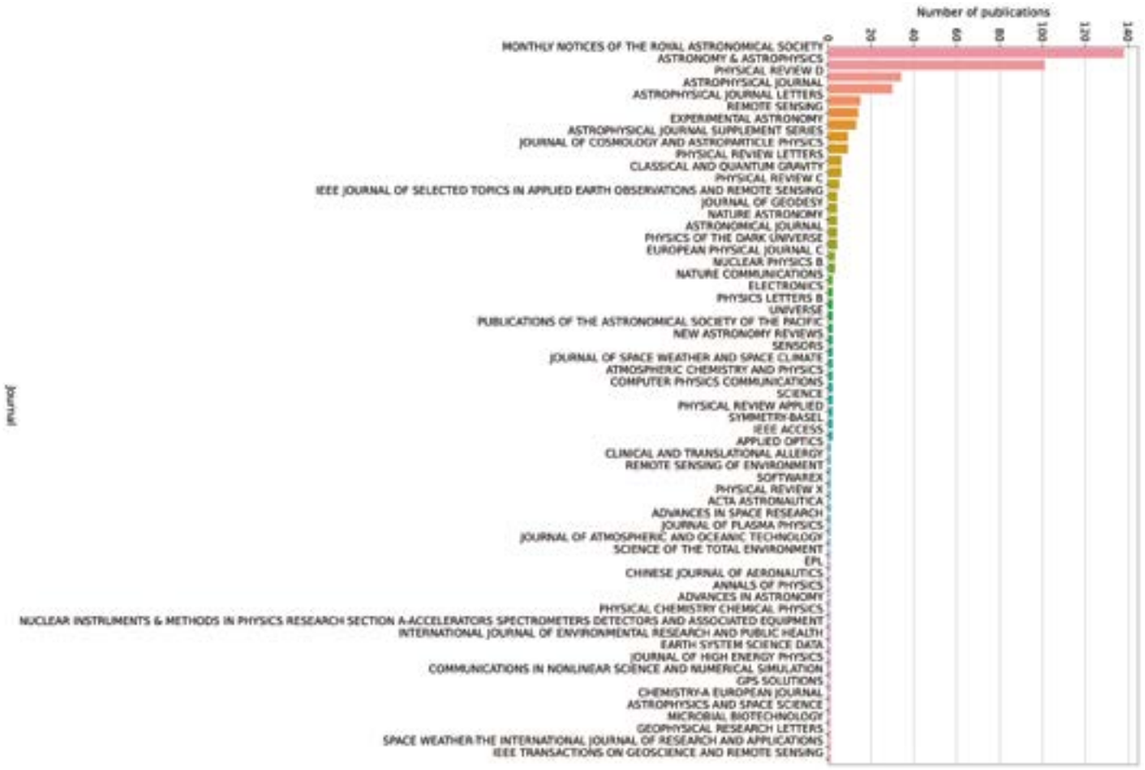
16. Number of publications by Research Unit



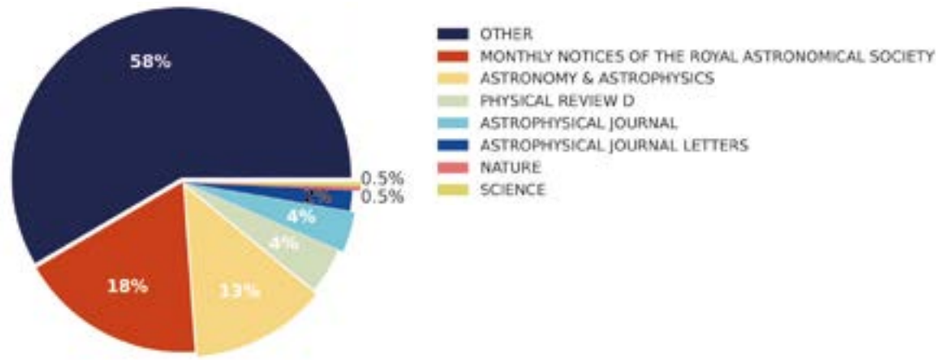
17. Percentage of publications by journal quartile

Publications

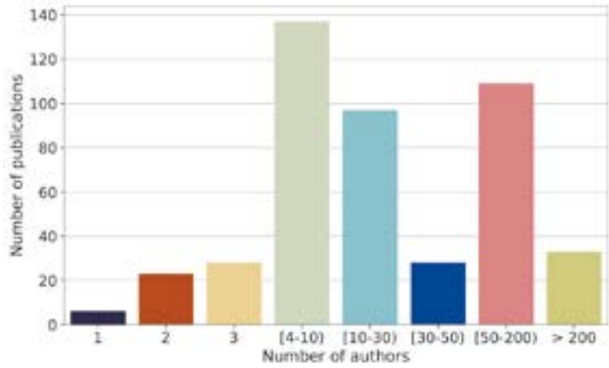
The total number of publications include the 30 publications by authors at Universitat de les Illes Balears (UIB).



18. Number of publications by journal



19. Publications by journal



20. Number of publications according to number of authors

21. Number of publications by subject

Moreover, some publications were collaborations between authors at different IEEC Research Units:

- ICCUB + CERES + ICE-CSIC = 2 publications
- ICCUB + CERES = 7 publications
- ICCUB + ICE-CSIC = 3 publications
- ICCUB + CTE = 1 publication
- ICE-CSIC + CERES = 1 publication
- ICE-CSIC + CTE = 4 publications
- ICE-CSIC + IEEC = 6 publications
- CTE + IEEC = 3 publications
- ICCUB + UIB = 16 publications
- ICE-CSIC + UIB = 2 publications

Facilities And Key Projects

Montsec Observatory

A leading infrastructure for astronomical research, satellite services, and climate and environment monitoring.

The Montsec Observatory (OdM, oadm.ieec.cat) is a scientific infrastructure that is managed by the IEEC by virtue of an agreement with the Direcció General de Recerca of the Generalitat de Catalunya. It is located at an altitude of 1,570 metres in the Montsec mountain range, 50 km north of the city of Lleida, in the municipality of Sant Esteve de la Sarga, near Àger, in the Catalan pre-Pyrenees. This area is recognised as one of the most suitable on the European continent for astronomical observation, thanks to the combination of weather conditions and the low effect of light pollution. The sky to be observed is, undoubtedly, exceptional.

The project of siting an astronomical observatory in the Montsec range emerged in the early 1990s, and the main ideologists were the biochemist from Lleida, Joan Oró, and the foundation that bears his name. The main equipment at the OdM 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 most technologically advanced 1-metre-class robotic telescopes in the world. A decade after its inauguration, the Montsec 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 working to improve them.

The OdM comprises three facilities for research in astronomy. The astronomical equipment consists of two robotic telescopes: the Telescopi Joan Oró (TJO, managed by IEEC-Generalitat de Catalunya) and the Telescopi Fabra-ROA Montsec (Reial Acadèmia de Ciències i Arts de Barcelona and Real Observatorio de la Armada). In the past, the OdM 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 OdM also hosts the Satellite Ground Station Montsec (SGSMontsec), formed by several antennas for low orbit satellite communications, designed, implemented and installed by the NanoSat Lab of the Universitat Politècnica de Catalunya · BarcelonaTech (UPC), and managed by the UPC and the IEEC. The Observatory also hosts an automatic station of the Meteorological Service of Catalonia (Servei Meteorològic de Catalunya, SMC), an environmental quality measurement station of the XVPCA network (Institut de Diagnosi Ambiental i Estudis de l'Aigua – CSIC) and two wide-field video surveillance cameras to help firefighters monitor a very wide area around Montsec.

The main goals of the OdM are to provide tools to carry out cutting-edge research in astronomy, to provide the necessary support to exploit the OdM facilities, to serve as a 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 the IEEC. The main feature of the TJO is its robotic operation, so that observations and the decision-making process in the event of incidents are carried out automatically and without human intervention (without "in situ" or remote personnel supervising the operation).

The scientific facilities of the OdM have yielded important findings in the fields of exoplanets, supernovae and solar system research. Moreover, they have contributed to the tracking of satellites and the monitoring of atmospheric quality in the Montsec area. During 2021, despite the pandemic situation, the IEEC achieved various milestones at the OdM. Below, we provide a summary of these.

OdM infrastructures

During 2021, a number of improvements were made to the OdM infrastructures. Several computers were upgraded or integrated into the system, and their maintenance plans have been designed and carried out. A new computer was installed in order to manage and control accessibility to the OdM and its various buildings through the new doors and digital lockers installed during 2020. The new computer registers the entrance and exit of any authorised staff members of the different organisations with infrastructures at the OdM. An additional computer was installed in order to manage network access to the OdM via VPN, thereby increasing security and facilitating the control and maintenance tasks performed by OdM staff. Moreover, the main computer responsible for the backup and storage of the TJO data and their accessibility for external users was moved from the ICE-CSIC to the IEEC's facilities at the Nexus building (Barcelona), in order to increase security and facilitate control and maintenance tasks. The computers in the TJO control room, responsible for telescope and observatory control, environmental control and data reduction processes, were moved to a new rack with more space for future devices and improved accessibility for maintenance tasks. There are also plans to replace the computer responsible for data reduction with a new one in the near future. In addition, an energy monitoring system has been installed in the OdM, for the purpose of obtaining statistics about the energy consumption of the different infrastructures. This was done in order to evaluate the environmental footprint of the facilities, as well as to adjust the available power for future infrastructures at the OdM.

MONTSEC OBSERVATORY

Montsec Observatory

In 2021, two new installations related to the space sector have been made at the OdM. On the one hand, a corner reflector for the calibration of the Sentinel 6 satellite of the joint European Space Agency (ESA) and European Commission Copernicus programme was installed through a cooperative agreement between the IEEC and isardSAT S.L. (see Figure 2-left). On the other hand, an antenna was installed by the i2CAT Foundation on the roof of the SGS-Montsec building, in order to test the connectivity of IoT devices which need to communicate data to *Enxaneta* and the future nanosatellites of the Catalan NewSpace Strategy (see Figure 2-right). The device is composed of several test sensors, a data logger, and the antenna for data transfer.

Figure 1: View of the OdM in February 2021.

Figure 2: Corner reflector for the calibration of the Sentinel-6 satellite installed at the OdM (left); i2Cat antenna for IoT communication testing installed at the OdM (right).

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. The TJO is equipped with a high-performance CCD camera for astronomical imaging (Large Area Imager for Astronomy, LAIA), with a set of Johnson-Cousins UBVRcIc filters. LAIA was dismounted for repair in September and replaced with the previous MEIA2 camera (still installed at the end of the year). Since 2018, the TJO has also had a spectrograph (ARES). In addition, several associated instruments for environmental monitoring are acquiring data continuously: two weather stations, a GPS antenna and a storm detector, among others. A fibre-optic 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, including the telescope scheduler (ISROCS), data pipeline (ICAT) and 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, which is accessible at mur.ieec.cat. During 2021, ISROCS has been modified in order to optimise the scheduling of observations with a variety of priorities and scientific requirements, thereby improving the efficiency of the TJO operations. Furthermore, a new environmental monitoring system has been designed in order to achieve better handling of weather alerts, including sensor redundancy. A first stage of the implementation of the system has been completed by designing and installing a redundant system with 3 rain detectors, thereby preventing false rain alarms.

The 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-vignetted field of view of 30 arcmin diameter in the TJO with a pixel size of 0.4”x0.4”.

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 2021. While there are numerous photometric robotic telescopes in the world, only a few of them have spectroscopic capabilities. ARES raises the TJO to a world-class level.

Figure 3: The Joan Oró Telescope (TJO) observing at night.

Montsec Observatory

Since 2013, the TJO has been operating in routine mode and it provides useful data that is distributed through the OdM web portal and also through the node of the Spanish Virtual Observatory (SVO). In 2021, the SVO was updated to include all the public raw images of the TJO with a total of over 500,000 images, obtained during 2,600 different nights. The telescope carries out multi-purpose astronomical observations and is also a testbed for developing new instrumentation. The TJO offered around 70% of its available time in 2021 to the international astronomical community, with the sole requirement of maximising the scientific and technical performance of the instrumentation. In this regard, the 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 with a proven capacity 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 2021, the TJO SST software was further improved to allow the telescope to track moving satellites. This will be implemented in the TJO's operations in the future, thereby improving the detection capabilities of small objects.

At the end of 2021, the OdM had 179 registered users on MUR, 65 of them from the IEEC, 47 from other Spanish institutions, and 67 from international institutions. This represents approximately a 15% increase in the number of registered users compared to 2020 (which was already 25% higher than in 2019). This is primarily due to the new scheme of two calls for proposals implemented in 2019, with more advertising inside the IEEC, at a 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 an average of 13 per call in the period 2020-2021. This also increased the telescope pressure time, with a fraction of requested over available scientific time of about 1.2. In addition, the TJO also received a proposal 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 should be noted that the useful time decreased around 2% compared to 2020 because of the worse weather conditions in 2021. However, the production and duty cycle increased by 5% and 2% compared to 2020, reaching values in 2021 close to 94% and 85%, respectively.

Observation statistics

- Useful time (night-time hours with good weather conditions): 1872 h (61.8% of total night time)
- Time acquiring data (regardless of quality): 1755h (93.7% of total night-time with good weather)
- Time acquiring useful data: 1592h (85.0% of total night-time with good weather) → Duty cycle

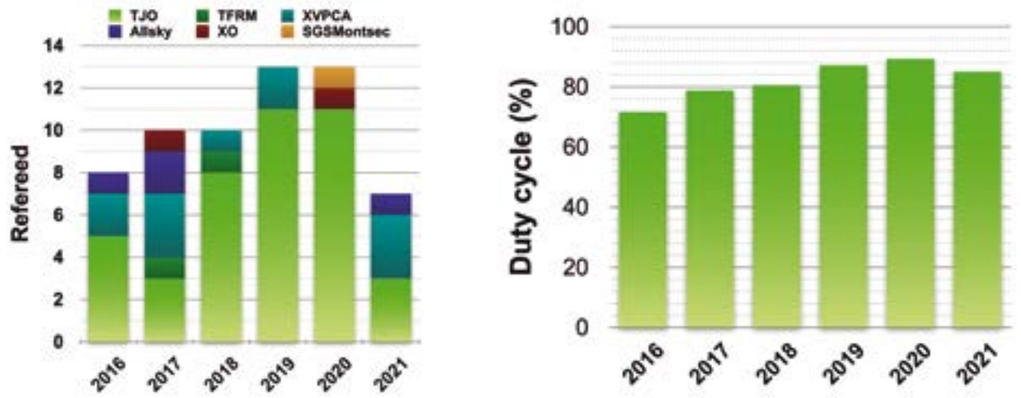


Figure 4: Number of refereed publications per year from the facilities at OdM. The decrease in the number of Joan Oró Telescope (TJO) publications in 2021 is due to having fewer publications related to CARMENES. An increase in the following years is expected from MAGIC publications (left). Fraction of time acquiring useful data per year from TJO, i.e., duty cycle (right).

Science with the TJO

The TJO (see previous subsection) 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 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 (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);

Montsec Observatory

- X-ray binaries (rotational variability, accretion phenomena, radial velocity curves);
- 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 considerable 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. Participation in the networks of robotic observatories means it is possible to make observations requiring continuous time coverage. Similarly, the TJO can be used as a support facility for space missions or other ground-based facilities 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: The Needle Galaxy (NGC 4565) captured by the Joan Oró Telescope (TJO).

During 2021, 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, and monitoring of faint blazars.

The number of nights with TJO observations has slightly increased since 2016, and it is now equivalent to the number of nights with good weather windows. Also, the amount of time dedicated to scientific observations remains as high as in 2019 and 2020, which is very close to the granted time for scientific proposals. The pressure of requested time remains around 20% above the amount of time available.

In summary, with an efficient use of the LAIA and MEIA2 cameras and the continuation of shared-risk scientific observations with the ARES spectrograph, 2021 has been a very productive year for the TJO.

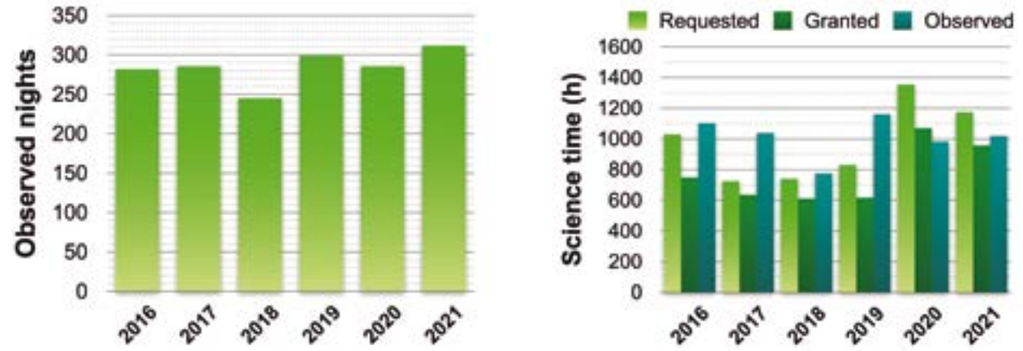


Figure 6: Number of nights with scientific observations at the TJO during the last 6 years (left); amount of time requested, granted and observed for scientific proposals at the TJO during the last 6 years (right).

Satellite Ground Station Montsec

During the last few years, significant efforts have been made to build a ground station for communication with low-Earth orbit (LEO) satellites, and the end result is the Satellite Ground Station Montsec (SGSMontsec). This station has been installed and is managed by the UPC NanoSat Lab in collaboration with the IEEC.

The privileged location of the OdM free of obstacles on the horizon and with a clean electromagnetic environment makes SGSMontsec ideal for a ground station. An antenna to work in the UHF and VHF bands was installed at the OdM in 2018, together with computing services in the TJO building. In 2019, a 3-metre dish S-band RX antenna was also installed to enhance the communication bandwidth. These antennas are controlled by automated software responsible for scheduling and data retrieval through an optical fibre connection to the Barcelona Operation Centre. A REST API is used to interface with the Operation Centre to request passes or download retrieved data.

On 5 February 2021, a visit was made to the OdM, and in particular to SGSMontsec, by the then Minister of Digital Policies and Public Administration of the Generalitat de Catalunya, Jordi Puigneró, and by the Secretary of Digital Policies of the Generalitat, David Ferrer. Jordi Navarra, Mayor of Sant Esteve de la Sarga, the municipality where the OdM is sited, was also invited to co-host the visit (see Figure 7-left).

In 2021, SGSMontsec was used to operate nanosatellites such as those of FSSCAT. Also in 2021, the computing services of SGSMontsec were moved to a room closer to the S-band antenna. In addition, a formal agreement of collaboration to operate SGSMontsec was signed by the IEEC and the UPC. The station was officially opened on 12 June 2021, and this event was attended by Adriano Camps as Head of the UPC NanoSat Lab, Daniel Crespo as Rector of the UPC, Lluís Rovira as Director of the CERCA research centres, and Daniel Marco as Director General of Innovation and Digital Economy of the Generalitat de Catalunya (see Figure 7-right).

Figure 7: Visit of authorities to the OdM and SGSMontsec on 5 February 2021. From left to right: Marc Ribó, Jordi Navarra, Ignasi Ribas, Jordi Puigneró, David Ferrer, and Pep Colomé (left). Visit of authorities and the SGSMontsec team for the inauguration of the SGSMontsec on 12 June 2021 (right).

Outreach

During 2021, the pandemic situation prevented the organisation of the usual monthly visits from May to September. However, an online talk was organised on 30 April 2021 in collaboration with Agrupació Astronòmica de Figueres. Also, in collaboration with Sant Esteve de la Sarga council, an observation of the night sky was conducted on 18 August 2021, following all the recommendations of the health authorities. In addition, a virtual visit of the OdM was made by Kike Herrero through the IEEC YouTube channel on 19 November 2021 within the framework of Science Week 2021. Finally, a visit to the SGSMontsec and the rest of the OdM was organised on 5 June 2021 for the 5 winners of the contest for the *Enxaneta* name, including an appearance on the TV programme infoK.

In the field of education, an online seminar about the TJO was organised for the students of the Universitat de l'Experiència (UB) on 16 April 2021. Also, a seminar about the spectrograph ARES and the robotic operations of the TJO was given on 16 May 2021 to the students taking Observational Astronomy as part of their Physics degree (UB). Some of these students visited the OdM on 17 May 2021. Finally, a visit to the OdM with some members of the Agrupació Astronòmica de la UAB took place on 24 September 2021.

The Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA, https://www.cta-observatory.org/) 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, the 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 Telescope (IACT). Together, the northern and southern CTA arrays will constitute the CTA Observatory (CTAO), which will be the first ground-based gamma-ray observatory open to the worldwide astronomical and particle physics communities as a resource for data from unique, high-energy astronomical observations. This is expected to significantly boost the scientific output of the CTA by engaging a much wider research community. Additionally, the CTA will feed its data into a virtual observatory, which will enable scientists to probe multiple data centres seamlessly and transparently, provide analysis and visualisation tools, and give other observatories a standard framework for publishing and delivering services using their data.

The improvement in sensitivity is expected to match the development achieved by X-ray and low-energy (20 MeV-50 GeV) gamma-ray space-borne telescopes in recent decades. With an initial expectation of a thousand source detections over the lifetime of the array, the CTA is poised to make a significant impact on fundamental facets of Physics and AstroPhysics. The current generation instruments H.E.S.S., MAGIC, and VERITAS have already demonstrated the huge physical potential of astrophysical measurements at teraelectronvolt (TeV) energies. The 200+ sources detected by these instruments, and the wide range of high impact scientific results, suggest that particle acceleration is common in nature, and that the known objects are just the tip of the iceberg. CTA will seek to address issues that fall under three major areas of study: Understanding the origin and role of relativistic cosmic particles, probing extreme environments, and exploring frontiers in Physics.

The CTA was included in the 2008 roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) and promoted to a Landmark project in 2018. It is one of the "Magnificent Seven" of the European strategy for astroparticle physics published by ASPERA, and highly ranked in ASTRONET's "strategic plan for European astronomy" (leaflet). In addition, the CTA is a recommended project for the next decade in the US National Academies of Sciences Decadal Review.

The Cherenkov Telescope Array

IACTs image the very short (between 5 and 20 ns long) and faint flash of Cherenkov radiation generated by the cascade of relativistic charged particles, known as an Extensive Air Shower (EAS), produced when a very-high-energy gamma ray strikes the atmosphere. Thus, the atmosphere itself acts as the calorimeter of the detector. The total area on the ground illuminated by this flash corresponds to some hundreds of square metres, which is why the effective area of IACT telescopes is so large. The Cherenkov light is focused into the telescope camera through highly reflective mirrors. The camera captures and converts it into data. A graphic showing how IACTs work can be seen in Figure 8. The CTA will use more than 7,000 highly reflective mirror facets (90 cm to 2 m in diameter). Each telescope has its own variation of camera, but the designs are all driven by the brightness and short duration of the Cherenkov light flash. Both photomultiplier tubes (PMTs) and silicon photomultipliers (SiPMs) will be used to convert the light in the cameras into an electrical signal which is then digitised and transmitted.

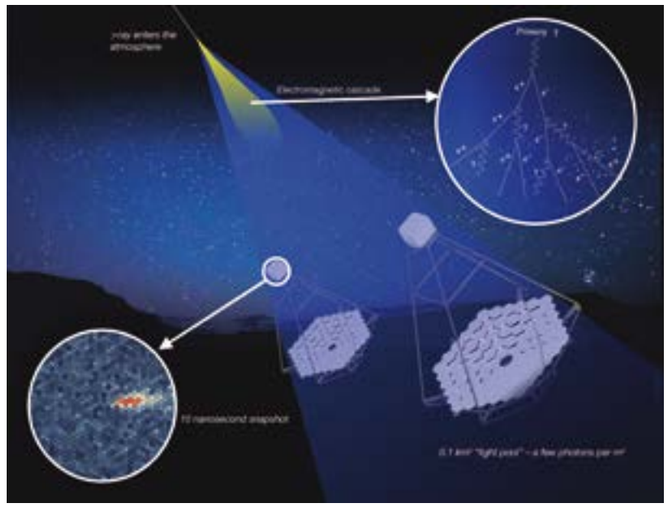


Figure 8: How IACTs indirectly detect a VHE gamma ray. Credit: CTA Consortium (https://www.cta-observatory.org/about/how-cta-works/).

While the northern hemisphere array will be more limited in size and will focus on the CTA's low- and mid-energy ranges from 20 GeV to 20 TeV, the southern hemisphere array will span the entire energy range of the CTA, covering gamma-ray energies from 20 GeV to 300 TeV. Figure 9 shows an artist's impression of the Northern array, which is being constructed at the Roque de los Muchachos observatory on the island of La Palma in the Canary archipelago. Three classes of telescope will be distributed in the northern and southern hemisphere based on their sensitivity: the Small-Sized Telescope (SST), with a 4 m diameter primary mirror; the Medium-Sized Telescope (MST), 12 m diameter; and the Large-Sized Telescope (LST), 23 m diameter. Because the SSTs are tuned to be the most sensitive to detect high-energy gamma rays, they are better suited to the southern site's detection of higher-energy gamma rays, while the MSTs and LSTs will be installed on both sites.

Figure 9: Northern Hemisphere Site Rendering. Credit: Gabriel Pérez Díaz, IAC, SMM.

IEEC members from the ICE-CSIC, ICCUB, and the CERES have been very active in the definition of the concept and in the development of the CTA from the very beginning thanks to their participation in MAGIC. The main initiatives of IEEC members in 2021 were the following:

Electronic developments for the CTA

IEEC members at the 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 the CTA. These ASICs allow for significantly better performance than available components in the market and with a significantly smaller power consumption and heating. The Pre-Amplifier for the CTA (PACTA) is part of the LST1 already installed at ORM, and the 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 the 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 2021, IEEC members managed the production of ASICs for the MST-NectarCAM 2-9 (PACTA, ACTA and L0-trigger). The reception of these units was delayed until December 2021 due to the COVID-19 pandemic, and their validation will extend to 2022. In addition, the production of the ACTA amplifier to include a pulse-injection functionality was completed, although the reception of these units was delayed until January 2022. On the other hand, the IEEC engineers, in collaboration with the Microelectronics section of the Electronics Systems for the Experiments group (ESE-ME) at CERN, designed an 8-channel 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 digitisation. This ASIC, which was validated during 2021, will be studied for future upgrades of the LSTs.

Commissioning of LST1

IEEC members at the ICCUB and the ICE-CSIC are members of the first Large Size Telescope (LST1) that was built at the CTA-North site and inaugurated in October 2018 (Figure 10). LST1 includes developments by the IEEC, in particular, camera electronics. The commissioning phase has suffered delays due to the COVID-19 pandemic and the eruption of the Cumbre Vieja volcano in La Palma in 2021, and it is expected to end in 2022. During 2021, apart from the testing of many subsystems on a regular basis, scientific observations have also been conducted regularly to test the reliability of the data taking process. In addition, apart from the Crab Nebula calibration observations, LST1 has detected several AGNs, most notably the BL Lac blazar during its outburst in July 2021 and other transient sources (Figure 11).

Figure 10: The Large Size Telescope 1 (LST1) at the Observatorio del Roque de los Muchachos (La Palma, Canary Islands, Spain).

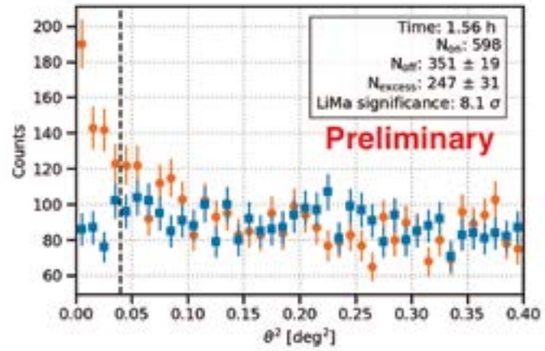


Figure 11: Detection of BL Lac by the LST-1 on the night of July 10 after an observation of 1.5 hours. The orange circle data points are the gamma-ray signal from BL Lac and the blue square data points are the background from cosmic-ray events. Credit: Daniel Morcuende (Universidad Complutense de Madrid).

Construction of LST2, LST3 and LST4 telescope cameras

Construction of the three remaining large-size telescopes (LST2-4) began in 2019, and several tendering calls were triggered from the Instituto de Astrofísica de Canarias (IAC) to carry out the construction of the different parts of the system. The IEEC and the Institut de Física d'Altes Energies (IFAE) 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 work was carried out through a "Unión Temporal de Empresas" (UTE – Temporary Union of Companies). The IEEC team at the ICCUB contributes with the camera electronics where, during 2021, the three remaining deliverables (810 L0-trigger units delivery) have been completed.

A second offer was submitted by the IEEC, involving teams from the ICE-CSIC and the 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 camera calibration and data visualisation and for weather monitoring data visualisation. The activities carried out are the consolidated design and the first release of the software, and a prototype GUI has been developed.

Coordination of CTA Array Calibration and Environmental Monitoring

The CERES member Markus Gaug has been coordinating this project since 2013, and he has participated in coordination meetings with the CTA Observatory and other projects involved on a monthly basis. As part of his duties, Markus Gaug represented the CTA in the SUCOSIP, the committee for the study and coordination of the site properties of the two IAC-owned observatories on the Canary Islands of Tenerife and La Palma. An outcome of this work established the potential impact of adaptive optics lasers on large optical telescopes, like the GTC, the TMT or ELT on the CTA (Gaug, M. & Doro, M., MNRAS, 481:727–748, 2018).

Weather monitoring system prototype

Lluís Font (CERES) is coordinating weather monitoring activities as part of the CCF project. In 2018, a collaboration was established between the CERES and ICE-CSIC groups, together with the CTA group of DESY-Zeuthen, to design a weather monitoring system prototype that includes an interface to the Telescope Control Unit ACS foreseen for LST1, the first Large Size Telescope that is already being commissioned on La Palma, a prototype stand-alone data acquisition system, and a test bench for prototypes of the CTA monitoring database and the CTA Graphical User Interfaces.

Commissioning of the CTA Barcelona Raman LIDAR prototype

An advanced Raman LIDAR optimised to fulfil the requirements of the CTA is being commissioned at the UAB campus. It is a key instrument to obtain the range-resolved and wavelength dependent atmospheric transmission in the line of sight of the telescopes, required to estimate the extinction of the Cherenkov light on its way to the telescope reflector surface. This Raman LIDAR has been designed and built as a collaboration between the CERES members, the IFAE group of the CTA, and other CTA members from Padova (Italy). It includes highly innovative elements, such as a 1.8 m diameter telescope and 8 mm liquid light guide. In 2018, we started the commissioning phase and demonstrated that the concept works. Figure 12 and Figure 13 show the Raman LIDAR and the signal obtained with three channels respectively.

Figure 12: The Barcelona Raman LIDAR after installation, seen in front of the LST-1 telescope (left); the green part of the laser beam can be observed, after exiting the system (right). Credit: Paolo Calisse (CTAO).

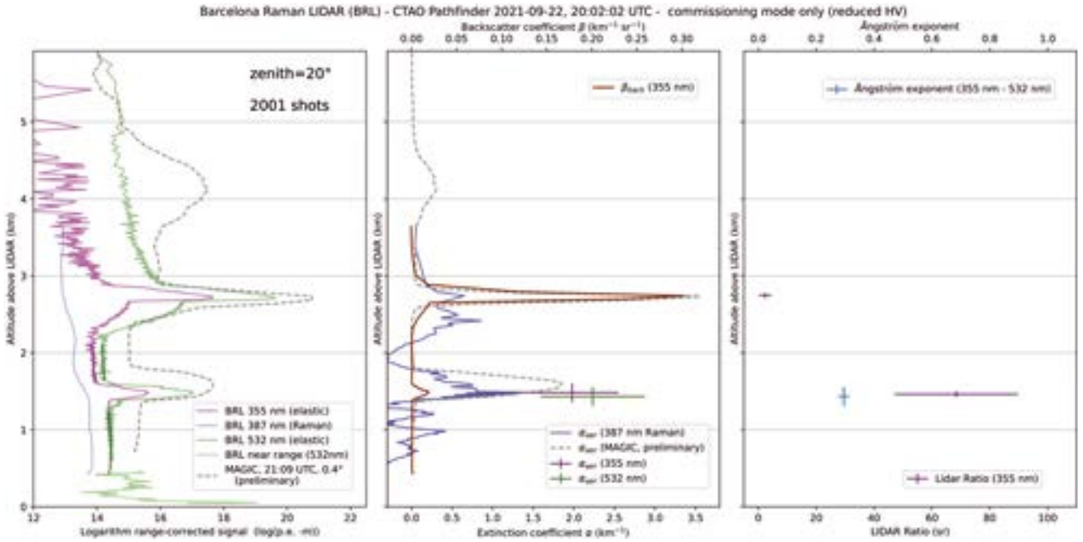


Figure 13: The range-corrected back-scatter profile as a function of altitude, observed at different wavelengths (left), and a preliminary analysis of the aerosol properties: backscatter and extinction coefficients (centre) and the Ångström exponent (right). The data indicate a volcanic ash layer at around 1.5 km altitude above the LIDAR. See also https://www.cta-observatory.org/brl-detects-volcano-dust-plume/.

CTA scheduler

Scheduling software applications for the operation of telescopes and space missions contribute to improving the scientific and technological exploitation of astronomical facilities. The 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. This expertise can also be extended to the concept of Multi-Facilities Scheduling, which is of enormous relevance in the context of the multiwavelength/multimessenger era of the large infrastructures 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 in terms of 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 very few professional operators.

The Cherenkov Telescope Array

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-CSIC. An initial release of the ACADA software, including the STS package, was finally published in June 2021. This first release (or R0) was focused on putting existing dispersed ACADA prototypes into a SW structure and official code repository, and on beginning to use the ACADA workflows and the environment for continuous integration and QA. 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 industrialised in accordance with 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 is also under the responsibility of the IEEC. The LTS scheduling algorithm is under development and 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. the Ariel mission of the European Space Agency).

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.

The Laser Interferometer Space Antenna (LISA, https://www.elisascience.org) will be the first space-borne gravitational wave observatory, an all-sky observatory that will offer a wide view of a dynamic cosmos using Gravitational Waves as new and unique messengers to unveil the Gravitational Universe. The mission was selected as the third large-class (L-class) mission of the European Space Agency (ESA) by its Senior Programme Committee (SPC) on 2 June 2017, with a launch expected in 2034. It 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 14). The main objective of LISA is to carry out the scientific programme that was presented in the document "The Gravitational Universe", approved by the 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. From these measurements we expect revolutionary discoveries in Astrophysics, Cosmology, and Fundamental Physics.

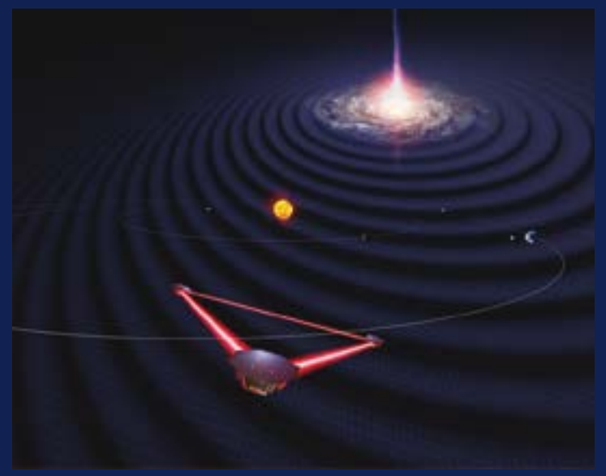


Figure 14: Artistic representation of LISA (the ESA-L3 mission). The constellation of three spacecraft is seen following a heliocentric orbit around the Sun following the Earth. In the background, a representation of the emission of gravitational waves by a binary system of supermassive black holes.

LISA

Figure 15: ESA's LISA Pathfinder payload, the "LISA Technology Package" (LTP), where all of the mission's science experiments were performed. Credit: ESA.

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, which 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 to 30 June 2017. LISA Pathfinder tested the fundamental concept of gravitational wave sensing in flight (see Figure 15): 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). On 7 June 2016, at the European Space Astronomy Centre (ESAC, near Madrid), the LISA Pathfinder collaboration announced the success of the LISA Pathfinder mission by showing an acceleration noise sensitivity curve that was much better than the one required initially (improvement factors are typically 5-1,000 depending on the frequency range) and very close to the one required by the LISA mission (see Figure 16).

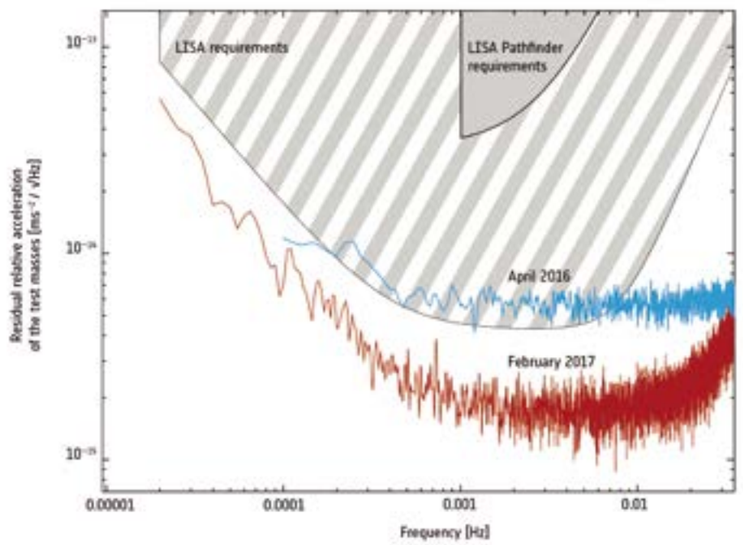


Figure 16: Parasitic differential acceleration of LISA Pathfinder test masses as a function of the frequency. The data refer to a long run of about 13 days taken at a temperature of 11 °C. Data are compared with LISA Pathfinder requirements and with LISA requirements. Fulfilling requirements implies that the noise must be below the corresponding shaded area at all frequencies.

The Gravitational Astronomy Group

The Gravitational Astronomy Group of the Institute of Space Sciences (ICE-CSIC) 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 UPC-IEEC and UB-IEEC groups) and has led the Spanish contribution to LISA Pathfinder (in collaboration with the UPC-IEEC and the Institut de Física d'Altes Energies (IFAE). 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 organises the member states' contributions to the LISA payload, and a member of the ESA's "LISA Science Study Team" (SST). Miquel Nofrarias (ICE-CSIC) is the Diagnostics Lead from the LISA Instrument Group (LIG), representing the Spanish contribution to the mission, and also a member of the ESA's LISA System Engineering Office (SEO). Josep Colomé (ICE-CSIC) acts as the Spanish LISA National Project Manager.

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 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 Diagnostics Subsystem, consisting of a series of sensors and actuators of high precision and unprecedented stability, together with all the associated electronics, which will provide essential information about the environment of the LISA measurement system. These diagnostics are: thermal (sensors and thermal actuators), magnetic (magnetometers, coils and electromagnetic antenna), and radiation (radiation monitor).

Figure 17: LETS test bench. The vacuum chamber includes a series of active and passive thermal shields to isolate the sensors inside from external temperature fluctuations.

Thanks to the expertise acquired with the LISA Pathfinder mission, the Gravitational Astronomy Group at the 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 readout and an ultra-stable test bench installed at the ICE-CSIC premises. Figure 17 shows the current setup under testing at the ICE-CSIC. M. Nofrarias is leading the IEEC in this international effort, together with the German Space Agency (DLR) and the company SENER Aeroespacial.

LISA

LISA has just finished phase A of design (December 2021), having successfully passed the Mission Formulation Review (MFR). The Gravitational Astronomy-LISA group (ICE-CSIC and IEEC), in collaboration with the UPC-IEEC and UB-IEEC groups (which constitute the LISA-IEEC group within the LISA International Consortium), has supported the ESA in the phase A studies to define a baseline design for the mission. In particular, working in collaboration with the two primes (Airbus, Thales), running parallel design studies and 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 other hand, the LISA-IEEC group participates in the LISA Data Challenges (LDCs). The main aim is to develop the necessary Data Analysis Tools for the future scientific exploitation of the mission. We also participate in the LISA Data Processing Group (LDPG), whose aim is to develop tools for the ground segment of the mission. Finally, different members of the LISA-IEEC group take part in the activities of several other 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, we also work on the description/simulation 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 maximise 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 contribution made by the group to these infrastructures will be its knowledge of experimental techniques of measurement at low frequencies, as well as its expertise in theoretical studies and data analysis techniques for Gravitational Wave Astronomy.

ARIEL

The Atmospheric Remote-sensing Exoplanet Large-survey (Ariel, https://arielmission.space) is an exciting mission that will address the fundamental questions concerning what exoplanets are made of and how planetary systems form and evolve, by investigating the atmospheres of many hundreds of diverse planets orbiting different types of stars. This large and unbiased survey will contribute to answering the first of the four ambitious questions listed in the European Space Agency’s (ESA) Cosmic Vision: “What are the conditions for planet formation and the emergence of life?”. Thousands of exoplanets have now been discovered with a huge range of masses, sizes and orbits: from rocky Earth-like planets to large gas giants grazing the surface of their host star. There is no known, discernible pattern linking the presence, size, or orbital parameters of a planet to the nature of its parent star. We have little idea whether the chemistry of a planet’s surface and atmosphere is linked to its formation environment, or whether the type of host star drives the physics and chemistry of the planet’s birth and evolution.

Ariel was selected by the ESA in March 2018 and adopted in October 2020 as the M4 mission of the Cosmic Vision programme, with a planned launch in 2029. Ariel will observe ~1000 transiting planets, including gas giants, Neptunes, super-Earths and Earth-size planets around a range of host star types. This comprehensive approach will underpin statistical understanding, generating robust conclusions which are simply not possible with smaller samples or patchy coverage of the relevant parameter space. Ariel will use transit spectroscopy with a 1 m class telescope in the 1.1-7.8 μm spectral range and photometry in multiple narrow bands covering the optical and near-infrared (NIR). The mission will focus on warm and hot planets to drive understanding of the early stages of planetary and atmospheric formation during the nebular phase and the following few million years. In this way, Ariel will provide a complete picture of the chemical nature of the exoplanets and relate this directly to the planetary parameters and the type and chemical environment of the host star.

For this ambitious scientific programme, Ariel is designed as a dedicated survey mission for transit and eclipse spectroscopy, capable of observing a large and well-defined planet sample within its 4-year mission lifetime. Transit, eclipse and phase-curve spectroscopy methods, whereby the signals 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 10-50 part per million (ppm) relative to the star. Given the brightness of the target host stars, more sophisticated techniques, such as eclipse mapping, will also be used to give deeper insights. These observations require a specifically designed, stable payload and satellite platform with broad, instantaneous wavelength coverage to detect many molecular species, probe the thermal structure, identify clouds and monitor the stellar activity.

ARIEL

The Ariel mission concept is developed by a consortium of more than 70 institutes from 17 countries. The IEEC is one of the co-PI institutes (co-PI: Ignasi Ribas) and leads the Spanish contribution (PI: Ignasi Ribas; National Project Manager: Josep Colomé), which also includes the Instituto de Astrofísica de Canarias and the Universidad Politécnica de Madrid. The IEEC, through researchers at the CSIC and UB, participates in various aspects of the mission, as shown in Figure 18, which illustrates the technical involvement.

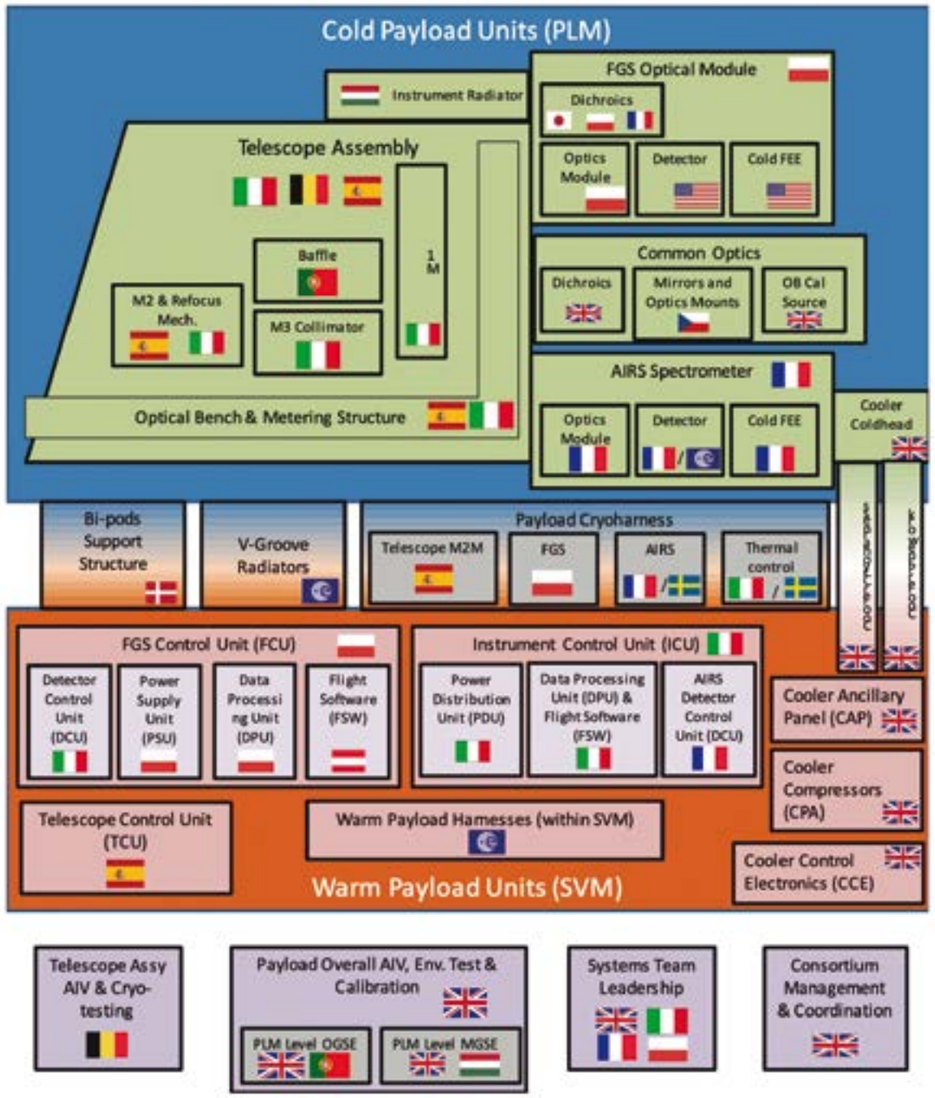


Figure 18: Ariel payload hardware block diagram. Credit: IEEC.

The IEEC's participation in Ariel has two aspects, one eminently scientific and the other of a technological nature. With regard to 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 in this way keep Ariel's data free of any bias.

With regard to technology, the IEEC is responsible for the design, implementation, assembly and verification of the Telescope Control Unit (TCU; diagram in Figure 19). It also controls the M2 refocusing mechanism under operation from the ground. It will also implement command handling, data formatting and communication with the Instrument Control Unit (ICU). To improve the robustness of the full Ariel payload, the TCU is cold-redundant. For this reason, the TCU elements are duplicated, one set being the nominal system and a second set the redundant system. The IEEC is using the expertise gained in previous missions (Solar Orbiter and LISA Pathfinder) for the development of flight electronics and software. The IEEC is also responsible for supervising the design and manufacture of the mechanisms of the secondary mirror (M2M) refocusing system, which is being developed via a PRODEX project by the company Sener Aeroespacial. The IEEC therefore holds responsibility for a critical part of the Ariel payload, from the electro-mechanics to the software logics. Furthermore, the IEEC leads the mission planning system by applying our expertise in scheduling techniques using artificial intelligence algorithms to ensure that observing time is fully optimised. This is a key building block of the Science Ground Segment of the mission.

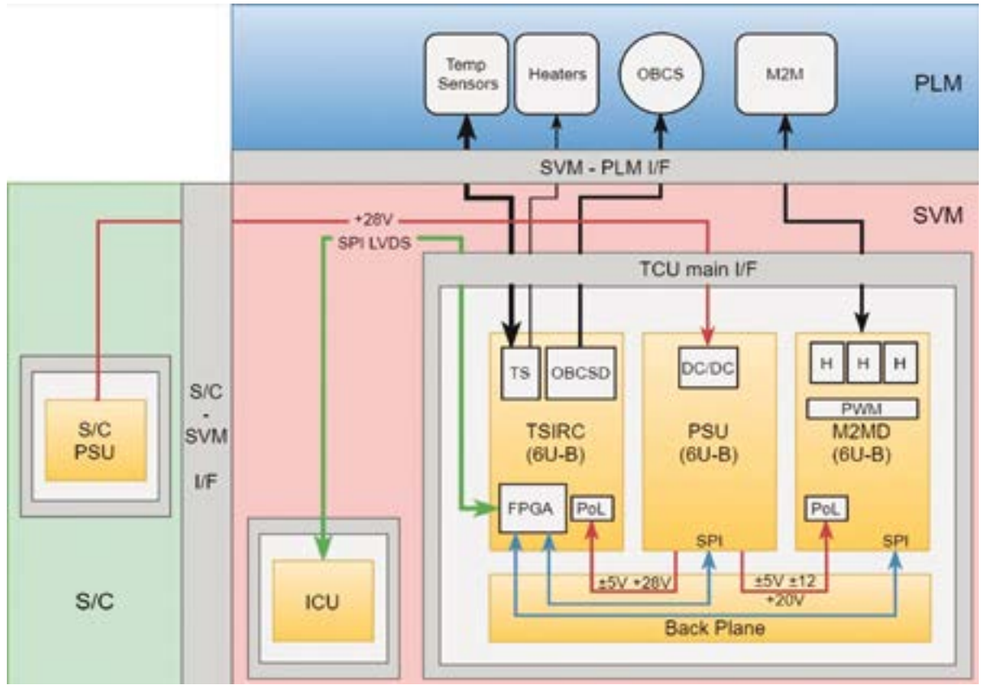


Figure 19: ARIEL TCU system block diagram. Credit: IEEC.

ARIEL

Ariel was selected by the ESA in March 2018 and adopted in October 2020 as the M4 mission of the Cosmic Vision programme, after a successful Payload System Requirements Review (pSRR) in Q2 2020 and a successful Mission Adoption Review (MAR) in Q3 2020. The successful MAR led to formalisation of the relationship between the ESA and the Ariel Mission Consortium through the signature of a Multilateral Agreement (MLA) in October 2020, whereby the Spanish contributions to the mission construction were consolidated, including payload and ground-segment work-packages. The current planned launch date of the Ariel mission is early 2029.

The technical activity during 2021 has been focused on preparing the System Readiness Review (SRR), which has culminated in the adoption of the mission by the ESA Space Programme Committee. The team has worked to increase the Technology Readiness Level (TRL) of the different subsystems. The objective was 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. The M2M requirements were fully consolidated and integrated as part of the Ariel telescope requirements specification. The M2M design was largely upgraded to fulfil the stringent requirements (Figure 20). A new motor-reducer, developed and manufactured by Sener Aeroespacial, will be used. The new motor-reducer is currently being qualified to work at the operational temperature of 40K and is expected to provide a much longer lifetime for M2M. However, most of the M2M development will occur as part of a new ESA-PRODEX project awarded to Sener Aeroespacial. This project represents a major milestone, since it ensures the funds needed to develop M2M until the mission launch.

Figure 20: New M2M motor-reducer design (left); upgraded M2M design (right). Credit: IEEC.

Regarding the TCU, work has focused on the development of the new design of the On-Board Calibration Unit Driver (OBCUD), as it includes not only a tungsten filament, but also LED emitters. Figure 21 (left) shows the thermal control system, including the multiplexer circuit and the high resolution analog-to-digital converter, while Figure 21 (right) shows the OBCUD. The latter includes the circuitry needed to drive the tungsten filament using a constant impedance control law. It also has high-precision current sources to control the LED that will help during the calibration process. The stability required for all systems is remarkable, and together with the M2M device, these are the most challenging aspects of the TCU. By the third quarter of 2021 all the subsystems were at TRL6, thereby reaching the objective.

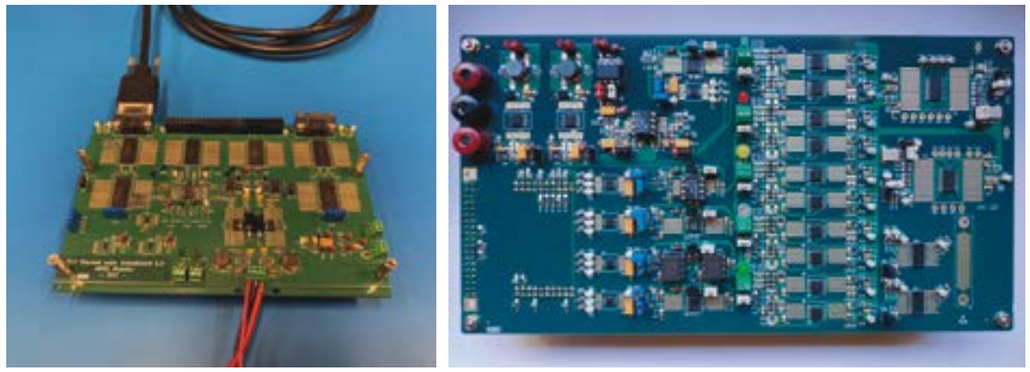


Figure 21: Thermal control (left); On-Board Calibration Unit Drive (right). Credit: IEEC.

During 2021, the company Sener Aeroespacial was awarded a contract after a tender process to support the IEEC in the design of the TCU. The activities have mainly been focused on the analysis of the thermal sensing circuitry and the power supply unit of the TCU. At the end of 2021, the baseline of Ariel was modified, and the OBCU is no longer part of the payload. As a result, the TCU is under a redefinition process that has to be finished during the first quarter of 2022, and a first functional model will be available by mid-2022.

At the IEEC, we are also contributing to the Ground Segment activities of the Ariel mission. In particular, we are responsible for the design and development of a scheduling software that will be used for the planning of the observations. An automatic tool is needed, because the goal is to study about 1,000 exoplanets by monitoring several transits/occultations and phase curves, which are time-constrained events. The large number of possible combinations makes the optimisation of the mission plan a crucial task. Different methods were investigated, including Artificial Intelligence techniques (evolutionary algorithms, particle swarm optimisation) and metaheuristic rules. During 2021, we have been testing different possibilities and we concluded that a hybrid approach combining metaheuristics and swarm optimisation provides the best performance. The simulation of the Ariel survey mission plan demonstrated that it is possible to fit the observation of ~1000 planets into the nominal mission lifetime of 3.5 years. Figure 22 shows an example of the timeline of tasks produced by the scheduler. Furthermore, the scheduler allows us to study the impact of including the observation of phase curves of several of the exoplanets, or the possibility of increasing the sample of exoplanets to be observed. Besides, it proved to be a useful tool to select the best planetary systems to be observed, taking the observability constraints into account. All these results have recently been published in the Experimental Astronomy journal , and a description of the algorithm has been submitted to the International Journal of Intelligent Systems.

ARIEL

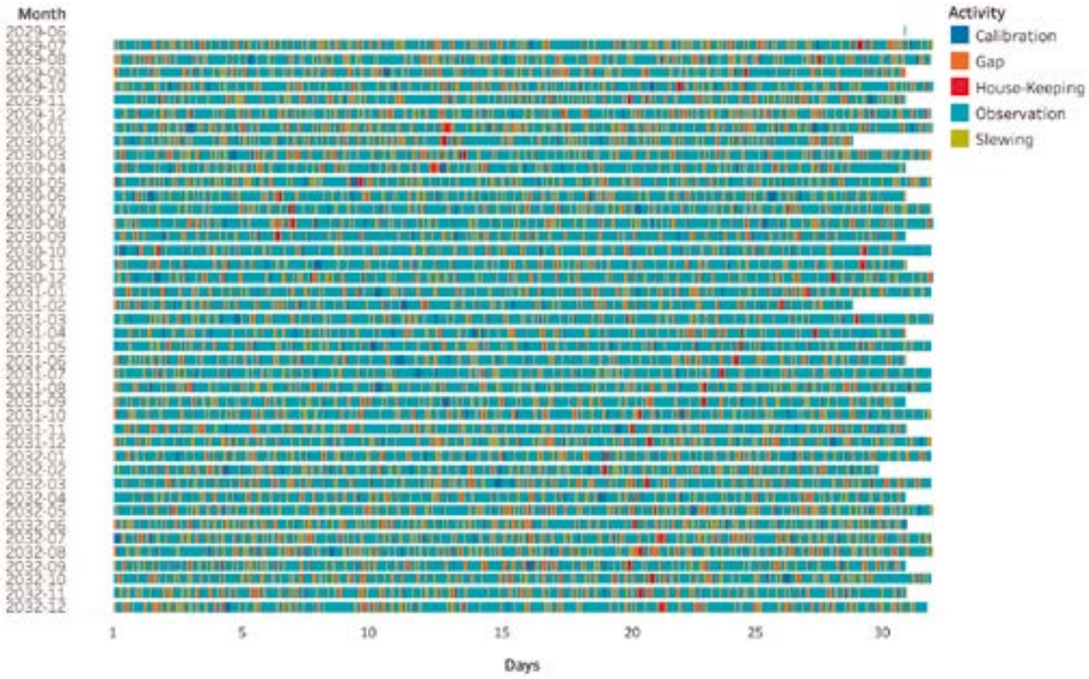


Figure 22: Timeline of a mission planning simulation of the Ariel survey using the scheduling software that is being developed at the IEEC. Each row corresponds to a different month, and each colour to a different task: target observation (cyan), calibration (dark blue), station keeping manoeuvres (red), and slewing between different telescope pointings (green). Periods of time not used for exoplanet transit/occultation observations are labelled as “gaps” (orange). The goal of the scheduler is to maximise the time making exoplanet observations. Credit: IEEC.

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. A major part of the work during 2021 has been focused on the improvement of the StarSim code. Initial studies carried out over the course of two PhD Theses (E. Herrero, A. Rosich) yielded the development of StarSim, which uses a physical model to simulate light curves in various passbands and spectroscopic time-series of rotating stars accounting for the effects of active regions. It holds the potential to become the ultimate tool to address activity-induced variability in radial velocities and transits. Our results show that only by using wide-band photometric monitoring can we retrieve a full set of meaningful stellar and activity parameters. The pilot studies that we have been performing validate a completely novel activity correction methodology for RVs and atmosphere transit spectrophotometry. The proposed methodology 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. With StarSim it will be possible to correct out activity effects in Ariel transit spectroscopy and determine fundamental properties of planet atmospheres.

NewSpace Strategy

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

The new space economy (or NewSpace) represents a disruptive leap in the use of space thanks to the deployment of small, cheaper, rapid-development satellites (nanosatellites). 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).

NewSpace provides a set of digital services and creates a new economy with strong growth. It 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, navigation, and telecommunications, such as the 5G network and the Internet of Things (IoT).

Figure 1: NASA begins testing a spacecraft designed to improve the robustness of CubeSat platforms. Credit: NASA’s Marshall Space Flight Center licensed CC BY-NC 2.0.

NewSpace Strategy

This is a change of paradigm for the space sector that contributes to a huge number of new applications for better management of the territory, ways in which to measure and mitigate the effects of climate change, the provision of homogeneous coverage of IoT and 5G, including remote areas of the territory, among many other initiatives. Therefore, NewSpace has a big impact on the services that end users receive from space.

NewSpace is based on the democratisation of access to space and the space industry. New private actors have appeared recently, seeking new opportunities in the exploration of space. It is a growing sector that will enter a 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 IEEC aims to grow the space sector, including academic and industrial activities, build a strong national space capability, invest in early-stage R&D and foster international collaboration. This work, in support of the Catalan NewSpace Strategy, aims to maximise economic and social benefits, as well as inform policy making for Catalonia. The IEEC contributes to the definition and execution of the Strategy, with key initiatives that cover R&D activities, talent support and retention, and the construction of key space- and ground-based infrastructures.

In 2021, the IEEC continued with the implementation of various initiatives begun in 2020 in addition to new initiative funded through a new agreement with the Catalan Government.

NewSpace Hub and space ecosystem

One of the key principles of the Catalan NewSpace Strategy is to support, consolidate, and grow the space ecosystem. Several initiatives have been taken in 2021 to achieve these goals, and the IEEC has collaborated in these. The main initiatives are listed below:

- Launch of the NewSpace Community within the Digital Catalonia Alliance (DCA), an initiative fostered by the Catalan Government and the i2CAT Foundation, in collaboration with the IEEC, the the Institut Cartogràfic i Geològic de Catalunya (ICGC) and the Barcelona Chamber of Commerce. Community members are listed on the DCA web site: https://dca.cat/ca/dca-newspace/.
- A report on the economic impact produced by the NewSpace economy in Catalonia was made by the Catalan government and the Barcelona Chamber of Commerce, in collaboration with i2Cat and the IEEC. This resulted from a mapping of the space sector and was based on the data provided by the members of the ecosystem. This mapping is very important, as it provides the most updated view of the ecosystem in Catalonia. It is also very useful to analyse the expected growth of the sector, according to the roadmaps of the different entities, and the impact on the economy measured in terms of revenue and number of new direct jobs to be created in the coming years. The report is available at: https://politiquesdigitals.gencat.cat/en/tic/estrategia-new-space-de-catalunya/index.html.
- An online international investment programme of 8 months' duration has been implemented to help start-ups: The Tech Tour Space 2021. It has been designed to help European start-ups that develop technological solutions in the Space sector or develop applications based on satellite data to boost their investment readiness and build relationships with investors. Hosted by the Government of Catalonia, under the NewSpace strategy, the Tech Tour Space 2021 has been organised by Tech Tour, in collaboration with acceleration and incubation programmes such as Go2Space-Hubs and Point.IoT, the European Union's Horizon 2020 initiatives; the i2CAT Foundation, the research and innovation centre focused on advanced digital technologies; the IEEC Foundation, the space science and technology research and innovation centre; and the KIMbcn Foundation, experts in knowledge economy and innovation in Catalonia. The "Catalonia Prize" has also been awarded for the first time within the framework of the Tech Tour Space programme, and the recipient has been Sateliot. The NanoSat Lab of the Universitat Politècnica de Catalunya · BarcelonaTech (UPC) is going to be offered to Sateliot as part of the Catalonia Prize, supported by the resources allocated for this purpose by the IEEC within the framework of the NewSpace Strategy of Catalonia. More information about the programme and the winners can be found at: https://techtour.com/events/2021/10/event-tech-tour-space-2021.html.
- NewSpace Economy 2.0 event: The second edition of the NewSpace Economy day was organised by the Catalan Government and the Barcelona Chamber of Commerce on 22 October 2021, with the collaboration of the IEEC and the participation of several IEEC members and researchers.
- A collaboration agreement has been signed between the IEEC and the Barcelona Chamber of Commerce, in order to jointly promote the space sector in Catalonia and collaborate in various national and international initiatives.

NewSpace Lab

The IEEC is leading the development of the Catalonia NewSpace Lab, an initiative coordinated by the Generalitat de Catalunya aimed at promoting, developing and strengthening key NewSpace infrastructure in Catalonia. Laboratories, equipment, capacities, and services across the whole NewSpace value chain are included, covering both academic and industrial backgrounds. Currently, a mapping of infrastructures is being carried out to identify the Catalan NewSpace ecosystem strengths and mid to long-term infrastructure opportunities.

The NewSpace Lab will define the framework for space and non-space agents to cooperate by developing, testing and validating NewSpace solutions in the upstream, midstream and downstream sectors. The goal is to create an innovative environment encouraging business and public

administration to work together to cultivate new technologies and services. This also implies fostering the growth of research and innovation centres, universities, incubators, accelerators and start-ups.

The IEEC provides direct support to the construction and maintenance of key laboratories and infrastructure in Catalonia for research in space science and technology. This is done by collaborating with its patron institutions through their respective research units. This infrastructure includes the NanoSat Lab linked to the UPC, the clean room of the Department of Electronic Engineering at CTE (UPC-IEEC), ICE-CSIC laboratories (clean rooms, radiation laboratory authorised by the Nuclear Safety Council - CSN, optical laboratory, and others), and laboratories and facilities located at the ICCUB (IEEC-UB) within the Science Park, as well as those of CERES (UAB-IEEC) located at the UAB campus.

Space missions: IoT and EO nanosatellites

Within the framework of the NewSpace Strategy for Catalonia, the IEEC is launching two missions to provide data services in two different areas:

- Earth observation (EO) mission (technically known as GENEO): A 6U nanosatellite (six units, according to the cubesat standard) with a Multispectral camera payload for obtaining images of the Earth from space in different spectral bands for the study of the territory (see Figure 2-left).
- Internet of Things (IoT) mission (technically known as GENIOT, and also known as *Enxaneta* after the poll organised by Catalan TV in which children participated in the proposal and selection of the mission name): A 3U nanosatellite and payload that provide wireless communication between terrestrial devices and satellites to offer connectivity in parts of the territory that are difficult to access or not covered by conventional terrestrial networks (see Figure 2-right).

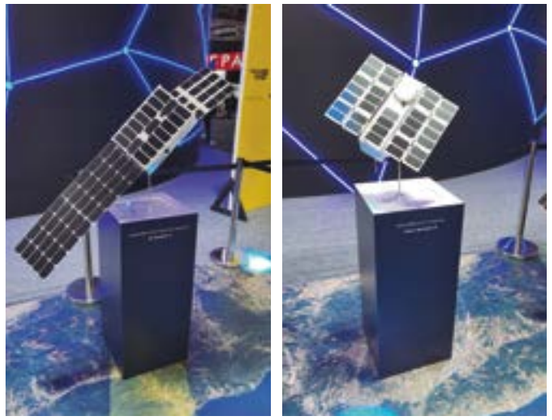


Figure 2: Mock-ups of the GENEO (left); GENIOT (*Enxaneta*) in scale 1:1 (right). Credit: IEEC.

These services are in line with the research and innovation activity of the IEEC with regard to the implementation of missions based on space technologies. They 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 are provided to the IEEC, which collaborates with other R&D centres, departments and bodies of the Generalitat de Catalunya in the study of different cases of use and their possible applications. In this respect, it is important to mention the close collaboration with with i2CAT and the ICGC. These services are ultimately aimed at creating an ecosystem that encourages the growth and consolidation of the NewSpace sector based on digital technologies.

Different phases have been implemented and various milestones have been achieved in 2021 by each of these two missions:

- GENEO achievements:
  - PDR (Preliminary Design Review) was successfully achieved in May 2021. This phase presents a preliminary design of the entire system, ensuring that all requirements are going to be met.
  - CDR (Critical Design Review) was successfully achieved in July 2021. This phase establishes the final design of the satellite, detailing all technical solutions and decisions.
- GENIOT achievements:
  - PDR (Preliminary Design Review) was successfully achieved in March 2021.
  - CDR (Critical Design Review) was successfully achieved in April 2021.
  - FRR: (Flight Readiness Review) was successfully achieved in November 2021. This phase defined all IoT services, from ground modems to satellite SDR.
  - Launch: 21 March 2021. GENIOT (named *Enxaneta*) was launched by a Soyuz-2.1A/Fregat. The prime satellite for this launch was a South Korean satellite (CAS500-1) for Earth Observation.

Adoption of satellite services by the Catalan administration

Considerable efforts are devoted to identifying high-level use cases in the Catalan administration, in order to promote the adoption of space-based data services that can cover existing needs. New applications are also foreseen thanks to the access to satellite and data processing services.

Many meetings have been held in 2021 with different Ministries of the Catalan administration, with the participation of Director Generals and their deputies from different departments covering infrastructure, safety, climate agenda and agriculture. Meetings with technical staff will continue in 2022, in order to extract a subset of tasks identified as pilot activities or technological challenges. Use cases will be prioritised and elaborated with the contribution of both public and private sectors, which will have to provide suitable solutions based on space data that benefit from public-private partnerships.

R&D activities

The IEEC actively collaborates with groups in the research units to identify early-stage R&D activities holding high innovation value that are suited to the goals of the Catalan NewSpace Strategy. New technologies in the upstream and downstream close to pre-commercial demonstration are fostered for their future transfer to the production sector. There are various successful examples of these kinds of mature technologies linked to Earth Observation, GNSS or telecommunication applications that reach high TRL based on IOD opportunities and/or reach the market in collaboration with industrial partners.

Two initiatives have received support from the IEEC in 2021, and others have been identified and selected for further funding support in the years to come.

Multipurpose platform C3SatP

The C3SatP project emerged with the aim of developing a versatile platform for nanosatellites (see Figure 3). 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), and it is funded by a grant from the Generalitat de Catalunya. Once the first phase was completed, the project continued to evolve and was adapted to specific applications, such as the GENEO mission. The main applications of the platform are those needed by Earth Observation missions that require processing of images on board the same satellite, with the use of Artificial Intelligence algorithms.

The C3SatP platform is going to be used in the EO nanosatellite (GENEO) mission that will be launched in 2022 within the framework of the IEEC satellite service contracts. The platform Flight Model has been implemented and integrated in 2021, in order to serve as the on-board secondary payload for technology demonstration and to gain the required flight heritage for use as a main payload in future missions.

Figure 3: Image of the C3SatP Flight Model with 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). Credit: IEEC.

The 3Cat-Gea project is focused on the implementation of a multipurpose Earth Observation Payload for the next satellite generation. It is composed of:

Software defined radio:

- GNSS receiver with built-in RFI detection and mitigation
  - GNSS reflectometer
  - Microwave Radiometer with built-in RFI detection and mitigation (different bands to be achieved using different RF front-ends)
  - RF spectrometer for RFI identification and analysis
  - IoT communications payload (LoRa, NBIoT…) or satellite / inter-satellite communications system at S- or X-bands (with the appropriate RF front-ends)
- Hyperspectral camera.
- Data compression algorithms and software.
- A high-performance platform (On-Board Computer) based on the C3SatP platform design and implementation, and with enough computing capability to run the software to pre-process the acquired data.

The activities carried out in 2021 have been the consolidation of knowledge to upgrade the C3SatP platform and extend its use and interfaces for integration with the on-board sensors (SDR, Hyperspectral camera). Data processing activities could not be covered and are expected to be carried out in 2022, together with the development of the engineering model for the electronics and software subsystems.

^{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 and resulting from different research projects funded through competitive funding calls.

Based on the experience gained with the ^{3}Cat-1 and the 3Cat-2, the UPC NanoSat Lab has designed the ^{3}Cat-4 with only one unit (1U) to demonstrate the suitability of this type of platform for performing Earth Observation applications with passive instruments. The ^{3}Cat-4 has a GNSS-R (Global Navigation Satellite System - Reflectometry) instrument capable of measuring various meteorological phenomena, geographical features and oceanic parameters, detecting and analysing the reflected signals from the constellations of satellite navigation systems. It will be launched in the Ariane 6 maiden flight.

The UPC NanoSat Lab has started the initial developments of a new mission, 3Cat-8, which includes innovative technological demonstrators (electrospray ion engine, automatic beacon, PocketQubes deployer, Fresnel Zone Plate -FZP- type deployable antenna) with two scientific experiments to obtain polarimetric images of the ionosphere, and ionospheric scintillation. Two of these PocketQubes will be financed by two grants from the IEEE for the development of the Open PocketQube kit.

NewSpace Strategy

FSSCAT mission

The FSSCat mission was developed in the NanoSat Lab of the UPC and was launched on 9 September 2020. It is a mission of two 6U cubesats (Cat-5/A and Cat-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).

The data analysis of the FSSCat mission was carried out during 2021 and appart from recovering soil moisture and polar ice, it allowed to recover water salinity over the arctic and antarctic seas. This was not considered initially in the mission goals due to its high difficulty.

HydroGNSS

HydroGNSS is the second mission of the European Space Agency's (ESA) Scout Programme, which aims to demonstrate the important role that small satellites—with a budget of less than €30 million and a three-year calendar—can play in Earth Observation. HydroGNSS complements other missions of the agency, such as SMOS and Biomass.

The HydroGNSS mission paves the way for a future constellation of small satellites that can offer measurements with a space-time resolution that is not accessible to traditional remote sensing satellites. This would provide a new tool for monitoring highly dynamic phenomena and help fill in the gaps in our monitoring of the Earth's vital signals in the future. This mission is funded by the ESA.

Efficient transmission of multi- and hyperspectral images for EO missions

NewSpace companies have not yet developed very advanced compression techniques: they either do not consider compression, or they use the JPEG (1993) standard for lossy compression or the PNG format for lossless compression. The IEEC has extensive expertise in image compression standard algorithms and can point to a long collaboration in the CCSDS standard definition and implementation with the ESA and other space entities. This technological research area and the software products developed to run on board have an important innovation impact, as they are key to maximising the efficiency of Earth Observation missions based on nanosatellites.

In 2021, the IEEC has collaborated with the ESA in this area with a new knowledge transfer contract (see KTO section for more information). In addition, the IEEC research groups at the ICCUB and the CERES implemented compression algorithms within the C3SatP platform for nanosatellites, and these will be tested in orbit as a key demonstrator activity planned in the GENEO mission.

LEO-PNT

Low-Earth orbit (LEO) PNT technologies can allow for alternative Positioning, Navigation and Timing systems, complementing the existing Global Navigation Satellite Systems (GNSS) by means of a higher number of LEO satellites, stronger signal strength and higher speeds, contributing to the geometric diversity of signals. This can promote a wide range of applications within a variety of fields, including mobility, logistics, smart cities and climate change monitoring, among others. Within the IEEC, there are key research groups working on LEO PNT signal quality, resilience with respect to GNSS and their usage for low-cost and low power consumption Internet of Things (IoT) devices (SPCOMNAV at UAB-IEEC), and their potential usage for precise positioning and atmospheric sciences (UPC-IonSAT at UPC-IEEC).

In particular, and since 2020, the SPCOMNAV research group at the UAB unit has conducted several knowledge transfer projects, mainly for the ESA, to investigate and pave the way for future LEO PNT alternative approaches to the classic MEO-based GNSS PNT. In this context, SPCOMNAV has been responsible for analysing chirp spread spectrum signal modulation for positioning with LEO satellites, enabling low-cost and low-energy solutions of special relevance for IoT devices. More recently, SPCOMNAV has been actively contributing to the design, development and testing of the baseband algorithms for the acquisition and tracking of the new LEO-PNT signals at user equipment level. Moreover, they are working on a testbed for the remote monitoring of GNSS and LEO satellites, making use of cloud computing for signal processing and quality assessment.

Infrastructures

Sant Esteve de la Sarga Teleport for satellite TT-TC at the Montsec Observatory

The IEEC manages the operations of the Montsec Observatory (OdM), located in Sant Esteve de la Sarga (Pallars Jussà, Lleida). The Observatory is in a privileged position, since it has an obstacle-free horizon that allows optimal visibility in all directions, leading to 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 excellent conditions.

NewSpace Strategy

The OdM hosts the Montsec Satellite Ground Station (SGSMontsec), which was developed by the NanoSat Lab of the UPC and is operated and managed in collaboration with the IEEC (see Figure 4). It is composed of UHF/VHF and S-Band antennas. A key part of each space mission lies in the ability of the ground segment (GS) to contact the satellite in order to transmit remote controls and receive the results of scientific measurements or telemetry data that the system has acquired. Therefore, the SGSMontsec plays a key role in supporting the space missions launched by the IEEC.

Figure 4: Detail of the Montsec Satellite Ground Station (SGSMontsec), located at the Montsec Observatory (OdM). Credit: IEEC.

The S-Band antenna upgrade has been partially carried out in 2021, and it is expected to finish in Q2-2022. The upgrade is focused on providing transmission capacity and enabling the use of the SGSMontsec as the reference ground station for Spanish satellites. In parallel, the procedure has been commenced to gain official certification as a formal ground station from the Spanish Ministry, so that it may communicate with the GENIOT-*Enxaneta* and GENEO satellites as the reference station.

On the other hand, in 2021 the IEEC has completed the technical report and the market analysis to prepare the way for the construction of the industrial teleport at the Montsec Observatory. The technical report has been prepared by following the technical needs and the sector trends for the coming decade, stating the baseline needs that should be covered in the short- and mid-term timescales. The market analysis has been completed in collaboration with the KIM Barcelona Foundation, which has undertaken an exhaustive comparative analysis, consulting the market on the economic feasibility and the potential exploitation models for the industrial teleport planned.

SpacePort at the Alguaire Airport

Innovative technologies and operational solutions for easy and cheaper access to space are of fundamental strategic importance to the space sector world-wide. This access has been identified as a strategic priority by the European Union in full alignment with the EU Access to Space Programme.

Industry and academia in the Catalan space ecosystem are working in this key area from different perspectives, as they look for synergies to develop disruptive solutions that can compete at an international level.

Clearly, it is very important to have a suitable site with testing facilities to speed up the development process. Alguaire Airport (see Figure 5) has been used as the testing facility for several companies and universities in recent years (Pangea Aerospace Company and Cosmic Research UPC students association). It has shown that it has excellent conditions to grow as the site for this emerging industry. Therefore, it is identified in the NewSpace Strategy as the best location to develop a Space Port with three main areas:

- Spaceport: the first in Catalonia and one of the first in Europe dedicated to suborbital or orbital flight missions based on horizontal launch.
- Propulsion test centre for rocket engines.
- Business park: key in the NewSpace space sector, including educational centres for technology companies linked to the space and research centres.

Figure 5: View of Alguaire Airport. Credit: Aeroports de Catalunya.

A general collaboration agreement was signed in 2021 between the IEEC and Aeroports de Catalunya, in order to jointly promote the construction of the test centre and the spaceport at Alguaire Airport. The first steps to develop the test centre for rocket engines have been made, based on the following goals:

- Testing of rocket engines under controlled conditions. Ignition tests, experimental data generation and testing of protocols. Pre-commercial disruptive technology validation.
- Environmentally friendly model: priority fuels with low ecological impact (Hydrogen, Methane).
- Incremental development as a test centre for:
  - Subcomponents (low cost, high profitability in the short to medium term).
  - Low / medium power engines (medium / high cost, high profitability in the medium to long term).
  - High power engines (high cost, low profitability in the medium-long term) have been discarded and will be evaluated once the previous phases have been completed.

Knowledge Transfer

One of the main missions of the IEEC is to facilitate the transfer of knowledge and the space technologies generated, in order to achieve greater impact and benefit for the institute, companies and society. The institute engages in 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 portfolio drawn from its scientific and technological production of excellence, structured in four scientific-technological units (Research Units) with the capacity to raise challenges on the knowledge frontier. These units are led by a very competitive group of teams in space science and instrumentation with a high degree of internationalisation. The high level of complementarity between the scientific and technological fields is based on the fact that space is not just an object of research in itself, but also a means to pave the way for new methodologies and technologies to generate knowledge beyond the current state of the art. Historically, and especially over the last few decades, research in the space science field has transformed the world we live in, impacting people's lives at multiple levels.

Collaboration with the space industry, especially the so-called Traditional Space industry and, to a lesser extent, the NewSpace industry, mainly takes place through industrial contracts funded by state-level projects (Spanish Plan Estatal de I+D+i and, more recently, the European Space Agency, ESA, PRODEX) aimed at the construction of large scientific missions (e.g. LISA Pathfinder, Gaia, Solar Orbiter, etc.). These funding mechanisms for industrial contributions are the usual mechanisms for ESA missions. The active participation and leadership of IEEC researchers and engineers is required in the definition and construction phase of the mission, in order to attain significant responsibilities and contributions for high visibility. Successful participation in these missions has a powerful impact on the industrial network and enables high value-added technologies and scientific tools to be exported. The IEEC is particularly effective in this regard and currently leads the Spanish contribution in ESA missions such as LISA, ARIEL and the Chinese mission in which the ESA participates, eXTP. This 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 NewSpace industry, agreements are established and technological development projects are executed, especially in the field of Earth Observation. The IEEC has collaborated, for example, with companies such as Thales Alenia Space (France), Spire (UK), Tyvak (USA), and GomSpace (Denmark), and it has ongoing missions for the launch of nanosatellites within the framework of the Catalan New Space Strategy approved in October 2020, and the technology demonstration programmes of the ESA. It is also important to mention the commitment to developing capabilities on the ground segment and downstream, with the Satellite Ground Station developed by the Universitat Politècnica de Catalunya · BarcelonaTech (UPC) at the Montsec Observatory (SGSMontsec) and devoted to satellite communications, and technologies for data compression, management, and processing for various applications. In this context, Low Earth Orbit (LEO) Positioning Navigation and Timing (PNT) developments have also been conducted.

Finally and importantly, the IEEC also collaborates closely with the transfer offices belonging to the different trustee institutions for knowledge transfer promotion at all levels.

Successful innovation cases

Examples of new and ongoing transfer and innovation agreements in 2021 include a collaboration agreement related to the Montsec Observatory for the S-band SGSMontsec, astronomy and atmospheric sciences projects, scientific infrastructures, space mission developments, including proposals for new future missions and projects developing optical and magnetic sensors, contributions to EGNOS and Galileo augmentation and positioning systems, as well as data compression developments. Knowledge transfer is linked to direct contracts and agreements with industry, agencies (ESA, EUSPA, EUMETSAT) and government entities (i-CERCA, CDTI), and through European consortia within the framework of H2020 projects.

Below is a list of the new and ongoing innovation and transfer projects in which the PI is an IEEC member and/or the IEEC and/or one (or more) of its scientific units is responsible for management of the project. The activities are grouped by topic, taking ESA topics as a reference, as shown in Figure 1, which illustrates the ESA budget distributed by domain for 2022. In this way, a label is provided for most of the innovation activities carried out by the research groups, identifying the area of knowledge involved.

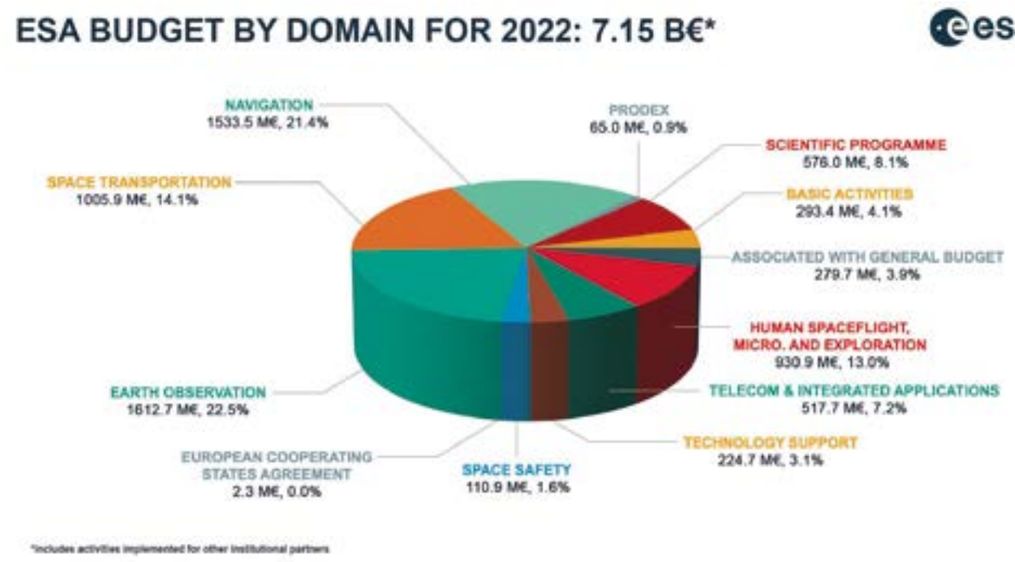


Figure 1: ESA budget for 2022 distributed by domain.

Scientific/Technology Research Programmes

KTT Contract: Optical Fiber Micro-Kelvin Temperature Sensor Network for Sensitive Optical Payloads (LIRA)

The main objective of the current ITT is the design of an optical fibre temperature subsystem prototype (TRL4) for the future gravitational wave observatory LISA. The design of the current proposal builds upon the experience of the IEEC-led team in the design of the LISA Pathfinder temperature diagnostic subsystem, the analysis of the results obtained during the LISA Pathfinder operations phase with the aforementioned subsystem and, finally, the expertise acquired with the LETS (LISA Enhanced Temperature Subsystem) contract (4000127051/19/NL/BW). The study is coordinated by the IEEC and carried out together with INESCTEC, with responsibility for the design and implementation of the optical fibre sensor head, requiring a dedicated design.

Coordinator: Miquel Nofrarias (IEEC-CSIC)
Funding Institution: European Space Agency (Contract No. 4000135481/21/NL/AR)
Partners: IEEC, INESC TEC (Portugal)
Duration: 09/2021-03/2023

KTT Contract: OSIP - GNSS Astronomy: characterisation of EUV stellar superflares detection and first multi-GNSS test bed

This project aims to show the capability to test a new field of astronomy: GNSS astronomy. GNSS (Global Navigation Satellite System) has recently been used to detect and source stellar superflares. The technology has the potential to contribute to other major astronomical questions, such as determining the habitable zones of stars recently discovered to host exoplanets. In particular, this relies on the indirect real-time solar flare detection and estimation of the associated flare EUV flux rate measurement with the existing GNSS infrastructure, and it draws on the usage of the overall Earth's ionosphere as a giant sensor for the detection of extreme flaring events from stellar sources.

Coordinator: Manuel Hernández-Pajares (IEEC-UPC)
Funding Institution: European Space Agency
Duration: 05/2021-12/2022

Earth Observation

KTT Contract: 2nd Scout Mission HydroGNSS

The IEEC, as partner in the HydroGNSS mission proposal to the ESA's Scout Programme, is subcontracted to Surrey Satellite Technologies Ltd (SSTL, UK) to contribute to the implementation of the mission, planned for launch in 2024. The IEEC supports SSTL in developing parts of the End-to-end simulator (E2ES), a package of software to process ultra-low level data (intermediate frequency samples of unprocessed signals) once downloaded into ground, and the official ground based algorithms to generate level-2 products related to inundation of the surface (flooding, wetlands...)..

Coordinator: Estel Cardellach (IEEC-CSIC)
Funding Institution: European Space Agency
Partners: SSTL UK, La Sapienza University (Italy), Finnish Meteorological Institute (FMI, Finland); National Oceanographic Centre (NOC, UK), Tor Vergata University (Italy), IFAC-CNR (Italy), University of Nottingham (UK)
Duration: 2021-2026

KTT Contract: Sentinel-3 CD – Topography and GNSS Reflectometry for data processing over sea ice

The objective of this activity consists in advancing: a) in the theory and processing of ideal grazing GNSS reflectometry (specular surface and no atmosphere), b) in the modelling of surface reflection over lakes, open ocean and sea ice, c) in the modelling of ionospheric and tropospheric effects and their correction, and d) in the acquisition of further co-located data sets with Sentinel-3 over instrumented lakes using all acquired raw data sets (those in Table 1 plus the 3 new acquisitions) and supporting ancillary data from other sources (such as Sentinel-3 altimetry and surface roughness, meteorological ground-based stations, weather balloons, TEC maps from IGS, information on physical conditions from ECMWF, SMOS-Cryosat derived sea ice thickness, SAR satellite images, etc...). The activity will cover all objectives, but with a focus on inland water bodies and sea-ice altimetry. Advancing and consolidating this alternative technique could provide means to validate Sentinel 3 acquisition over lakes (and other surfaces) where in situ measurements are not available.

Coordinator: Weiqiang Li (IEEC-CSIC)
Funding Institution: European Space Agency
Duration: 12/2021-12/2022

KTT Contract: MAXSS – Marine Atmosphere eXtreme Satellite Synergy

The primary objective of the ESA Marine Atmosphere eXtreme Satellite Synergy (MAXSS) project is to provide guidance and innovative methodologies to maximise the synergetic use of available Earth Observation data (satellite, in situ) to improve understanding about the multi-scale dynamic characteristics of extreme air-sea interaction. In MAXSS, three developments are conducted: (1) The development of a Multi-Mission Wind Product, (2) The development of an extreme Winds (severe storm, cyclone) atlas, and (3) The development of added-value products to analyse storms.

Coordinator: Estel Cardellach (IEEC-CSIC)
Funding Institution: European Space Agency
Partners: SSTL UK, La Sapienza University (Italy), Finnish Meteorological Institute (FMI, Finland); National Oceanographic Centre (NOC, UK), Tor Vergata University (Italy), IFAC-CNR (Italy), University of Nottingham (UK)
Duration: 01/2021-01/2023

KTT Contract: PITHIA-NRF - Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities

PITHIA-NRF aims to build a European distributed network that integrates observing facilities, data processing tools and prediction models dedicated to ionosphere, thermosphere and plasmasphere research. For the first time, PITHIA-NRF integrates on a European scale, and opens up to all European researchers, key national and regional research infrastructures, such as EISCAT, LOFAR, Ionosondes and Digisondes, GNSS receivers, Doppler sounding systems, riometers, and VLF receivers, ensuring optimal use and joint development. PITHIA-NRF is designed to provide organised access to experimental facilities, FAIR data, standardised data products, training and innovation services. Furthermore, PITHIA-NRF facilitates research advances in the field of upper atmosphere and near-Earth space, through the integration of data collections from satellite missions (such as Cluster, DEMETER, Swarm and CHAMP) and results from key prediction models, which can be accessed by scientific users for joint exploitation with the data collected from the research infrastructures of the network. IEEC-UPC group operates the node of thermosphere-ionosphere coupling models based on ground and space-based GNSS data providing hands-on access to research users. In addition to this, the group strongly contributes to the registration of data and models in PITHIA-NRF e-science centre, and participates in training, dissemination and innovation activities.

Coordinator: Manuel Hernández-Pajares (IEEC-UPC)
Funding Institution: European Commission (H2020 Grant Agreement no 101007599; H2020-INFRAIA-2018-2020)
Duration: 04/2021-03/2025

Navigation

KTT Contract: LEO-PNT-USER - Proof of Concept of user segments technologies for complementary LEO system

The objective of this project is to develop enabling technologies at user equipment level related to hardware, algorithms (baseband and positioning engines), and access to the candidate frequency bands, as a contribution to the technical understanding of the LEO PNT landscape. The project will produce a testing environment, combining simulation, laboratory and field trials, to demonstrate and assess the performance of LEO-based positioning in different frequency bands (from VHF to S-band), different use cases (outdoor and indoor, low-energy consumption, static or dynamic user, etc.) and different positioning techniques (hybridisation with other measurement, code or carrier-phase based positioning, etc.). SPCOMNAV is in charge of the design, development and testing of the baseband algorithms for the acquisition and tracking of the new LEO-PNT signals.

Coordinator: Gonzalo Seco-Granados (IEEC-UAB)
Funding institution: European Space Agency
Partners: Thales Alenia Space (France), Thales Alenia Space (Italy), IEEC (Spain), Orolia (France), Saphirion (Switzerland)
Duration: 02/2021–01/2023

KTT Contract: EGNOS-NEXT – EGNOS Evolutions Systems Engineering (Phase 0/A1)

The aim of this activity is to prepare for future stages of EGNOS developments to support the consolidation of future EGNOS Evolutions HLD (eHLD). The study will assess the System feasibility (Phase 0/A1) to preliminary mission requirements, assessing expected system performances, security constraints, dependability and safety goals. It also supports the definition of the EGNOS Evolutions roadmap presenting different implementation scenarios, where trade-off analyses are performed considering time-to-service, cost, architecture complexity and performances. SPCOMNAV is in charge of the SBAS E5b signal design.

Coordinator: Gonzalo Seco-Granados (IEEC-UAB)
Funding institution: European Space Agency
Partners: GMV (Spain), GMV GmbH (Germany), UAB (Spain), Qascom (Italy)
Duration: 09/2021–08/2023

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

In this project, we have developed a full implementation of the OSNMA protocol in open-source code. It is probably the first implementation publicly available. OSNMA is an integral function of the Galileo Open Service, providing data authentication to all enabled receivers. OSNMA is authenticating data for geolocation information from the Open Service through the Navigation Message (I/NAV) broadcast on the E1B signal component. This is executed by transmitting authentication specific data in previously reserved fields of the E1 I/NAV message. The transmission of OSNMA data was started in December 2021.

Coordinator: Gonzalo Seco-Granados (IEEC-UAB)
Funding institution: European Union Agency for the Space Programme (EUSPA)
Duration: 01/2021–05/2021

KTT Contract: PAULA - Test Platform on Galileo HAS/CAS/OSNMA

The objective of this project is to study and test the benefits that can be obtained from the Galileo High Accuracy Service (HAS), Commercial Authentication Service (CAS) and Open Service Navigation Message Authentication (OSNMA) service, in standalone mode or in combination with other technologies for improving the Position, Navigation and Timing (PNT) performance and robustness. SPCOMNAV's contribution to the project consists in the study, provision of implementation guidelines and test of the semi-assisted CAS, considering in particular how it can be used for initialisation of OSNMA synchronisation. Advanced anti-spoofing and signal integrity techniques are also investigated.

Coordinator: Gonzalo Seco-Granados (IEEC-UAB)
Funding institution: European Commission (EC No DEFIS/2020/OP/0002)
Partners: GMV (Spain), Qascom (Italy), IEEC (Spain), Finnish Geospatial Research Institute (Finland), Université catholique de Louvain (Belgium).
Duration: 01/2021–10/2022

Space Safety

KTT Contract: SWESNET - Space Weather Service Network

The Space Weather Service Network in the ESA Space Safety programme consists of five expert service centres that provide crucial information on the space weather situation. The network provides services in the following domains: Solar Weather, Heliospheric Weather, Space Radiation, Ionospheric Weather and Geomagnetic Conditions. The IEEC-UPC group participates as part of the Ionospheric Weather expert service centre, contributing with real-time services for the GNSS-based solar flares' detection and monitorisation based on the world-wide distributed network of permanent GNSS receivers. Alerts are also triggered in case of solar flares impacting the Earth's ionosphere.

Coordinator: Manuel Hernández-Pajares (IEEC-UPC)
Funding Institution: European Space Agency
Partners: BIRA-IASB (Belgium); 42 Europe-wide partners.
Duration: 02/2021-02/2023

Telecom

KTT Contract: WhiteDwarf

This project dealt with the maintenance of the ESA's Whitedwarf suite of CCSDS data compressors and decompressors, with the objective of ensuring high quality implementations of compression standards CCSDS 121.0-B-3, CCSDS 122.0-B-2, and CCSDS 123.0-B-2. The ESA's existing implementations required extensive modifications to either correct known defects, or to be upgraded to the latest versions of the standards. Hence the project included extensive rewrites of the aforementioned software suite, including a full implementation of a CCSDS 122.0-B-2 decoder created from scratch, as well as a significant testing and validation campaign so that they could be used as reference models in other projects.

Coordinator: Joan Serra-Sagristà, Ian Blanes (IEEC-UAB)
Funding Institution: European Space Agency
Duration: 01/2021-12/2021

Planetary Exploration Technologies

IEEC Contract: MELISA – MEMS miniaturised low-noise magnetic field sensor for LISA

The objective of MELISA (MEMS miniaturised low-noise magnetic field sensor for LISA) is the design and fabrication of a prototype (TRL4) magnetic field sensor implementing magnetic field modulation by means of micromechanical resonators. The prototype will show the feasibility of applying this noise-reduction technique to fulfil the stringent requirements of the LISA mission. The proposal plans to explore the exploitation of the resulting high performance sensor for its application in surface planetary exploration missions and Cubesats in LEO or other planetary bodies' orbits.

Coordinator: Manuel Domínguez Pumar (IEEC-UPC)
Funding Institution: CERCA & IEEC
IEEC units: IEEC-UPC, IEEC-CSIC, IEEC-UB
Duration: 04/2021-05/2022

KTT Contract: MiniPINS – Miniature Planetary In-situ Sensors (CCN extension)

MiniPINS is an ESA study to develop and prototype miniaturised surface sensor packages (SSPs) for Mars and the Moon. The study aims at miniaturising the scientific sensors and subsystems, as well as identifying and utilising commonalities of the packages, making it possible to optimise the design, cut costs and reduce the development time. The group has participated in the analysis and selection process of the different sensor systems in view of the multiple science requirements and mission constraints. The group has also participated in the prototyping of some of the sensor systems that have been selected for demonstration in the contract. Specific effort is devoted to the miniaturisation of the different electronic and sensor systems. SSPs are capable of working on the surface of Mars or the Moon and they can produce high quality science data with state of art instrumentation. In particular, Mars SSP MINS is a penetrator with approx. 25 kg mass, piggy-backed by another Mars mission spacecraft to the Martian orbit and deployed from there. The science programme is focused on the study of Mars' atmosphere, seismology, magnetic field and chemistry. The Moon SSP will be a miniature 5 kg station deployed on the Moon's surface by a rover. Both Mars and Moon SSPs will be miniaturised, light and robust, and still capable of surviving high G loads and extreme thermal environments. The output of this contract will enable the ESA to prepare the technological programmes required for these ambitious planetary missions.

Coordinator: Manuel Domínguez Pumar (IEEC-UPC)
Funding Institution: European Space Agency
Partners: FMI, INTA, SCIS-INTA, AVS, UPC, IMSE, IMDEA, Talvioja Consulting Ltd.
Duration: 04/2021-10/2021

Ground Segment

Collaboration Agreement for the exploitation of the S-band Ground Station at Montsec Observatory

Collaboration Agreement between the UPC and the IEEC for the creation of the scientific infrastructure that consists of the S-band Ground Station for LEO-orbit satellite communications, located at Montsec Observatory (OdM). The agreement establishes the conditions for its installation, exploitation and operations.

Entities: UPC BarcelonaTech & IEEC
Responsibility: Ignasi Ribas, Adriano Camps, Josep Colomé
Duration: 01/2021-01/2031

Networks

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 this community to maintain its leadership in the study of our Galaxy, its stars and planets, while enabling 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 IEEC member at the ICCUB, 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 2021 were mostly in virtual or hybrid formats: four workshops, one school and few exchange visits were organised. Within the network, the ICCUB organised and hosted the workshop “Star clusters: the Gaia revolution” (5-7 October 2021). A Virtual Mobility grants programme, coordinated by the IEEC member at the ICCUB, Lola Balaguer-Núñez, was put in place. The aim is to strengthen the MW-Gaia networks by allowing individual participants to foster collaboration, exchange knowledge, learn new techniques, etc., performing activities that do not necessarily require in-person presence.

PHAROS

The multi-messenger Physics and Astrophysics of Neutron Stars (PHAROS) network is an ESF-COST Action lasting four years (autumn 2017 - spring 2022), aimed at studying neutron stars via a multi-disciplinary approach. In the years thereafter, the recent discovery of gravitational waves will allow 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 in which the most extreme gravity and electromagnetism can be probed, and 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 runs from particle and nuclear physics to astrophysics, from experiment to theory, from gravitational waves to the electromagnetic spectrum.

This COST Action is led by the ICE-CSIC 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 the different communities with several tools and deliverables prepared in a shared language and easily accessible to scientists coming from different physics disciplines, 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 multidisciplinary 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 there is a crucial need for brainpower and resources from complementary kinds of expertise.

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 the IEEC at the ICE-CSIC 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, we were only able to organise one event in 2021, a PhD school on nuclear physics in Poland. We produced two outreach projects focused on disseminating our scientific research on neutron stars: 1) “A Star Blast: a VR tour of the outcome of stellar explosions”, and 2) “Simulation: Gravitational waves from eccentric compact binaries”. They can be found on the PHAROS website: http://www.pharos.ice.csic.es/.

25th IEEC Anniversary

The IEEC Forum 2021, celebrating a quarter of a century

On 9 June 2021, the 3rd IEEC Forum took place at the Centre de Cultura Contemporània de Barcelona (CCCB). This year's edition was a special one, as it also formed part of the activities organised to celebrate the 25th anniversary of the IEEC's founding, on 6 February 1996. At the same time, it was one of the first face-to-face events held by the Institute after more than a year, in accordance with the safety protocol and general COVID-19 measures established by the health authorities.

The event, which gathered more than 80 attendees, opened with a welcome speech from Ignasi Ribas, director of the IEEC, who also gave a general presentation about the Institute. The afternoon continued with an appraisal of the IEEC's leading role in the NewSpace environment in Catalonia, focusing on the NewSpace activities currently overseen by the IEEC, the Satellite Ground Station at Montsec Observatory (SGSMontsec) and the future of NewSpace.

Next, the proposals submitted to the IEEC Internal Call, with the participation of members of all four the IEEC Research Units, were presented: the MELiSSA project, the 3Cat-GEA project and the "Jets in Pulsar Systems" project. Nüwa —a sustainable city design for a Mars colony— and the CCCB exhibition "Mars. The Red Mirror" were also presented to the audience. The event continued with presentations about scientific missions in which the IEEC played a key role during the last year: Signal Processing for Communications and Navigation, the eXTP mission & PODIUM project, the FSSCAT mission, GNSS reflectometry and the HydroGNSS mission, together with the latest scientific results from the Solar Orbiter mission, and results from the Gaia mission.

The forum ended with the showing of a video produced to mark the 25th anniversary of the IEEC. The video briefly reviews the history of the Institute, as well as the most important milestones since its establishment, through the voices of various representative figures: Jordi Isern, founding director (1996-2015); Francesca Figueras, executive director during the management of Jordi Torra (2015-2017; deceased); Ignasi Ribas, current director (2017-present); and Pilar Montes, manager (1997-present). You can find the video on the IEEC YouTube channel.

Figure 1: The IEEC Forum 2021, held at the Centre de Cultura Contemporània de Barcelona (CCCB). Credit: IEEC.

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Scientific Highlights

Cloud computing for Gaia

The Gaia group at ICCUB, awarded with computing resources by the Open Clouds for Research Environments (OCRE) project

The “Galactic RainCloudS” project (Galactic Research in Cloud Services) was top-ranked in the first round of cloud computing grants from OCRE, the Open Clouds for Research Environment Horizon 2020 project. Here, researchers from the IEEC/ICCUB Gaia group will take advantage of the unprecedented accuracy of the Gaia EDR3 and DR3 catalogues to investigate, for the first time in a holistic way, the Milky Way star formation and its interaction with its satellite galaxies.

Our researchers will use the data of up to 1.8 billion sources from the Gaia catalogue, combined with the BGM FASt Galaxy Model, Bayesian techniques, Machine Learning, Data Mining tools and an N-body simulation of interacting galaxies. Using these tools, complementary scientific analyses will be developed: the star formation history in the last 6-7 Gyrs and the effects from the interaction of the Milky Way with the Sagittarius satellite galaxy; the analysis of interaction of the Magellanic clouds with an unprecedented spatial and temporal resolution; and the search for substructures in the Milky Way predicted by cosmological models, aiming to reveal crucial information on its formation history and its Dark Matter content.

The cloud resources that will be used include a Spark cluster with up to 1,400 computing cores running during several days, Linux Virtual Machines running uninterruptedly during several months, Machine Learning services, and 3TB of storage in a Data Lake – all supported by cloud architects and experts from private companies specialised in cloud services. Scientists and engineers from our team will also benefit from bespoke training sessions and workshops delivered as part of this programme.

This first call for the adoption of the cloud services available through the OCRE Infrastructure-as-a-Service (IaaS) framework agreements was aimed to ease access to commercial cloud services for researchers and research institutions in 40 European countries. OCRE received 31 applications, which were screened by the OCRE cloud adoption funding team and overseen by the OCRE External Advisory Board. 15 projects were funded, including subjects such as medical imaging, dynamical systems, atmospheric studies, computer vision and economics. The project from the Gaia group will demonstrate the effectiveness of cloud services in astrophysical research, revealing the scalability of scientific codes in different cloud infrastructures, quickly deploying data mining infrastructures, and illustrating the high availability and fault tolerance for long computing runs. The group is in a privileged position to show new ways to make science, and to set the technologies and methodologies used here as a precedent for the data processing and analysis in future space missions and large surveys.

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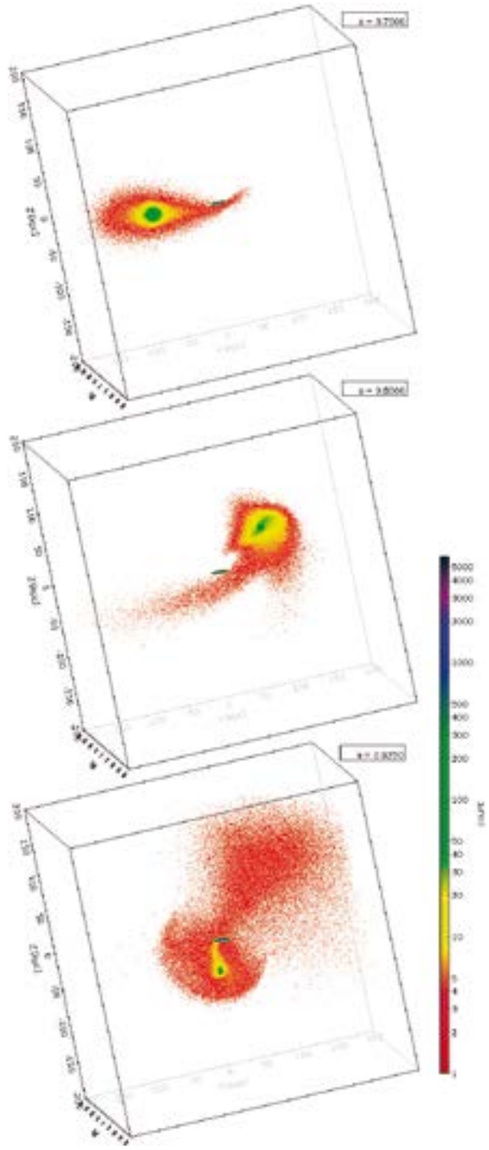

Figure 1: Time evolution of a Magellanic Clouds N-body simulation. In each plot centre, we observe the Large Magellanic Cloud baryonic matter (disk-like shape) interacting with the Small Magellanic Cloud. Thanks to OCRE, we will be able to generate a much larger simulation, allowing us to perform an orbital analysis of the interaction of the Magellanic clouds with unprecedented spatial and temporal resolution. Credit: Ó. Jiménez-Arranz and ICCUB Gaia Group.

IEEC researcher selected for an international leadership programme for women scientists

Dr. Anna Ferré-Mateu was selected for the international leadership initiative Homeward Bound, which aims to help build the skills needed to create more inclusive and sustainable research for the future of our planet.

Under the motto 'Mother Nature needs her daughters', Homeward Bound was created in 2016 with the aim of creating a global network of 1,000 women with a background in STEMM over a period of 10 years. It was an urgent call to action to stand up to be the collaborative, inclusive and legacy-minded leaders our planet needs. Science will guide much of the strategy and solutions needed to tackle the critical issues our planet and societies are facing now, from climate change to redefining our post-pandemic world. But what took us here, and what kind of leadership will move us forward, are the key questions. So, by 2026, this programme aims at having equipped the participating women to lead, influence and contribute to policy and decision-making with a mindset shifted towards more equitable and long-term decisions.

Dr. Ferré-Mateu was selected from more than 400 candidates all over the world to be part of the 6th team of this programme. Along with a hundred other women related to STEMM disciplines from all around the world, Dr. Ferré-Mateu started her 12-month journey in March 2021. It is a virtual programme founded on four pillars: leadership, science, visibility, and strategy, aided by a wellbeing component. The virtual journey thus comprises lectures, personal and professional development tools and individual coaching sessions, all focused on covering the four pillars of the programme. Moreover, it is an opportunity to develop meaningful collaborations with a focus on areas of interest.

One of the key parts of the project is the final 3-week long intensive leadership course taking place on board a ship around Antarctica. The goal is to culminate the year-long programme in which the 100 women have been working together, to further reinforce the bond between these similar-minded women from so many diverse STEMM disciplines, but the course also provides the foundation for a breakthrough introspective and reflective personal journey. Antarctica is a crucial component of this programme. On the one hand, it symbolises the claim for a seat at the table for women, being a place that has been, until very recently, forbidden to them. But it also symbolises how when nations collaborate, they can easily reach a greater good, as Antarctica does not belong to any country. Finally, it highlights the current issues in the climate crisis. Despite being one of the most remote and inaccessible places on Earth, it is where we are seeing the effects of this crisis more dramatically and at vertiginous timescales.

Unfortunately, the current pandemic has put a halt on the voyage of teams 5 and 6, and although Dr. Ferré-Mateu is about to finish the year-long virtual programme, this vital component of the programme will have to wait at least another year until it can be carried to term and she can finally meet face to face with the rest of Team#6. In the meantime, the participants continue to work with their teams, and a newly defined year-long virtual programme is envisioned to start in mid-2022, which will bring together the participants of all the teams.

Figure 2: Team members of the HB6 cohort, and their workplace location. Credit: A. Ferré-Mateu.

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Unexpected optical and ultraviolet pulses from an accreting millisecond pulsar

Presentation of the first-ever detection of pulsations at optical and ultraviolet wavelengths from a millisecond pulsar in an X-ray binary system during an accretion phase.

Neutron stars represent one of the possible final evolutionary stages of the gravitational collapse of massive stars and constitute prime astrophysical laboratories in which to study the properties of matter under extreme physical conditions that cannot be reproduced on Earth. Besides, a magnetised neutron star orbiting a companion star in a binary system constitutes an unmatched opportunity to study the nature of the interaction between matter accreting onto extreme astrophysical objects and magnetic fields.

SAX J1808.4-3658 is a neutron star that completes 401 rotations in a single second and orbits another star, making a complete revolution about every two hours. Every two years or so, the companion star actively transfers matter and angular momentum to the neutron star through a disk that extends to within a few kilometres of its surface, resulting in enhanced emission at optical, ultraviolet and X-ray wavelengths. The accreting matter is channelled by the magnetic field of the neutron star and impacts upon its magnetic poles, heating up to temperatures of millions of degrees. This process releases X-ray radiation in the form of two cones of light, making the radiation appear pulsating at the neutron star spin period, like that of a lighthouse. And in fact, X-ray pulses have been observed in all active phases of SAX J1808-3658 recorded over the last 20 years or so.

During the last active phase in 2019, observations of SAX J1808.4-3658 with the Hubble Space Telescope and the Galileo National Telescope at La Palma (Canary Islands), equipped with the fast optical photometer SiFAP2, revealed for the first time that the neutron star was surprisingly pulsing also at ultraviolet and optical wavelengths. The brightness of these pulses was too high to be explained in terms of accretion of matter on the pulsar, pointing to a different physical mechanism that probably takes place in the magnetosphere of the neutron star (or just outside it) and is ultimately powered by the rotation of the magnetic dipole of the pulsar. This interpretation, if correct, would imply that in this type of system rotation-powered phenomena can occur in combination with the emission of X-rays due to matter accreting on the stellar surface. This is in contrast with current theoretical models that assume that these two emission mechanisms are mutually exclusive.

The discovery of ultraviolet and optical pulses in SAX J1808.4-3658 thus sheds new light on the properties of neutron star magnetospheres and their interaction with accreting matter. It also opens up a new perspective in the search for fast pulsations at ultraviolet and optical wavelengths from many other weakly magnetic accreting neutron stars in binary systems from which pulsations have never been detected at over wavelengths, despite very extensive studies. In this context, neutron stars accreting at very high rates are particularly important, since the detection of pulsations from them and the precise determination of their orbit would drastically increase the sensitivity of searches for the gravitational wave signal that is expected from these systems.

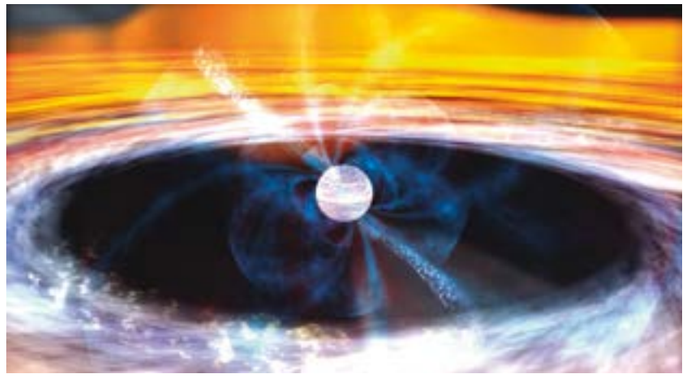

Figure 3: Artist's impression of a bright X-ray millisecond pulsar in a binary system accreting mass and angular momentum from a low-mass companion star.
Credit: NASA/Goddard Space Flight Center.

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Gl 486b: A nearby rocky, hot exoplanet

Figure 4: Artistic impression of the surface of the hot super-Earth Gl 486b. With a temperature of about 700 K (230 °C), the planet may show a hot and dry landscape interspersed with glowing lava rivers, in addition to a tenuous atmosphere.
Credit: RenderArea. 2000.

Exoplanets detected both by transits and radial velocity surveys are jewels for the study of exoatmospheres and for understanding their evolution. Gl 486b is one of the few exoplanets close and bright enough to conduct such studies with current instrumentation.

The CARMENES exoplanet survey revealed a new planet that will potentially contribute to our understanding of planet formation and evolution. The mid-type M-dwarf star Gliese 486 has been observed with the CARMENES spectrograph since 2016. The radial velocity analysis revealed an interesting signal, corresponding to a planet candidate at an orbital period of about 1.5 days. A photometric follow-up was triggered from different ground-based observatories, such as the Montsec Astronomical Observatory, in order to confirm the planetary nature and look for transits of the planet in front of the star. The planet was finally discovered to be transiting by the NASA TESS space mission, also in search of exoplanets. This confirmed the exceptional importance of this planetary system for the advancement of our knowledge.

The combination of radial velocity observations (from CARMENES) and transits (from TESS) provides both the absolute mass and radius of the planet, with respect to its host star. This led to estimating that Gl 486b is a rocky planet with a mass 2.8 times that of Earth and a radius only 30% larger. Due to the proximity to its host star, despite being an M dwarf, the planet surface can reach a temperature of about 700 K, slightly below the limit where rocks are molten and atmospheres are evaporated. Thus, this is an excellent system for studying the evolution of exoatmospheres. Actually, it is an excellent target for the recently launched James Webb Telescope. Being the third closest star with a transiting planet, its brightness makes the study of its atmosphere feasible using the transit and emission spectroscopy techniques, i.e. observing the planet when it crosses in front and behind the star using spectrographs. This will reveal if the planet has retained part of its original atmosphere, and if so, what its components and its structure are, providing a wealth of information about the evolution of exoplanet atmospheres.

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The first nanosatellite of the Catalan Government successfully launched

The nanosatellite *Enxaneta* successfully took off on 22 March 2021 from the Baikonur Cosmodrome (Kazakhstan), marking an important milestone in Catalonia's NewSpace strategy

During 2021, a major milestone was achieved with the launch of the first nanosatellite of the Catalan government (Generalitat de Catalunya). This was the first of several nanosatellites which are planned to be launched in the next few years as part of the Catalan government's NewSpace strategy.

The contract for this first nanosatellite, among other satellites for earth observation, was tendered in the last few months of 2020 and awarded in January 2021. The second satellite is due to be launched in 2022. There are plans to publish more tenders for satellite applications in the forthcoming years within the framework of NewSpace in Catalonia.

This first nanosatellite, named *Enxaneta* (the crowner of the Catalan human towers) after a children's competition to name it, with a factor of 3-unit CubeSat and a weight of about 10 kg, aims to provide coverage for the Internet of Things and will serve as a flying experiment platform for 5G Non-Terrestrial Network testing and experiments.

Enxaneta offers Direct-To-Satellite IoT connectivity, allowing devices to connect directly to the satellite without any intermediate gateway, facilitating and speeding up deployment. A first use case has been developed, consisting of soil moisture sensing on remote sites. The device deployed is made up of a set of soil moisture sensors, a small processing element acting as a data logger, and the satellite modem with its antenna. The entire system is powered by solar panels to ease its installation in the field.

Figure 5: Exact moment of the launch of the Soyuz 2 rocket that carried and put in orbit the nanosatellite *Enxaneta*. Credit: GK Launch Services.

Tests of the ground devices started in October 2021, yielding good results. The next steps will be to increase the number of use cases. These use cases are designed with departments and entities of the Generalitat de Catalunya with R&D centres and it is planned to invite private companies.

Furthermore, during the commissioning phase, *Enxaneta* performed NB-IoT NTN tests that were presented to 3GPP (an organisation that develops cellular protocols and standards). More tests are planned to be performed this year.

The second satellite will be used for Earth Observation on visible and near-infrared bands. The mission requirements were defined with the help of the Institut Cartogràfic i Geològic de Catalunya (ICGC), which will be the prime customer of the retrieved data. This mission is designed to complement the ESA's Copernicus Sentinel-2 satellite, acquiring images of Catalan territory more often. As a Copernicus programme, all data generated will be available on a future satellite data platform.

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Scientific Highlights

Teaching machines how to observe the Universe

Artificial Intelligence has been used to construct the largest catalogue of morphological classification to date, including 27 million galaxies.

The morphology of galaxies is closely related to the type of stars they contain, their formation mechanisms and their kinematics. In particular, they can be divided in two main classes: spiral galaxies, which are rotating disks where new stars are being born; and elliptical galaxies, which are composed of old stars, dominated by random motions and some of the most massive galaxies in the Universe. Understanding how the shape of galaxies affects their evolution is still an open question.

It is easy to distinguish these two galaxy types at a glance. However, the morphological classification of galaxies faces two main problems: first, the huge number of galaxies to be classified makes it necessary to use automated classifications, and secondly, the fact that distant galaxies look fainter and smaller, which usually makes images very noisy.

The researchers, including Helena Domínguez from ICE-CSIC, which has played a major role in the project, degraded high-quality images of local galaxies from the Dark Energy Survey in order to give them the appearance they would have if they were at greater distances, and used the correct morphological class to train a convolutional neural network (CNN). This type of neural network is a deep learning algorithm capable of taking in an input image and assigning a class to it. According to the study, the algorithm guessing the galactic morphology is correct 97% of the time, regardless of the noise and the spatial resolution of the images.

This study proves that machines are able to recover features which remain hidden to the human eye and to separate useful signals from noise when trained with the correct labels, even in the most difficult cases.

The use of CNN has proved extremely successful for analysing and classifying galaxy images, and has enabled researchers to perform a classification of 27 million galaxies and produce the largest morphological galaxy catalogue published to date.

Some of the galaxies included in the catalogue are as far away as 8 billion light years. This catalogue provides us with an approximate picture of what the galaxies looked like when the Universe was half the age it is today, and gives us the opportunity to study how the structural changes are linked to their evolutionary paths.

The automatic pattern recognition in noisy data can have direct applications in other fields, such as security (i.e. facial recognition), industrial image recognition, clinical diagnosis and climate change.

Figure 6: Original images (left-most panels) of a spiral (top) and an elliptical (bottom) galaxy and their degraded versions, used for training the convolutional neural network. For the more distant galaxies (right-most panels) it is difficult to distinguish the two classes with the naked eye.
Credit: J. Vega Ferrero *et al*., 2021.

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Scientific Highlights

Implementation of the ESA's second Scout mission, HydroGNSS, kicked off with IEEC's participation

The implementation of the mission HydroGNSS, which will measure key hydrological climate variables, has kicked off in 2021, with launch planned for 2024.

A group of researchers from the IEEC at ICE-CSIC are participating in the mission HydroGNSS, the ESA's second Scout mission. Following the selection of the first Scout satellite mission in 2020, in 2021 the ESA approved the development of a second mission and commenced its implementation. These missions are a new element in the ESA's FutureEO programmes of Earth Observation, and seek to demonstrate the capability of small satellites to deliver value-added science.

HydroGNSS will provide measurements of key hydrological climate variables, including soil moisture, freeze-thaw state over permafrost, inundation and wetlands, and above-ground biomass. These variables help scientists understand climate change and contribute towards weather modelling, ecology mapping, agricultural planning and flood preparedness. The mission is led by the British company Surrey Satellite Technology Ltd. (SSTL).

In order to obtain these measurements, scientists will use a technique called "Global Navigation Satellite System (GNSS) reflectometry". IEEC researchers in the Earth Observation Group at the ICE-CSIC have more than 20 years of experience in this technique, and are involved in HydroGNSS as part of the mission consortium and in its Science Advisory Group (SAG).

This mission presents several new features with respect to other reflectometry missions. For the first time, the signals will be received at two polarisations, and large amounts of data at high sampling rate will be acquired in a nearly continuous mode to enable new science and improved products.

ESA Scout missions aim to demonstrate how small satellites on a budget of less than €30 million and a three-year schedule can play an important role in Earth Observation, and be scaled up for future missions. The concept behind HydroGNSS is scalable to larger constellations of satellites – an important aspect of the Scout missions, which would represent an effective and sustainable way to densify these Essential Climate Variable measurements.

The mission consortium also includes teams from La Sapienza University, Tor Vergata University and the Istituto di Fisica Applicata (IFAC-CNR) in Italy, the Finnish Meteorological Institute (FMI) in Finland, the National Oceanography Centre (NOC) and the University of Nottingham in the United Kingdom.

HydroGNSS paves the way for an affordable future constellation that can offer measurements with a temporal-spatial resolution not accessible to traditional remote sensing satellites, thereby offering new capacity to monitor very dynamic phenomena and helping to fill in the gaps in our monitoring of the Earth's vital signs for the future.

Figure 7: Artist's impression of the HydroGNSS satellite in orbit.
Credit: Surrey Satellite Technology Ltd (SSTL).

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Scientific Highlights

The Dark Energy Spectroscopic Instrument creates the largest 3-D map of the Cosmos

During its first seven months of operations, DESI has smashed all previous records, mapping out more galaxies than all previous 3-D surveys combined… and it's just getting started!

The Dark Energy Spectroscopic Instrument (DESI) has ended the first seven months of its survey operations by breaking all previous records for three-dimensional galaxy surveys, releasing the largest and most detailed map of the cosmos ever. Yet it's only about 10% of the way through its total five-year mission. Once completed, this extraordinarily detailed 3-D map will yield a better understanding of the constituents of our Universe, how it has been evolving, what is driving the current acceleration of its expansion, and eventually how it will end.

In order to achieve such astonishing performance, DESI benefits from a complex instrument: the robotic fibre positioners. This widget consists of 5,000 cutting-edge robots that are able to accurately position optical fibres to collect the light of the galaxies pointed by the telescope at a given time. In order to achieve the precision demanded by the science requirements, these positioners need to be as accurate as 10 microns, which is less than the thickness of a human hair. This technology has the record of delivering as many spectra on a single good night as the typical amount delivered by a whole galaxy survey in the 1990s. After these first months of observations, this technology has shown itself to be successful, smoothing the way towards the completion of the project.

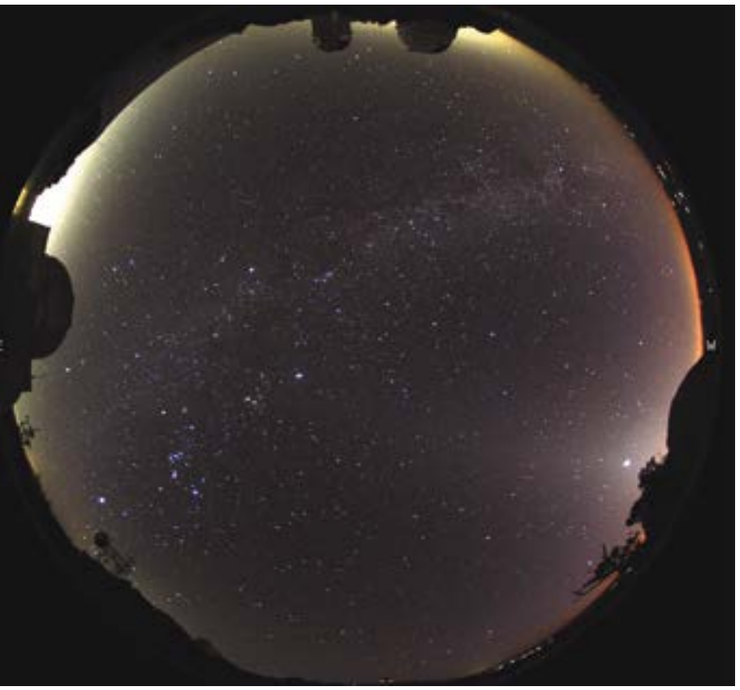

Figure 8: Fisheye image from the Kitt Peak National Observatory (Arizona, USA) during the night of 20 January 2022, corresponding to the current first-year DESI observation campaign. The Mayal 4-metre telescope, where the DESI spectrographs are installed, can be seen at the top of the image. Credit: H. Gil-Marín & KPNO.

When we take a detailed look at the distribution of the DESI galaxies, we find that these galaxies are not randomly distributed, but they form huge clusters, filaments, and voids. Imprinted in their distribution, these cosmic structures have signals from the acoustic waves which oscillated in the primordial plasma, when the Universe was less than 300,000 years old. These signals are precisely what allow cosmologists to measure the expansion of the Universe over a period of more than 10 billion years. Understanding this expansion history is crucial to understanding the laws and the nature of the constituents of the universe. We know from previous observations that about 70% of today's content of the universe is dark energy, a mysterious form of energy responsible for the acceleration of the expansion of the universe. As the universe expands, more dark energy is released into existence, which speeds up the expansion even more, in a cycle that drives the fraction of dark energy in the universe ever upwards.

Dark energy will ultimately determine the destiny of the universe: will it expand forever? Will it collapse onto itself again, in a Big Bang in reverse? Or will it rip itself apart? Answering these questions means learning more about how dark energy has behaved in the past – and that's exactly what DESI is designed to do.

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Scientific Highlights

Novel Earth-Observation maps provided by CubeSat nanosatellites

FFSCat is the first CubeSat mission contributing to the EU Copernicus programme with soil moisture, sea salinity, and ice extent, concentration, and thickness maps.

The 'Federated Satellite Systems/3Cat-5' (FSSCat) is the first mission based on CubeSats, which contributes to the Copernicus programme by providing data for the land and marine services. The mission won the ESA's Sentinel Small Satellite (S^3) Challenge Award and was the Copernicus Masters Overall Winner in 2017.

Launched into space on 3 September 2020 using a novel VEGA SSMS, FSSCat consists of two 6-unit CubeSats ¡. The mission's primary goals were the generation of coarse resolution soil moisture, sea ice extent and thickness maps using L-band microwave radiometry and GNSS-Reflectometry, enhanced resolution soil moisture maps applying pixel downscaling techniques, and the testing of techniques for future satellite federations. Secondary goals are sea surface salinity and wind speed maps.

3Cat-5/A (ID 2020-061W) carries the UPC's Flexible Microwave Payload–2 (FMPL-2), a software defined radio payload implementing an L-band microwave radiometer and a GNSS-Reflectometer. 3Cat-5/B (ID 2020-061X) carries Cosine's HyperScout-2 visible and near infrared + thermal infrared hyperspectral imager, enhanced with the PhiSat-1 board, the very first Artificial intelligence experiment on board a satellite for cloud detection. Both CubeSats include an optical inter-satellite link from Gölbriak Space, and a UHF inter-satellite link tech-demos from the UPC to test the concept of satellite federations.

The implementation of this challenging mission in just 1.5 years would not have been possible without the participation of Deimos Engenharia (PT), prime contractor of the mission and responsible for the Data Processing Ground Segment; Tyvak International (IT), platform provider, system integrator, CubeSat deployer and launch interface provider, and operations manager; and ESA EOP, which initiated the ESA Sentinel Small Satellite Challenge, provided technical and programmatic advice and expertise, the funding scheme, and access to ESA testing facilities.

Figure 9: Artist's impression of FSSCAT. Credit: A. Camps, NanoSatLab.

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Scientific Highlights

Gravity induced magnetic whirlpools during the formation of massive stars

An international team, including IEEC member Josep Miquel Girart, have found that during the formation of massive stars the magnetic fields are significantly twisted, forming a whirlpool around the cloud centre.

Using the Atacama Large Millimeter/submillimeter Array (ALMA), the team observed a source called IRAS 18089-1732, a star-forming region 7,600 light years away, and found a well-organised magnetic field that resembles a spiral "whirlpool". Until now astronomers only had a limited amount of observational evidence to prove or disprove the influence of the magnetic field on star formation. Contrary to some theoretical predictions, the magnetic field in this region appears overwhelmed by another of the four fundamental forces in nature, gravity.

Stars form in the densest parts of interstellar molecular clouds, the so-called dense cores. The large amount of mass in the dense core surrounding IRAS 18089-1732 makes this region invisible to the optical wavelengths. However, the dense core is bright at millimetre wavelengths because of the radiation emitted by the core's dust particles. Because these particles are aligned with the magnetic field that threads the region, the dust emission is partially polarised. ALMA is very well suited to detect the small amount of the dust polarisation radiation, which makes it possible to image the magnetic field distribution in the region. The research reveals that gravity can shape the gas morphology and dominate the energy balance. Gravity is so great that the gas moves in a spiral "whirlpool"-like way towards the centre of the core, where the massive stars are being formed, dragging the magnetic fields in the same fashion.

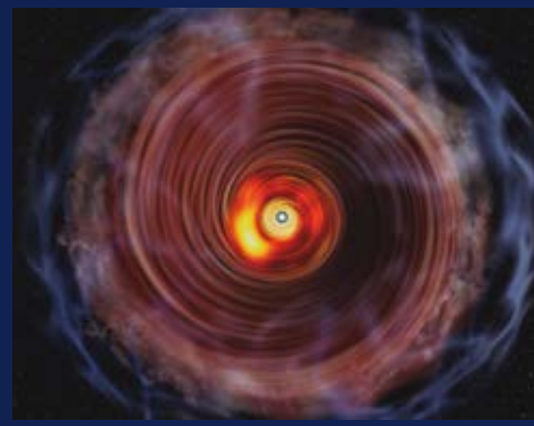

Figure 10: Artist's impression of the gaseous disk and envelope surrounding a massive protostar. Credit: National Astronomical Observatory of Japan.

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Mass distributions and fluxes of meteoroid streams produced by comets

The study of meteor showers teaches us about the inner nature of comets

Comets are fragile objects formed in remote regions of the protoplanetary disk from the accretion of primordial materials made of grains consisting of minerals, organics and ices. When a comet approaches the Sun, its surface is heated and the ices sublimate into space, dragging solid particles away from the comet nucleus. Micron-sized particles produce the dust trail, while the largest particles form the dust trail later evolve and redistribute along the entire orbit forming a meteoroid stream. Our MNRAS paper answers several key questions concerning the delivery of these materials to our planet: How do these particles evolve after their release from their parent comets? What is the flux of cometary meteoroids to Earth and their role in the chemical enrichment of our planet?

Figure 11: An active comet crossing the near-Earth region exemplifies the continuous delivery of cometary materials to Earth. Credit: J.M. Trigo (ICE-CSIC).

When the Earth crosses a dense meteoroid stream, a natural firework in the night sky is observed: a meteor shower. Behind the observation of a meteor display, there is significant science when the meteor rate is measured using modern instrumentation. It provides clues on the particle size and numbers that are used in this paper to compute the flux of cometary materials reaching our planet. Meteor physics provides clues about the size, structure, and density of cometary disintegration products, establishing a bridge between different research fields. The mass distributions of the main meteoroid streams crossed by the Earth have been computed and compared with observations of dust particles released from several comets, e.g. 1P/Halley and 81P/Wild 2, measured by spacecraft. From these mass distributions, the incoming mass for the most significant meteor showers was integrated. By comparing these fluxes with the mass of the IDPs collected in the stratosphere, a gap of several orders of magnitude was found. The largest examples of fluffy particles are clusters of IDPs no larger than 100 µm in size (or 5×10-7 g in mass), whereas the largest cometary meteoroids are centimetre-sized objects. Most visual meteors are produced by mm- to -cm-sized particles. These particles, usually called pebbles, must be abundant, because they can be associated with the building blocks of comets in the current comet-formation scenario in which a cloud of pebbles in the solar nebula was concentrated by the streaming instability and then collapsed due to a gravitational instability. These pebbles are products of collisional growth processes of tiny dust/ice grains in the solar nebula, and their size depends on a variety of parameters related with the formation location and the dust-to-ice ratio for the particular region in which each comet formed.

This research is important, because the meteoroid flux is quantified under different scenarios, both now and in the ancient past, providing clues on the chemical relevance of the flux of cometary materials to our planet. Comet disruptions in near-Earth space probably participated in a massive delivery of volatile elements, reactive metals and organics to early Earth with significant astrobiological implications. The study describes the significance of the disruption of comets in close approaches to the Earth as a more efficient way to deliver volatiles than by direct impacts.

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The Spanish astronaut Pedro Duque visits the MELiSSA Pilot Plant

An experimental ESA and UAB facility for the development of technologies enabling long-term manned missions in Space

The astronaut Pedro Duque visited the MELiSSA Pilot Plant at the UAB School of Engineering together with representatives of the European Space Agency (ESA), the Universitat Autònoma de Barcelona (UAB), and the MELiSSA Consortium on 9 November 2021. The laboratory is part of the ESA MELiSSA project, involving a total of 15 partners across Europe. It aims to be the only facility in Europe for demonstration of Closed Loop Life Support Systems, paving the way to human autonomy during long duration space missions. MELiSSA is the acronym for Micro-Ecological Life Support System Alternative, a project initiated as part of a research programme on life support Technologies, in order to facilitate long duration manned space missions such as Mars Transit Habitat. These types of missions cannot be performed without regenerative life support systems like MELiSSA, which will drastically reduce the logistics needed to support the crew. For this purpose, a regenerative circular system is proposed, with the generation of edible material from higher plants and microalgae, revitalisation of the atmosphere for respiration, recovery of water, and recycling of the waste generated by the crew and plant growth. The MELiSSA project ideally targets 100% recycling of all chemical elements, i.e. a fully self-sustainable ecosystem without any resupply. In terms of processes, control, stability, safety and robustness, this target represents a very daunting challenge. The recycling challenges of MELiSSA are reinforced by the closed environment conditions and the presence of humans. Consequently, intensive characterisation, safety analysis, comprehensive integration, verification, validation and qualification activities are mandatory steps in the development and validation of MELiSSA.

MELiSSA is a regenerative circular system for food, water and oxygen recovery from waste, carbon dioxide and minerals. In October 2021, the MELiSSA Pilot Plant completed an experiment lasting 18 months and involving the continuous operation of 3 of its 6 compartments. Performance was excellent and robust, representing a remarkable proof of concept of the approach followed in its development. The experiment consisted in the connection of the nitrification unit (preparing the nitrogen source), the microalgae compartment (producing the food precursor biomass, fixing CO2 and producing oxygen) and the rats' isolator mimicking the respiration of astronauts (consuming oxygen and producing CO2). It enabled testing the capacity of the MELiSSA loop in terms of food complement production, water recycling and oxygen generation, working under a dedicated control system, in a continuous dynamic, long-term experiment, representative of missions in Space. Additionally, the compartment growing plants is also ready for connection to the MELiSSA loop.

Figure 12: The Spanish astronaut Pedro Duque, accompanied by Dr. Francesc Gòdia and the rest of the MELiSSA team, visiting the MELiSSA Pilot Plant located at the UAB School of Engineering. Credit: UAB.

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Black holes throwing their weight around in a Galactic star cluster

Using gravitational N-body simulations, a team led by the University of Barcelona showed that the peculiar properties of the Galactic star cluster Palomar 5 and its majestic tidal stream can be explained if the cluster is full of black holes.

Palomar 5 is a unique star cluster in the halo of the Milky Way. Firstly, because it is one of the "fluffiest" clusters, the average separation between stars being a few light years, comparable to the distance from the Sun to the nearest star. Secondly, it has a spectacular tidal stream associated with it, spanning more than 20 degrees across the sky. An international team of scientists, led by ICREA Professor Mark Gieles from the ICCUB, showed that both distinguishing features of Palomar 5 are likely to be the result of an oversized black hole population of more than 100 black holes in the centre of the cluster.

Tidal streams are streams of stars that were ejected from disrupting star clusters or dwarf galaxies. In the last few years, nearly thirty streams have been discovered in the Milky Way halo. It is not known how these streams form, but it is often assumed that the majority of them formed from disrupted star clusters. However, this idea is hard to confirm, because none of the recently discovered streams have a star cluster associated with them. To understand how these streams formed, a stellar stream with a surviving stellar system is required. Palomar 5 is the only case, making it a Rosetta Stone for understanding stream formation, and this is why the authors decided to model this star cluster and its tidal stream in detail.

The authors simulated the orbits and the evolution of each star from the formation of the cluster until the final dissolution in the Milky Way galaxy. They varied the initial properties of the cluster until a good match with observations of the stream and the cluster was found. In their best model, Palomar 5 formed with a "normal" black hole fraction of a few per cent. These black holes formed in supernova explosions at the end of the lives of massive stars in the early stages of the evolution of the cluster. They each have a mass of about 20 times the mass of the Sun, and because of their high mass they spiralled towards the centre of the cluster. As a result, stars escaped the cluster more efficiently than black holes during the evolution, and the black hole fraction gradually increased to its estimated present-day value of more than 20% of the total cluster mass. The black holes dynamically puffed up the cluster in gravitational slingshot interactions with stars, which led to even more escaping stars and the formation of the stream. Just before it completely dissolves – roughly a billion years from now – the cluster will consist entirely of black holes.

The results show that the presence of a large black hole population may have been common in all the clusters that formed the streams. This is important for our understanding of globular cluster formation and evolution, the initial masses of stars and the evolution of massive stars. This work also has important implications for gravitational waves.

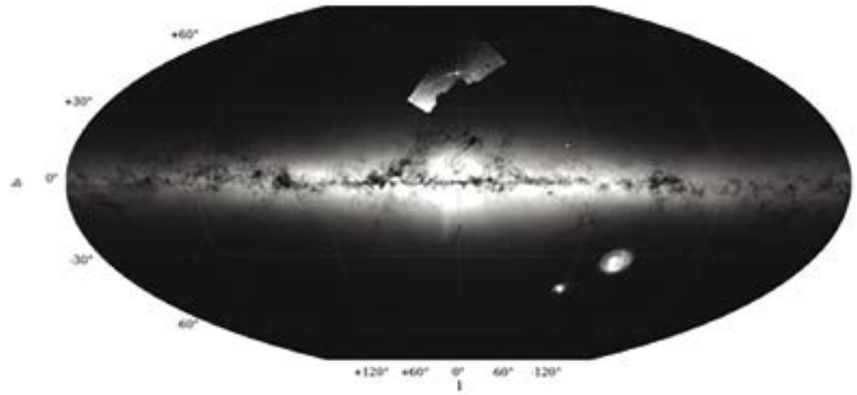

Figure 13: All-sky view of the Milky Way based on Gaia data, with an inset of deeper ground-based observations of Palomar 5 and its stream. Credit: Gaia eDR3/DESI DECaLS, E. Balbinot, and M. Gieles.

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Study reveals that giant planets could reach their ‘maturity’ much earlier than previously thought

The results suggest that these objects can reach their final size within their first 20 million years of evolution

Current theories of planetary evolution predict that infant giant planets have large radii and very low densities before they slowly contract to reach their final size after about several hundred million years. These theoretical expectations remain untested thus far, as the detection and characterisation of very young planets is extremely challenging, due to the intense stellar activity of their host stars. Only the recent discoveries of young planetary transiting systems allow initial constraints to be placed on evolutionary models. With an estimated age of 20 million years, V1298 Tau is one of the youngest solar-type stars known to host transiting planets. It was observed by the K2 mission. Analysis of the K2 data revealed the presence of four transiting planets in the system. The three inner planets (*b*, *c* and *d*) were determined to have orbital periods of 24, 8 and 12 days, and radii of 0.92, 0.50 and 0.57 Jupiter radii. The fourth planet, e, was identified with only a single transit event, with a radius of 0.78 Jupiter radii and an orbital period estimated to be between 40 and 120 days. To measure the planetary masses, we performed an intensive spectroscopic campaign, collecting more than 260 radial velocity (RV) measurements of V1298 Tau using the high-resolution spectrographs HARPS-N, CARMENES, SES and HERMES between April 2019 and April 2020.

Through an analysis described in Suárez-Mascareño et al. (2021; Nature Astronomy), we obtained significant measurements of the RV semi-amplitudes induced by planet b and by planet e. For the two innermost planets, c and d, we could only set upper limits. We derived the masses of planets b and e to be 0.64 ± 0.19 and 1.16 ± 0.30 Jupiter masses, respectively. We derived densities of 1.20 ± 0.45 g cm−3 and 3.6 ± 1.6 g cm−3, respectively. V1298 Tau b occupies a position in the mass–radius diagram compatible with the old giant planets of the Solar System. Planet e is more compact and lies in a less populated region of the mass–radius diagram. For the two smaller planets, c and d, we calculated 3σ upper limits on their masses of 0.24 and 0.31 Jupiter masses, respectively.

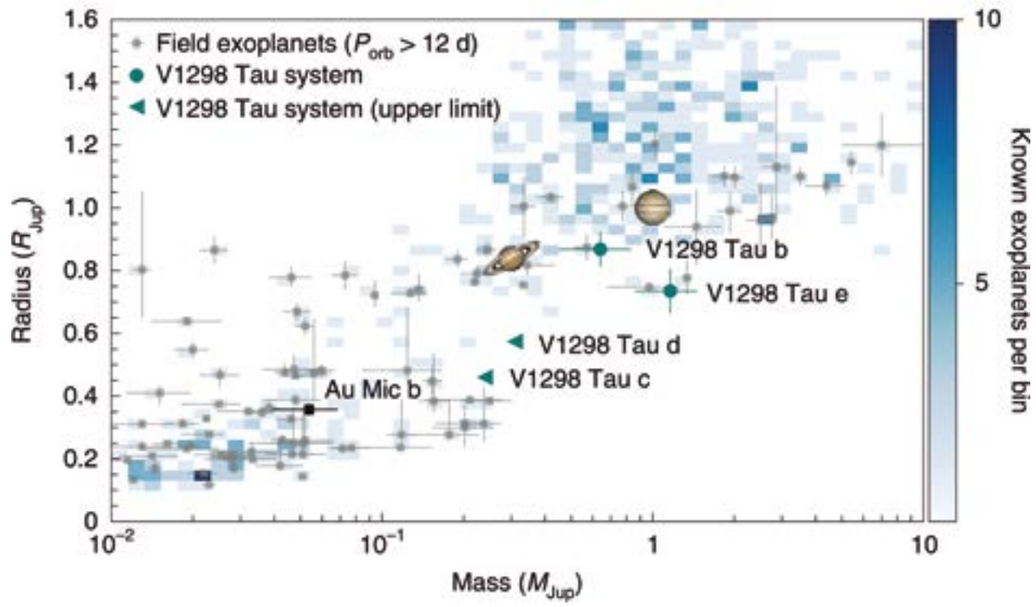

Figure 14: Masses and radii of known planets for which the two parameters are determined with a precision better than 33%. The planets orbiting V1298 Tau are highlighted in teal symbols, with their 1σ error bars. The left-pointing arrows show the upper limits for the masses of V1298 Tau c and d. Jupiter and Saturn have been added for comparison. Credit: Suárez-Mascareño *et al*. (2021, NatAs).

Core-accretion models of planetary evolution predict planets of ~20 Myr to be at the early stages of their contraction phase, showing very large radii and low densities. Our results indicate that V1298 Tau b and e deviate from this picture. According to current theories, these planets cannot reach this mass–radius configuration until hundreds of millions of years later. Considering their densities, it is not expected that the planets orbiting V1298 Tau will contract significantly in the future due to evaporation. Our result suggests that some giant planets reach a mass–radius configuration compatible with the known mature population of exoplanets during their first 20 ± 10 Myr of age.

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The last breaths of massive galaxies

A team of astronomers has found that galaxies with active nuclei may undergo a period of rapid star birth before star formation shuts down completely, challenging the standard scenario, from which the star formation in galaxies gradually decreases with time until it is quenched.

The Universe is filled with trillions of galaxies, each one comprising billions of stars. The star formation in galaxies has, until now, been found to steadily decline with time; however, the cause of halting star formation in galaxies is an ongoing and continuously debated mystery. Most, if not all, of the massive galaxies are believed to harbour supermassive black holes at their centres. When supermassive black holes are actively accreting gas as Active Galactic Nuclei (AGN), they can radiate as much energy as the galaxy in which they reside. The popular picture is that powerful winds and jets produced by the central AGN are able to expel or heat gas within the host galaxy, removing the material needed to make stars.

A team of researchers, including Mar Mezcua from the IEEC, has used new data analysis techniques equipped with a large sample of more than three thousand nearby active galaxies hosting AGN to measure how the star formation of the galaxies has changed over cosmic time. Challenging the expectations from the standard scenario, researchers found that nearby galaxies hosting AGN are not simply gradually quenching their star forming rate. On the contrary, they are going through a “rejuvenation phase”: most of the galaxies in the sample with active black holes show clear signatures of a sudden increase in star formation in recent times just before it shuts down. The study suggests that galaxies with an AGN have temporarily increased the rate at which they form stars by accumulating fresh gas from their surroundings.

Galaxies may undergo several such rejuvenation episodes until they finally become quiescent. Star formation is typically extremely short-lived in cosmological terms – the period when galaxies form stars can be a hundredth of the age of the Universe, or shorter. The team concluded that energy cumulatively released by supermassive black holes during the rejuvenation episodes may be contributing to, but not causing, the observed quenching of star birth.

The rejuvenation of galaxies with active nuclei may be the “last breaths” in the lives of galaxies, before they completely stop forming new stars, but there is still a lot of theoretical and observational work to do until we can gain a satisfactory understanding of such a complex process.

Figure 15: The jet of matter (in purple) ejected by the AGN in the galaxy M87 (in yellow). Image taken by the Hubble Space Telescope. Credit: NASA and The Hubble Heritage Team (STScI/AURA).

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The perturbed Milky Way

Unveiling substructures at the edge of the Galaxy

An international team of astronomers, led by researcher Chervin Laporte from ICCUB, has used data from the Gaia space mission to create a new map of the Milky Way's outer disc. Intriguingly, newly found structures include evidence for fossil spiral arms.

Customarily, this region of the Milky Way has remained poorly explored, due to the intervening dust which severely obscures most of the Galactic midplane. While dust affects the luminosity of a star, its motion remains unaffected. As a result, one can use bulk kinematic motions to scan the structure of the Milky Way's outermost region. The team analysed the Gaia motion data from the 3rd Data Release (eDR3), available from December 2020, to identify coherent structures. Their resulting map revealed the existence of many previously unknown spinning filamentary structures at the edge of the disc and gave a sharper overall view of previously known structures. Numerical simulations predict such filamentary structures to form in the outer disc from past satellite interactions, but the sheer quantity of substructure revealed by this map was not expected and remains a mystery.

What could these structures possibly be? One possibility is that they are the remains of tidal arms from the Milky Way disc which were excited at different times by various satellite galaxies. Our Galaxy is now surrounded by 50 of these satellites and has engulfed numerous other galaxies in its past. At present, it is thought that the Milky Way is being perturbed by the Sagittarius dwarf galaxy, but in its more distant past it interacted with another intruder, the Gaia Sausage, which has now dispersed its debris into the outskirts of our Galaxy.

In an earlier study, the same team showed that one of the filamentary structures in the outer disc, the Anticenter Stream, had stars which were predominantly more than 8 billion years old. This makes it potentially too old to have been excited by Sagittarius alone and instead points to the Gaia Sausage. Another possibility is that not all these structures are actual genuine fossil spiral arms, but instead form the crests of large scale vertical distortions in the Milky Way disc. The scientists believe that discs respond to satellite impacts which set up vertical waves that propagate like ripples on a pond.

To try to distinguish between the two explanations, the team has now secured a dedicated follow-up programme with the William Herschel Telescope on the Canary Islands, in order to study the properties of the stellar populations in each substructure, in the hope of revealing the sequence of events which led to their formation and shed light on the nature and origin of these heavenly wispy structures.

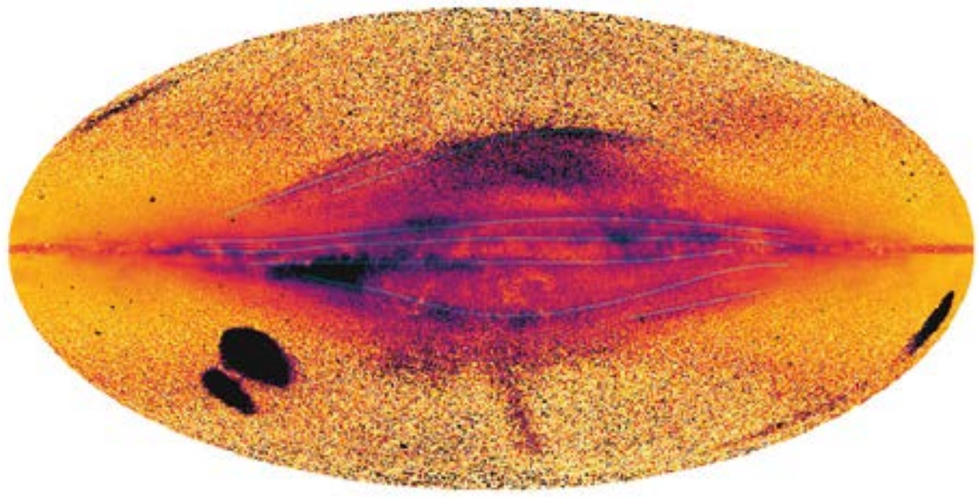

Figure 16: All-sky map of the Milky Way's outskirts showing the structure of tidal arms supposedly created by interaction with other satellite galaxies in the past of the Milky Way (highlighted in blue transparent lines) as well as the Sgr galaxy and its associated stream and the Magellanic Clouds. Credit: C. Laporte (ICCUB).

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The VOLS survey is granted 306 observing hours to study the cloud Orion A

The survey will observe the northern region of the molecular cloud Orion A with the Very Large Array Telescope.

The Large Project VOLS has been granted 306 observing hours with the Karl G. Jansky Very Large Array (VLA) to study the molecular cloud Orion A. VOLS will be the first radio survey to cover a large area of Orion A at sub arcsecond resolution at an unprecedented sensitivity. VOLS has 46 researchers around the globe, including several members of the IEEC at the Institute of Cosmos Science of the University of Barcelona (ICCUB) and the Institute of Space Sciences (ICE-CSIC).

The early stages of star and planet formation involve a balance between accretion and ejection of material during the gravitational collapse. Hence there is an underlying accretion-ejection connection that governs and keeps track of the protostellar evolution, crucial in determining the final properties of stars and their planetary systems. In this context, both mass accretion rate and mass-loss rate are fundamental, albeit still uncertain, quantities in star formation. It is, therefore, logical to ask how these quantities evolve with time and, just as importantly, how they vary across the entire mass spectrum.

The goal of the VOLS project is to build a census of the stellar population to investigate how the mass accretion rate and mass-loss rate proceed with the protostellar evolution and how they depend on the birth environment and on the mass of the star. To answer these questions, the team will use the VLA to observe, at two frequency bands, the northern part of the Orion A molecular cloud covering an area of ~0.5 deg2 (see Figure 17). Orion A is the nearest star-forming complex containing a broad range of environments populated by protostars and Young Stellar Objects (YSOs) with different masses and evolutionary stages, representing a testbed for star formation theories.

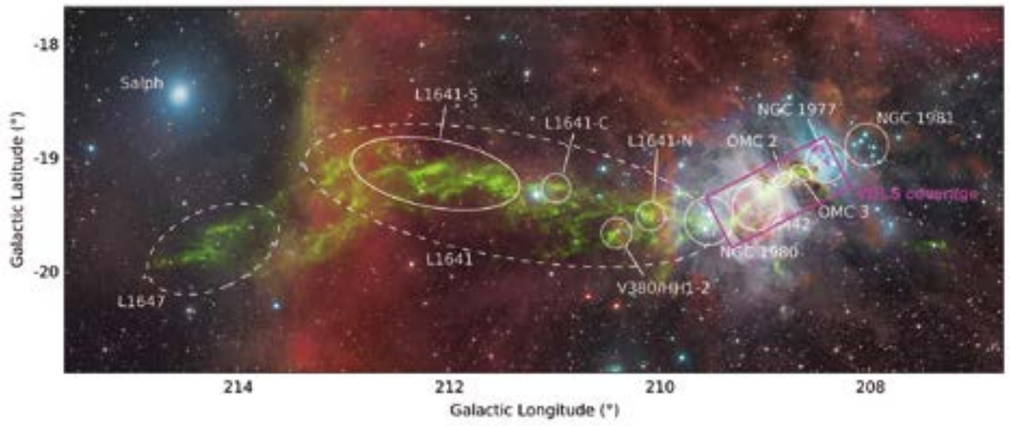

Figure 17: Composite of optical data overlaid with the Planck-Herschel column density map of Orion A in green. Positions of noteworthy objects and regions are marked and labelled. The pink rectangle depicts the area covered by the VOLS project. Figure adapted from Meingast *et al*. (2016). Credit: G. Busquet (ICCUB).

By combining the information of the stellar properties from previous ancillary datasets across the electromagnetic spectrum with the radio emission from YSOs together with the information of the Hα line from Gaia Data Release 3 (DR3), VOLS will provide the ultimate correlation between the characteristics of the radio emission from YSOs and their stellar properties.

The VOLS dataset is going to be a crucial guide for the next generation of radio facilities, such as the Square Kilometer Array (SKA) and the Next Generation Very Large Array (ngVLA), since it will provide a radio template of YSOs and protostars.

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PLATO: Revealing habitable worlds around Sun-like stars

The PLATO mission will detect terrestrial exoplanets in the habitable zone of solar-type stars and characterise their bulk properties.

PLATO (PLAnetary Transits and Oscillations of stars) is a mission developed by the European Space Agency. The main goal of PLATO is to detect and characterise terrestrial exoplanets, including planets in the habitable zone of Sun-like stars, with the aim of determining the habitability of these unknown worlds. PLATO's launch is planned in 2026.

The spacecraft has twenty-six 20-cm class telescopes, equivalent to a 1-metre telescope, with a total field-of-view of about 2,200 square degrees – 10,000 times the area of the full Moon. PLATO will operate at Lagrangian point 2 (L2).

During the 4 years of the nominal science operations phase (with a potential extended phase lasting up to 4 years), PLATO will survey the brightness of the stars to search for transiting planets. Two different observational strategies are considered: on the one hand, some fields of view will be observed for a long period of time, allowing the survey of small planets out to the Habitable Zone of solar-like stars. On the other hand, there will be shorter coverage of different fields (step-and-stare), devoted to shorter-period planet detections. The current baseline observation scenario assumes a Long-duration Observation Phase (LOP) consisting of continuous observations of two sky fields, lasting 2 years each. An alternative scenario would consist of a LOP of three years and a step-and-stare phase (SOP) of one year. It is expected that PLATO's catalogue will contain thousands of characterised planets and between 300,000 and ~1,000,000 high precision stellar light curves (depending on the final observing strategy).

The data collected by PLATO will allow the detection of exoplanets in orbit around bright stars ($V < 11$), including Earth twins and super-Earths, and their size determination. The data will also be used to measure stellar oscillations in order to study the internal structure of stars and how this evolves with age. PLATO's data will be complemented with ground-based observations to determine planet masses from radial velocity measurements. Finally, some bright targets will be identified to investigate the exoplanets' atmospheres from spectroscopic measurements.

The IEEC is involved in several aspects of the PLATO mission. A set of simulations of the star characteristics at different sky areas, including the photometry in PLATO's photometric band, has been performed to help with choosing the LOP fields. Currently, a team is working on the definition of the PLATO Ground-based Observations Programme (GOP). The work comprises the definition and optimisation of the observation planning and the definition of the database and interfaces.

With regard to the status of the mission, the Preliminary Design Review (PDR) was approved in October 2020. Some systems, such as the Engineering Models of the telescope and of the on-board data processing, have already been integrated and are ready for testing, while others, such as the Structural Thermal Models (STMs) of the optical bench, are being manufactured.

Figure 18: Artistic representation of the PLATO spacecraft. Credit: OHB Systems AG.

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Moving EGNOS forward

EGNOS, the European satellite-based augmentation system for GNSS users, is currently undergoing a major upgrade with the development of its third generation, EGNOS V3, in which the IEEC is playing a key role.

Global navigation satellite systems (GNSS) have become the de facto and essential tool for outdoor positioning and navigation, providing coverage anytime, anywhere and without the need for additional infrastructure. At the present time, GNSS is a rapidly growing market with a global installed base of 6 billion GNSS devices and €200b of total revenue, according to the latest market report of the European Union Agency for the Space Programme (EUSPA). Such success is the result of the growing demand for positioning services across all segments, from agriculture to road transportation and automotive, maritime, aviation, consumer services, logistics, critical infrastructures, and smart mobility, just to mention a few.

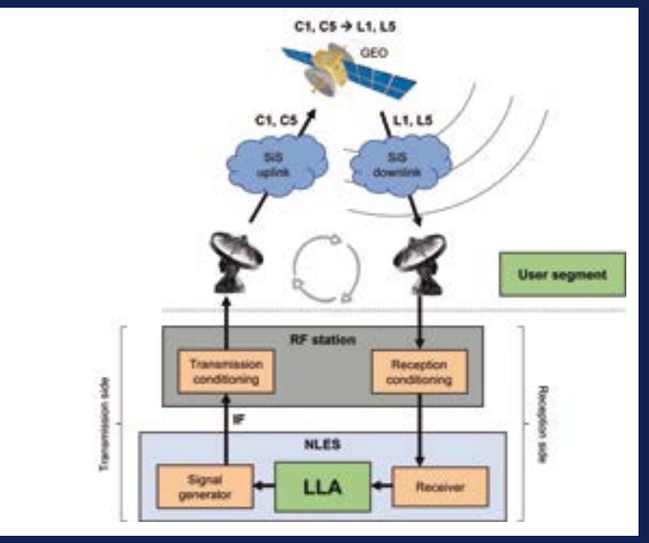

Figure 19: Illustration of the signal steering controlled by the LLA algorithm developed by the IEEC/UAB for EGNOS V3 NLES. Credit: IEEC/UAB.

In parallel with such market traction, GNSS have experienced an unprecedented development in recent years, from the upgrade and modernisation of GPS and Glonass, to the deployment of new GNSS such as Beidou and Galileo, the latter being the European GNSS. All these systems can provide positioning accuracies that are good enough for most applications, typically in the order of a few metres of error. Unfortunately, this is not enough for some applications where stringent requirements are needed not only in terms of accuracy, but in particular, in terms of integrity. The latter refers to the level of trust that can be placed on the correctness of the information provided by the GNSS signals, and this plays a key role in safety-critical applications such as, for instance, aviation.

Satellite-based augmentation systems (SBAS) were specifically designed to both improve the accuracy of GNSS and to provide integrity information on the GNSS signals being received by users in a given geographical area. For this purpose, SBAS are composed of a network of ground stations that continuously monitor the received GNSS signals on that area, as well as master stations that determine differential corrections that should be applied by users on that area to remove most of the atmospheric effects and thus improve their accuracy. At the same time, master stations compute the corresponding confidence bounds and embed all this information into a GNSS-like signal that is uplinked to a geostationary (GEO) satellite. Such signal, in turn, is broadcast back by the GEO satellite down to GNSS users, who can readily process it and extract the information needed to improve their performance. There are various SBAS already deployed worldwide, and the European Geostationary Navigation Overlay Service (EGNOS) is the SBAS augmenting the GPS signal and providing service to Europe.

Since the start of the EGNOS operations in 2005, the system has undergone a series of updates and improvements that culminate into the third generation of the system, EGNOS V3. This new version will constitute a major leap forward for the EGNOS system, extending its augmentation to GPS L5 and including, for the first time, the augmentation of Galileo in both E1 and E5 bands. EGNOS V3 is currently under development by a consortium led by Airbus with the participation of Indra, as part of a contract awarded by the European Space Agency (ESA), which manages the EGNOS development under a working arrangement signed with EUSPA.

The IEEC, through the Centre for Space Studies and Research (CERES) at the Universitat Autònoma de Barcelona, is also part of this project through a subcontract with Indra for the design, development and validation of the long-loop algorithm (LLA). This is a key element of the EGNOS system, which is responsible for steering the signals that are generated on the ground by the Navigation Land Earth Stations (NLES), uplinked to the EGNOS GEO satellites, and then broadcast back to EGNOS users. The criticality of such an algorithm relies on the fact that, for the EGNOS signals to be received properly by EGNOS users, these signals should look as if they had been generated on board the satellites and not on the ground, as they actually are. This means that the signals received by EGNOS users should be time-aligned with the GNSS time and they should only experience the downlink propagation effects. Thus, the uplink propagation effects should be compensated at the NLES before the EGNOS signal is uplinked to the GEO satellites. This operation requires a control loop in order to monitor the received signals and make sure that the transmitted signals are steered/corrected, accordingly, as schematically shown in Figure 19.

The first experimental tests on the LLA algorithm developed by the IEEC/UAB were carried out in November 2021 during the first EGNOS V3 on-site proof-of-concept event, where the algorithm was successfully tested on a real NLES station transmitting to a real satellite. The successful results constitute a major milestone for the modernisation of EGNOS and bring the work done by the IEEC to the forefront of the current state of the art on GNSS.

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DES announces its second data release & publishes new cosmological results

The Dark Energy Survey (DES) collaboration has published the second data release in the survey's seven-year history, making this catalogue one of the largest astronomical catalogues released to date

The Dark Energy Survey (DES), a global collaboration including the Fermi National Accelerator Laboratory, the National Center for Supercomputing Applications and the National Science Foundation's NOIRLab, has released DR2, the second data release in the survey's seven-year history. DR2 is a massive collection of astronomical data and calibrated data from the six years of survey.

The researchers from the IEEC at the ICE-CSIC, Francisco J. Castander, Pablo Fosalba, and Enrique Gaztañaga, and Martin Crocce, also from the ICE-CSIC, have been involved in the development of DR2: the catalogue is the culmination of over a half-decade of astronomical data collection and analysis with the ultimate goal of understanding the accelerated expansion of the universe and the phenomenon of dark energy, which is thought to be responsible for this accelerated expansion.

DR2 contains nearly 700 million astronomical objects, enlarging the 400 million objects catalogued with the survey's prior data release (DR1), and it also improves on DR1 by refining calibration techniques, which, with the deeper combined images of DR2, lead to improved estimates of the amount and distribution of matter in the universe.

Astronomical researchers around the world can access these unprecedented data and mine them to make new discoveries about the Universe, complementary to the studies being carried out by the DES collaboration.

Figure 20: Elliptical galaxy NGC 474 – excerpt from the Dark Energy Survey. Credit: DES/DOE/Fermilab/NCSA and CTIO/NOIRLab/NSF/AURA.

Later in the year, the DES collaboration published the scientific results extracted from the first three years of the survey. For the analysis, the weak lensing and galaxy clustering information was joined together to produce the most constringent determination of the cosmological parameters when combined with other datasets. DES scientists compared their results with measurements from the European Space Agency's orbiting Planck observatory. Planck used light signals known as the cosmic microwave background to peer back to the early universe, just 400,000 years after the Big Bang. The Planck data give a precise view of the universe 13 billion years ago, and the standard cosmological model predicts how dark matter should evolve to the present. If DES's observations don't match this prediction, there is possibly an undiscovered aspect to the universe. While there have been persistent hints from DES and several previous galaxy surveys that the current universe is a few per cent less clumpy than predicted – an intriguing find worthy of further investigation – the recently released results are consistent with the prediction.

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Short News

Nanda Rea, ambassador for Research Integrity

The ICE-CSIC researcher and IEEC member Nanda Rea is one of the outstanding researchers who are members of the Path2Integrity Community for Research Integrity. Path2Integrity is a H2020 project that supports formal and informal learning methods and will contribute to establishing a culture of research integrity. The aims pursued include raising awareness of scientific facts about research integrity, achieving widespread implementation of excellent learning paths, and creating units for learning research integrity that address everyone either directly or indirectly involved in research, including secondary school students, undergraduates, graduates, and young researchers.

Launch of the campaign *Catalunya, ens posem en òrbita*, with the presence of IEEC

On 23 February 2021, the campaign *Catalunya, ens posem en òrbita* ("Catalonia, we're going into orbit") was launched, within the framework of the NewSpace Strategy for Catalonia promoted by the Generalitat de Catalunya. The IEEC is one of the research and innovation centres that currently form part of the NewSpace Ecosystem in Catalonia, where there is also room for many start-ups, some of them world leaders, such as the business incubator of the European Space Agency, ESA BIC Barcelona. The first testimonial of the campaign came from UPC-IEEC researcher Miquel Sureda.

Opening of the exhibition "Mars. The Red Mirror" at the CCCB, attended by many IEEC members

The exhibition "Mars. The Red Mirror", organised by the Centre de Cultura Contemporània de Barcelona (CCCB) in collaboration with researchers from the IEEC, among many other entities and individuals, was opened on 25 February 2021. Members of all IEEC's Research Units participated in the activities that were organised around the exhibition, which ran until 11 July 2021. The theme of the exhibition was the link between humans and Mars, from ancient times to the present day. "Mars. The Red Mirror" explored the human condition and its future as a species, and the ultimate nature of the Universe.

Scientific video to mark IEEC's 25th anniversary

On 6 February 2021, the IEEC celebrated the 25th anniversary of its creation in 1996. To mark this milestone, the Institute made a promotional video highlighting the main space missions in which the Institute and its four Research Units are currently involved, the key role the IEEC plays in the nanosatellite environment, and its participation in European programmes.

IEEC signs an agreement to boost aerospace activity at the Lleida-Alguaire Airport

The IEEC and Aeroports de Catalunya (AC) signed an agreement to formalise the aerospace activity of our Institute at Lleida-Alguaire Airport at an event that took place on 5 March 2021. The purpose of the agreement, which is part of the NewSpace Strategy for Catalonia promoted by the Department of Digital Policy and Public Administration of the Catalan Government, is to establish the working basis for collaboration between AC and the IEEC, with a view to undertaking the project to create the business development area linked to outer space, due to be hosted by the airport infrastructure.

IEEC joins the celebration of 8M

On 8 March, the IEEC joined the celebration of International Women's Day, recognised by the United Nations (UN). As the international 2021 campaign theme was #ChooseToChallenge, the Institute took the time to recognise all the women at the IEEC, who are challenging the frontiers of knowledge and space science. At the same time, the Institute also wanted to remember the past challenges that have been overcome by women everywhere and the imbalance in society they continue to face today.

Presentation of the winning name for the first nanosatellite of the NewSpace Strategy for Catalonia

The Super3 TV programme "InfoK", in collaboration with the IEEC and the Department of Digital Policies and Public Administration, organised a competition to find a name for the first nanosatellite put into orbit by the Catalan Government. The winning name was finally announced on 10 March 2021 at an event attended by the director of the IEEC, Ignasi Ribas. The winning name for the nanosatellite was *Enxaneta* and it was proposed by five different girls from different counties in Catalonia.

Historical video to mark the IEEC's 25th anniversary

During the IEEC Forum 2021, a historical video created to mark the 25th anniversary of the Institute was presented. The video briefly reviews the history of the IEEC, highlighting its most important achievements since its establishment, through the voices of various key figures related with the Institute: Jordi Isern, founding director (1996-2015); Francesca Figueras, executive director during the management of Jordi Torra (2015-2017; deceased); Ignasi Ribas, current director (2017-present); and Pilar Montes, manager (1997-present).

Maria Teresa Antoja, awarded a Leonardo Grant for Basic Sciences

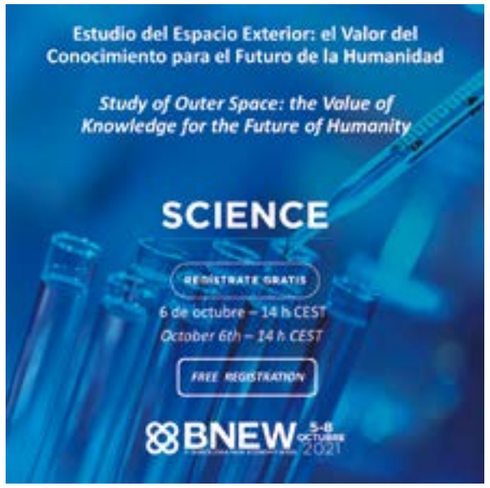
The IEEC researcher at the ICCUB, María Teresa Antoja, was awarded one of the 59 Leonardo Grants for Researchers and Cultural Creators presented by the BBVA Foundation in 2021. The fellowship awarded to Antoja, who is a "Ramón y Cajal" researcher, was one of the 6 Leonardo Grants awarded in the area of Basic Sciences (Physics, Chemistry and Mathematics) and will help to promote her research work in the field of Galaxy formation and evolution.

ICE-CSIC receives the "María de Maeztu" Excellence Distinction

The ICE-CSIC has been awarded the "María de Maeztu" seal of excellence, a distinction given to centres and units that engage in highly competitive, cutting-edge research and which enjoy international recognition in their respective scientific areas. The programme is aimed at funding and accrediting research centres and units that are able to prove scientific impact and leadership at an international level and which actively collaborate with their social and business environment. Thanks to this distinction, the ICE-CSIC will receive two million euros and eight pre-doctoral contracts in the next four years.

Nanda Rea awarded Knight of the Order of the Star of Italy

Nanda Rea, IEEC researcher at the ICE-CSIC, received the insignia of Knight of the Order of the Star of Italy in a ceremony that took place on 2 September 2021 at the Palau Robert in Barcelona. This distinction is awarded by the President of the Italian Republic, at the proposal of the Minister of Foreign Affairs, honouring those who have shown special merit in promoting good relations and collaboration between Italy and other countries.



IEEC researchers at the Barcelona New Economy Week

Three IEEC researchers, Carme Jordi (ICCUB), and Nanda Rea and Guillem Anglada (ICE-CSIC), took part in the second edition of the Barcelona New Economy Week – BNEW, which was held from 5 to 8 October 2021. This physical and digital event, which focuses on the new economy, brought together more than 800 speakers from around the world. Scheduled events explored topics related to logistics, digital industry, e-commerce, real estate, mobility, sustainability, talent and science.

Short News

NewSpace Economy 2.0 Conference

The IEEC collaborated in the organisation of the “New Space Economy 2.0 Conference: New business opportunities for companies”, organised by the Barcelona Chamber of Commerce and the Ministry of the Vice-presidency, Digital Policies and Territory of the Catalan Government. The conference, held on 22 October 2021 at Casa Llotja de Mar, was aimed at companies and entrepreneurs interested in learning about new opportunities in the sector and addressed the new business models offered by the NewSpace Economy. Several members of the IEEC participated in the activities organised within the framework of the conference.

Chervin Laporte, awarded an ERC Starting Grant

ICCUB researcher and IEEC member Chervin Laporte was awarded an ERC Starting Grant by the European Research Council (ERC). The grant, for which he applied in 2019, was given for his project “Numerical Simulations of the Milky Way’s Accretion History”. The ERC Starting Grants, which are part of the Horizon 2020 programme, are designed to help talented researchers who want to establish their research teams in Europe.

IEEC joins the International Astronautical Federation

Since 25 October 2021, the IEEC has been a new member of the International Astronautical Federation (IAF). Based in Paris, the IAF, which recently celebrated its 70th anniversary, is an international space advocacy organisation that was founded to establish a constant dialogue between scientists around the world and to lay the foundations for international space cooperation. The announcement of this new membership was made during the 72nd International Astronautical Congress, held from 25 to 29 October 2021 in Dubai, United Arab Emirates.

Presentation of the Digital Catalonia Alliance and the NewSpace Community

On 29 November 2021, the Digital Catalonia Alliance (DCA) was officially presented in Barcelona. The DCA is a new initiative of the Ministry of the Vice-presidency, Digital Policies and Territory of the Catalan Government that seeks to boost and revitalise the emerging technological ecosystem. A fortnight later, on 17 December, the NewSpace Community, one of the five technological communities within the DCA, was also presented. The IEEC plays a key role in the DCA NewSpace Community as a collaborator, contributing with its expertise in the NewSpace field.

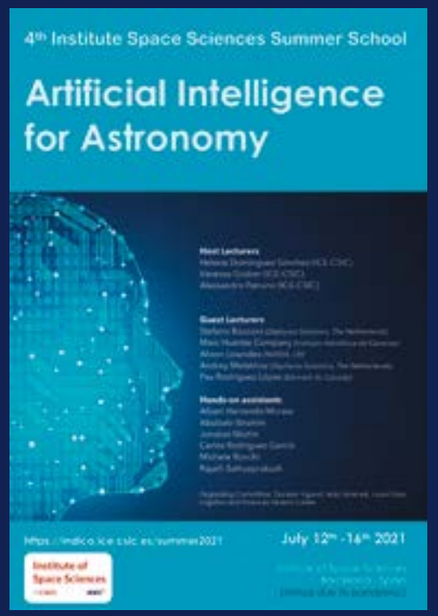
Héctor Gil-Marín receives the BBVA Foundation's Young Researcher in Theoretical Physics Award

ICCUB researcher and IEEC member Héctor Gil-Marín received the Young Theoretical Physics Researcher Award from the Spanish Royal Society of Physics and the BBVA Foundation. The jury highlighted Dr. Gil-Marín's outstanding contributions to the analysis and interpretation of galaxy mapping, in which he has advanced our understanding of the accelerated Universe and shown himself to be one of the most brilliant researchers of his generation in the field of Cosmology.

Meetings, Schools & Training

4th Institute of Space Sciences Summer School

The 4th Institute of Space Sciences Summer School, held from 12 to 16 July 2021, explored artificial intelligence (AI) methods for astronomy research, with a special focus on neural networks for image classification, natural language processing and graph neural networks. The topics covered the mathematical concepts as well as the development of software tools and applications. Through this ICE-CSIC Summer School organised every year, students from all over the world have the opportunity to broaden their knowledge, network with researchers and use the experience acquired for their thesis, PhD or post-doc research in the future. Due to the pandemic situation, the summer school was held virtually.



'Star Clusters: the Gaia Revolution' workshop

The workshop "Star Clusters: the Gaia Revolution" was held from 5 to 7 October 2021. Organised by the ICCUB as part of the EU COST action MW-Gaia, it covered various topics such as stellar associations, open clusters in the Milky Way disc, globular clusters and streams in the halo, as well as synergies between Gaia and other missions and observational campaigns. The sessions were spread over three and a half days and were entirely online.

The NewSpace Conference series begins with ‘Earth Observation Opportunities’

The IEEC collaborated with the NewSpace Conference Series, a group of virtual talks organised by the Ministry of the Vice-presidency, Digital Policies and Territory of the Catalan Government and the i2CAT Foundation. On 5 November 2021, the session “Opportunities for Earth Observation” analysed the potential benefits of NewSpace technologies related to this field. Use cases where NewSpace Earth Observation can provide great value (in particular, the control of vegetation, soil moisture and distribution and density of forest masses) were analysed in this session and participants shared successful business experiences in the field. Josep Colomé, head of the IEEC Knowledge Transfer Office, took part in the event.

PhD Theses

Author: **Rocío Martín Navarrete**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Departament d’Enginyeria Mecànica
Title: Computational Aeroacoustics in the Automotive Industry
Date: 2 February 2021
Director: Manel Soria Guerrero and Juan Carlos Cante Teran

Author: **Camilla Maggio**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Física
Title: Indirect search for WIMP Dark Matter with the MAGIC telescopes
Date: 26 February 2021
Directors: Markus Gaug and Lluís Font

Author: **Pablo Renard Guiral**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Física
Title: Lyman-alpha Intensity Mapping forecast with the PAU survey
Date: 03 March 2021
Director: Enrique Gaztañaga and Enrique Fernández Sánchez

Author: **David Sánchez Gonzalo**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Optimized PET module for both pixelated and monolithic scintillator crystals
Date: 15 April 2021
Director: Sergio Gómez Fernández and David Gascón Fora

Author: **Jianlin Chen**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Departament de Física
Title: Spacecraft state propagation and orbit determination using jet transport
Date: 23 April 2021
Director: Jianping Yuan, Gerard Gómez Muntané and Josep Joaquim Masdemont Soler

Author: **Alfred Castro Ginard**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Detection, characterisation and use of open clusters in a Galactic context in a Big Data environment
Date: 30 April 2021
Director: Carme Jordi Nebot and F. Xavier Luri Carrascoso

PhD Theses

Author: **José Ignacio Añez López**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Observational and theoretical perspective of massive star formation
Date: 05 May 2021
Director: Josep Miquel Girart Medina and Gemma Busquet Rico

Author: **Enrique Mestre Guillén**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Física
Title: Plasma-magnetic field interaction in extreme astrophysical environment
Date: 31 May 2021
Director: Emma de Oña and Diego F. Torres

Author: **Joan Francesc Muñoz Martin**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Departament de Teoria del Senyal i Comunicacions
Title: Development of novel instruments and techniques for passive microwave remote sensing
Date: 17 June 2021
Director: Adriano Camps Carmona

Author: **Albert Escrivà Mañas**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Numerical simulations of primordial black holes
Date: 21 June 2021
Director: Cristiano Germani

Author: **David Baroch López**
Department/Institute: Universitat Autònoma de Barcelona. Departament de Física
Title: Rocky exoplanets and stellar activity with CARMENES
Date: 27 July 2021
Director: Juan Carlos Morales

Author: **Hector Linares Arroyo**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Study and characterization of light pollution in Catalonia
Date: 27 July 2021
Director: Salvador Ribas Rubio and Eduard Masana Fresno

Author: **David Valcin**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: How cosmology can help and benefit from other areas of physics
Date: 28 September 2021
Director: Licia Verde

Author: **Edgar Molina Lumbreras**
Department/Institute: Universitat de Barcelona. Departament de Física Quàntica i Astrofísica
Title: Modeling and observations of relativistic outflows in high-energy binary systems
Date: 29 September 2021
Director: Marc Ribó Gomis and Valentí Bosch Ramon

Author: **Yago Herrera**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Departament de Física
Title: Models of stellar winds from X-ray bursts
Date: 15 December 2021
Director: Glòria Sala Cladellas and Jordi José Pont

Outreach

IEEC opens the celebration of its 25th anniversary with a Tandem of scientific couples from public and private entities

On 6 February 2021, the IEEC celebrated the 25th anniversary of its creation in 1996. The Institute opened the celebration of this milestone on 8 February with the conversation "Future prospects of space science", the first of a series of "Tandems of scientific couples: public and private entities". The director of the IEEC and ICE-CSIC researcher Ignasi Ribas, and Monica Roca, founder and director of the company isardSAT and vice president of the Chamber of Commerce of Barcelona, talked with the science journalist for the newspaper Ara, Toni Pou, about the most ambitious space research projects today, the "health" of the academic and industrial network of the space sector in Catalonia, as well as the current position of NewSpace in Catalonia, in Spain and internationally. The conversation can be found on the IEEC YouTube channel.

IEEC joins the celebration of the International Day of Women and Girls in Science

11 February is the International Day of Women and Girls in Science and the IEEC was not going to miss the opportunity of joining this celebration. The aim of this special day is to promote the full and equal participation of women and girls in education, training, employment and decision-making processes in science, and to eliminate all discrimination against women in the fields of education and employment. Some of our women researchers wanted to have their say on this important occasion. Their statements were compiled on the Institute Twitter account (@IEEC_space). Moreover, several IEEC women researchers also took part in the #100tífiques event, an initiative to promote female roles and models in the fields of science and engineering and to foster the scientific vocations of boys and, especially, girls. With their small contribution, initiatives like these aspire to give visibility to women in science while identifying good practices that lead to gender equality in the sector. Thank you all for your contributions and your commitment!

ALIA Mission, an educational project of the CCCB, has IEEC onboard

The ALIA Mission, an educational project linking scientific dissemination and literary creation, was launched within the framework of the exhibition "Mars. The Red Mirror", which opened at the Centre de Cultura Contemporània de Barcelona (CCCB) on 25 February 2021. In collaboration with the IEEC and the Banc de Sabadell Foundation, the ALIA Mission took six groups of students from the 4th year of Secondary School and the 1st year of High School to the Red Planet for three months. The schools taking part received support material to work on the challenge assigned to them, visited the CCCB exhibition and learned about an IEEC research project from its researchers. The students were also accompanied by a science fiction writer, and the stories that emerged from this experience formed part of a podcast that revisited Ray Bradbury's classic "Martian Chronicles". This podcast was presented at the CCCB in June.

IEEC organises a round table about the role of women in science together with WiA Europe - Barcelona

A virtual round table entitled “Space from home: get to know IEEC through its women researchers”, was organised by the IEEC and the Barcelona representation of Women in Aerospace Europe (WiA - Europe) on 6 May 2021. The purpose of this event was to explain what the IEEC is and the research it is carrying out, adopting an inclusive perspective and giving voice to the Institute’s female researchers. The four members of the round table were all women scientists at the IEEC, and the discussion focused on the role of women in science from a generational point of view. Each of the women work in a different IEEC Research Unit and they are at different stages in their academic career. The participants were Francesca Figueras, professor in the Department of Quantum Physics and Astrophysics at the UB and ICCUB researcher; Mercè Vall-llossera, tenured professor in the CTE-CRAE research group at the UPC; Mar Mezcua, researcher and senior scientist at the ICE-CSIC; and Camilla Maggio, who defended her PhD at the CERES (UAB). The round table can be seen on the IEEC YouTube channel.

The Universitat de Barcelona organises 1st Session of the UB Institutes, focusing on the subject of space

On 22 June, the Universitat de Barcelona (UB) hosted the “1st Session of the UB institutes: The exploration (and exploitation) of space”. The aim of this meeting, which could be followed live on UBtv, was to address the issue of space from a multidisciplinary perspective, based on the research carried out by the various research institutes at the UB. One of these is the ICCUB, which holds the María de Maeztu accreditation and is one of the four scientific units of the IEEC. The event began with a round table on the NewSpace Strategy for Catalonia, promoted by the Generalitat de Catalunya. It was moderated by Xavier Luri, director of the ICCUB, and Ignasi Ribas, director of the IEEC, took part in the discussion. In the second half of the conference, researchers from various UB research institutes talked about the exploration and exploitation of space, as well as the science that derives from it, in a series of short presentations. The economic impact of space exploration and a historical view from a social and humanistic perspective were also discussed at this event.

IEEC participates in the EUROAVIA Mission international hackathon during World Space Week

The online 24-hour hackathon entitled “The EUROAVIA Mission European Students Space Hackathon” was held on 8 and 9 October 2021. The event, which took place in World Space Week, was organised by Euroavia and Knowledge Innovation Market Barcelona (KIMbcn), in collaboration with the European Space Agency (ESA). As a key sponsor, the IEEC took part in this contest, which was aimed at students across Europe enrolled on a space-related degree course. Participants took the opportunity provided by this event to get to know the leading companies in the space sector in Europe, while receiving advice from experts on technical and business issues. The technical mentors included Alberto Garcia-Rigo, head of the Project Management Office at the IEEC. The winning team in each category received a prize of 1,000 euros from the Generalitat de Catalunya, the IEEC, and the i2CAT Foundation.

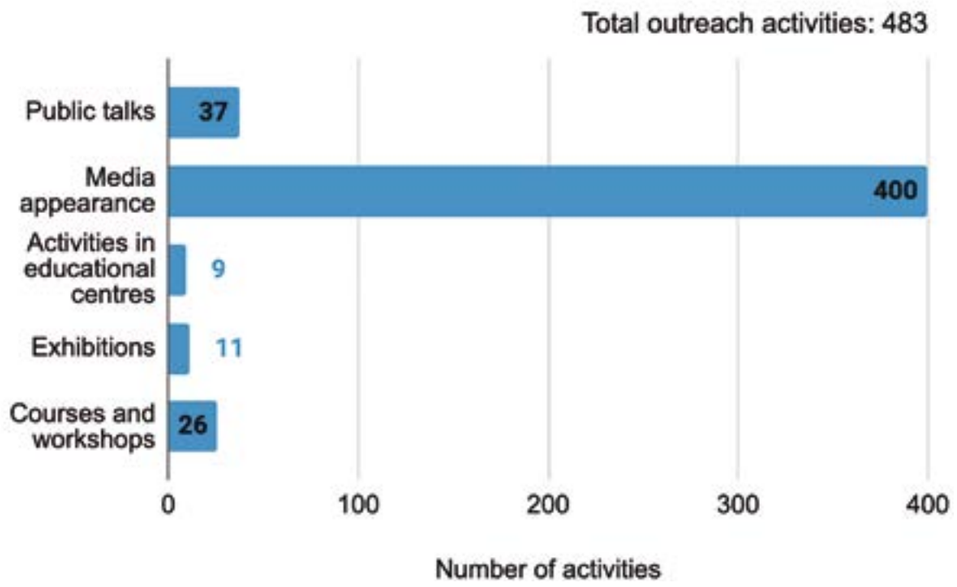
IEEC director participates in Science in Schools Day

The activity Science in Schools Day took place on 17 November 2021. The event, aimed at 3rd and 4th year secondary school students, was organised by the Ministry of Education of the Catalan Government and the Catalan Foundation for Research and Innovation (FCRi) within the framework of Catalan Science Week (12-21 November 2021). This year, four main topics were addressed: circular economics, robotics, astrophysics and cybersecurity. In the first part of the project, experts in each of these fields proposed a simple challenge to the students through a presentation video. The students then had to work together with the teachers to complete the challenge, while the scientists assisted with any doubts or questions. Within this framework, the ICE-CSIC astrophysicist and director of the IEEC, Ignasi Ribas, prepared a challenge focused on the discovery of exoplanets. On Science in Schools Day, the researchers taking part connected online with the students to present and comment on the results of the challenges, and students also had the opportunity to ask them more personal and research-related questions.

ICCUB and ICE-CSIC activities in the 26th Catalan Science Week

Catalan Science Week is an initiative coordinated by the Catalan Foundation for Research and Innovation (FCRi) and targets a very wide audience. Its aim is to bring science and technology closer to the public and to encourage scientific vocations among the youngest by organising activities to promote science throughout Catalonia. The 26th edition of this event was held from 12 to 21 November 2021. The IEEC took part, organising the virtual talk “Discovering the Universe from Montsec”. In addition, some of the IEEC Research Units organised a series of outreach events, in which researchers from the IEEC participated. On the one hand, the ICCUB was involved in three activities: the Toc-Toc talk “Space in cinema: fiction and reality”, the activity “Public observation of the moon with the planting of telescopes in La Verneda”, and the workshop “3D constellations and a virtual voyage through the galaxy with Gaia”. On the other hand, the ICE-CSIC organised its usual Friday-held #PizzaSeminars, devoted on this occasion to a special informative edition aimed at the general public, consisting of five-minute micro-talks by junior staff at the Institute and the engineering team.

Outreach statistics



Hubble spots swirls of dust in the Flame Nebula (NGC 2024), a large star-forming region in the constellation Orion that lies about 1,400 light-years from Earth. Credit: NASA, ESA, and N. Da Rio (University of Virginia); Processing: Gladys Kober (NASA/Catholic University of America).

IEEC

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Espacials de Catalunya

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Universitat de Barcelona

CSIC

UAB
Universitat Autònoma de Barcelona

CERCA