IEEC

Institut d'Estudis
Espacials de Catalunya

Annual Report 2022

Cover image:
Artist's impression of the binary star system *LS I 61 303* shining over the FAST telescope.

An international team of scientists has discovered for the first time pulsations at radio wavelengths from the binary star system *LS I 61 303*. This finding, made using the 'Five-hundred-meter Aperture Spherical radio Telescope' (FAST) radio telescope, is the first evidence of pulsations from this source at any frequency after more than four decades of searching and demonstrates the existence of a rotating neutron star in this system, i.e., a pulsar. The results of the research were published in the journal *Nature Astronomy*.

Credit: D.F. Torres, S. Weng and K. Rappaport, Science Communication Lab.

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Foreword

This annual report provides a summary of the main results, accomplishments and events that have shaped the year 2022 at the IEEC.

2022 marked a turning point. After the difficulties caused by COVID in the previous two years, the pandemic started to fade away. We managed to return to social interaction, our general mood lifted, and stronger ties were forged between all the members of the Institute. The high spot of the year was the 4th IEEC Forum, which took place in June and could be held without restrictions. Remarkably, we succeeded in staging each of our annual IEEC forums throughout the pandemic! In terms of meetings and congresses, 2022 saw a return to some sort of normality. Examples can be found in the 4th Symposium on Space Educational Activities and the NewSpace Economy Congress 2022, both held in Barcelona and where the IEEC was one of the co-organisers, as well as a number of other gatherings at which the IEEC featured prominently, such as the Mobile World Congress in Barcelona and the International Astronautical Congress in Paris, both of which showcased the nanosatellite missions that we lead.

At the institutional level, a major piece of news was the renewal of the IEEC's Science Advisory Board (SAB). Five renowned scientists and engineers were appointed by the Board of Trustees, and they joined three former members of the SAB, who will remain for an additional term. As part of the renewal process, Prof. Stephen Eikenberry and Joan de Dalmau ended their terms. We are deeply indebted to them for generously offering their time and advice and helping the IEEC to accomplish its goals. The expertise and advice of our new SAB, with eight world-class scientists and engineers, will help the IEEC to achieve even more ambitious objectives.

Once again, this year has been extraordinarily productive in terms of both inputs and outputs. Not only have our IEEC members managed to publish 420 peer-reviewed articles, but 90% of these have also appeared in first-quartile journals. Furthermore, most of our published results have been made openly accessible to everyone, in line with our open science policy. You will find a full statistical report in the Publications section below, and we offer a taste of the science results in the Highlights section, covering topics within astrophysics, cosmology, Earth observation and navigation.

The role of the IEEC in the NewSpace strategy of the Catalan Government has intensified during 2022. This report includes a detailed account of all the activities and main results achieved this year. It is worth noting here that the two nanosatellites developed within the strategy have been in the spotlight. Enxaneta, the 3U cubesat for telecommunications launched in 2021, has been working as planned, and results were presented in early 2022. Menut, the 6U Earth observation cubesat, was manufactured and tested during 2022. As a result of the Russian invasion of Ukraine, the planned launch with a Soyuz rocket was cancelled and a new launch vehicle had to be selected. Finally, the Menut mission was launched on 3 January 2023 with a Falcon 9 rocket from Cape Canaveral. However, this will be described in further detail in next year's annual report. In 2022, many other activities took place at the IEEC in the NewSpace domain, including several research projects and the development of key infrastructures. You will find many more details in the relevant section of this report.

The various facilities at the Montsec Observatory (OdM) have maintained their very high standard in terms of efficiency and productivity. The scientific observations from the Joan Oró Telescope (TJO), 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…). The number of registered users has seen a 10% increase compared to 2021 (and a 100% increase since 2018) to reach a total of 200, split fairly evenly between the IEEC, Spanish and international users. This success is due to the flexible robotic operation (reaching over 80% duty cycle), the competitive instrument suite of the TJO, and the high quality of the data provided. In addition to astronomy, the Montsec Observatory has infrastructures in other domains that have been in the news during 2022. For example, the corner reflector installed within a public-private partnership to calibrate Sentinel-6 data from the EU Copernicus programme, and the S-band and UHF/VHF antennas for nanosatellite communication in partnership with the UPC.

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 navigation, 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 2022, 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 this report describe these projects and provide updated information on their status and the main activities throughout 2022, including the milestones achieved.

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. The main topics of such contracts cover areas such as ESA space missions, Earth observation, navigation, space safety, telecommunications, and ground infrastructures. Knowledge transfer to the general public is also an integral part of IEEC's mission. Our Communication Office has organised many outreach actions throughout 2022. Round tables, workshops, activities during the Science Week and the International Day of Women and Girls in Science are just a few select examples of the many more described below. The KTO and the Communication Office also worked closely

together in the co-organisation of the local edition in Barcelona of the 4th CASSINI Hackathon, held simultaneously in 10 European locations. Furthermore, a quarterly newsletter edited by the Communication Office is distributed by e-mail to all IEEC members and keeps us all informed about the latest events and developments.

In addition, in this annual report you will also find articles on the COST networks that we manage, as well as training activities such as PhD theses, among others. We also include short notes explaining that the IEEC was officially admitted as a member of the Eurisy and the NEREUS association, in both cases representing the Catalan space sector.

Finally, I would like to wholeheartedly congratulate the IEEC members who have received awards and recognitions during 2022, also reported here. This is a perfect tribute to the world-class quality of the work performed. I would also like to take this opportunity to thank each and every one of the members of the IEEC for their ongoing commitment and for the part they have played in helping the Institute to reach the highest levels of excellence in 2022. It is an honour and a pleasure to work alongside you.

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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 public sector 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 (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 University of 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 organisation chart of the IEEC 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. The management structure of the IEEC is organised into through 3 general Areas and 13 Offices with clearly defined roles and responsibilities.

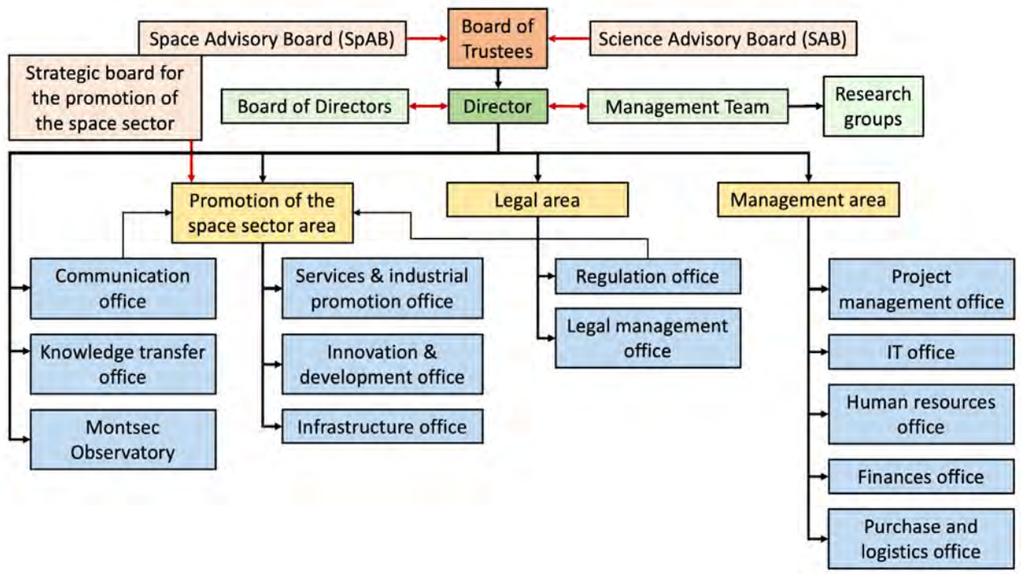


Figure 1: IEEC organisation chart.

The IEEC has taken a leading role in the implementation of the New Space Strategy of the Catalan Government, and acts as the Catalan Space Office. Therefore, a managerial and advisory structure is being implemented to optimally fulfil the associated 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 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 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 the IEEC participation.

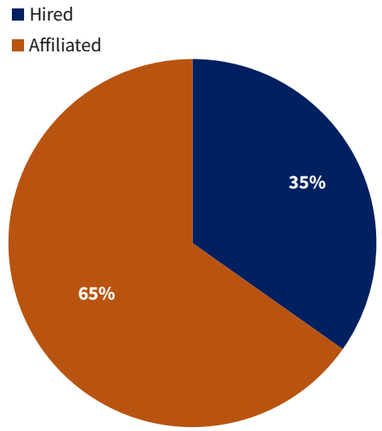
Personnel

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

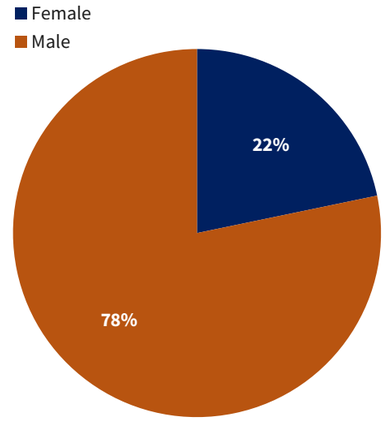
Total personnel: **250**	Male: **197 (79%)**	Female: **53 (21%)**
	Hired: **88 (35%)**	Affiliated: **162 (65%)**

IEEC contracts	
Management area + IT	9
Legal area	3
Knowledge transfer office	2
Communication office	3
Montsec Observatory	4
Faculty	2
Researchers & engineers	55
Postdoctoral Researchers	11
Research Engineers	44
Research Fellows	0
PhD Students	10
Total	**88**

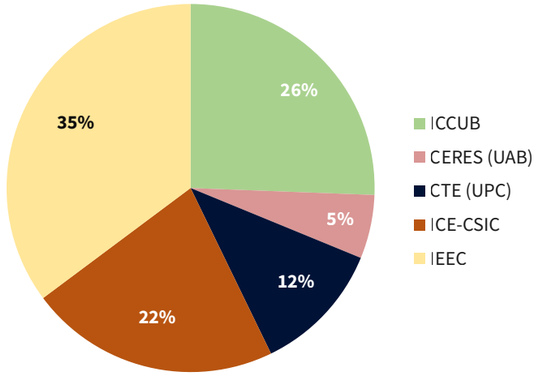
Affiliated members					
	ICCUB	CERES (UAB)	CTE (UPC)	ICE-CSIC	TOTAL
Administration	1	0	1	0	2
Faculty	32	9	22	22	85
Researchers & engineers	15	4	2	21	42
Postdoctoral Researchers	2	3	0	11	
Research Engineers	9	1	0	5	
Research Fellows	4	0	2	5	
PhD Students	16	1	4	12	33
Total	**64**	**14**	**29**	**55**	**162**



1. Personnel according to work situation

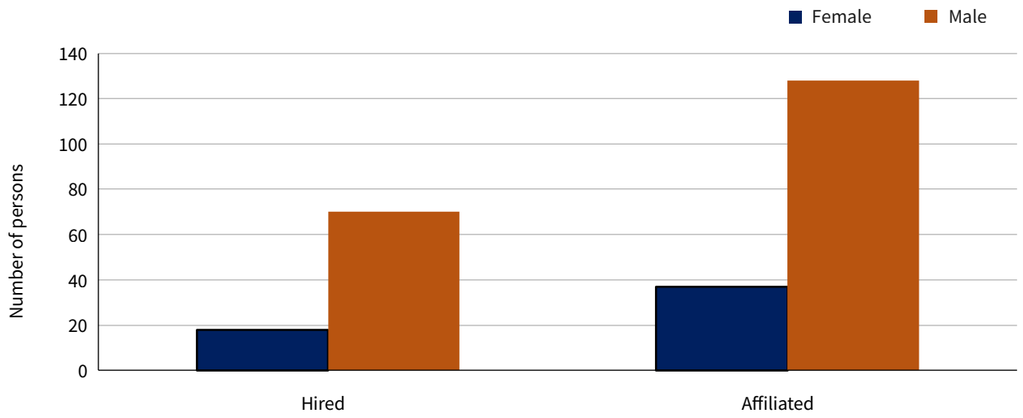


2. Personnel by gender

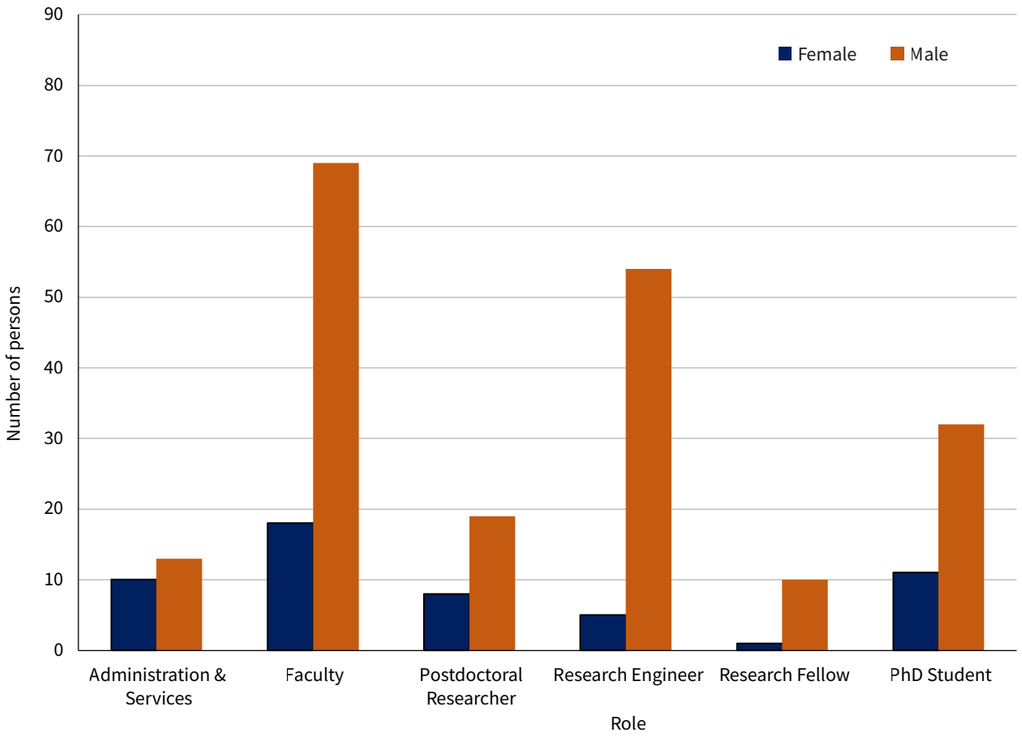


3. Personnel by Research Unit

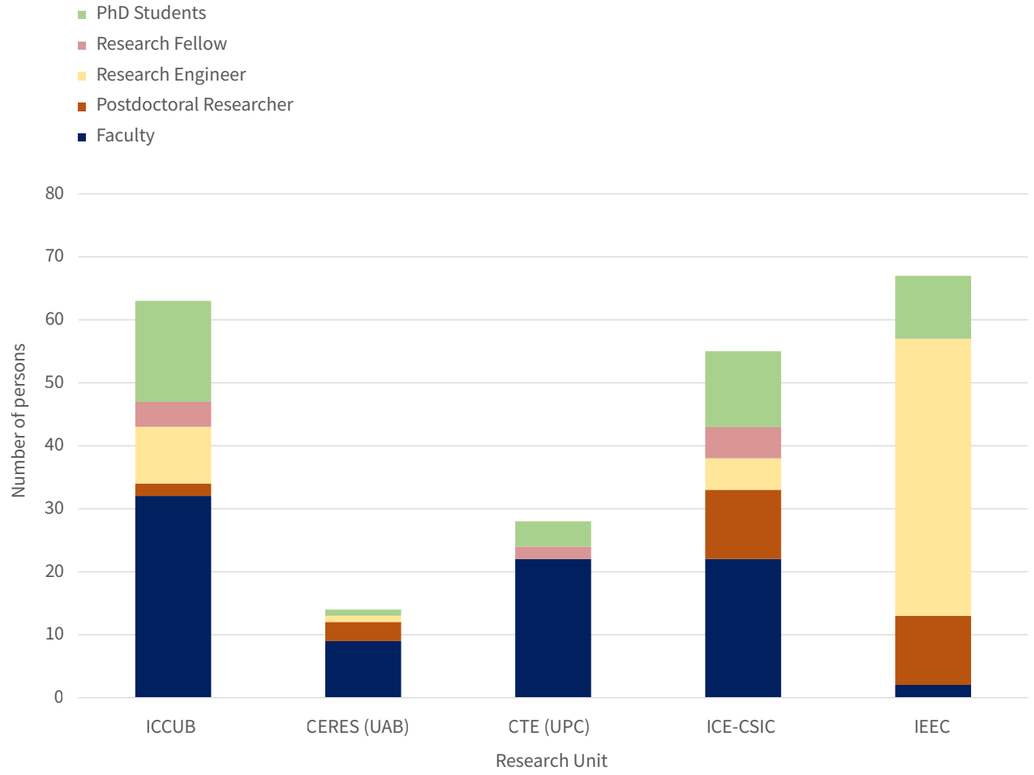
Personnel



4. Personnel according to work situation and gender



5. Personnel by role and gender



6. Researchers by role and Research Unit

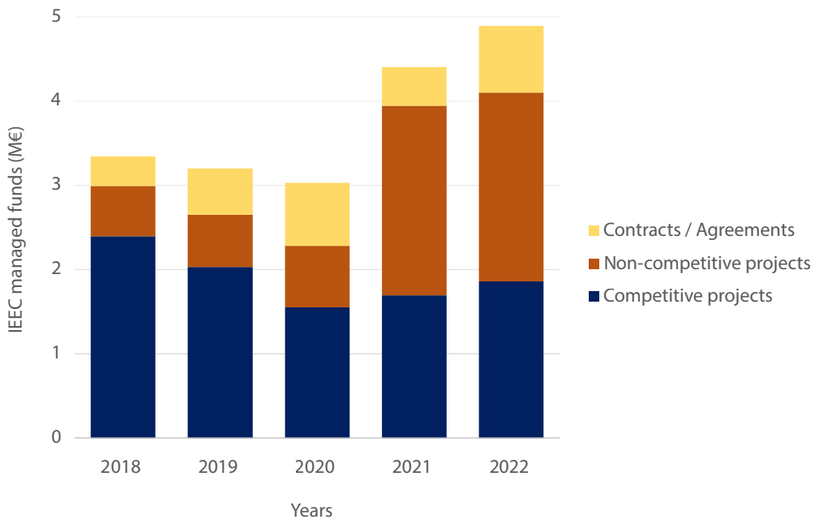
Projects

The plots 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 evolution over time.

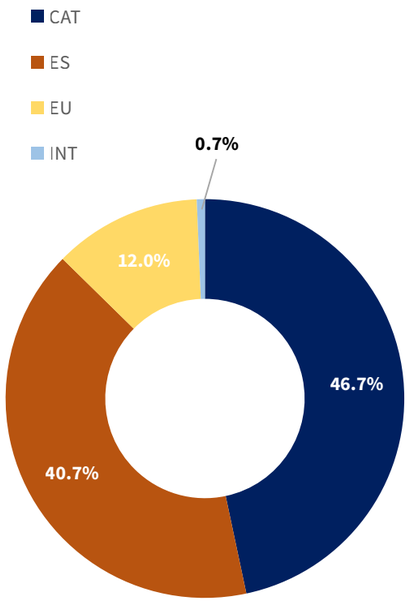
* Provisional economical data pending closure of the 2022 financial year.

Contracts/Agreements	Income (k€)
European public sector	418.6
European private sector	3.3
National industry	95
National public sector	238.3
International (non-European)	32.1

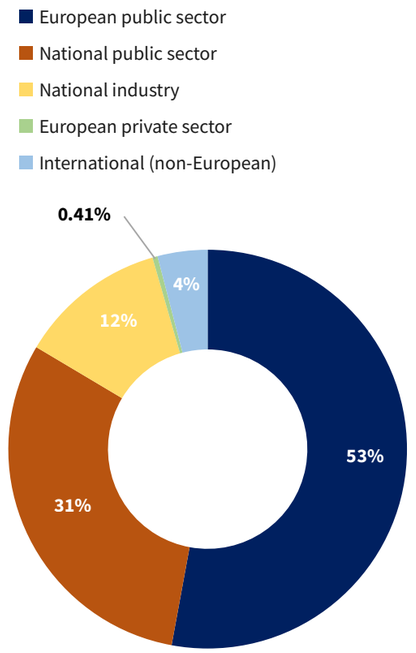
Subsidies	Income (k€)
Competitive projects	
AGAUR	42.3
MCIU	1,652.4
EU	161.6
Non-competitive projects	
NewSpace strategy	1,321.3
Programme contract	846.8
iCERCA + others	72.6



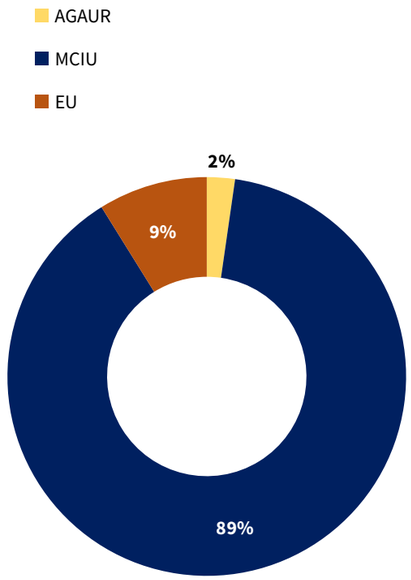
7. Incomes by year and type of project



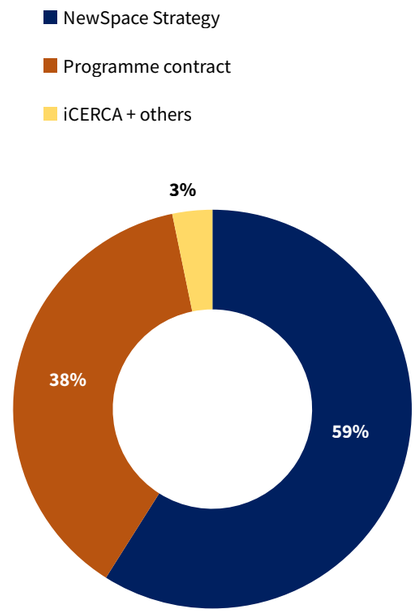
8. Income by geographical area



9. Income from contracts/agreements



10. Income from competitive projects

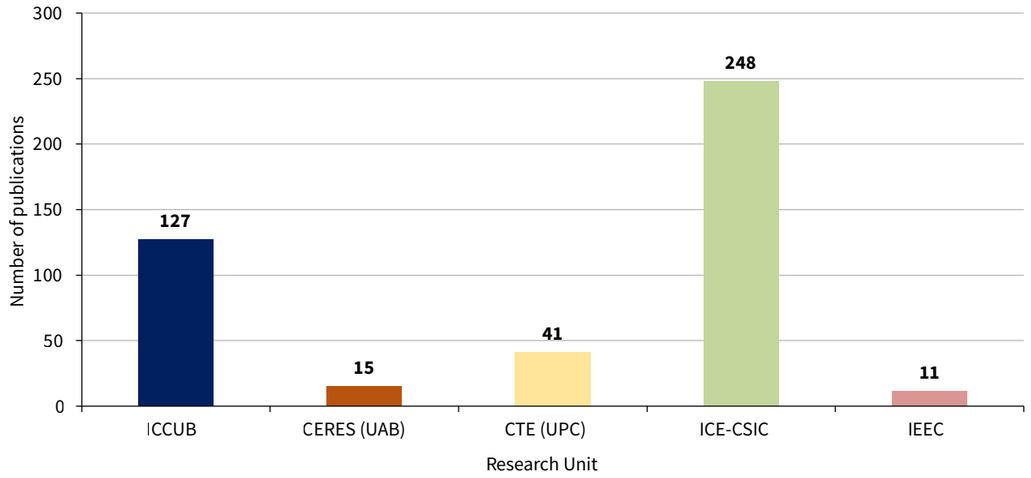


11. Income from non-competitive projects

Publications

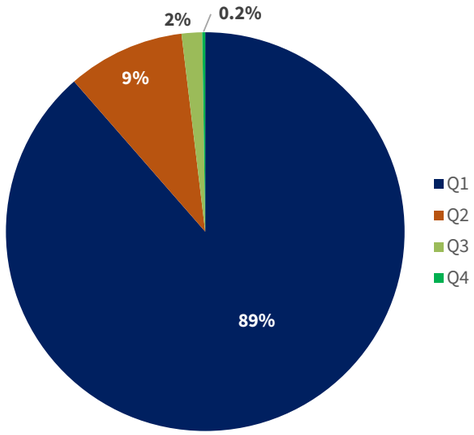
The total number of publications authored by IEEC members is 420. Below is a graphical summary of all the scientific and technical publications produced by IEEC members according to the Research Unit, journal quartile, journal, scientific subject and author.

96.2% of publications authored by the IEEC are classified as Open Access (OA).

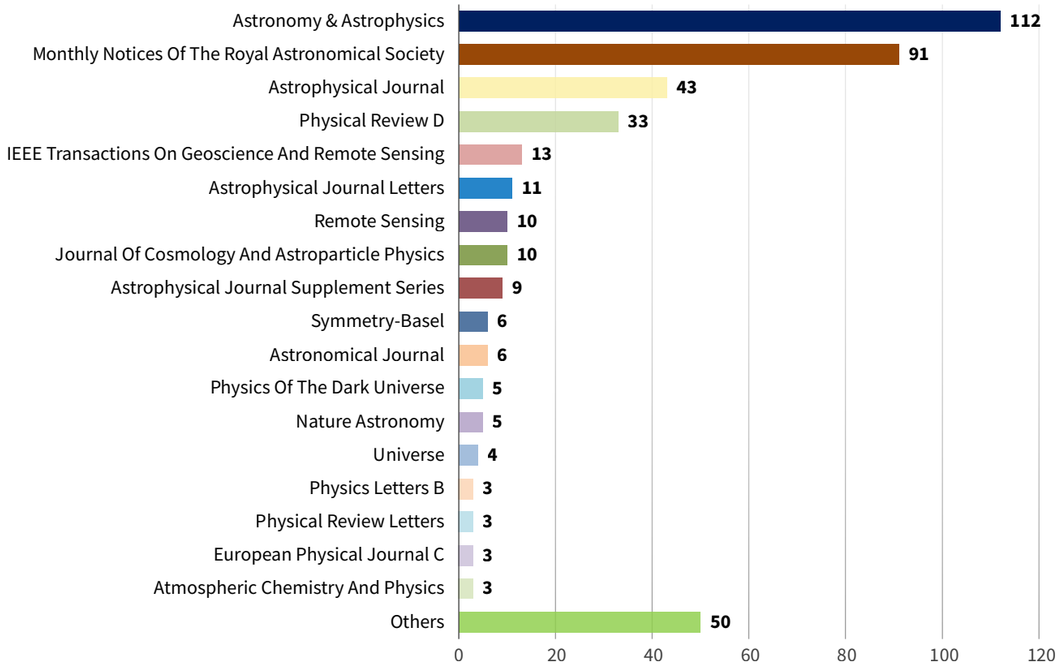


12. Number of publications by Research Unit

The total number of publications includes the 10 publications done by authors at Universitat de les Illes Balears (UIB).



13. Number of publications by journal quartile

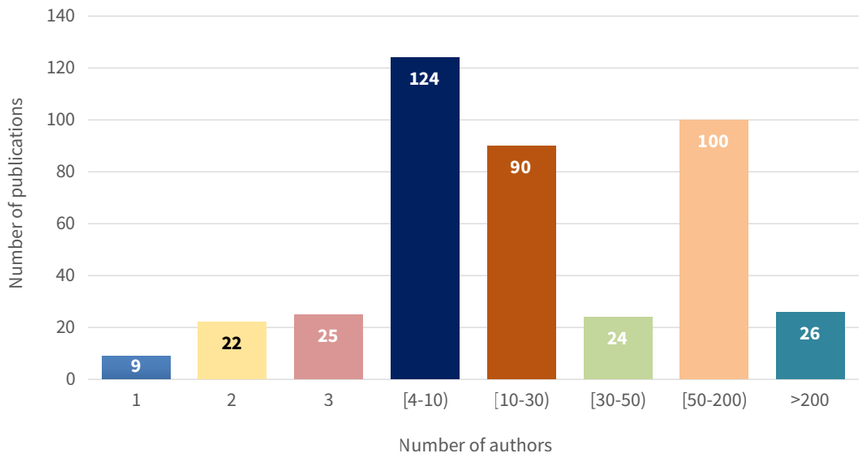


14. Number of publications by journal

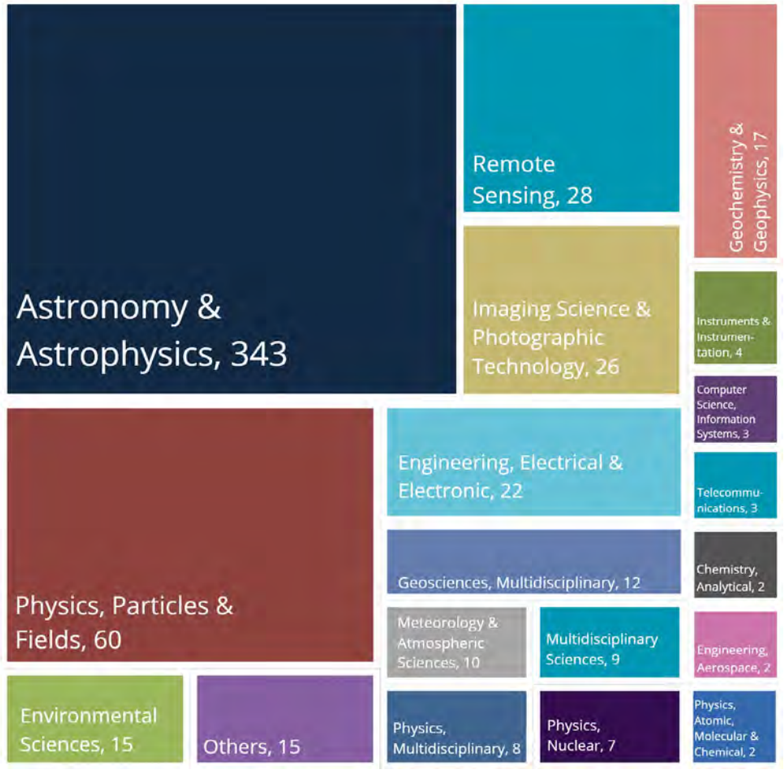
(*) Others:

- **Journals with 2 publications**: EPL, Frontiers In Astronomy And Space Sciences, GPS Solutions, IEEE Access, Journal Of High Energy Astrophysics, Sensors.
- **Journals with 1 publication**: Acta Astronautica, Astrobiology, Atmosphere, Biogeosciences, Communications In Nonlinear Science And Numerical Simulation, Digital Signal Processing, Elementa-Science Of The Anthropocene, EPJ Quantum Technology, European Physical Journal A, Experimental Astronomy, Fortschritte Der Physik-Progress Of Physics, Frontiers In Marine Science, Frontiers In Plant Science, General Relativity And Gravitation, IEEE Geoscience And Remote Sensing Letters, IEEE Geoscience And Remote Sensing Magazine, IEEE Journal Of Selected Topics In Applied Earth Observations And Remote Sensing, IEEE Transactions On Information Forensics And Security, IEEE Transactions On Signal Processing, International Journal Of Modern Physics D, Journal Of Atmospheric And Oceanic Technology, Journal Of Climate, Journal Of Guidance Control And Dynamics, Journal Of Instrumentation, Journal Of Space Weather And Space Climate, Journal Of The Atmospheric Sciences, Journal Of Physics G-Nuclear And Particle Physics, Living Reviews In Relativity, **Nature,** Nature Communications, Nuclear Physics B, Physical Chemistry Chemical Physics, Physical Review C, Progress In Particle And Nuclear Physics, Progress Of Theoretical And Experimental Physics, Publications Of The Astronomical Society Of Australia, **Science,** Space Weather-The International Journal Of Research And Applications.

Publications



15. Number of publications according to number of authors



16. Number of publications by subject

(*) Others:

- **Subjects with 2 publications**: Chemistry, Analytical; Engineering, Aerospace; Physics, Atomic, Molecular & Chemical.
- **Subjects with 1 publication**: Biology, Chemistry, Physical; Computer Science, Theory & Methods; Ecology; Engineering, Ocean; Geography, Physical; Marine & Freshwater Biology; Mathematics, Applied; Mathematics, Interdisciplinary Applications; Mechanics; Optics; Plant Sciences; Physics, Fluids & Plasmas; Physics, Mathematical; Quantum Science & Technology.

Moreover, some publications were collaborations between authors at different IEEC research units. These are:

	Publications
ICCUB + ICE-CSIC	13
ICE-CSIC + IEEC	7
ICCUB + CERES (UAB)	5
CTE (UPC) + IEEC	3
ICE-CSIC + ICCUB + IEEC	1
ICCUB + CTE (UPC)	1
ICE-CSIC + CTE (UPC)	1

PRODUCTIVITY

	2019	2020	2021	2022
Total number of researchers (incl. engineers & students)	189	184	255	227
Articles in peer-reviewed journals (Source: Web of Science)	402	436	450	420
Number of articles per researcher	2.1	2.4	1.8	1.8
% of articles in Q1 journals (Source: Web of Science)	91.7	87.4	86.6	88.6
PhD Theses	11	11	15	15

Facilities and Key Projects

Montsec Observatory

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

The Montsec Observatory (OdM, in its Catalan acronym, montsec.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 (see Figure 1).

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.

Figure 1: View of the OdM in July 2022.

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 observa-tions 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 2022 the IEEC achieved various milestones at the OdM. Below, we provide a summary of these.

MONTSEC OBSERVATORY

Montsec Observatory

OdM infrastructures

In 2022, a number of improvements were made to the OdM infrastructures. Several computers were upgraded and their integration into the system was improved, keeping track of their maintenance plans. The OdM's access control system was improved by adding an SAI to the access keyboards of the various controlled entrances, which include the main entrance to the OdM, the TJO building and the SGSMontsec. A new computer responsible for data logging of the energy monitoring system at the OdM was installed. The data that have been collected will be used to evaluate the environmental footprint of the facilities, as well as to adjust the available power for future infrastructures at the OdM. A TESS-W night sky background monitor was installed at the OdM to obtain regular information about the darkness of the sky at the observatory. The measurements from a first 2-month campaign were analysed, showing a mean sky background magnitude of 21.7 on nights with good weather and no Moon. During summer 2022, a Differential Image Motion Monitor (DIMM) was installed at the OdM (Figure 2-left) and used to obtain seeing measurements at the site (Figure 2-right). The measurements were taken over two weeks and their analysis showed that the seeing is below 1 arcsec around 65% of the time. In addition, work was carried out on the roofs of the OdM main building thanks to funding from CERCAGINYS. This work consisted in improving the insulation of the building, as well as the installation of railings and lifelines (see Figure 3). In addition, an MoU was signed with the Institut Cartogràfic i Geològic de Catalunya (ICGC) to install a GNSS antenna and an accelerometer at the OdM. This GNSS antenna will be used to calibrate the position of the corner reflector installed at the OdM by IsardSAT S.L. in 2021 (see Figure 4).

During 2022, the IEEC issued a call for proposals to receive ideas for a new facility to be installed at the OdM in the future. A total of six different projects were received and a proposal of a 2-m class telescope with an Integral Field Unit (IFU) that could satisfy most of the scientific interests of the proposals received was submitted to the Generalitat de Catalunya for further discussion. In parallel, documentation has been prepared with the local authorities to extend the area of the observatory for research and innovation. In this context, the technical project to extend the services (power and fibre connections) outside the current premises has been prepared.

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. During 2022, the LAIA required a number of repairs, and for most of the year the previous MEIA2 camera was used. Since 2018, the TJO has also had a spectrograph (ARES). In addition, several associated

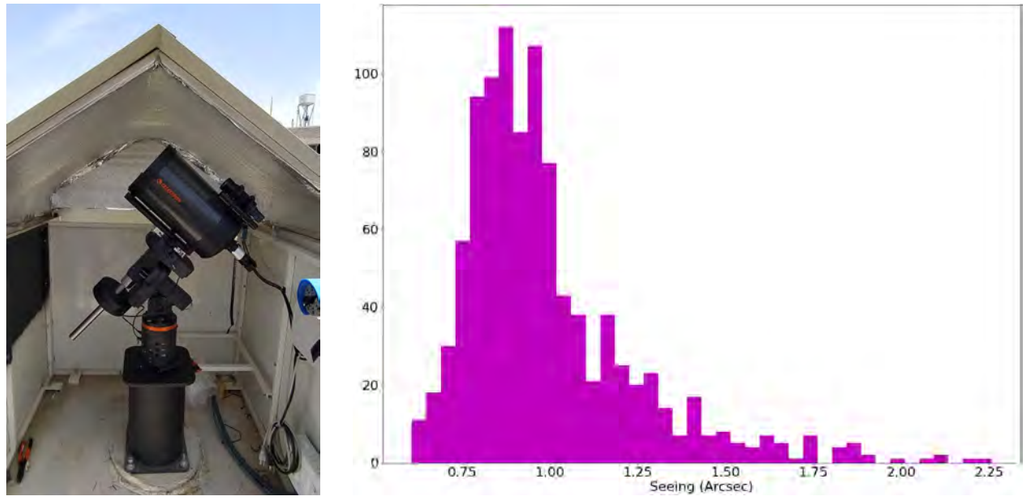


Figure 2: DIMM installed at the OdM (left). Histogram of seeing measurements obtained in July 2022 (right).

Figure 3: Railings (left) and lifelines (right) installed on the roof of the TJO building.

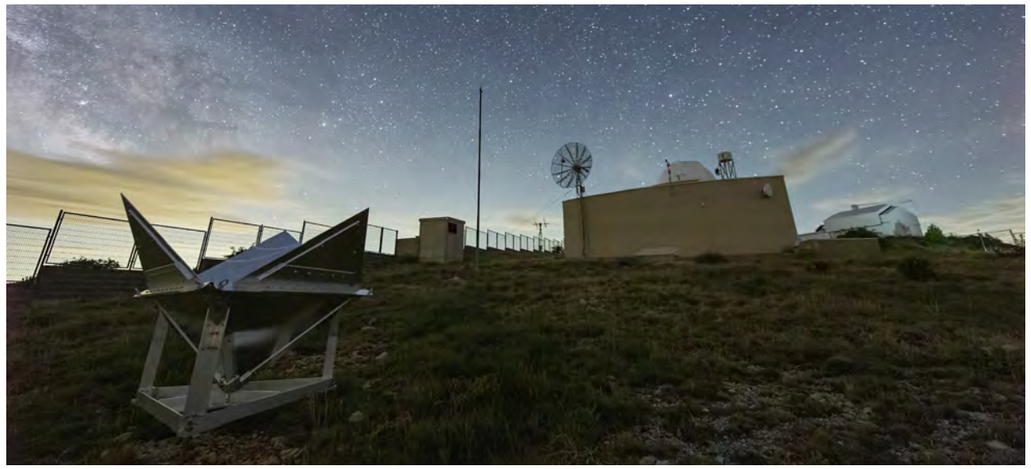


Figure 4: Corner reflector for the calibration of the Sentinel-6 satellite installed at the OdM, with the SGSMontsec S-band antenna in the background.

Montsec Observatory

instruments for environmental monitoring are acquiring data continuously: two weather stations, a GPS antenna, a storm detector, and a photometer, 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 2022, ISROCS has been improved to optimise the scheduling of observations. In particular, a real-time planner has been developed, tested and is currently used for the TJO. This allows users to set up observations that can be performed just a few minutes afterwards without intervention from TJO staff (provided the weather permits, the source is visible, and the priority of the proposal is high enough). Additionally, the algorithm that computes the priority of observation sequences has been modified in order to improve the completeness of the proposals at the end of the semesters. Also, during 2022, the new environmental monitoring system has been tested and implemented. It achieves better handling of weather alerts, including sensor redundancy.

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 2022. 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.

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 2022, the SVO was updated to include all the public raw images of the TJO with a total of over 560,000 images, obtained during 2,900 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 2022 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. Since it became a member, the TJO has participated in this network with tracking mode service.

At the end of 2022, the OdM had 200 registered users on MUR, 65 of them from the IEEC, 66 from other Spanish institutions, and 69 from international institutions. This represents approximately a 10% increase in the number of registered users compared to 2021 (and a 100% increase since 2018). This is primarily due to the new scheme of two calls for proposals implemented in 2019, but also to the first call for long-term (2 yr) proposals issued in 2022, 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, has increased the telescope pressure time, with a fraction of requested over available scientific time below 1 in 2018 and in the range 1.0-1.4 since 2020. 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 although the percentage of useful time showed a slight increase with respect to previous years, the duty cycle showed a slight decrease due to a few nights lost when replacing the cameras. At all events, the total of around 1600 h of time acquiring useful data was on a par with the previous two years.

Observation statistics

- Useful time (night-time hours with good weather conditions): 1975 h (66.3% of total night time)
- Time acquiring data (regardless of quality): 1786 h (90.5% of total night time with good weather)
- TiTime acquiring useful data: 1619 h (82.0 % of total night time with good weather) → Duty cycle

Montsec Observatory

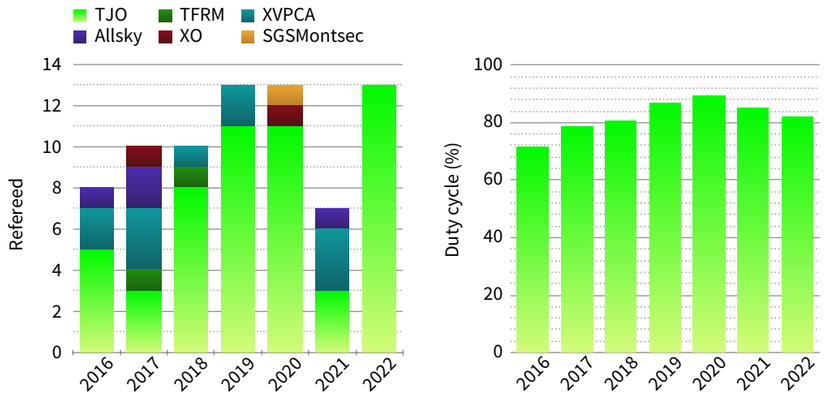


Figure 5: Number of refereed publications per year from the facilities at the OdM during the last 7 years (left). The recovery and slight increase in the number of Joan Oró Telescope (TJO) publications in 2022 is due to the new observation programmes begun during the last few years. Fraction of time acquiring useful data per year from the 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);
- 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 6: The Hercules Cluster (M13) captured by the Joan Oró Telescope (TJO).

During 2022, the TJO participated in different scientific projects, including the study of Solar System objects, monitoring of exoplanet transits, characterisation of M dwarf stellar activity, study of eclipsing binaries, monitoring of novae, detailed studies of white dwarfs or newly discovered black hole X-ray binaries, light curves of type Ia and type Ic supernovae, Gaia transients such as the ones producing microlensing events, and monitoring of gamma-ray emitting 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 (Figure 7-left). Also, the amount of time dedicated to scientific observations has remained nearly constant during the last few years and very close to the granted time for scientific proposals (Figure 7-right).

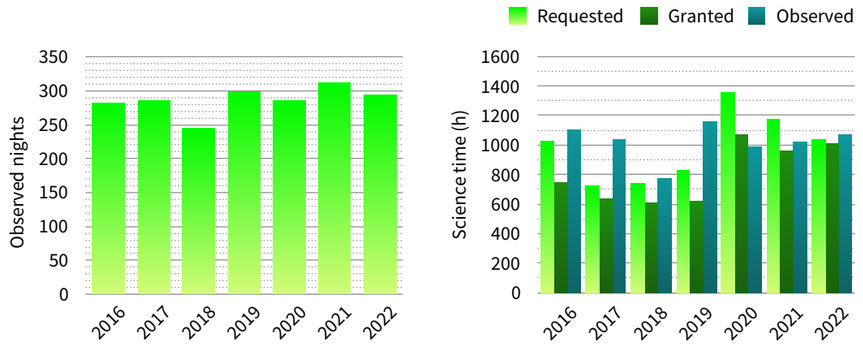


Figure 7: Number of nights with scientific observations at the TJO during the last 7 years (left). Amount of time requested, granted and observed for scientific proposals at the TJO during the last 7 years (right).

Montsec Observatory

In summary, with an efficient use of the LAIA and MEIA2 cameras and the continuation of shared-risk scientific observations with the ARES spectrograph, 2022 has been a very productive year for the TJO.

Science with the TFRM

The Telescopi Fabra-ROA Montsec (TFRM) is a 50-cm diameter modified Baker-Nunn Camera. It operates with a longpass filter above 475 nm and with a 4k x 4k front-illuminated CCD camera that provides a Field of View of 4.4º x 4.4º and a resolution of 3.9”/pixel. Since 2022, 30% of the observation time of the TFRM has been managed through the same Time Allocation Committee (TAC) as for the TJO (effectively the OdM TAC). The pressure of this public observation time is a factor of 1.2, and includes the search for trojans, small asteroids, transneptunian objects through occultations, the search for exoplanets, the monitoring of gamma-ray binaries and the study of M-dwarf flares.

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 (see Figure 8 and Figure 9). 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.

Figure 8: S-band antenna of the SGSMontsec.

In 2022 an upgrade of the S-band antenna to allow data transmission started and is still ongoing. In parallel, the IEEC has been registered as a satellite communications operator by the Spanish Ministry. A temporary experimental permit for S-band transmission has been received.

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

Visits and outreach

On 2 March 2022, a visit to the OdM was made by the then Minister of Universities and Research of the Generalitat de Catalunya, Gemma Geis, and by the Research General Director, Joan Gómez. Representatives of Sant Esteve de la Sarga, the municipality where the OdM is sited, were also invited to co-host the visit (see Figure 10).

Figure 10: Visit of authorities to the OdM on 2 March 2022. Ignasi Ribas explaining basic concepts of the OdM to the authorities (left). Kike Herrero showing the TJO (right).

Montsec Observatory

During 2022, the standard monthly visits to the OdM were restarted after a 2-year lapse due to the pandemic. Four different sessions were scheduled during July and August. However, one of these had to be cancelled because of access restrictions to Montsec due to fire risk, and numbers on the other visits were very low, mainly due to the extremely hot weather conditions. Also, a talk about the scientific highlights of the TJO was organised on 22 June in collaboration with Agrupació Astronòmica de Terrassa. Finally, in collaboration with Sant Esteve de la Sarga council, an observation of the night sky was conducted on 20 August 2022. The activity was attended by more than 100 people.

In the field of education, a visit to the OdM was arranged for secondary school students from the Institut de Tremp on 9 November. The visit was attended by 54 students and 3 teachers. Finally, on 30 September a virtual visit to the OdM was organised through the IEEC YouTube channel to coincide with the IV STEM in Space Symposium.

The Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA) will be the world's largest and most sensitive gamma-ray observatory for very high energies (~20 GeV - ~300 TeV). With over 80 telescopes located in the northern and southern hemispheres, the CTA is expected to improve sensitivity by a factor of 10 over current Air Imaging Cherenkov Telescopes (IACT). The northern and southern CTA arrays will constitute the CTA Observatory (CTAO), the first ground-based gamma-ray observatory open to the worldwide astronomical and particle physics communities as a resource for data from high-energy astronomical observations. The CTA's data will feed into a virtual observatory that will allow scientists to probe multiple data centres seamlessly and transparently, provide analysis and visualisation tools, and give other observatories a standard framework for publishing and delivering services using their data.

The CTA is expected to detect thousands of sources over its lifetime, making a significant impact on fundamental questions of Physics and Astrophysics. The current generation of instruments, H.E.S.S., MAGIC, and VERITAS, have already demonstrated the huge physical potential of astro-physical measurements at teraelectronvolt (TeV) energies. The 200+ sources detected by these instruments suggest that particle acceleration is common in nature and that the known objects are just the tip of the iceberg. The CTA will address questions under three themes: understanding the origin and role of relativistic cosmic particles, probing extreme environments, and exploring frontiers in Physics. The CTA will conduct a comprehensive survey of the Galactic Plane at very-high-energy gamma-rays, presenting challenges for source identification due to potential source confusion. A recent study by IEEC members tested the CTA's ability to identify and manage source confusion, with results published in MNRAS.

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 the "strategic plan for European astronomy" (leaflet) of ASTRONET. Additionally, the CTA is a recommended project for the next decade in the US National Academies of Sciences Decadal Review.

The Cherenkov Telescope Array

IEEC members from the ICE, ICCUB and CERES have played a vital role in the development of the Cherenkov Telescope Array (CTA) since its inception. Their involvement in MAGIC led to the creation of the CTA Consortium during a meeting in Barcelona organised by ICCUB members. The ICE participated in the CTA Task Force responsible for drafting a new Memorandum of Understanding for a redefinition of the collaboration, adapting it to the current European ERIC structure. The final paperwork for the Memorandum was submitted this year and it is expected to take effect in 2023. The Task force worked for the whole year, and it is expected to deliver its conclusions in April 2023.

IACTs detect Cherenkov radiation generated by a cascade of relativistic charged particles produced when a high-energy gamma ray hits the atmosphere. 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. Fig. 11 shows an artistic representation of how IACTs work. The CTA will use more than 7,000 highly-reflective mirror facets to capture and convert Cherenkov light into data. Both photomultiplier tubes (PMTs) and silicon photomultipliers (SiPMs) will be used in the cameras to convert the Cherenkov light into electrical signals that are then digitised and transmitted.

The northern hemisphere array will focus on the CTA's low- and mid-energy ranges, while the southern hemisphere array will span the entire energy range. Three classes of telescopes based on their sensitivity - SST, MST and LST - will be distributed in both hemispheres. Small-Sized-Telescopes (SSTs), with a 4 m diameter primary mirror, are tuned to detect high-energy gamma rays and are more suited for the southern site, while Medium-Sized-Telescopes (MSTs, 12 m) and Large-Sized-Telescopes (LSTs, 23 m) will be installed on both sites. The northern array is being constructed at the Roque de los Muchachos observatory on the Canary Island of La Palma (see Fig. 12).

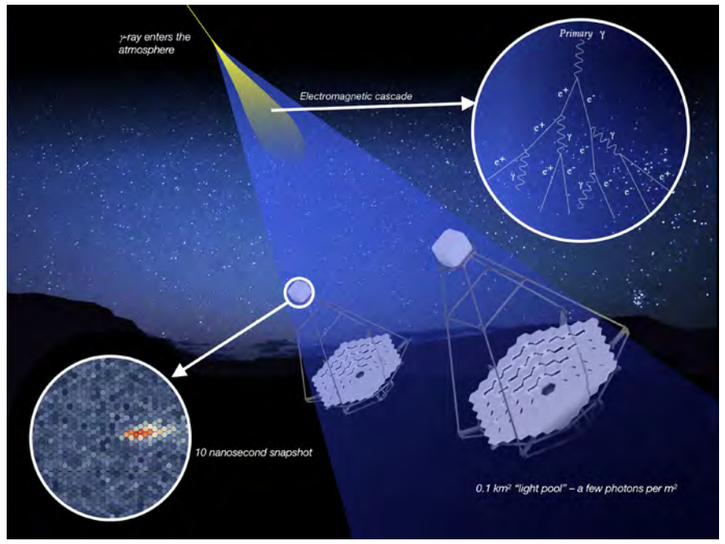


Figure 11: How IACTs indirectly detect a VHE gamma ray. Source: CTA Consortium (https://www.cta-observatory.org/about/how-cta-works/)

Figure 12: Northern Hemisphere Site Rendering. Credit: Gabriel Pérez Diaz, IAC, SMM

The main initiatives of IEEC members in 2022 were the following:

Electronic developments for 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 CTA (PACTA) is part of the LST1 already installed at the ORM, and the IEEC signed a contract and, in 2018, delivered 10,000 PACTA units to the University of Tokyo for the following three LSTs of CTA-North (LST 2-4). The Amplifier for CTA (ACTA) is part of the MSTs that will include the camera developed by the NectarCAM consortium, in particular the first MST prototype, MST1, which is planned to be installed at the 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 2021-2022, ICCUB members managed the ASICs production for the MST-NectarCAM 2-9 (PACTA, ACTA, and L0-trigger), in which they added pulse-injection functionality to the ACTA amplifier. The testing of these units started in 2022 and is still on-going. In collaboration with CERN's ESE-ME, the IEEC designed FASTIC, an 8-channel ASIC for SiPM readout that can perform active summation in two groups of 4 channels, providing a linear Time over Threshold response for energy measurements that can be sent to an FPGA for digitization. FASTIC is being considered for future LST upgrades.

The Cherenkov Telescope Array

Commissioning of LST1

IEEC members at the ICCUB and ICE are part of the LST1 team, the first Large Size Telescope of CTA-North, inaugurated in October 2018 (see Fig. 13). The IEEC contributed to the development of camera electronics and testing and debugging of the analysis software. Throughout 2022, the reliability of the data taking process has been tested through scientific observations, including calibration observations of the Crab Nebula and detections of several AGNs, the detection of the RS Ophiuchi nova outburst in 2022 in which ICCUB has a relevant participation, and other transient sources. Recently, the LST Collaboration published their inaugural scientific paper in Astronomy & Astrophysics. The study involved a multi-wavelength investigation of the galactic Pevatron candidate LHAASO J2108+5157, an unidentified ultra-high-energy gamma-ray source, using 49 hours of data collected from LST-1 (see Fig. 14).

Figure 13: The Large Sized Telescope 1 at the Roque de los Muchachos Observatory (La Palma, Canary Islands, Spain).

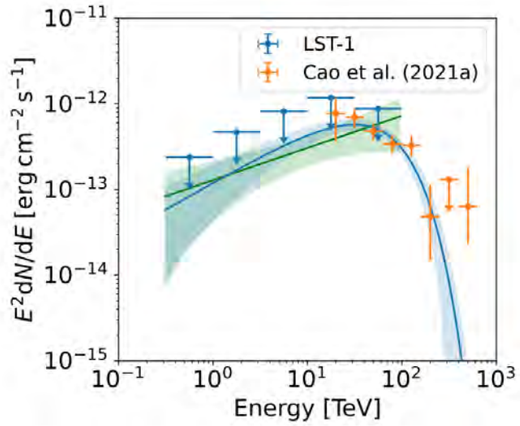


Figure 14: Emission spectrum of LHAASO J2108+5157. The blue arrows represent the upper limits on the source's emission at TeV energies as established by the LST-1. The orange points correspond to the higher-energy emission detected by LHAASO in 2021. The green and blue bands correspond to the best fit of the data assuming a source's emission described by a power law and a power law with cut off scenario, respectively. Although no significant detection was achieved, the integration of data from LST-1 and other instruments allowed the team to establish rigorous upper limits on the source's emission, contributing to a better understanding of its characteristics.
Credit: LST Collaboration, https://doi.org/10.1051/0004-6361/202245086

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 has contributed with the camera electronics and has delivered tested units of the L0-trigger ASIC.

A second offer was submitted by the IEEC, involving teams from the ICE-CSIC and CERES, for the production of the Camera Control Software to allow the data acquisition of the Cherenkov radiation with the camera detector and the calibration light, and the use of weather sensors to provide a high-logic behaviour ensuring the correct instrument operation. The tendering process finished in mid-2020 and the IEEC offer was selected. The specific purpose of this contract is the development of the GUI for camera calibration and data visualisation and for weather monitoring data visualisation, known together as "CaWeCS" (Camera Calibration and Weather Control System). The software can launch different calibrations on the LST2-4 cameras, collect and display meteorological metrics, and issue alerts based on current forecasts and metrics.

The software is set to be delivered by mid-2023, with the final developments carried out in 2022. A visit to test the software on the LST1 camera is scheduled before the end of the contract in early May 2023.

Coordination of CTA Array Calibration, Atmospheric Characterization and Environmental Monitoring

The CERES member Markus Gaug has been coordinating this project since 2013 and is seconded to the CTA Observatory within the framework of a collaboration agreement between the IEEC and the CTAO. As part of his duties, Markus Gaug represented the CTA on 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. In 2022, CERES provided a weather station for the LST1, used for a weather monitoring system prototype.

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. LIDAR will help obtain range-resolved and wavelength-dependent atmospheric transmission in the line-of-sight of the telescopes, which is required to estimate the extinction of the Cherenkov light on its way to the telescope reflector surface. The Raman LIDAR has been designed and built through collaboration between CERES members, the IFAE group of CTA, and other CTA members from Nova Gorica (Slovenia) and Padova (Italy). It includes innovative elements such as a 1.8 m diameter telescope and 8 mm liquid light guide. The Raman LIDAR underwent a commissioning phase in 2018, and in 2021, it was brought to the Observatorio del Roque de los Muchachos (ORM) in La Palma for a 15-month test period. During this period, it monitored the volcanic ash plume emitted by the Cumbre Vieja volcano, and the results of these measurements were presented at the International AtmoHEAD conference in Italy in July 2022. Fig. 15 and Fig. 16 show the Raman LIDAR and the signal obtained with three channels, respectively.

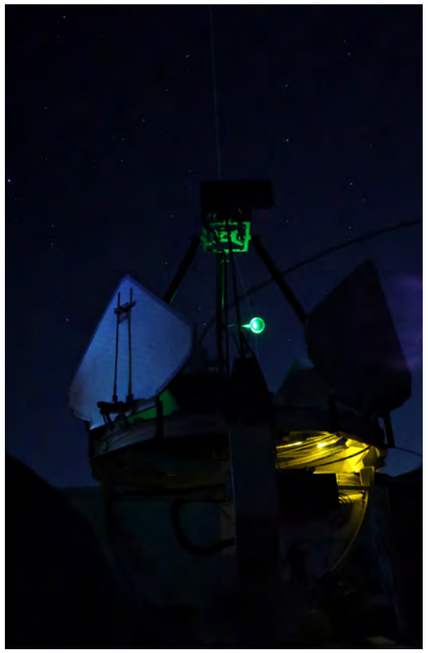


Figure 15: The Barcelona Raman LIDAR at the ORM, in front of the LST-1 telescope; the green part of the laser beam can be observed, after exiting the system. Credit: Roger Grau (IFAE).

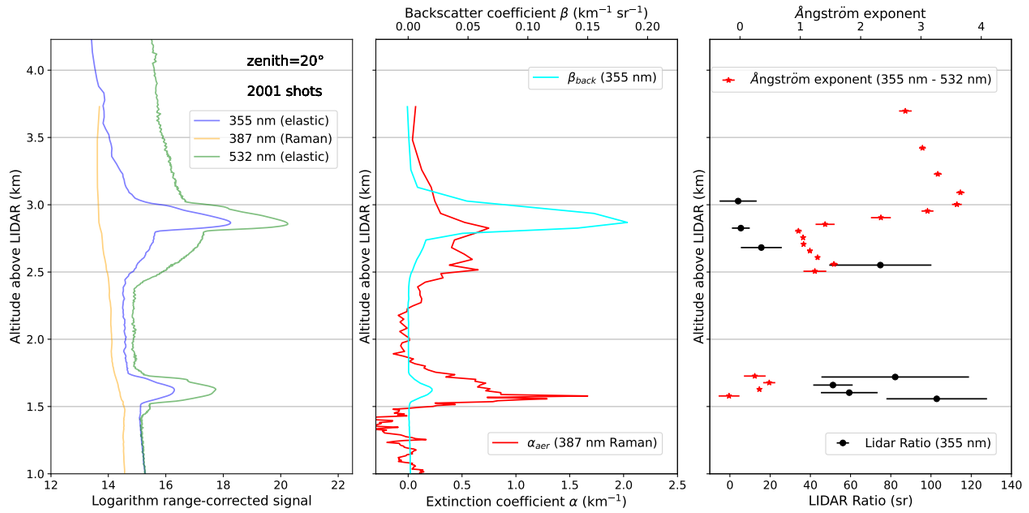


Figure 16: Range-square corrected LIDAR returns (left) in three channels, where two features at around 1.6 km and from 2.4 to 3.1 km are visible. The lower feature corresponds to the volcanic ash plume, whereas the upper feature is a cloud. The extinction α_aer (centre) and backscattering β_aer coefficients (centre) exhibit the same peaks that are visible in backscattering channels, but in the case of extinction, the lower peak is much more prominent, as expected for large volcanic dust particulates suspended in air. Ångström exponent (right) profiles (right) are shown as red stars, and the LIDAR ratio in black dots. Again, a very different behaviour is shown found for the two aerosol ranges, consistent with the properties of volcanic ash and clouds. From Živec et al., Journal of Physics: Conference Series 2398 (2022) 12013, https://dx.doi.org/10.1088/1742-6596/2398/1/012013.

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.

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 various contributors.

The Cherenkov Telescope Array

The Short-term Scheduler (STS) is one of the high-level sub-systems of ACADA and is under the responsibility of the ICE. An initial release of the ACADA software, including the STS package, was published in 2020. It was devoted to the implementation of a minimum set of features to basically test the integration of all software packages. The STS implemented the reception of the planning, the Scheduling Block validation and the execution management. The scheduling algorithm that is based on Artificial Intelligence technologies evolved to cover the increased number of constraints and is going to be industrialised in accordance with quality standards in further releases. A new release of the ACADA system is expected in summer 2023 and our software engineering team has been developing many of the use cases for it.

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

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

Facilities and Key Projects

LISA

Space-borne gravitational wave detection

On 15 September 2019, the Laser Interferometer Gravitational-wave Observatory (LIGO, United States of America) detected gravitational waves (GWs) 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 GWs coming from the coalescence and final merger of two Black Holes, the first time we have observational evidence of such a system. The Nobel Prize in Physics 2017 was awarded to this discovery that inaugurated the new area of Gravitational Wave Astronomy. Nowadays, the ground-based detectors (covering the high-frequency band of the GW spectrum, between 10 - 10^4 Hz) LIGO, Virgo (a gravitational-wave European detector located in Italy), and KAGRA (Japan) are routinely making detections of binary compact systems that emit GWs: 90 detections at the end of the third scientific run (O3). As with the electromagnetic spectrum, there are other parts of the GW spectrum that are also very interesting from a scientific point of view. In particular, by looking at the low-frequency band (between 10^{-5} - 1 Hz) we can access very massive systems, such as, for instance, the coalescence of a supermassive binary black hole system. These systems are not accessible to ground detectors due to seismic and Newtonian gravity gradient noises.

LISA consists of a fleet of three satellites that will be located in a triangular formation separated by 2.5 million km and connected by laser beams, following the Earth in its orbit around the Sun (see Figure 17). The main objective of LISA is to carry out the scientific programme that was presented in the document The Gravitational Universe, approved by the European Space Agency (ESA) in October 2013, by detecting low-frequency GWs from the most extreme phenomena in the Universe, such as the fusion of black holes a million times more massive than the Sun. LISA was selected as ESA's third large-class (L-class) mission by its Senior Programme Committee (SPC) on 2 June 2017, with a launch expected around 2035.

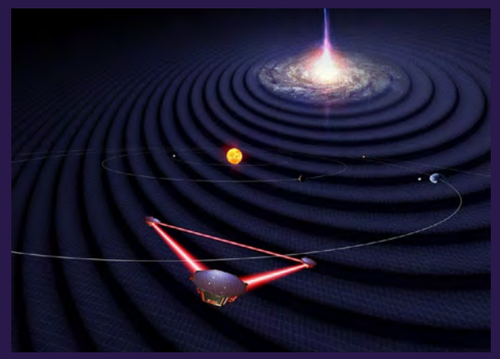


Figure 17: Artistic representation of LISA (a Large-Class ESA mission). The constellation of three spacecraft is seen following a heliocentric orbit around the Sun following the Earth. In the background, a representation of the emission of gravitational waves by a binary system of supermassive black holes.
Credit: University of Florida / Simon Barke (CC BY 4.0).

LISA

LISA is an all-sky monitor that will offer a wide view of a dynamic cosmos using GWs as new and unique messengers to unveil *The Gravitational Universe*. It will provide the closest ever view of the infant Universe at TeV energy scales, has known sources in the form of verification binaries in the Milky Way (ultra-compact binaries), and can probe the entire Universe, from its smallest scales near the horizons of black holes, all the way to cosmological scales. The LISA mission will scan the entire sky as it follows behind the Earth in its orbit, obtaining both GW polarizations simultaneously, and will measure source parameters with high sensitivity in the low-frequency band (see Figure 18 for a representation of the main LISA GW sources in relation to the LISA instrument sensitivity). From these measurements we expect revolutionary discoveries in Astrophysics, Cosmology and Fundamental Physics.

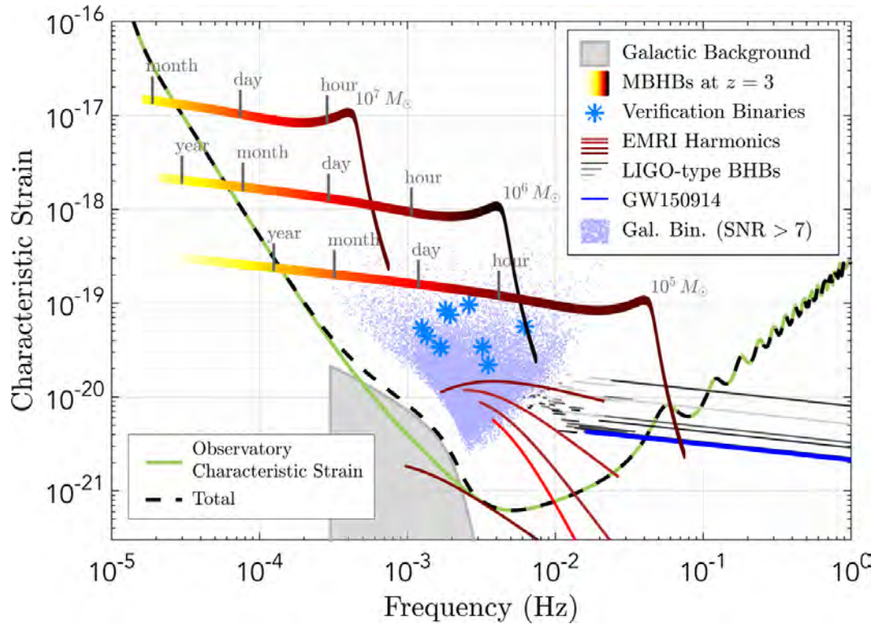


Figure 18: Examples of gravitational-wave sources in the frequency range of LISA, compared with its sensitivity for a 3-arm configuration. The data are plotted in terms of dimensionless 'characteristic strain amplitude'. The tracks of three equal mass black hole binaries, located at z = 3, are shown. The source frequency (and SNR) increases with time, and the remaining time before the plunge is indicated on the tracks. The 5 simultaneously evolving harmonics of an Extreme Mass Ratio Inspiral source at z = 1.2 are also shown, as are the tracks of a number of stellar origin black hole binaries of the type discovered by LIGO. Several thousand galactic binaries will be resolved after a year of observation. Some binary systems are already known, and will serve as verification signals. Millions of other binaries result in a 'confusion signal', with a detected amplitude that is modulated by the motion of the constellation over the year; the average level is represented as the grey shaded area.
Credit: LISA Consortium.

The selection of LISA was in part a consequence of the LIGO discovery, but above all, of the great success of the ESA LISA Pathfinder mission, 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 June 2017. On 18 July the last telecommand was sent to the spacecraft, permanently disconnecting it after 16 successful months of scientific measures. LISA Pathfinder tested the fundamental concept of gravitational wave sensing in flight (see Figure 19): It contained two test masses in free fall together with an optical metrology (laser) system that monitors and measures its relative motion with precision without precedents (picometers). LISA Pathfinder used the most advanced technologies to minimise the non-gravitational forces that can act on test masses and take measurements. Inertial sensors, a laser metrology system, a drag-free control system and an ultra-precise propulsion system made this a unique space laboratory. LISA Pathfinder also had a payload from NASA, an alternative micro-propulsion system. On 7 June 2016, at the European Space Astronomy Center (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 5-1000 depending on the frequency range) and very close to the one required by the LISA mission. Later, by implementing a series of improvements, such as the reduction of the gas pressure around the test masses, the LISA Pathfinder achieved an improvement in the differential acceleration noise by a factor greater than three for the range of frequencies in which LISA will work (see Figure 19). These results were published in an article entitled *'Beyond the required LISA free-fall performance: New LISA Pathfinder results down to 20 micro-Hz'* in the prestigious journal Physical Review Letters (volume 120, page 061101), and show that the results are much better than the initial requirement for LISA Pathfinder and better than the requirement for LISA (see Figure 20).

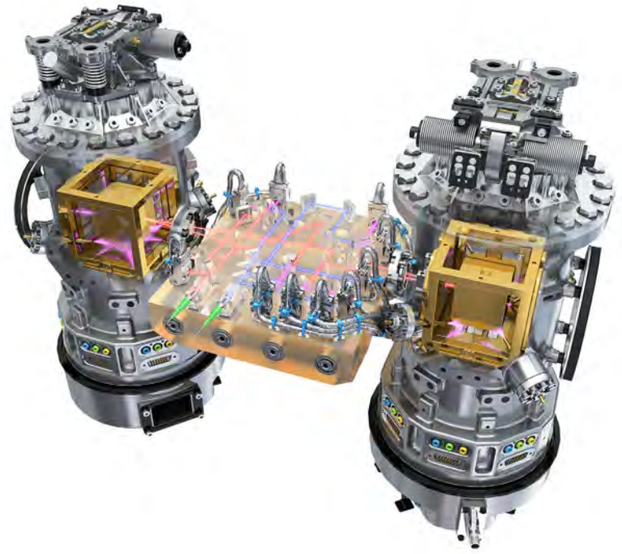


Figure 19: ESA's LISA Pathfinder payload, the "LISA Technology Package" (LTP), where all of the mission's science experiments were performed. Credit: ESA.

LISA

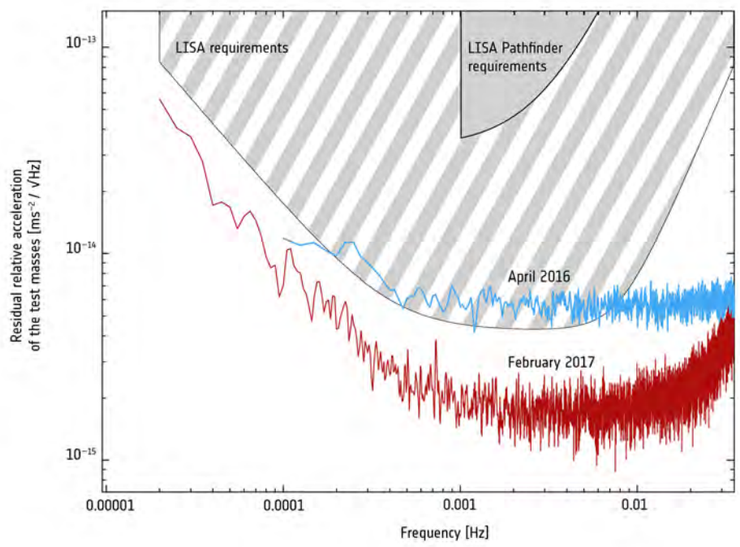


Figure 20: Parasitic differential acceleration of LISA Pathfinder test masses as a function of the frequency. The data refer to an ~ 13-day long run taken at a temperature of 11 °C. Data are compared with LISA Pathfinder requirements and with LISA requirements. Fulfilling requirements implies that the 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) 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 UAB-IEEC groups). To understand the relevance of the group to the LISA mission, it is important to mention that Carlos F. Sopuerta (ICE) is a member of the LISA Consortium Board, which organises the scientific community contributing to the LISA mission (with more than 1,700 members), and a member of ESA's "LISA Science Study Team" (SST). Miquel Nofrarias (ICE) is the Science Diagnostics Subsystem (SDS) Lead, representing the Spanish contribution to the mission, and he has also been a member of ESA's LISA System Engineering Office (SEO). Josep Colomé (ICE) acts as the Spanish LISA National Project Manager on the LISA National Project Manager Board (NMPB).

The main activities of the group in these two missions have been carried out principally thanks to research grants from the National Plan of the Ministry of Science and Innovation (the current grant is PID2019-106515GB-I00) and technological contracts from competitive calls from ESA. The group is a Generalitat de Catalunya-funded quality group (2021 SGR 01529).

The expected contribution to LISA, following the successful experience of the LISA Pathfinder mission, is the Science Diagnostics Subsystem (SDS), 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. Diagnostics are: Thermal (sensors and thermal actuators), Magnetic (magnetometers, coils and electromagnetic antenna), and Radiation (radiation monitor).

Thanks to the expertise acquired with the LISA Pathfinder mission, the Gravitational Astronomy-LISA Group won the ESA Core Technology Programme (CTP) contract 'LISA Enhanced Temperature Subsystem for LISA' (LETS) to develop a first prototype (TRL4) of the future LISA temperature subsystem, together with DLR-Bremen and SENER Aeroespacial. This includes technological improvements in the read-out and an ultra-stable test bench to be installed at the ICE premises. Figure 21 shows the current setup under testing at the ICE. M. Nofrarias (ICE) is leading the IEEC in this international effort, together with the German Space Agency (DLR) and SENER Aeroespacial. Currently, we are running a contract extension to further study low frequency excess noise.

The group also won the ESA Technology Development contract 'Optical Fibre Micro-Kelvin Temperature Sensor Network for Sensitive Optical Payloads' (2021-23), also led by M. Nofrarias. The goal is to design a prototype at TRL 4 of a temperature subsystem fulfilling the requirements for LISA using optical fibre sensors. The project has successfully passed the Detailed Design Review and is moving towards the Test Readiness Review, which will take place in February 2023.

On the other hand, we are also developing compact magnetometers based on anisotropic magnetoresistive technologies for their potential use in LISA. Moreover, we have participated in the project MELISA (MEMs miniaturised low-noise magnetic field sensor for LISA), funded by an internal IEEC call, to develop compact magnetometers based on MEMs (Micro-Electro-Mechanical systems) technology fulfilling the LISA requirements. A prototype has already been designed, manufactured and tested. The results show that successful performance below 10 nT/sqrt(Hz) at 1 mHz has been achieved.

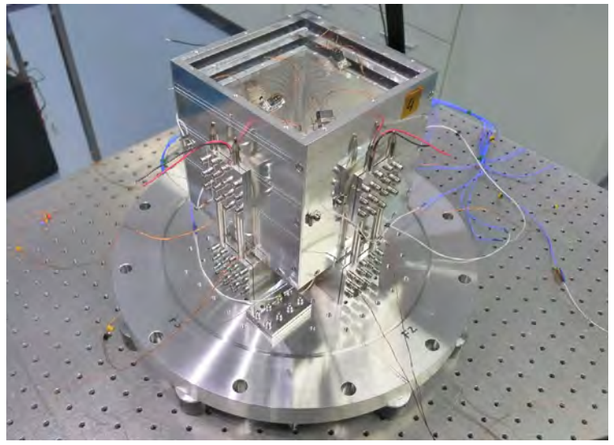


Figure 21: LETS test bench. A series of concentric cubes (shown in the picture) act as passive thermal shields. Also shown in the picture, external Peltier elements are used to actively control the temperature to a very high precision. This setup, inside a vacuum chamber, makes it possible to suppress external environment fluctuations and reaches the restringent LISA temperature stability requirement on ground, meaning resolving fluctuations in the micro-Kelvin regime in long-term periods that can last days.

LISA Mission Status and related activities of the Gravitational Astronomy-LISA Group

After successfully passing the Mission Formulation Review, LISA is in phase B1 of design and developments. The Gravitational Astronomy-LISA group (ICE, CSIC and IEEC), in collaboration with the UPC-IEEC and UB-IEEC groups, is supporting ESA during phase B1 of preliminary design of the mission. Our role in this phase is to work in collaboration with the two primes (Airbus and Thales), who run parallel design studies, in order to provide recommendations on the Science Diagnostics Subsystem (SDS) definition. There is an opportunity for LISA to be adopted by the end of 2023. During 2023, there are a number of activities leading towards adoption (Red Book, technical documents, preparation of international agreements on the mission, etc.) in which our group is also participating. If the mission is adopted, it is expected that the mission implementation phases will begin in 2025.

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

On the other hand, the group participates in the LISA Data Challenges, whose aim is to develop the necessary Data Analysis Tools for the future scientific exploitation of the mission. We are also working on the development of the ground segment of the mission, in particular on the design of a future Data Computer Center that will analyse the data of the LISA mission. We also participate in several LISA Consortium Working Groups, and we have recently participated in most of the LISA Science White Papers that are appearing. On a more theoretical level, the group also works on the descriptions/simulations of the main sources of gravitational waves for LISA to obtain templates of the gravitational waveforms needed for data analysis and the correct estimation of physical parameters of the sources. In addition, different studies of Astrophysics, Cosmology and Fundamental Physics are being carried out to maximise the scientific return of the LISA observations and to achieve all the scientific objectives described in the scientific case *The Gravitational Universe*.

ARIEL

Ariel (Atmospheric Remote-sensing Exoplanet Large-survey; 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 ESA's 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 ESA in March 2018 and adopted in October 2020 as the M4 mission of the Cosmic Vision programme, with a planned launch in 2029. It 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 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, the mission is designed as a dedicated survey 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. 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 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 visible and near-infrared (NIR). The Ariel mission payload is developed by a consortium of more than 70 institutes from 17 countries. The IEEC is one of the co-PI institutes (co-PI: Ribas) and leads the Spanish contribution (PI: Ribas; National Project Manager: Colomé), which also includes the Instituto de Astrofísica de Canarias and the Universidad Politécnica de Madrid. The IEEC, through researchers at the CSIC and UB, participates in various aspects of the mission, as shown in Figure 22, which illustrates the technical involvement.

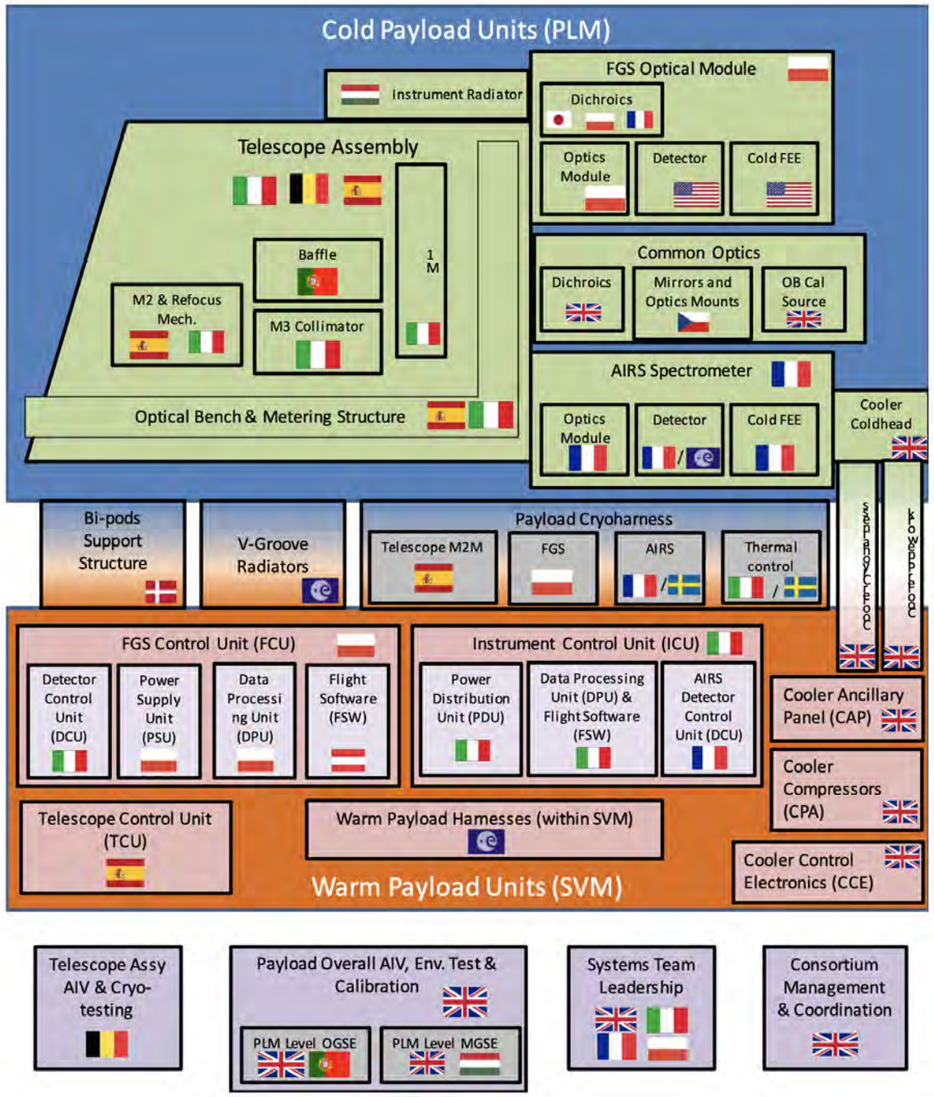


Figure 22: Ariel payload hardware block diagram

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 23). It also controls the M2 refocusing mechanism under operation from the ground. It will implement command handling, data formatting and communication with the 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 its 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.

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.

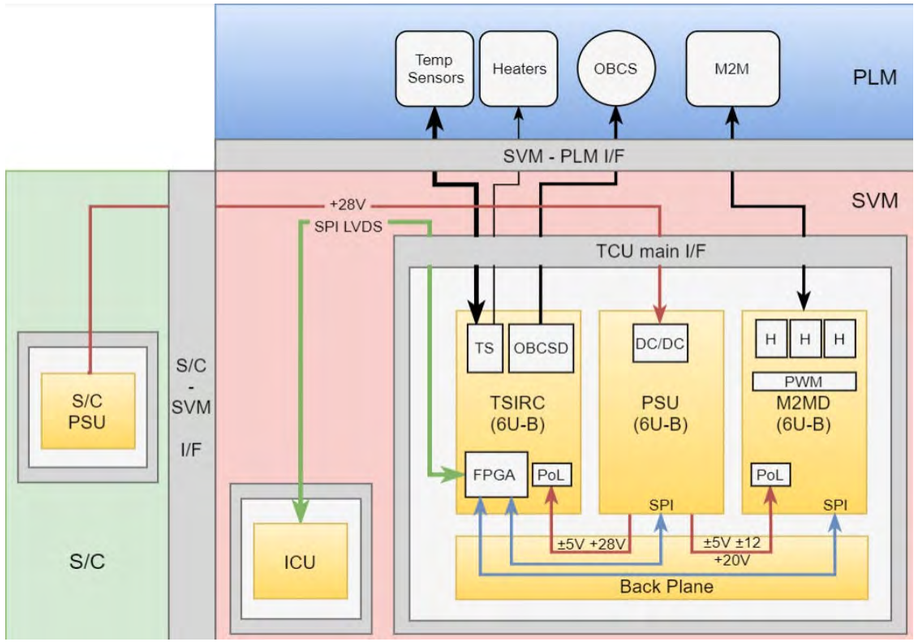


Figure 23: ARIEL TCU system block diagram.

ARIEL

The Ariel mission held the payload Preliminary Design Review (pPDR) in autumn 2022. The IEEC team actively participated in the preparation of the necessary documentation for this review, a milestone in which ESA has taken part as the evaluation agency of the maturity of the mission. In the same way, the iPDR (instrument Preliminary Design Review) for M2M was held and successfully passed in autumn. Work during 2022 has been aimed at consolidating the subsequent phases of the mission, in particular, focusing on the detailed design of the electronics associated with the TCU, and on preparing the Preliminary Design Review (PDR), which is expected to be held during the first half of 2023. One of the main tasks has been to improve the Technical Readiness Level (TRL) of the cryogenic motor that is being developed by Sener Aeroespacial (Figure 24). It is the first European design able to work at 40 K and is expected to significantly expand the lifetime of the M2M.

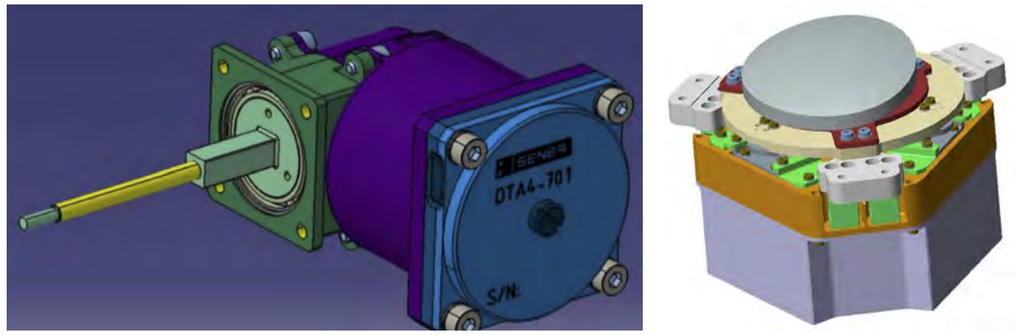


Figure 24: New M2M motor-reducer design (left) and upgraded M2M design (right).

The project has suffered some setbacks during 2022, due to stock problems associated with the present economic and geopolitical situation. In particular, in spite of already having reached TRL-6 on the Control and Temperature Sensing (CTS) board (see Figure 25), it has been necessary to change some of the components as a result of their shortage or unaffordable lead times. A replanning of the model delivery milestones will absorb potential delays in the TCU design and manufacture during 2023 and help fulfil the mission schedule.

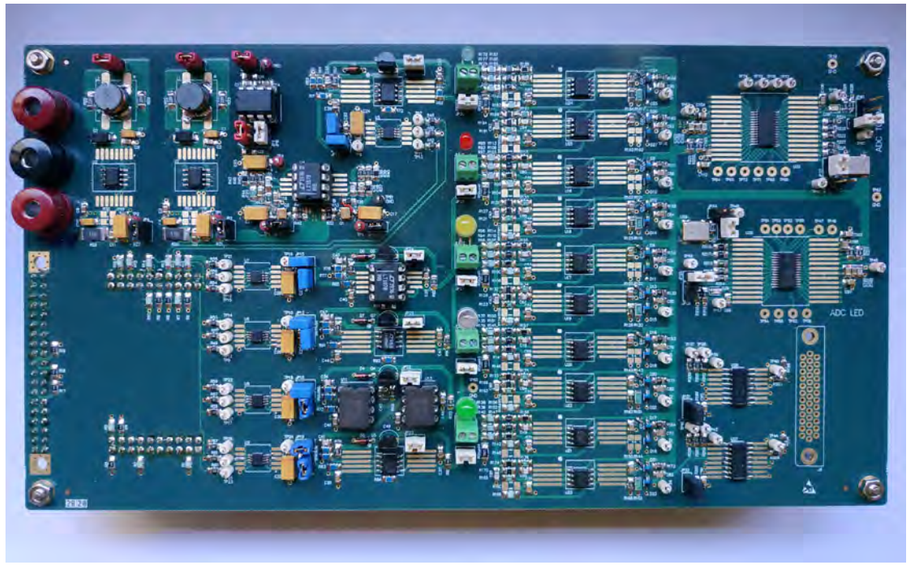


Figure 25: Bread-board of the Thermal Sensing subsystem

The IEEC is also responsible for providing a scheduling tool to automatically plan the observations as part of the Ground Segment of the Ariel mission. At present, the Ariel Long Term Planning Tool (LTPT) has been identified as a key element due to the complexity of the planning of observations. This is because it must ensure that about 1000 exoplanets are characterised by stacking several transit or occultation observations, which are time-critical events. This translates into a large number of possible combinations producing different plans from which only a small subset are highly efficient. At the IEEC, we have the expertise to identify the most efficient plans using Artificial Intelligence algorithms. A prototype of the Ariel LTPT was developed, demonstrating that the mission is feasible and can monitor the events of 1000 exoplanets several times during the 3.5 years of mission lifetime (Morales et al., 2022). Several optimization algorithms have been tested to achieve the best performance (Nakhjiri et al., subm.).

The LTPT software will be delivered to the European Space Agency. During 2022, we started the standard development of the software package within the STARS framework, a general library for astronomical scheduling problems. This is being done in close collaboration with the ESA Ground Segment station at ESAC (Madrid), with regular meetings to define the requirements and development plans of the software. The LTPT design consists of three modules (see Figure Z). First, a “pre-scheduler” takes the list of targets and applies the observational constraints, producing a list of timeslots when each target can be observed. In a second step, the “Optimization Core” looks for the combination of observations and mission operations (telescope slew, calibrations, station keeping) producing the most efficient plans, in terms of the number of targets completed and the total time used for science operations. Finally, a graphical user interface allows the user to check the plan and compute statistics to evaluate its performance before it is sent to the Mission Operations Control. A first version of the software is about to be delivered to ESA.

ARIEL

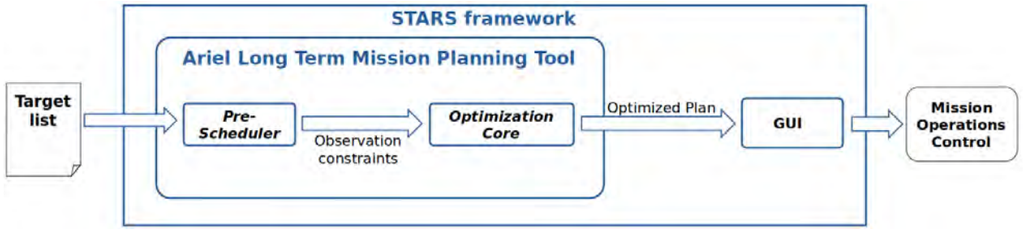


Figure 26: General design of the Ariel Long Term Mission Planning Tool with the three main modules, the pre-scheduler, the optimization core and the graphical user interface (GUI).

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 2022 has been focused on further improving our StarSim code. Work performed as part of two PhD Theses (E. Herrero, A. Rosich) was the core of the initial development of StarSim. The code 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 contemporaneous multi-band and multi-technique 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 approach 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. The StarSim code is publicly available on GitHub and a new version with new functionality will be released shortly together with a publication (Baroch et al., in prep.).

NewSpace Strategy

NewSpace represents a new use of space with small satellites and rapid development, with an emphasis on lower costs, operational agility and the reliance on private capital. This new technology has made it possible to create a new set of digital services and a new economy of increasing strength. This new ecosystem constitutes a change of paradigm for the space sector and can contribute to better management of the territory, enhanced measurement of the effects of climate change, uniform Internet of Things (IoT) and 5G coverage, even in remote areas of the territory, and improved positioning and timing for many applications on Earth.

What is NewSpace?

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

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

NewSpace represents a new economy based on the democratisation of access to space and the aerospace industry. New private actors have appeared recently, seeking new opportunities in the exploration of space. It is a growing sector that will 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 launches completed in the last few years.

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

NewSpace

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).

The current commitment shown by the NewSpace sector to develop a new market and a new technological fabric will have a dynamic and unifying effect on other technologies, such as 3D printing, artificial intelligence, advanced electronics for sensors and computers, and secure communications. In addition, the transversality of space will lead to the generation of highly diverse applications, partly thanks to synergies between sectors.

The IEEC has a number of capabilities that make it a key player in the space sector. The Institute is playing an important role to promote the ecosystem and its positioning at an international level. The IEEC represents these interests in different international organisations such as the International Astronautical Federation (IAF), Nereus and Eurisy, where a significant push can be made for the promotion of the NewSpace sector.

In the field of NewSpace, the following projects stand out:

Space missions: IoT and EO nanosatellite services

Within the framework of NewSpace in Catalonia, the IEEC initiated the deployment of a promising space-based infrastructure in LEO by launching two missions that were defined to provide data services in two different areas:

- Earth observation (EO): a 6U nanosatellite (six units, according to the CubeSat standard), and a payload for obtaining images of the Earth from space in different spectral bands for the study of the territory (see Fig. 1). The mission is called Menut and will focus on remote sensing applications. It was planned to be launched in the second half of 2022 with a Soyuz launcher, but the geopolitical situation caused by the conflict in Ukraine forced a change in the launcher provider and a delay of several months.
- Internet of Things (IoT): 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. This mission was named Enxaneta and was launched in March 2021. It is providing communication services with devices measuring data on the ground for different purposes.

These EO and IoT services are in line with the research and innovation activity of the IEEC with regard to the implementation of missions based on space technologies, and 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).

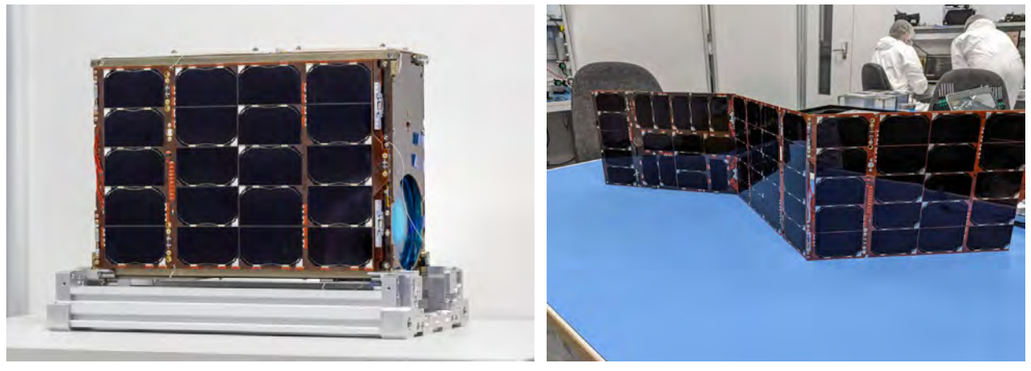


Figure 1: Earth observation 6U nanosatellite *Menut* (left) and detail of its solar panels (right). Credit: IEEC.

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 particular, these activities are carried out in collaboration with the I2Cat Foundation and the Institute of Cartography and Geology of Catalonia (ICGC) within the framework of the NewSpace strategy of Catalonia. These services are ultimately aimed at creating an ecosystem that encourages the growth and consolidation of the NewSpace sector based on digital technologies.

On 2 February 2022, the results of the first use case in a real environment obtained by Enxaneta were presented in Tremp (Pallars Jussà) (see Fig. 2). The first use case consisted of measuring physical and environmental parameters of the soil in vineyards via an Internet of Things (IoT) connection with the nanosatellite. The pilot test was developed by the Catalan Ministry of the Vice-presidency and Digital Policies and Territory in collaboration with the IEEC, the ICGC, the i2CAT Foundation and Sateliot. All data collected by Enxaneta are transmitted to the Satellite Ground Station of the Montsec Observatory, located in Sant Esteve de la Sarga (Pallars Jussà) and managed by the IEEC. The station is composed of several antennas for communication with low orbit satellites, developed and installed by the NanoSat Lab of the Universitat Politècnica de Catalunya · Barcelona Tech (UPC) (see above).

Figure 2: (From left to right) Pere Renom, scientific communicator and presenter of the event, together with the CEO and co-founder of Sateliot, Jaume Sanpera; the CIO of the i2CAT Foundation, Sergi Figuerola; the Vice President of the Catalan Government and Minister of the Ministry of the Vice-presidency and Digital Policies and Territory, Jordi Puigneró; the director of the ICGC, Jaume Massó; and the director of the IEEC, Ignasi Ribas, during the presentation of the first use case of the nanosatellite Enxaneta in a real environment in Tremp. Credit: Government of Catalonia.

Innovation activities in the NewSpace sector

The IEEC is promoting several R&D lines within the framework of the NewSpace strategy of Catalonia. They all have a strong potential impact on the industrial sector and with a short time to market, with the aim of facilitating the transfer of key technologies to the productive sector. These lines have a track record of industrial collaborations and their potential impact is considered to be one of the key indicators for the NewSpace strategy. They are grouped in three main areas and mainly cover EO technologies, but also GNSS:

- Enabling on-board technologies
  - 3Cat-Gea: Multipurpose Earth Observation Payload based on a Software Defined Radio, a high-performance on-board computer, and data compression algorithms and software for the next satellite generation. This payload has the heritage of the C3SatP platform that was integrated in the Menut EO mission as a secondary IOD payload. The C3SatP platform is planned to be tested in orbit in 2023.
  - Efficient data transmission using machine learning techniques.
  - IA processing on-board using open code RISC-V and other options based on COTS (GPUs, neuronal processors, etc.).
- Enabling on-ground technologies:
  - Data processing algorithms devoted to increasing spatial resolution of EO space data using different sources of data, including Sentinel 2 (see Figure 3).
  - EO data exploitation using explainable AI techniques.
- Opportunity signals:
  - Reflected signal processing and modelling to obtain soil moisture maps at surface and root level, using L band and P band, respectively.
  - LEO-PNT positioning system for IoT applications and with ultra-low consumption, secure and resilient.

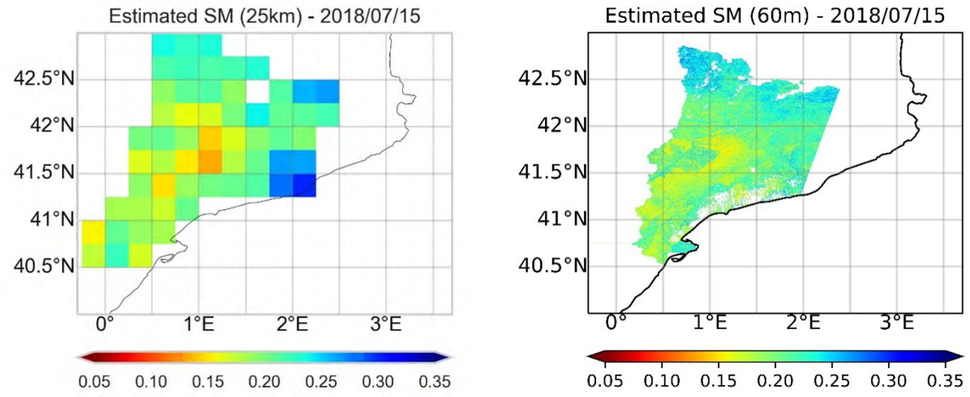


Figure 3: Disaggregation algorithm using Machine Learning for obtaining high resolution soil moisture maps: from 25km to 60m. Credit: IEEC-UPC.

The research activities carried out at the IEEC by the research groups at the four research units are also partially focused on NewSpace technologies. In this respect, the activities on the ^{3}Cat series developed in the NanoSat Lab of the UPC have continued in 2022, focusing particularly on an IOD mission called ^{3}Cat-8 and selected by the DLR in Germany for a future launch in 2024. The contribution to the HydroGNSS mission, on the other hand, is also progressing at the ICE.

Key infrastructures for NewSpace in Catalonia

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

Several infrastructures are identified as key cornerstones for the space sector in Catalonia and are being supported to develop capacities that consolidate the ecosystem within an international context. In addition, within the framework of the NewSpace strategy, the IEEC has made an analysis of the private and public infrastructures with the aim of identifying the capacities of the ecosystem and contributing to their promotion.

Teleport of Sant Esteve de la Sarga at the Montsec Observatory

A key part of every space mission lies in the ability of the ground segment (GS) to contact the satellite to transmit remote controls and receive the results of scientific measurements or telemetry data that the system has acquired. The Montsec Satellite Ground Station (SGSMontsec, see Figure 4), located in the Montsec Observatory (OdM-IEEC) in Sant Esteve de la Sarga, is managed by the IEEC in conjunction with the NanoSat Lab of the UPC, operates an UHF/VHF, and an S-Band GS. The Observatory is in a privileged position for satellite communications: 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, and presents very low radiofrequency noise. The Observatory participates in satellite surveillance and tracking and satellite communication programmes thanks to these excellent conditions.

The upgrade of the S-Band antenna to have transmission capacity began in 2022 and is expected to be completed in 2023.

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

Alguaire spaceport

Innovative technologies and operational solutions for easy and cheaper access to space are of fundamental strategic importance for 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.

Alguaire Airport (see Figure 5) has been used as the testing facility for several companies and universities in recent years (e.g. Pangea Aerospace Company and Cosmic Research UPC students association). It has shown 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 mainly devoted to testing innovative technologies for new engines for microlaunchers. A public tender for the construction of a propulsion test centre for rocket engines was published in 2022, including an execution period to complete the construction in 2023.

Figure 5: View of the Engine test site at the Lleida Alguaire Airport, with the airport's air traffic control tower behind. Credit: Aeroports de Catalunya

Knowledge Transfer and Innovation

A Knowledge and Technology Transfer Strategy (KTTS) is fundamental in outlining how the IEEC can transfer its expertise, knowledge and technology to external partners, in order to promote economic development, foster collaborations and partnerships, and make a positive social and environmental impact. Given that the IEEC is a space research centre, this strategy should involve identifying and leveraging the expertise, capabilities and intellectual property developed by the IEEC members to benefit other organisations, industries and communities.

One of the key aspects of the strategy envisages the commercialisation of research. By licensing its technology or forming partnerships with industry, the IEEC can turn its research into marketable products and services that can benefit society. By partnering with industry, the Institute can help to accelerate the adoption of new technologies and improve the productivity and competitiveness of businesses in the sector.

Defining a strong strategy will help to ensure that the knowledge generated within the IEEC is effectively disseminated to stakeholders and end-users who can benefit from it. Overall, identifying valuable IP assets, building strategic partnerships, and establishing effective collaboration and licensing agreements are of key importance.

Furthermore, a well-defined knowledge and technology transfer strategy (KTTS) can help to create a culture of innovation within the centre. By promoting a focus on commercialisation and technology transfer, researchers are incentivised to think about the practical applications of their work. And for such activities, it is important to generate and establish a robust network of contacts composed of different actors, such as companies, governmental and non-governmental institutions, researchers, professionals in the space field and organisations.

The IEEC Knowledge and Technology Transfer Office (KTO) acts as a connection point between these actors, facilitating communication and collaboration between them. It works to build a dynamic and diverse network that will promote the transfer of knowledge and technology from the space field to society.

The IEEC KTO also promotes the participation of researchers and other technical members in funding programmes and initiatives. It coordinates and promotes projects and proposals and establishes partnerships with other entities, broadening the spectrum of sectors and fields of interest benefitting from the technological developments of the different research groups.

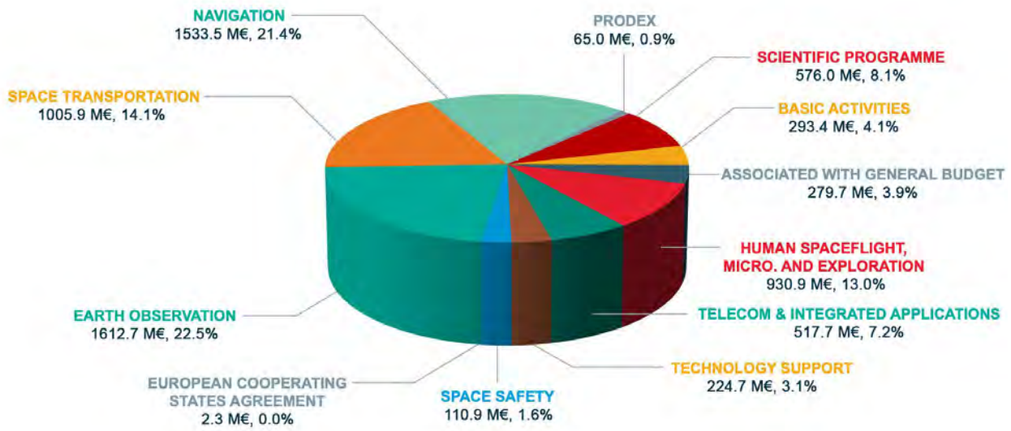
Overall, the KTO is essential as a vehicle for maximising the value of the Institute's research and development efforts. By defining a clear strategy and implementing it effectively, the IEEC will ensure that the knowledge and technology emanating from its members make a real-world impact and contribute to the greater good.

Finally, the IEEC KTO also collaborates closely with the corresponding offices of the different trustee institutions in order to promote knowledge transfer at all levels.

Success innovation cases

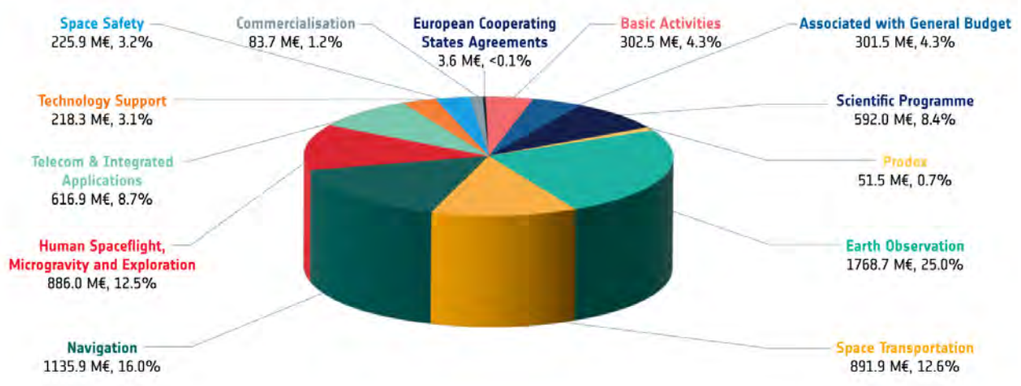
Below is a list of the new and ongoing innovation and transfer projects in which the Principal Investigator is an IEEC member, and where the IEEC or one of its scientific units is responsible for management of the project. The activities are grouped by topic, taking ESA topics as a reference, as shown in the figure above which illustrates the ESA budget distributed by domain for 2023. 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. .

ESA BUDGET BY DOMAIN FOR 2022: 7.15 B€*



*includes activities implemented for other institutional partners

ESA BUDGET BY DOMAIN FOR 2023: 7.08 B€*



*Includes activities implemented for other institutional partners

Figure 1: ESA budget distributed by domain for 2022 and 2023.

Earth Observation

Evaluation of Polarimetric Radio Occultation for Global Rain Estimation (PROGRES)

Support to Spire Global Inc. for the validation of the GNSS polarimetric radio occultation (GNSS PRO) products this company is producing from a CubeSat launched in January 2023 and funded by ESA. This activity is structured through a Memorandum of Understanding (MOU) between both entities, according to which the IEEC has privileged access to the new GNSS PRO data in return for its validation.

IEEC Coordinator: Estel Cardellach (IEEC-CSIC)
Funding Institution: MOU - Unfunded Agreement, linked to Contract between ESA and Spire Global Inc.
Partners: Spire Global Inc., IEEC
Duration: 11/2022 - 06/2023

Scientific Support for the nano-satellite mission PRETTY (PRETTY-SCIENCE)

Contract to structure the final pre-launch and initial post-launch activities of ESA's PRETTY mission to demonstrate interferometric grazing angle GNSS-R altimetry from a 3U CubeSat. The activities include advice on certain scientific and instrumental aspects provided to the prime contractor RUAG (now BeyondGravity), as well as processing and analysis of the initial data obtained from orbit.

IEEC Coordinator: Estel Cardellach (IEEC-CSIC)
Funding Institution: European Space Agency, subcontract RUAG/BeyondGravity, subcontract NTNU (PRETTY-SPACE-subIEEC, RSA subcontract MS-CON-100560, ESA No. 4000129499/19/NL/AS)
Partners: BeyondGravity (former RUAG), NTNU, GFZ, DLR-SO, IEEC.
Duration: 03/2022 - 12/2023

CentRE of Excellence in AerosoL remote sensIng technology and Science in The Indian oCean (REALISTIC)

The overarching goal of REALISTIC (GA nº 101086690) is to develop a Centre of Excellence in aerosol remote sensing technology and science in the Indian Ocean, through the creation of a Chair, with La Réunion, a European Outermost region, as a strategic pivot point of the European Research Area. REALISTIC aims at attracting and maintaining a high-profile researcher (ERA Chair holder) to lead a high-profile supporting team with excellent research and technical capabilities in the aerosol remote sensing domain. In particular, specific applications and research endeavours will be conducted in the area of quantifying the impact of wildfire and volcanic emissions on the tropical atmosphere composition and on the Earth-Atmosphere radiative balance.

IEEC Coordinator: Michaël Sicard (IEEC-UPC)
Funding Institution: Dirección General de Investigación de la Comisión Europea, Horizon Europe
Partners: UPC, Université de La Réunion
Duration: 12/2022 - 11/2027

Lossless/lossy multispectral & hyperspectral compression IP core

The project's main objective is to develop an IP core for lossless and near-lossless compression of hyperspectral images based on the CCSDS 123.0-B-2 standard.

IEEC Coordinators: Joan Serra-Sagristà, Ian Blanes (IEEC-UAB)
Funding Institution: European Space Agency (No. 4000136723/22/NL/CRS)
Partners: University of Las Palmas de Gran Canaria (main contractor), Thales Alenia Space Spain, National and Kapodistrian University of Athens, Universitat Autònoma de Barcelona
Duration: 03/2022 - 09/2023

Navigation

Enabling Technologies for Advanced Position-Navigation-Timing Ground Support Networks (OCTOPOS)

The goal of this project is to develop a testbed for the remote monitoring of GNSS and LEO satellites. The testbed is composed of a set of single-antenna remote radio heads (RRH) for LEO monitoring, and multi-antenna RRH for GNSS signal gathering with interference mitigation capabilities. The digital samples gathered at the RRHs are sent through the Internet to a remote processing facility where signal processing and performance assessment is carried out for GNSS, and signal quality monitoring for detecting potential anomalies is performed for LEO satellites. The IEEC-UAB is in charge of developing the array signal algorithms for GNSS, and demodulation and signal analysis techniques for LEO.

IEEC Coordinators: Gonzalo Seco, José A. Salcedo (IEEC-UAB)
Funding Institution: European Space Agency (ESA)
Partners: Airbus (Germany), Loctio (Greece), UAB
Duration: 02/2022 - 08/2023

Multipath and Spoofing Mitigation in Handheld Devices with Diversity Algorithms (DIVAL)

The objective of this project is to investigate signal processing algorithms for multipath, spoofing and interference mitigation that rely on the use of multiple antennas and multiple polarisations at the receiver side and which are suitable for implementation in a handheld device. The selected techniques will be implemented in a hardware testbed representative of a small size and a medium size handheld device (i.e. smartphone and tablet).

IEEC Coordinators: Gonzalo Seco, José A. Salcedo (IEEC-UAB)
Funding Institution: European Space Agency (ESA)
Partners: GMV (Portugal), UAB
Duration: 02/2022 - 08/2023

Prodex

ARIEL M2M Phases B2/C/D Development

The IEEC provides support to SENER Aeroespacial S.A. within the framework of the contract between SENER and ESA for the execution of phases B2, C and D of the construction of the Secondary Mirror Mechanism (M2M) for ARIEL.

IEEC Coordinator: José Maria Gómez Cama (IEEC-UB)
Funding Institution: European Space Agency (No.4000129634/16/NL/IB)
Partners: SENER Aeroespacial S.A., IEEC
Duration: 12/2022 - 03/2024

Space Safety

P3-SWE-XXXVII SWE Products for Southern Europe - Phase 1

Development of potential new Space Weather Products useful for users in Southern Europe, and specifically Mediterranean Europe, to be incorporated in the SWE Portal of ESA's Space Safety Programme. Products cover the monitoring of geomagnetic conditions and ionospheric weather.

IEEC Coordinator: Manuel Hernández-Pajares (IEEC-UPC)
Funding Institution: European Space Agency
Partners: UAH, GMV, Unv. Coimbra, GMVIS Skysoft S.A., UPC
Duration: 06/2022 - 01/2024

Telecom & Integrated Applications

SafetyIoT-5G - Internet of Things (IoT) applied to monitoring the health and safety of workers in the industrial sector through 5G communications

The project aims at monitoring the health and safety of workers in the industrial sector through 5G communications. This is based on the creation of several test laboratories for IoT-5G systems interconnected by satellite (Enxaneta) in FP institutes, in order to develop prototypes of real applications in telecommunications based on EPIs with biometric sensors. In particular, the integration of 5G networks with satellite connection is planned, using Enxaneta as a technology demonstrator and using the emulation systems provided by the IEEC, with appropriate training.

IEEC Coordinator: Màrius Montón (IEEC)
Funding Institution: Pla de Recuperació, Transformació i Resiliència, Gob. España / European Union.
Partners: Institut FP Sant Cugat del Vallès, Institut Narcís Xifra i Masmitjà, Centro de formación Somorrostro, ENGIDI S.L., IEEC
Duration: 05/2021 - 05/2023

Ground Segment

CTAO3 - IEEC support to the CTA Observatory in the CTA Calibration and Environmental Monitoring System

In this agreement, the IEEC provides the service of coordinating the activities related to the calibration of the array of telescopes of the Cherenkov Telescope Array Observatory (CTAO), characterisation of the atmosphere, and monitoring of the environmental conditions at the two sites where the CTAO telescopes will be installed.

IEEC Coordinator: Markus Gaug (IEEC-UAB)
Funding Institution: CTA Observatory
Duration: 05/2021 - 05/2023

Others

The 4th CASSINI Hackathon: Space for the Financial World

The Competitive Space Start-ups for Innovation initiative (CASSINI) is part of a broad effort in support of space entrepreneurship for a digital and sustainable Europe. The initiative includes extensive funds for EU seeds and growth fund, hackathons and mentoring, prizes, a business acceleration, partnering and matchmaking. The CASSINI Hackathon is a European-scale hackathon event taking place in 10 locations simultaneously. The IEEC co-organised the 4th edition of CASSINI Hackathon: Space for the financial world, where fintech, insurtech and VC entities reimagined the future of finance, insurance and investments, linking to sustainability concerns and making use of Copernicus and EGNSS programmes.

IEEC Coordinator: Alberto Garcia-Rigo (IEEC)
Funding Institution: European Commission
Partners: Fundació Privada Knowledge Innovation Market (KIM), Cambra de Comerç de Barcelona (CCB) & IEEC
Event dates: 04 - 06/11/2022

Gaia 4 Sustainability

The Project aim is creating a set of tools to evaluate light pollution in a simple and affordable way, leading to its commercialisation and use by administrative bodies, private companies and individuals, in order to study, prevent and reduce this phenomenon. It includes: A model of the natural brightness of the sky that serves as a reference to compare brightness measurements / A low cost photometer to perform these measurements / Activities to encourage the use of these tools in schools, public institutions and by other users, helping to standardise light pollution measures. The natural sky brightness model uses the photometric archive of ESA's Gaia mission, consisting of more than 1800 million sources, to assess the contribution of starlight.

IEEC Coordinator: Xavier Luri (IEEC-UB)
Funding Institution: MICINN - Ministerio de Ciencia e Innovación (PDC2021-121059-C21)
Partners: ICCUB-IEEC, Universidade da Coruña (UDC) and Universidade de Vigo (UVIGO)
Duration: 2022 - 2023

La veu còsmica (LVC)

'La veu còsmica' is a project that aims to open perspectives, promote the scientific process and link it to artistic creative processes. The project arose from the need to create a different scenario for science outreach. A means by which, in an understandable, direct way, and through art, the audience captures not only the most rational dimension of research, but also what has moved them from a more visceral and humanistic point of view. The ultimate goal is to link science, poetry and music, i.e. to disseminate scientific work through art. All this materialises in a podcast of 10 chapters, each with a clearly defined science topic, where an expert scientist on that topic talks about it with the three hosts, a musician, a poet and another astrophysicist. Each topic is developed by artists who will end up giving meaning to the research from a less theoretical vision, connecting technique with artistic expression.

IEEC Coordinator: Lluís Galbany (IEEC-CSIC)
Funding Institution: Fundació Catalana de Recerca i Innovació (FCRI) - #ID504
Duration: 09/2022 - 06/2023

Networks

MW-GAIA

MW-GAIA is a COST Action that began on 14 March 2019 and will be completed by 13 September 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, with the aim of fully maximising the scientific returns from Gaia's rich and complex data. Currently, it encompasses 30 COST countries plus some neighbour and international partner countries. Ukraine joined the Action as a full member in 2022.

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 and Grant Holder Scientific representative. Thanks to Jordi's position in the network, the ICCUB team is promoting broad participation in geographical, thematic and personnel terms.

As the pandemic has receded, the network's face-to-face activities have gradually been resumed. Five workshops, one school (all of them in hybrid format) and six exchange visits were organised in 2022. Within the network, the ICCUB participated in the organisation of two of these workshops. The portal gaiverse.eu has been updated with the aim of strengthening 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. These 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, and from gravitational waves to the electromagnetic spectrum.

This COST Action is led by the ICE and comprises 400 scientists from 30 different countries. It has the ambitious goal of tackling key challenges in the physics involved in neutron stars 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 from different physics disciplines, ranging, for example, from nuclear physics to radio astronomy. Furthermore, a key priority of this action is supporting 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 have important roles within this network. Nanda Rea was the proposer/PI, and she has been elected as Action Chair of PHAROS, and Laura Tolos is the 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 and sharing new techniques and infrastructure that may not be available in other participants' institutions or laboratories.

In 2022, we produced a 25 min long animation film on pulsars featuring Dame Dr. Jocelyn Bell Burnell on an imaginary trip around the Universe with a young student. The documentary won the 2022 "Ciencia en Acción" prize for outreach films.

Furthermore, in May 2022 we organised a large final conference at the University of Rome with about 300 people involved in PHAROS topics, including neutron stars, dense matter, gravitational waves, etc.

Scientific Highlights

The Dark Energy Spectroscopic Instrument completes the first year of its observations campaign

During 2022, DESI successfully completed the first year of its main observation campaign, surveying more than 10 million spectra corresponding to bright galaxies, luminous red galaxies, emission line galaxies, quasars, and Lyman alpha hydrogen lines. These will soon be employed to study the contents of the Universe and gain a better understanding of the nature of dark energy and gravity.

The Dark Energy Spectroscopic Instrument (DESI) has successfully completed the first year of its campaign. By May 2022, the instrument had already collected about 30% of the total expected data on its 5-year mission of planned observations, which we refer to as Data Release 1, or the first-year catalogue. After the summer shutdown, DESI continued its planned observations on the next data release. By February 2023, DESI had observed more than 17.5 million spectra and covered about 40% of its planned dark-time observations and 55% of its planned bright-time observations, employing only about ⅓ of the total funded time. With all these data, DESI will soon release the most detailed 3D map of the Universe covering a comoving radial distance of 6500 Mpc (~20 billion light-years).

Dark energy, gravity, and neutrinos

One of the key science targets of DESI is to better characterise how the universe has been expanding during the last 10 billion years. This expansion is dominated by a mysterious component we refer to as Dark Energy, which we have only just begun to understand. DESI data will help to discriminate between different theories of what the fundamental origin of this energy could be, whether it is a type of energy associated with the quantum vacuum or associated with an exotic scalar field, to name just two examples.

DESI will also help to test gravity on scales many orders of magnitude above the solar system scales. By looking at the effect of the gravitational attraction of galaxies across hundreds of Megaparsecs, we can perform a null test of General Relativity and test whether this is correct on those gigantic scales.

Furthermore, DESI data will allow constraints on the total mass of neutrinos by looking at its effect on the statistical distribution of galaxies.

Blind observers of the sky

One of the new features of the analysis of the first-year data of DESI is that it will be a blind analysis. This means that the members of the collaboration will perform the full analysis by looking at a modified version of the data, which prevents any type of unconscious fine-tuning of the analysis to recover the established concordance model of cosmology. The unblinding process, devised by members of the IEEC, will be applied as a very final step, just before the papers are written, when the true result of the analysis will be released to the surprise (or not) of the collaborators. This new approach will ensure that the results of DESI (especially those in the first year) will be very robust and will clearly signal the way in which galaxy surveys will be analysed in the future.

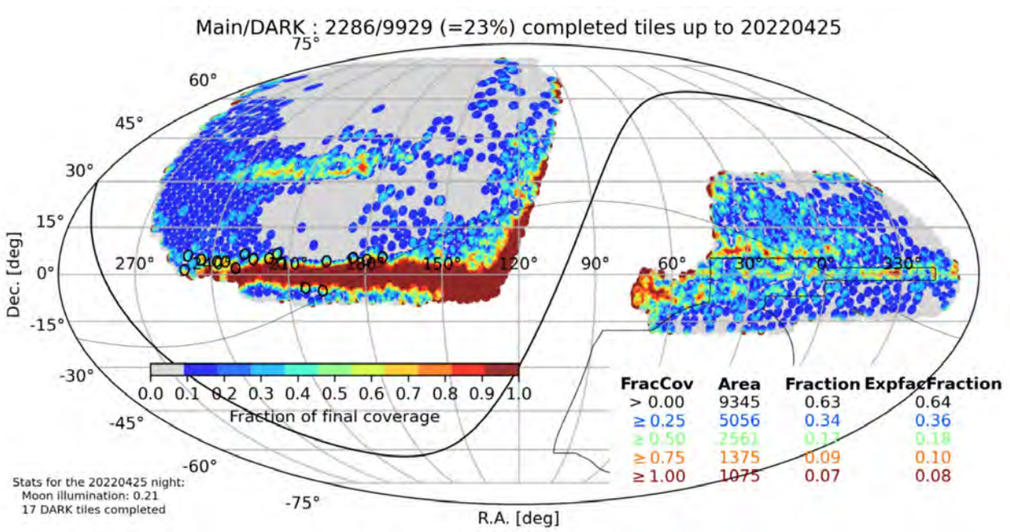


Figure 1: Distribution of dark time tiles corresponding to the first-year catalogue of the DESI observation campaign, as it was on 25 April 2022. We refer to 'dark time' as the observation time dedicated to measuring the spectra of the faintest galaxies and quasars, typically when the sky conditions are very good and the moon is below the horizon. The colour palette indicates the fraction of objects in that tile whose spectra have been observed. Credit: DESI Operation reports

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What can we learn about our Galaxy and its stars from the study of white dwarfs in binary systems?

The 4MOST project consists of 18 surveys that will obtain over 25 million spectra of stars and galaxies. One of these surveys is co-led by Dr Alberto Rebassa and will target 77,000 binary stars composed of a white dwarf – the most common stellar remnant – and a solar-type star. These observations will allow the team to constrain a wide variety of open issues in modern astronomy.

A large fraction of stars in the Milky Way form part of binary systems. Approximately 25% of these binary stars are close enough to initiate mass transfer episodes once the most massive star in the binary becomes a red giant. Because the companion cannot accumulate the transferred material, the system evolves through a common envelope phase. That is to say, the core of the giant and its companion orbit each other within an envelope of material made up of the outer layers of the giant star.

Frictional forces between the stars and the envelope lead to a dramatic shrinkage of the orbital separation and to the release of orbital energy, a fraction of which is deposited in the envelope to expel it. The result is a binary system made up of the core of the giant star (the future white dwarf) and its companion in a very tight orbit. This evolutionary process is responsible for forming compact binary stars containing not only a white dwarf, but also a black hole or a neutron star. However, we do not know the fraction of orbital energy that is used to eject the envelope.

The remaining 75% of binary stars are separated enough to avoid mass transfer processes and evolve as individual stars. Once the more massive star becomes a white dwarf, the orbital separation is similar to the initial one. Consequently, binaries formed by a white dwarf and a solar-like companion can be distinguished between two types. Those that evolved through the common envelope phase and now have very short periods, and those that avoided mass transfer episodes and have much wider separations. Both populations can be used to study a wide variety of open problems.

Spectroscopic observations of compact white dwarf binaries allow us to measure orbital periods and stellar parameters such as masses and temperatures. These measurements help us to analyse the past and future evolution of these systems, following theoretical models. The comparison of the theoretical expectations with the observed parameters allows us to improve our understanding of the common envelope phase and to elucidate the possible progenitors of thermonuclear supernovae. These are among the brightest explosions in the universe and have been used to test its accelerating expansion.

In the case of binaries that evolved without mass transfer, white dwarfs can be used as cosmic clocks to derive the age of their companions, which opens the door to the study of diverse topics such as the age-metallicity relation of the Milky Way and the age-rotation-activity relation of solar-type stars. However, we have spectroscopic observations of only a few thousand white dwarf binary systems. Our research team is leading one of the 18 surveys of 4MOST that will start operations in Chile in order to obtain spectra of 77,000 white dwarf binary stars. With these data we will be able to improve our understanding of this wide variety of open problems.

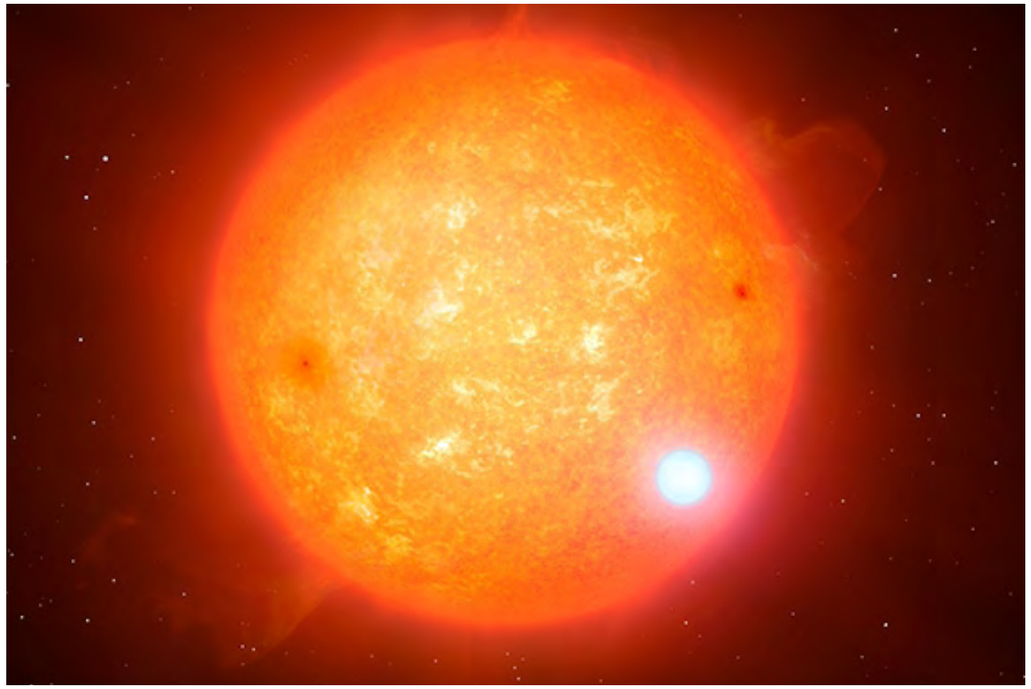

Figure 2: Artist's rendering of the eclipsing binary system composed of a cool subdwarf (in yellow, the large star, one-fifth the size of the Sun) and the white dwarf (in white and much smaller in size). Credit: Mark Garlick

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The MOSAiC expedition provides the first comprehensive picture of global warming in the Arctic

IEEC members from the CSIC and UPC units contributed to the expedition experiments, data analysis and results.

The IEEC participated in the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition, during which hundreds of environmental parameters were recorded in the central Arctic Ocean, with unprecedented precision and frequency, during a complete annual cycle.

Shrinking sea ice is a symbol of global warming. In the Arctic, its extent has almost halved in summer since satellite records began in the 1980s. Other properties of the ice, such as its thickness, have been studied to a lesser extent, but are equally relevant. Questions about what this means for the future of the Arctic and how it will affect climate change were the impetus for the landmark MOSAiC expedition, which took place on the German research icebreaker Polarstern between September 2019 and October 2020. During the expedition, the icebreaker entered an ice floe to become deliberately trapped and drift with the ice across the Arctic due to natural transpolar drift. The IEEC team, with CSIC and UPC members, was responsible for one of the experiments – funded by the European Space Agency (ESA) – that was installed on the ice floe to study the interaction between sea ice and navigation signals transmitted from satellites (such as GPS).

In February 2022, three papers with results from the expedition were published in the journal Elementa, compiling the efforts of hundreds of international researchers who analysed the measurements made during the MOSAiC expedition. The IEEC members participated in the sea ice study, which together with the snow and atmosphere studies presented the first complete picture of climate processes in the central Arctic, which is warming more than twice as fast as the rest of the planet, affecting both global weather and climate. These studies will serve as a reference for a wide range of future scientific work by providing increasingly important information on climate change, knowledge which is the base for societal transformation towards a sustainable approach to planet Earth.

Figure 3: 24-hour marathon sampling to record a “snapshot” of the daily cycles of the Arctic summer. Credit: Lianna Nixon (Alfred-Wegener Institut).

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Scientists detect a type Ia supernova one hour after the explosion of its progenitor star

Fast monitoring surveys of the night sky allow discoveries of young supernovae. These observations represent a major step forward in the understanding of this type of supernova and make it possible to distinguish between different explosion patterns.

A team of international scientists made the earliest detection of a type Ia supernova to date, just one hour after the event. The research team, including Lluís Galbany from the Institut d'Estudis Espacials de Catalunya (IEEC), was able to detect the supernova, named SN 2018aoz, on 29 March 2018 from one hour after its first light using the Korea Microlensing Telescope Network (KMTNet), a network of three telescopes in the southern hemisphere (Chile, South Africa, and Australia). The team also obtained information about its birth, which is vital to revealing how the explosion took place.

Type Ia supernovae are thermonuclear explosions of white dwarfs in binary systems, and they are the most commonly observed variety of supernovae, playing a crucial role in understanding the origin of metals and the accelerating expansion of the Universe. Despite their importance, the explosion mechanisms of type Ia supernovae are still under debate among the scientific community.

The data revealed a concentration of metals, particularly from the iron family, in the outermost layer of the material ejected by the supernova, indicating the explosion could have been initiated by the burning of material on the surface of the dying star or by an extreme mixing process that causes heavier elements from the interior to emerge to the surface. In addition, the data also show a rapid reddening of its light, a temporary absorption of its bluer light, during the first 12 hours after explosion. This discovery supports the "double detonation" model, in which the outburst of the outermost layer of a white dwarf would cause a shock wave with enough energy to trigger another detonation in the centre of the star. The study, published in Nature Astronomy, is a significant milestone in the understanding of how type Ia supernovae explode and allows scientists to distinguish between different models of type Ia supernovae explosions.

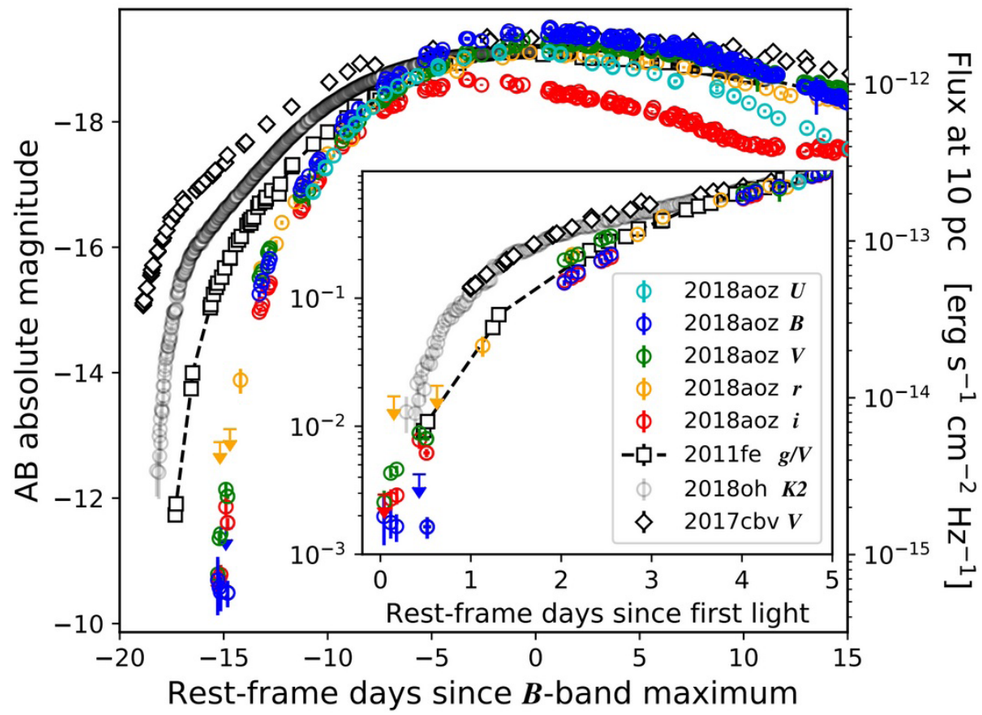

Figure 4: (from Ni et al. 2022, Nature Astronomy, Volume 6, p. 568-576): SN 2018aoz light-curves (colour) compared to other Type Ia supernovae with early detections: 2011fe, 2018oh, and 2017cbv. The light of SN 2018aoz shows a faster increase of the brightness than the other three SNe. The inset panel shows the light curves of these same supernovae within the first 5 days since explosion normalised to their luminosities at 5 days. SN 2018oh and 2017cbv both show excess emission between 1 and 5 days, whereas SN 2011fe shows a typical power-law-like rise. The light curves of SN 2018aoz after half day are similar to SN 2011fe, but in the first 12 hours the light curve in the B-band (blue wavelengths) stalls, showing a "plateau" feature, while the V and i bands rise rapidly at a rate of around 2 mags/day.

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First ever detection of radio-frequency pulsations of a very elusive binary star system

This is the first evidence of pulsations from the binary system LS I 61 303 after more than 40 years of searching. The finding is the result of lengthy efforts to find pulsations at any frequency and proves the existence of a pulsar in the system.

Using the largest radio telescope on Earth, the Five-hundred-metre Aperture Spherical radio Telescope (FAST, in China), an international team including ICREA Prof. Diego Torres, researcher at the Institute of Space Sciences (ICE-CSIC), has discovered radio pulsations from the system LS I 61 303. This is the first evidence for pulsations from this source at any frequency, and proves the existence of a rotating neutron star in this system, something that has been debated for decades.

LS I 61 303 is a rare system, one of the few known gamma-ray binaries. These systems emit most of their luminosity in photons with very high energies. They are stellar systems formed by a massive star and a compact object that can be either a black hole or a neutron star. To know for sure what the compact object is has implications for understanding the multifrequency emission and the evolutionary path of gamma-ray binaries, and how to relate them to other classes. In this case, LS I 61 303 has also shown super-orbital variability and magnetar-like flares.

Torres' group has carried out many deep searches for pulsations in X-rays, hard X-rays, and GeV gamma-rays before actually finding them in radio frequencies. It was a difficult task: not only were they trying to detect a pulsar that is not particularly bright, but, similarly to other pulsars, one for which pulsations are not permanent.

Prof. Torres is particularly concerned with the period actually found from a theoretical perspective as well. The period of the pulsar, 0.26 s, is right at the predicted range of a multi-frequency model he completed a decade ago (Torres et al. 2012, and A. Papitto, Torres & Rea 2012, both published in The Astrophysical Journal). In this model, the system transitions between two states along the orbit, according to the mass pressure in the vicinity, also explaining long-term multi-frequency recurrencies. The current period measurement brings increased interest to this possibility.

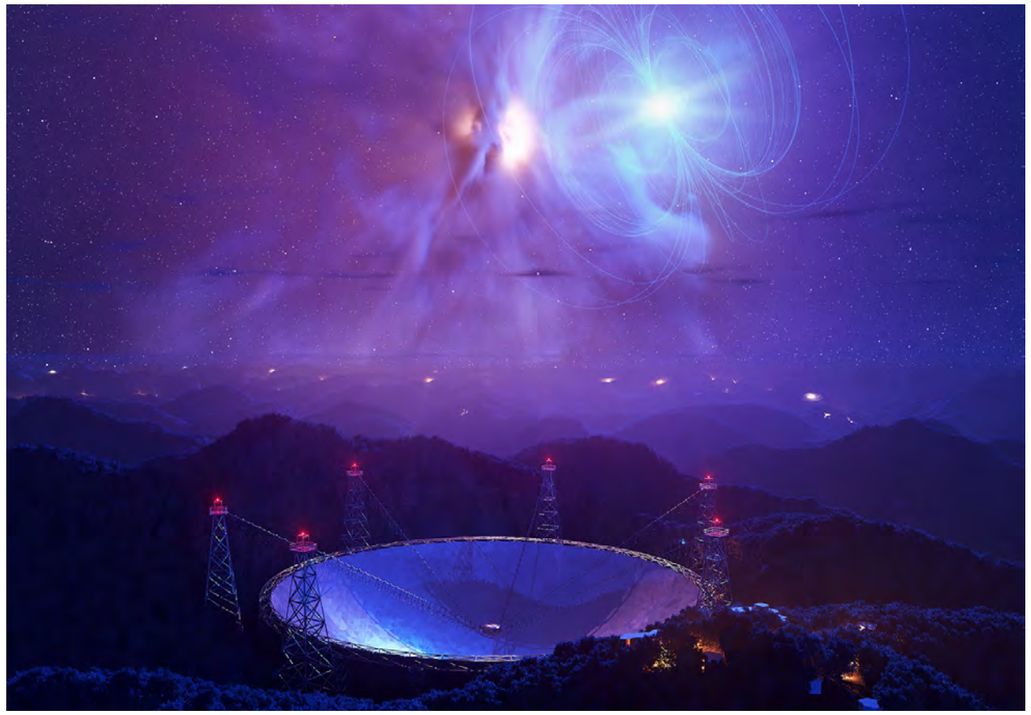

Figure 5: Artist's impression of the binary star system LS I 61 303 shining over the FAST telescope. Credit: D.F. Torres, S. Weng and K. Rappaport, Science Communication Lab.

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A new type of very high energy gamma-ray source has been discovered by MAGIC collaboration

Using a system of two 17m - diameter imaging air Cherenkov telescopes located on the Canary Island of La Palma, Spain, researchers from the MAGIC collaboration detected very high energy gamma rays from a recurrent nova in the Milky Way. This event is the first one that has been detected at such energies and may provide new insight into this class of eruptions and the potential role they play in producing the mysterious highly energetic cosmic rays that permeate the Milky Way. The results of such observations and the new findings on these stellar explosions have been published in an article in the prestigious journal Nature Astronomy, with the participation of IEEC members from the ICCUB and CERES-UAB units.

The end of a star after its death depends on its mass. In about five billion years, when the Sun burns out, it will expand into a red giant star and then collapse into a stellar corpse known as a white dwarf. These stellar remnants are very dense and, under certain circumstances, can produce large explosions.

In binary systems where the white dwarf has a red giant star as a companion, hydrogen from the outermost layers of the red giant can succumb to the gravitational pull of the white dwarf and accumulate on its surface. This ‘vampirism’ of a white dwarf onto an active-phase star results in a nuclear explosion on its surface, which causes it to expel most of the hydrogen and fusion products into interstellar space. Such explosions are very luminous, up to 100,000 times brighter than our Sun, and are known as novae. If the cycle of material transfer between the two stars starts again, it can restart the process that in the future will lead to another explosion in what are known as recurrent systems.

On 8 August 2021, an alert of the very high-energy gamma-ray burst of one of the most studied novae in the Milky Way, RS Ophiuchi, was received. The incredible explosion of the RS Oph nova reached Earth and was immediately detected by optical telescopes and the Large Area Telescope (LAT) on board the gamma-ray satellite Fermi. An extensive tracking mechanism was immediately activated and a whole series of observations followed, making this the first nova to be detected in such a wide energy range, both from Earth and from space. The following day, on 9 August 2021, the MAGIC collaboration used its twin Cherenkov telescope system, located at the Roque de los Muchachos Observatory (on the island of La Palma), to observe in the direction of RS Oph, also detecting the source. This detection in the energy range 60 GeV to 250 GeV, at energies one hundred billion times higher than visible light, allows identifying novae as a new type of very high-energy gamma-ray source. This event is the first to be detected at these energies and provides a better understanding of this kind of outburst and its potential role in the production of the mysterious cosmic rays in the Milky Way. The theoretical interpretation of the combined Fermi LAT and MAGIC data suggests that protons are accelerated to hundreds of gigaelectronvolts in the nova shock. Such protons should create bubbles of enhanced cosmic ray density, of the order of 10 pc, from the recurrent novae.

To fully understand the complex relationship between violent events in the interstellar medium of our Galaxy will require more observations like the ones presented here. The MAGIC collaboration will continue the celestial surveillance of stellar remnants in the Milky Way and other galaxies.

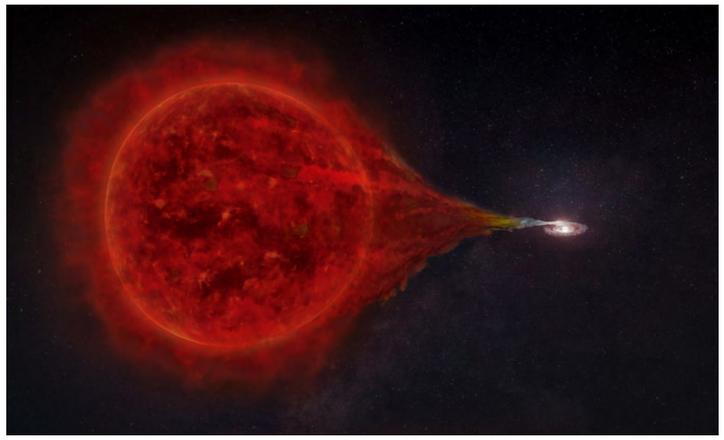

Figure 6: Artist’s impression of material transfer from a red giant to a white dwarf. This is how RS Ophiuchi might also have looked prior to the nova outburst. Credit: Max Planck Institute for Physics

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First detection of the initial fireball of a nova explosion

The fireball produces a short flash in X-rays that was detected by eROSITA.

When stars like our Sun use up all their fuel, they shrink to form white dwarfs. Sometimes such dead stars flare back to life in a super hot explosion and produce a nova explosion, which initiates as a fireball of X-ray radiation. These X-ray flashes last only a few hours and are almost impossible to predict, but the observational instrument must be pointed directly at the explosion at exactly the right time. The instrument in this case is the eROSITA X-ray telescope. On 7 July 2020, it measured strong X-ray radiation in an area of the sky that had been completely inconspicuous four hours previously. When the X-ray telescope surveyed the same position in the sky four hours later, the radiation had disappeared. It follows that the X-ray flash that had previously completely overexposed the centre of the detector must have lasted less than eight hours.

X-ray explosions such as this were predicted by theoretical research more than 30 years ago, but have never been observed directly until now. These fireballs of X-rays occur on the surface of stars that were originally comparable in size to the Sun before using up most of their fuel made of hydrogen and later helium deep inside their cores. These stellar corpses shrink until “white dwarfs” remain, which are similar to Earth in size but contain a mass that can be similar to that of our Sun. Since these burnt out stars are mainly made up of oxygen and carbon, we can compare them to gigantic diamonds that are the same size as Earth floating around in space. These objects in the form of precious gems are so hot they glow white. However, the radiation is so weak that it is difficult to detect from Earth.

In a binary star system, white dwarfs can be accompanied by another star that is still burning. In this case, the enormous gravitational pull of the white dwarf draws hydrogen from the shell of the accompanying star. In time, this hydrogen can collect to form a layer only a few metres thick on the surface of the white dwarf. In this layer, the huge gravitational pull generates enormous pressure that is so great that it causes the star to reignite. In a chain reaction, it soon comes to a huge explosion during which the layer of hydrogen is blown off. The X-ray radiation of an explosion like this is what hit the detectors of eROSITA on 7 July 2020. According to the results obtained from the analysis of the X-ray radiation detected, the white dwarf has around 90 per cent of the mass of our Sun and is therefore relatively large. The explosion generated a fireball with a temperature of around 327,000 degrees, making it around sixty times hotter than the Sun.

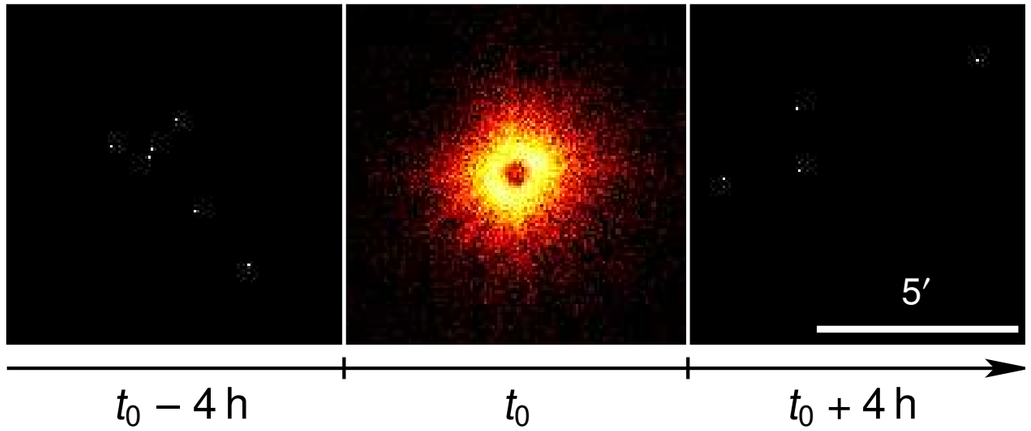

Figure 7: Sky image of the seven eROSITA cameras combined (0.2-0.6 keV). On t0 = 2020 July 7, 16 h 47 min 20.64 s TT, during the second all-sky survey, eROSITA detected a bright, new, soft X-ray flash that was severely affected by pile-up. No source can be seen in the scans 4 h before and after the event. Credit: Nature

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New calculations resolve a two decades-long controversy over the Sun's chemical composition

A new determination of the solar chemical composition, based on higher resolution solar spectrum, new analysis techniques, and better experimental atomic data, solves the long-standing apparent contradiction between the Sun's chemical composition and the mapping of the internal structure of our star.

The chemical composition of the Sun can be determined by the analysis of the solar spectrum, i.e. the decomposition of light into different wavelengths. Each chemical element leaves its unique fingerprint in the solar spectrum in the form of absorption lines at well determined wavelengths. By using accurate atomic data, models of the Sun's atmosphere and radiative transport, the depth of the absorption lines can be used to determine the abundance of chemical elements.

The advent of 3-dimensional models of solar atmospheres in the early 2000s led to a drastic reduction in the estimated metal content of the Sun, in particular for some of the most abundant metals C, N, and O. However, when calibrated against that set of solar abundances, the standard model of the Sun's evolution led to a reconstruction of the Sun's internal structure in contradiction to inferences from high-precision helioseismic data. This led to a crisis in our understanding of the internal structure of the Sun known as the 'solar abundance problem' that resisted any solution for almost 20 years.

Improving with respect to past works, the new study is based on the highest-ever solar spectrum, new atomic data for oxygen – a critical element – and a generalisation of more physically accurate models for radiation transport and spectral line formation for all elements. The results show that, among others, oxygen abundance had been previously underestimated by about 20%. This, in combination with other changes in the abundance of neon, silicon, carbon and nitrogen, leads to a revised set of solar abundances that shows the Sun contains 26% more metals than deduced in previous studies.

Now, when the new solar abundances are used to calibrate the standard solar model, the discrepancy between the results of solar models and helioseismic measurements disappears. The solution to the solar abundance problem then repositions the Sun as a fundamental reference in stellar physics studies. This is of central importance for several areas of astrophysics, in particular for the detailed characterization of the internal structure of other stars, a fundamental objective of the European Space Agency mission PLATO.

The data and methods employed in the analysis of the solar spectrum promise considerably more accurate estimates of the chemical composition of stars in general. This is of fundamental importance in the era of large-scale spectroscopic surveys which provide, at an ever-increasing pace, high-quality spectra for millions of stars. The results of this work therefore put future stellar chemistry and stellar evolution modelling on a firmer footing than ever before, with corresponding implications for the reconstruction of the chemical evolution of our Cosmos.

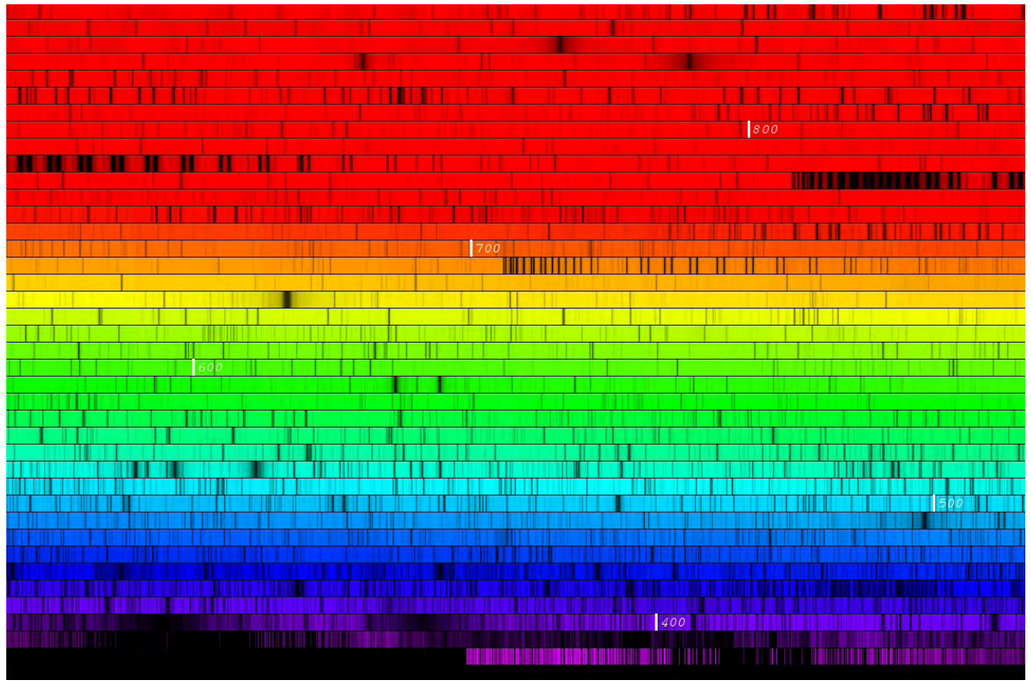

Figure 8: Solar spectrum from near-UV to near-IR. The imprints of chemical elements are visible as absorption atomic lines and molecular bands. Credit: M. Bergemann / MPIA / NARVAL@TBL.

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Computation on the Cloud to unveil the mysteries of our Galaxy

The OCRE European project has funded the use of commercial cloud services to explore new and efficient ways to scientifically exploit the Gaia catalogue.

The Gaia DR3 catalogue, published in June 2022, contains extensive information on nearly two billion sources, which poses a huge challenge to classical approaches on data analysis and astrophysics modelling. The Gaia group at the IEEC-ICCUB, with its Galactic RainCloudS proposal, was ranked first at the Cloud Funding For Research call of the Open Clouds for Research Environments (OCRE) European initiative. In collaboration with Pervasive Technologies (a local company specialised in Artificial Intelligence), and with the support of Telefónica and Altostratus, this grant of 100 k€ makes possible the extensive use of commercial cloud services (Google Cloud, in this case) for a variety of research projects related to Gaia.

The first project is the orbital study of the Magellanic Clouds (LMC and SMC) around the Milky Way. By means of N-body simulations we can learn about the history of the mutual interactions of these galaxies and with our Milky Way. By characterising these encounters, we can better understand the currently observed morphology of the Magellanic Clouds. We have been able to launch several low-resolution tests which aid in setting up the initial conditions for the high-resolution simulations. The main benefit of cloud computing here is the high reliability in very long executions and the flexibility in setting up virtual machines with different memory and processor characteristics.

The second project is the study of the kinematic substructure of our Galaxy. Here, the capabilities of the cloud platform have allowed us to re-execute the methodology presented by our group in the literature to the full six-dimensional sample of Gaia DR3, increasing by an order of magnitude both the number of stars and the algorithm resolution. It also allowed running a series of Test Particle simulations, exhaustively covering the parameter space of the galaxy models. The OCRE initiative has not only made possible this vast increase in achievable resolution, but also a decrease by an order of magnitude in computing time.

The third project makes use of an Apache Spark cluster deployed in the cloud platform to unveil, all at once, the mass distribution function during the initial process of star formation – one of the key pieces that trace the chemical evolution of the Universe – and the complete star formation history of our Galactic disk, an outline scenario that Gaia has revealed to be tremendously complex due to, among others, the gravitational effects from the interaction with satellite galaxies such as Sagittarius. This is achieved by applying the new BGMFast theoretical framework developed by our team, able to generate large Besançon Galaxy Model Fast Approximate Simulations to be fitted to the deep Gaia full sky data.

In general, the main advantage of cloud computing is the avoidance of hardware acquisition and maintenance, and the access to huge computers with hundreds of modern processor cores, over a terabyte of memory, and large solid-state storage volumes. Besides, and perhaps more importantly, it offers integrated services such as notebooks, extremely efficient databases, machine learning services, and other data analysis services depending on the provider.

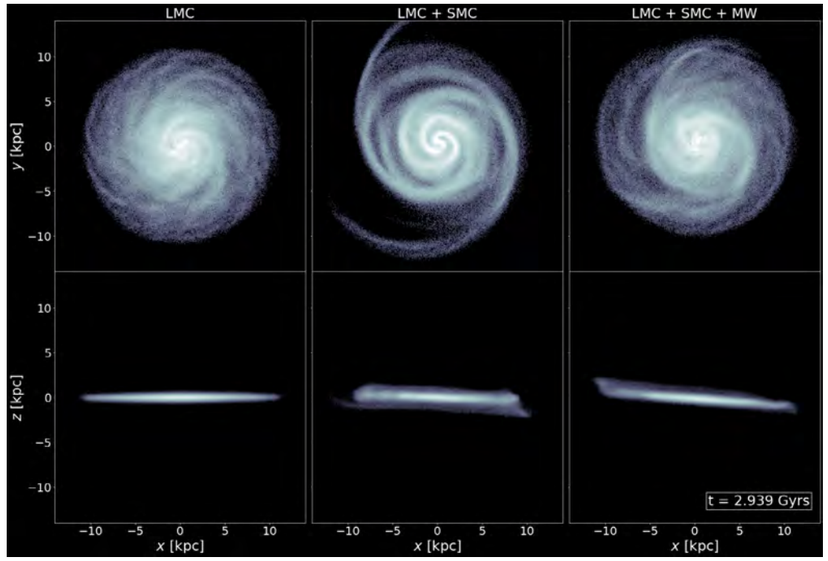

Figure 9: Comparison of the LMC stellar density distribution for three different high-resolution simulations, 2.9 billion years after initial conditions. Left: isolated LMC. Centre: LMC in interaction with the SMC. Right: LMC in interaction with the SMC and the Milky Way. Credit: Ó. Jiménez-Arranz et al.

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LISA, the mission to observe gravitational waves in space, going for adoption

LISA is a large-class ESA mission to create the first Gravitational-Wave (GW) observatory in space, where it will observe with high precision astrophysical and cosmological sources of GW not accessible from the ground. It is currently in Phase B1 and about to pass the Mission Adoption Review, which will mean the beginning of the implementation phase with a launch expected in 2035. The IEEC leads the Spanish contribution to the mission, the Science Diagnostics Subsystem (SDS), with the participation of researchers from the Institute of Space Sciences (ICE-CSIC), the Research Group in Space Sciences and Technologies (CTE) of the Technical University of Catalonia (UPC), and the Institute of Cosmos Sciences of the University of Barcelona (ICCUB).

Gravitational Wave Astronomy is approaching a stage where different observatories/detectors of Gravitational Waves (GWs) will be operating in different bands of the GW spectrum, enabling multiband detections as well as multi-messenger Astronomy with GWs. Indeed, the next decade will witness third-generation ground detectors (like the Einstein Telescope or Cosmic Explorer) making numerous detections per day in the kHz band, new Pulsar Timing Arrays like the Square Kilometre Array (SKA) operating in the nHz band, and even CMB polarisation detectors looking for GW signals just after the Big Bang.

LISA is an ESA large-class space mission that will complement this picture by observing the University in the mHz band. LISA is an all-sky monitor that will offer a wide view of a dynamic cosmos using GWs as messengers to unveil The Gravitational Universe. It consists of a fleet of three satellites following the Earth in its orbit around the Sun in a triangular formation separated by 2.5 million km and connected by laser beams (see the Figure), obtaining both GW polarizations simultaneously and measuring source parameters with high sensitivity in the mHz band. LISA will provide the closest ever view of the infant Universe at TeV energy scales, has known sources in the form of verification binaries in the Milky Way (ultra compact binaries), and can probe the entire Universe, from its smallest scales near the horizons of black holes, all the way to cosmological scales.

Moreover, the high accuracy of LISA measurements will allow us to test the geometry of black holes and even General Relativity and alternative theories of gravity. From these measurements we expect revolutionary discoveries in Astrophysics, Cosmology and Fundamental Physics.

The Gravitational Astronomy-LISA Group of the ICE-CSIC, in collaboration with the UPC-IEEC and UB-IEEC groups, leads the Spanish contribution to the LISA mission (it already led the Spanish contribution to LISA Pathfinder, the ESA technology demonstrator mission for LISA). This contribution is the Science Diagnostics Subsystem (SDS), 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 thermal, magnetic and charge-particle environment of the LISA measurement system. To this end, the ICE-CSIC group, in collaboration with the IEEC groups, international institutions like DLR, and the industry (SENER Aeroespacial), runs several ESA technology contracts to improve the technology readiness of the SDS.

After successfully passing the Mission Formulation Review, LISA is currently in the phase B1 of preliminary design. IEEC groups are supporting ESA during this phase by working in collaboration with the two primes (Airbus and Thales), who run parallel design studies, to provide recommendations on the Science Diagnostics Subsystem (SDS) definition. There is an opportunity for LISA to be adopted by the end of 2023. In order to secure the mission Adoption, IEEC groups are actively contributing to the scientific definition activities (LISA Red Book), preparation of the international agreements on the mission (Multilateral Agreement, MLA), and technical reviews at ESA level (Specification Requirement Review, SRR), the latter in cooperation with the industrial partner SENER Aeroespacial. After the mission adoption, LISA will enter the implementation phases in 2025 with a view to a launch in 2035. This is a great opportunity for the GW community, and the broad Astronomy community, to make a big leap in our knowledge of the Cosmos, and the IEEC will play a major role in this enterprise.

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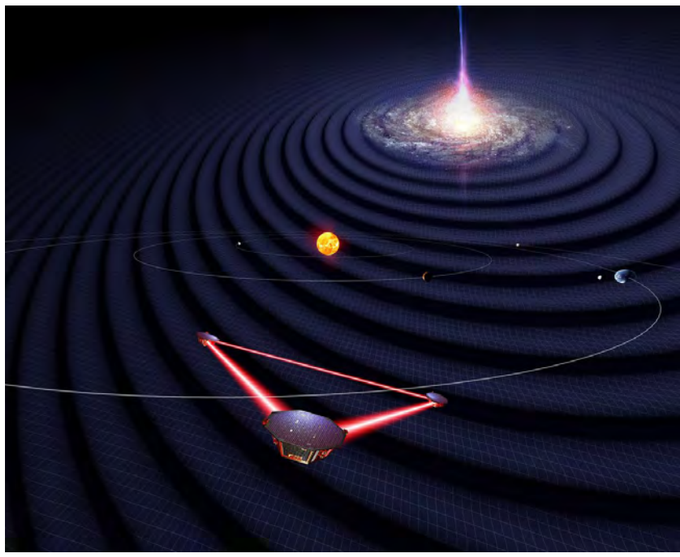

Figure 10: Artistic representation of LISA (a Large-Class ESA mission). The constellation of three spacecraft is seen following a heliocentric orbit around the Sun following the Earth. In the background, a representation of the emission of gravitational waves by a binary system of supermassive black holes. Credit: University of Florida / Simon Barke (CC BY 4.0).

The third release of data of the Gaia mission

Gaia's data release 3 contains new and improved details for almost two billion stars in the Milky Way. A team of astronomers and engineers from the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB) has been involved in the mission since its inception.

On 13 June 2022, ESA and the Gaia Data Processing and Analysis Consortium made public the full third data release, a new big milestone of the Gaia mission. It complements the early EDR3 in December 2020 by adding low and medium resolution spectroscopy and many other products like classification and parametrization of stars, solar system objects, galaxies and quasars. The number of spectra published, which surpasses the data collected by humans through the ages, and the variety of products are unprecedented and astonishing.

Gaia has two spectrophotometric instruments, one that observes in the blue range of the visible spectrum (Blue Photometer or BP which covers the 330-680 nm range of wavelengths) and another in the red range (Red Photometer or RP, 640-1000 nm). Gaia-DR3 includes the BP/RP spectra for sources with G<17.65 mag and more than 15 observations on the spectrophotometric instrument. In addition, the spectra of some intrinsically weaker objects have been explicitly included (white dwarfs, quasars, galaxies, ultracold stars, calibration stars...). Despite its low spectral resolution, Gaia's spectrophotometry also makes it possible to determine the astrophysical parameters of the sources. Thus, the Gaia team has provided the classification and parameterization of the different types of objects. Gaia-DR3 provides the classification of practically all the objects in the catalogue (1.59 billion), the atmospheric parameters (effective temperature, surface gravity, metallicity, absorption, etc.) of more than 470 million stars, and the redshift for about 6.3 million quasar and 1.3 million galaxy candidates.

Gaia-DR3 also includes a medium resolution (R~11500) spectrometer (RVS) at the calcium triplet IR region (845 to 872 nm) in order to determine the radial velocity of the observed sources and derive the astrophysical parameters using spectral lines. Gaia-DR3 includes almost 34 million radial velocities of all sources down to the RVS limiting magnitude of G_{RVS} ~ 16 mag, reaching a few kiloparsecs beyond the Galactic centre in the disc and up to about 10-15 kiloparsecs vertically into the inner halo. Rotational velocities are also provided for 3.5 million sources.

The new archive also includes many other relevant products, such as variability analysis for 10.5 million sources, orbital solutions for 155,000 solar system objects, all-sky total galactic extinction map, interstellar extinction map in the solar neighbourhood, 813,000 non-single stars, the photometric time series for 1.2 million sources around the Andromeda galaxy, and 2,612 science alerts triggered in the period underlying Gaia-DR3.

It is impressive to see how each of the promises made about the Gaia mission years ago are being fulfilled in each new data release, constituting the catalogue that will be (and already is) the basis of astrophysics in the coming decades.

The ICCUB/IEEC team, as part of the Data Processing and Analysis Consortium, has participated in all stages of the Gaia mission, including the design of the instrument, the monitoring of its health during the mission, the daily processing of the telemetry data, the production of the input data for whole pipeline, the calibration, and the production and validation of this DR3.

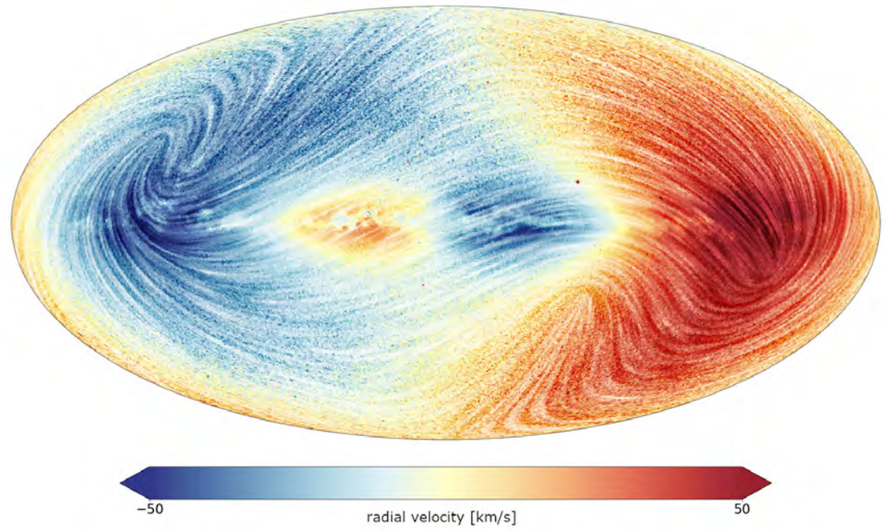

Figure 11: Sky map with the stellar velocities with respect to the bar extracted from Gaia data. The colour shows the line-of-sight velocity of stars relative to the barycenter of the Solar system. The lines overlaying the map show the streamlines of the proper motions of stars. The figure is also sensitive to the motion of the Sun within the Galaxy. Credit: ESA/Gaia/DPAC

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Gliese 486, the best studied planet outside the Solar System

Transiting exoplanets with accurate mass and radius determinations are the best candidates to characterise exoatmospheres and understand their evolution. The CARMENES survey is providing a number of such planetary systems, such as Gliese 486b, the planet with the best known properties until now.

Gliese 486 is a cool star around which a rocky exoplanet was found using the CARMENES high-resolution spectrograph in 2021. Further observations from the TESS satellite revealed that the planet was also transiting the star. This finding made this planetary system the perfect target to dig in the understanding of planet formation, internal structure, and exoatmosphere evolution. The discovery of the planet Gliese 486 b was published in 2021 in the Science journal, but observations to improve our knowledge of the system did not stop there.

Further observations were gathered with the CARMENES and MAROON-X spectrographs to determine the planet mass with an accuracy of about 4%. Besides, these spectroscopic data were also essential to estimate the abundance of refractory elements in the star. The CHEOPS satellite was used to obtain 7 transit light curves from which the radius of the planet was improved, reaching a 4.7% precision level. To achieve such a goal, interferometric observations with the CHARA array were also secured. Along with Gaia data, they yielded the absolute radius of the star, from which that of the planet is derived, independently of empirical calibrations. New photometric data, including time-series obtained with the TJO telescope at the Montsec observatory, allowed us to confirm the rotation period of the system. And Hubble Space Telescope observations were useful to characterise the high-energy radiation of the star, which plays a crucial role in the atmosphere of exoplanets.

With all this information in hand, it was not only possible to derive the mass and the radius of the star with unprecedented accuracy, but also to infer the internal structure of Gliese 486 b by using planetary models, and to estimate the properties of its atmosphere. In summary, this system became the best candidate for further studies using the James Webb Space Telescope in order to confirm the exoatmosphere properties, boosting our knowledge on exoplanet evolution.

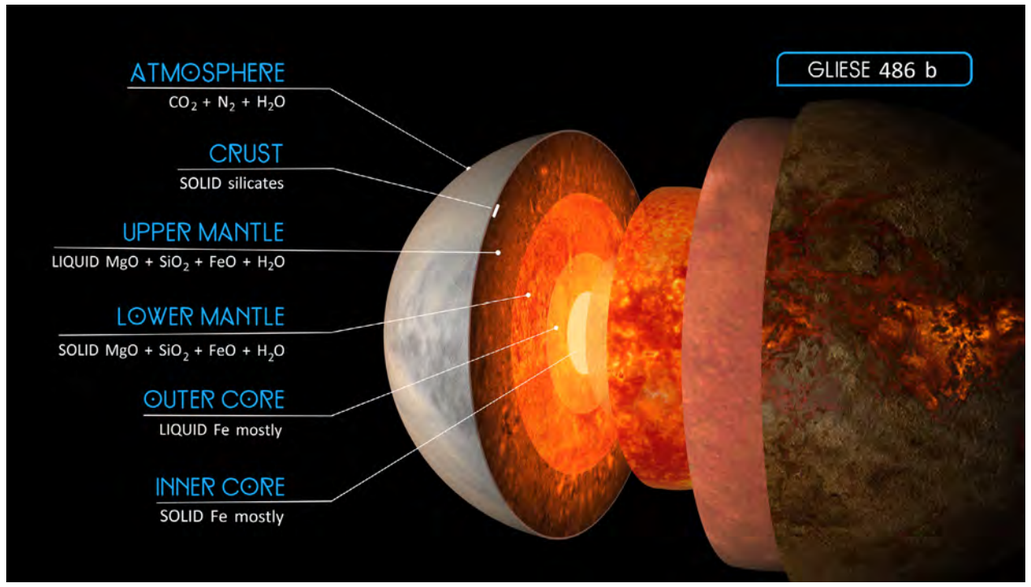

Figure 12: Artistic illustration of the hypothetical atmosphere and internal structure of exoplanet Gliese 486 b. Credit: RenderArea

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MELISA, a compact magnetic sensor prototype to reduce noise on large space missions

This project has shown that magnetic field modulation can provide a miniaturisation route for sensors monitoring magnetic field fluctuations in the very low frequency range required in some large space missions.

A group of researchers from three IEEC Research Units (CTE-UPC, ICE-CSIC and ICCUB) have developed and manufactured a prototype of a compact, low-power magnetic sensor that implements magnetic field modulation using microelectromechanical resonators (MEMS) over a magnetic resistive sensor.

This technique allows a significant reduction of the low frequency noise intrinsic to miniaturised magnetic sensors. This range is the one used in some space missions, such as the LISA (Laser Interferometer Space Antenna) ESA mission, which will be the first gravitational wave observatory in space.

In the ultra-low frequency range, when all other noise sources have been reduced or eliminated, the so-called 'pink noise', or 1/f, generally dominates and is the main problem. One way to mitigate the effect is using 'magnetic field modulation', which consists of modulating the local magnetic field on the sensor head (in this case a Tunneling Magnetic Resistor, TMR). By modulating the local magnetic field to the TMR, the spectral content of the signal is moved to higher frequencies, where this noise is much lower. For this purpose, a MEMS (Microelectromechanical System) resonator, in which a highly permeable ferromagnetic material is deposited, is placed close to the TMR and excited at its resonance frequency. Then, the field observed by the TMR is modulated at that frequency. Finally, the acquired signal is demodulated to recover the original magnetic field signal.

The prototype fabricated serves as a sample to validate the feasibility of this noise reduction technique to meet the stringent requirements of the European Space Agency's mission to detect gravitational waves in space, LISA. The project also describes a roadmap for a future integration of the control electronics into an Application Specific Integrated Circuit (ASIC), in order to achieve the extreme miniaturisation of the sensor.

In December 2020, the IEEC published an internal competitive call to provide seed funding for a high-potential, high-impact project. The aim was to stimulate collaboration between IEEC members and groups, as well as to foster innovative proposals, allowing for feasibility studies and proofs of concept that would facilitate their maturity. The winning project was MELISA (MEMS miniaturised low-noise magnetic field sensor for LISA), proposed by members of the IEEC in the Research Group in Space Sciences and Technologies (CTE) of the UPC, the Institute of Space Sciences (ICE-CSIC), and the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB).

The proposed project also envisaged exploring the application of the resulting high-performance sensor in a wide range of space missions. Applications include missions that explore planetary surfaces and CubeSats in Low Earth Orbits (LEO) or other planetary bodies, since the frequency range of the currents induced in planetary interiors by interplanetary magnetic field fluctuations and the solar wind is comparable to that of interest for LISA.

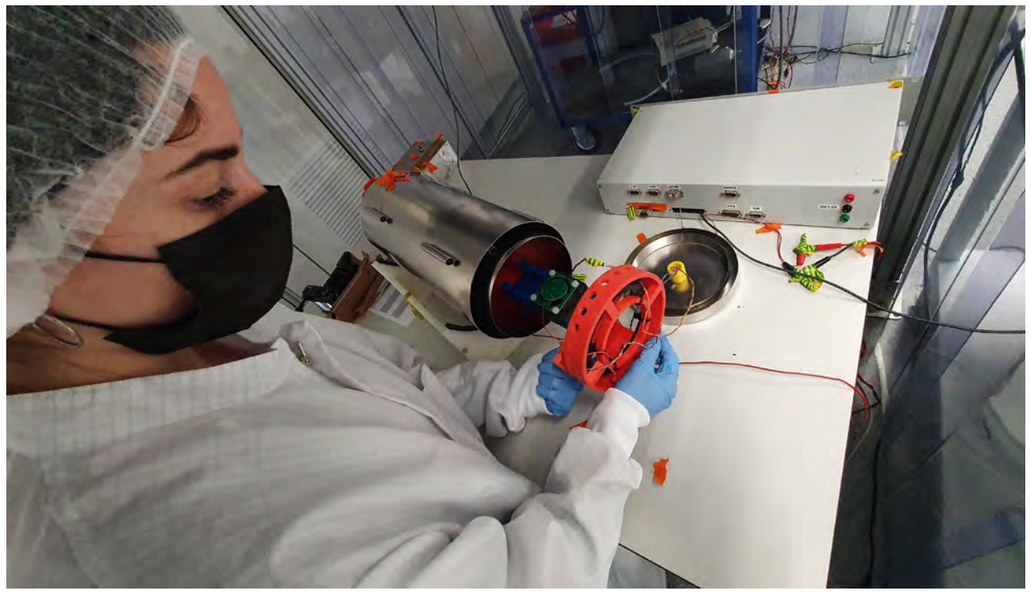

Figure 13: IEEC researchers working on the development of the miniaturised magnetic sensor prototype to reduce noise in space missions. Credit: MELISA Team (IEEC).

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A dormant black hole that formed without a bang

A team of international experts, renowned for having debunked several black hole discoveries, has identified a stellar-mass black hole in the Large Magellanic Cloud. They have also found that the star that gave rise to the black hole disappeared without any sign of a powerful explosion.

A team of international experts has identified a stellar-mass black hole in the Large Magellanic Cloud (LMC), thanks to six years of observations carried out with the Fibre Large Array Multi-Element Spectrograph (FLAMES) instrument on the European Southern Observatory's (ESO) Very Large Telescope (VLT).

Stellar-mass black holes form when massive stars reach the end of their lives and collapse under their own gravity. A black hole is considered to be dormant if it does not emit high levels of X-ray radiation – the most common way to detect black holes – and they are therefore particularly difficult to find.

If a black hole is in a binary system with a star, meaning that the star and the black hole orbit around each other, there is the possibility of finding the black hole from the motion of the luminous companion star. The collaboration analysed approximately 1,000 massive stars in the Tarantula Nebula region of the LMC to find those that might be accompanied by massive, dark objects, such as black holes. Making sure that a dark companion is truly a black hole is very difficult, as there are many alternative options. The one that has now been discovered is at least nine times the mass of the Sun and orbits a hot, blue star (O-type) that weighs twenty-five times the mass of the Sun and is called VFTS 243.

This finding gives the team a unique insight into the processes that accompany the formation of black holes: astronomers believe that a stellar-mass black hole forms when the core of a massive dying star collapses, but it is not yet known whether this is always accompanied by a supernova explosion. The team found that the star that gave rise to the now-discovered black hole disappeared without any sign of a violent explosion. The team could conclude this from the nearly circular orbit of VFTS 243, because if the black hole had formed in a violent supernova, it would have received a large velocity kick, which would have made the orbit elliptical.

Whether black holes form with or without a bang has important consequences for the number of gravitational wave sources that form from binary massive stars. Understanding the origin of gravitational wave sources is one of the primary research interests of ICREA professor Mark Gieles, co-author of the publication, and researcher at the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB), member of the IEEC and of the Department of Quantum Physics and Astrophysics of the UB. Gieles leads the ICCUB's Virgo gravitational wave research group, who analyse and interpret the increasing number of gravitational wave signals from colliding compact objects, such as binary black holes. In addition to the gravitational wave data, Gieles uses electromagnetic observations, like those of VFTS 243, to understand the origin of binary black hole mergers.

The discovery of the black hole in VFTS 243 was published in an article in the prestigious journal Nature Astronomy (Shenar et al. 2022, Nature Astronomy, 6, 1085), with the participation of researcher Mark Gieles from the ICCUB and the IEEC.

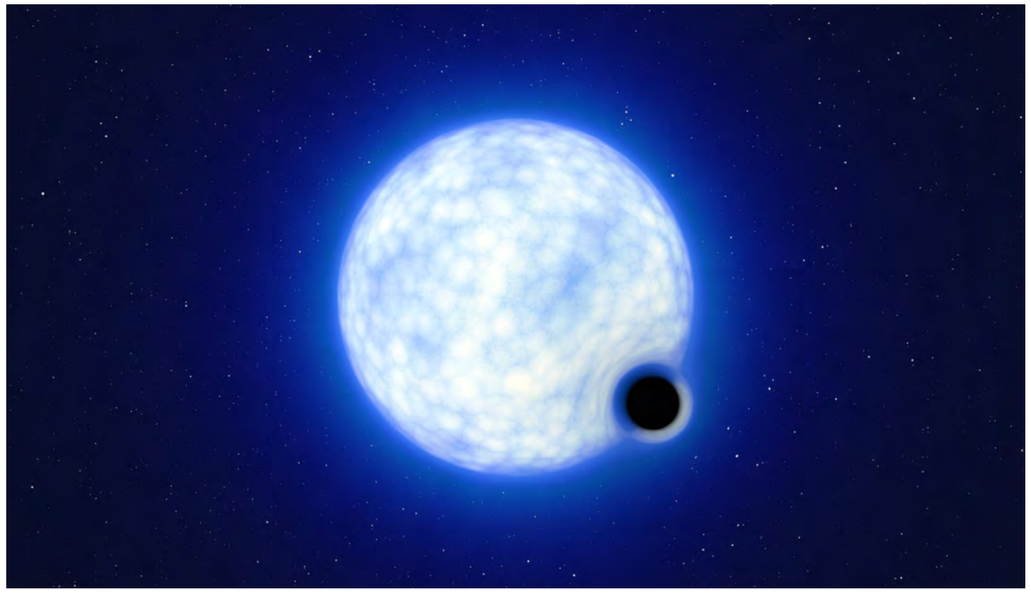

Figure 14: This artist's impression shows what the binary system VFTS 243 might look like if we were observing it up close. The system, which is located in the Tarantula Nebula in the Large Magellanic Cloud, is composed of a hot, blue star with 25 times the Sun's mass and a black hole, which is at least nine times the mass of the Sun. The sizes of the two binary components are not to scale: in reality, the blue star is about 200 000 times larger than the black hole. Note that the 'lensing' effect around the black hole is shown for illustration purposes only, to make this dark object more noticeable in the image. The inclination of the system means that, when looking at it from Earth, we cannot observe the black hole eclipsing the star. Credit: ESO/L. Calçada

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IEEC participation in DART and HERA missions to the Didymos binary asteroid

For the first time, the DART mission tested kinetic impact as a method to alter the orbit of potentially dangerous asteroids. DART impacted the asteroid Dimorphos, which posed no threat to Earth, on 27 September.

The “Double Asteroid Redirection Test” (DART) mission, led by NASA and the Johns Hopkins Applied Physics Laboratory, was launched on 24 November 2021. DART’s spacecraft successfully deflected its target – the asteroid Dimorphos – changing its orbital period in 32 minutes, on 27 September 2022 at 1:14 am CET.

DART’s target was the binary asteroid system composed of Didymos (with a 780-m diameter) and Dimorphos (with a 160-m diameter), which orbits the main. The system was located at 11 million km from Earth. Neither of them currently poses a threat to our planet, although the system is classified as a Potentially Hazardous Asteroid.

IEEC participation was assured by our expert in asteroids, comets and meteorites, the astrophysicist Josep M. Trigo-Rodríguez, member of the IEEC and researcher of the Institute of Space Sciences (ICE-CSIC). The success achieved with the deflection of Dimorphos confirms the kinetic impact method as instrumental in launching a new age of “Active Planetary Defence”. The DART mission was, in fact, NASA’s first test of planetary defence capabilities for future palliative scenarios.

The ICE-CSIC Meteorites, Minor Bodies and Planetary Science Group led by Dr. Trigo-Rodríguez studies the physical-chemical properties of asteroid and comet surface materials, making important contributions in this field. Asteroids have a diverse structure, as a result of the continuous bombardment by projectiles since their formation. The ICE-CSIC and the IEEC have carried out a series of experiments to infer the mechanical properties of the regolith, studying the shock processes experienced by meteorites to help understand the nature and mineralogy of the Didymos system.

Thanks to the DART mission, we have a much better understanding of the key aspects that influence the transfer of kinetic momentum by a projectile without an explosive charge. DART’s experiment allowed us to infer the efficiency with which a projectile excavates a crater in an asteroid, launching materials from the asteroid’s surface in the opposite direction to the incoming projectile. The greater the efficiency of this inelastic process, the greater the deviation of the asteroid, as there is a multiplicative factor in the process of impact excavation now accurately measured from this experiment.

The DART mission investigation team has characterised the surface of Dimorphos using the images obtained before the impact. In addition, it has quantified the crater’s excavation efficiency and the total mass excavated by DART’s impact. The team has studied the satellite’s new period of revolution through photometric light curve follow-up performed using some of the world’s largest ground and space telescopes.

The Didymos system will also be visited by ESA’s Hera mission in December 2026. DART’s investigation team has accurately determined the point of impact and the consequences of crater excavation over Dimorphos. Hera will study in great detail the nature of both asteroids and the consequences of the impact at high resolution. It is also planned to use CubeSat technologies to collect complementary information, including the inner asteroid structure, to mitigate future encounters with potentially hazardous asteroids for which Didymos can be a good proxy.

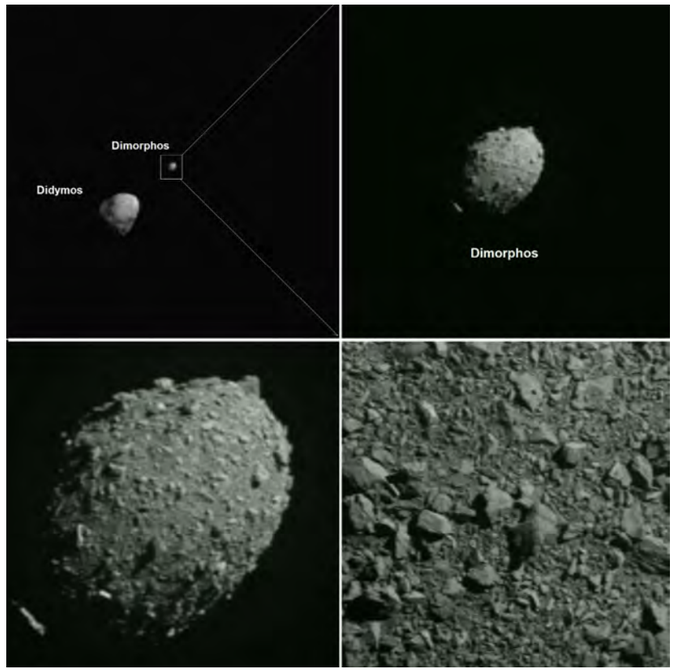

Figure 15: Draco camera images of the binary system during the approach of DART, until imaging Dimorphos, and the final region of crater excavation.
Credit: DART/NASA/JHU

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‘Vera Gravitas’, the female team that won the Barcelona ZeroG Challenge, flies its experiment in zero gravity

This team is composed of four engineering students from the University of Antioquia, in Medellín (Colombia). ‘Vera Gravitas’ seeks to analyse how the solder pond of microgravity electronic component plates is arranged, a little-studied research topic that may have many applications in the immediate future. The Barcelona ZeroG Challenge is coordinated by the professor at the Barcelona East School of Engineering (EEBE) of the UPC and IEEC member, Dr Antoni Pérez-Poch, researcher in microgravity science and technology.

Last 5 October, the winning all-women team of the Barcelona ZeroG Challenge 2021 successfully flew their microgravity experiment at Sabadell airport, consisting of a total of 20 parabolas with a microgravity exposure time of 8 seconds per parabola.

The team is composed of four female students from the University of Antioquia (Medellín, Colombia): Luisa Fernanda Mendoza (spokesperson), Paulina Quintero, Oriana Mejía and María del Pilar Monsalve, who called themselves ‘Vera Gravitas’, which in Latin means “true gravity” and is also a reference to Dr. Vera Rubin, a famous female astronomer who made important contributions to science.

This competition is led by the Universitat Politècnica de Catalunya · BarcelonaTech (UPC), in cooperation with Aeroclub Barcelona Sabadell and the international student association Space Generation Advisory Council (SGAC), with the aim of promoting aerospace research among young people and fostering new vocations in this field. The project is coordinated by the UPC Professor and member of the Institute of Space Studies of Catalonia (IEEC – Institut d’Estudis Espacials de Catalunya), Dr. Antoni Pérez-Poch. The UPC has pioneered the use of this platform since 2011 to carry out experiments in which the main characteristic is exposure to the absence of gravity.

For this edition, a total of 15 proposals were received from 16 different countries, spanning Europe and America to Asia. The final selection was made in January 2022 by a jury of education experts from the European Space Agency (ESA).

The students – who are members of the Colombian Association of Aerospace Women, which aims to arouse women’s interest in this science – focused on analysing the deposition of tin droplets on electronic components in the absence of gravity. This research topic is little studied and may have many applications in the immediate future. Along with their mentor, Professor Liliana Marcela Bustamante Goez, from the same University of Antioquia, they prepared their experiment during a brief stay at the Computer Science and Microgravity Laboratory of the Barcelona East School of Engineering (EEBE).

The ‘Vera Gravitas’ team also worked together with this laboratory during 2022 to adapt the experiment to the particular characteristics of the CAP10B aerobatic plane with which the flight was carried out. They received a grant of 2,500 euros to carry out the experiment, in addition to assistance from Barcelona City Council and other sponsors.

The ‘Barcelona ZeroG Challenge’ and the ‘Vera Gravitas’ experiment design were the focus of a scientific publication in the Proceedings of the 73rd International Astronautical Congress (IAC 2022), the most important in its field, held in Paris from 18 to 22 September.

The ‘Barcelona ZeroG’ Challenge aims to promote interest in science and technology among university students, and to bring space research closer to both students and the general public.

Figure 16: The ‘Vera Gravitas’ team, accompanied by Dr Perez-Poch, were received on 4th October 2022 by the UPC Vice-Rector for Social Responsibility and Equality, Dr Fina Antonijuan, who highlighted the importance of these actions to create role models for women in STEAM studies and promote scientific and technical studies. Credit: UPC

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Hubble telescope captures a rare ‘light echo’ from a supernova in Centaurus A

An international team of astronomers caught the cosmic phenomenon of a supernova explosion lighting up clouds of nearby gas years after explosion.

An international team of astronomers used the Hubble Space Telescope to capture rare “light echoes” around the supernova 2016adj, which was discovered in the well-known peculiar galaxy Centaurus A at a distance between 10 and 16 million light-years from Earth.

A supernova is an explosion of a star that sends out an intense burst of light in all directions. However, on rare occasions, rings of light or “light echoes” spread out from the original supernova position months or years that follow. This phenomenon is rarely seen, having been documented in only a handful of other supernovae.

The researchers studied the area around the supernova for a period of five years after the explosion, when the supernova slowly faded away, and observed how the sideways spreading light hit various layers of dust in the surroundings, producing light rings. These variations in the light echo rings enable researchers to probe the distribution of dust around the supernova. The team of international researchers, including Lluís Galbany from the Institut d’Estudis Espacials de Catalunya (IEEC), observed the evolution of these light echoes, and the data suggests the presence of dust columns with large holes in between. The study published in the Astrophysical Journal Letters also highlights the ongoing importance of the Hubble Space Telescope, which has been observing the sky for over three decades and continues to provide incredible images of the universe. While the James Webb Space Telescope has received much attention, the Hubble is still able to capture important scientific data. Plans are set to follow up on the observations with the Hubble Space Telescope in the future, in the hope that more light rings will emerge and more insight into supernova explosions can be gained.

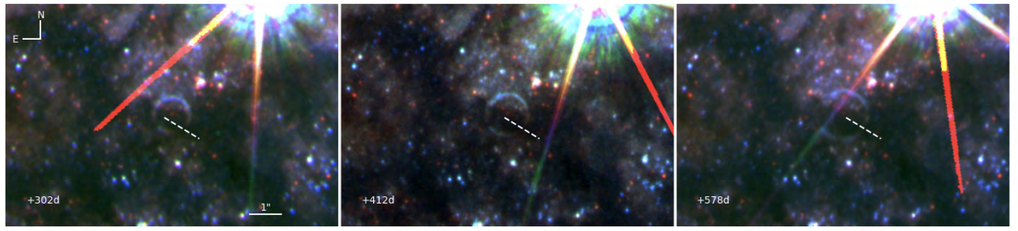

Figure 17: The image shows the supernova explosion at the centre at three different epochs: 302, 412 and 578 days after explosion. The light ring echo around that position grows in size as soon as the light from the explosion hit various layers of dust in the vicinity.
Credit: ICE-IEEC, UCD, Aarhus University, Hofstra University, European Southern Observatory.

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AT 2022cmc: a relativistic jet from the tidal disruption of a star by a supermassive black hole

The signal and its source are the brightest of this type of event and the farthest, respectively, discovered to date, at 8.5 billion light years away.

In February 2022, a group of astronomers detected a rare cosmic event thanks to the Zwicky Transient Facility, an all-sky survey based at the Palomar Observatory in California. This phenomenon was a bright flash produced as a result of a star straying too close to a supermassive black hole, known as a tidal disruption event (TDE).

The team that studied this signal, named AT 2022cmc, was led by astronomers from the MIT (Dheeraj Pasham as principal investigator), with the help of other international collaborators (Tomás E. Müller Bravo and Lluís Galbany from the IEEC, among others). The article in which this study was published appeared in Nature Astronomy. There, the authors report that AT 2022cmc most likely comes from a relativistic jet of matter ejected out from a supermassive black hole at an extremely high velocity, close to the speed of light.

Supermassive black holes are found in the centre of most galaxies and were formed very quickly in the Universe's first million years. This tells us that they feed very fast, although the exact feeding process is still unknown. Therefore, TDEs can be really good probes for how this process happens. AT 2022cmc was about 100 times more powerful than the most powerful gamma-ray burst afterglow. The team of astronomers gathered observations from X-ray, radio, optical, and UV telescopes and tracked this TDE over a few weeks, where they found that the signal had an extreme luminosity in the X-ray band and swung widely by a factor of 500 over this period of time. They suspected that such extreme X-ray activity must be powered by an extreme accretion episode. AT 2022cmc's X-ray luminosity was comparable to, though brighter than, three previously detected TDEs. These bright events happened to generate jets of matter pointing straight toward Earth, creating what's known as a "Doppler-boosting" effect, similar to the amped-up sound of a passing siren.

As technology advances and our observational capabilities improve, we expect to observe many more of these events in the upcoming years. In the near future, we might learn how exactly black holes launch these very powerful jets.

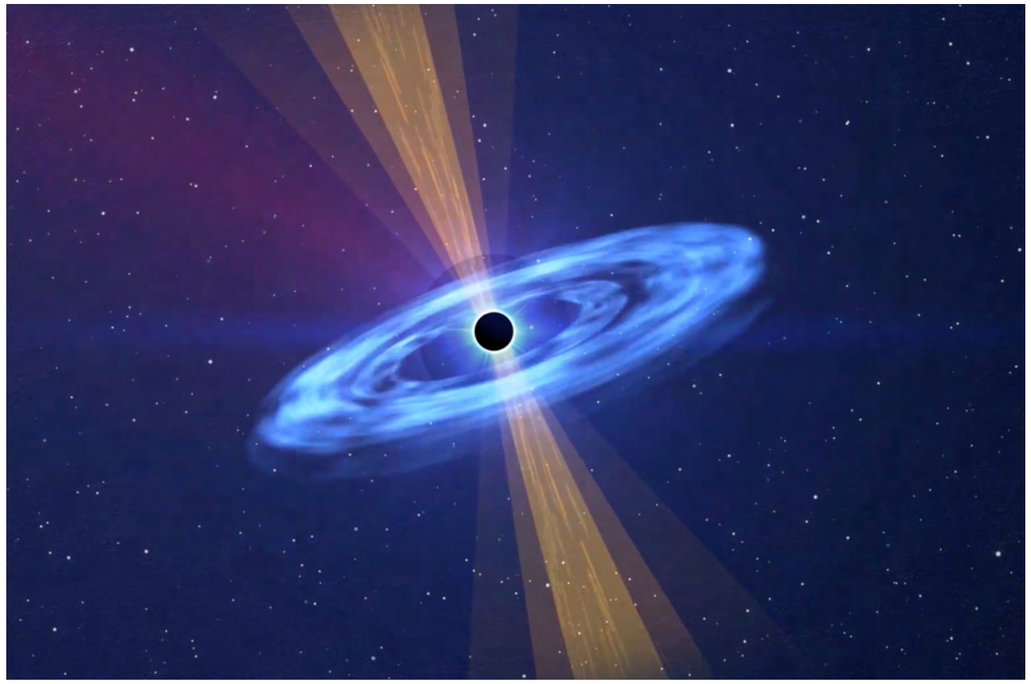

Figure 18: The signal known as AT2022cmc was a relativistic jet pointing at us produced by the tidal disruption of a star orbiting a supermassive black hole.
Credit: Dheeraj Pasham, Matteo Lucchini, and Margaret Trippe.

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Two potentially habitable exo-earths orbit a nearby star

Both Earth-mass planets orbit the star GJ 1002, a red dwarf, and are excellent candidates for atmospheric characterisation.

The search for potentially habitable Earth-like planets is one of the most exciting endeavours in the field of exoplanets. Currently we know a few tens of exoplanets with masses similar to that of the Earth, and hundreds with radii comparable to Earth's. However, the number of known exoplanets in the habitable zones (HZs) of their parent stars (i.e. the region in which liquid water can exist on the surface of the planet) with prospects for atmospheric characterisation remains very small. Nearby low-mass M-dwarfs offer a unique opportunity in the search of characterisable exoplanets in their HZs. Their low masses allow for the detection of small rocky planets without the need of a RV precision as extreme as that required to detect these planets orbiting solar-type stars. Their low luminosity moves the HZ closer to the star, making it possible to sample several orbits within the HZ over modest time intervals.

In Suárez Mascareño et al. (2022, A&A), we reported the discovery of two Earth-mass planets orbiting the nearby M5.5V star GJ 1002, located at just 4.84 pc from the Sun. GJ 1002 b is a planet with a minimum mass of 1.08 ± 0.13 $M_\oplus$ with an orbital period of 10.3465 ± 0.0027 days at a distance of 0.0457 ± 0.0013 au from its parent star, receiving an estimated stellar flux of 0.67 $F_\oplus$. GJ 1002 c is a planet with a minimum mass of 1.36 ± 0.17 $M_\oplus$ with an orbital period of 21.202 ± 0.013 days at a distance of 0.0738 ± 0.0021 au from its parent star, receiving an estimated stellar flux of 0.257 $F_\oplus$. The two planets are located within the HZ of the star. We also detected the rotation signature of the star, with a period of 126 ± 15 days.

Due to its cool temperature, GJ 1002 is too faint in visible light to study its radial velocity variations with most spectrographs. This discovery has only been possible thanks to the collaboration between the ESPRESSO and CARMENES consortia, both devoted to the search for exoplanets. The star was observed by the CARMENES instrument at the Calar Alto Observatory between 2017 and 2019, and later between 2019 and 2021 by the ESPRESSO instrument at the Paranal Observatory, collecting a total of 139 observations. The design of CARMENES, much redder than most other spectrographs focused on radial velocities, helped to obtain high-precision measurements and plenty of stellar activity diagnostics. The combination of ESPRESSO and the collecting power of the 8-m VLT telescopes made it possible to obtain radial velocity measurements with a precision of 30 cm/s, out of reach for almost any other facility in the world.

GJ 1002 is one of the few known nearby systems with planets that could potentially host habitable environments. The closeness of the host star to the Sun makes the angular sizes of the orbits of both planets large enough for their atmospheres to be studied via high-contrast high-resolution spectroscopy with future instruments such as the spectrograph ANDES for the ELT or the LIFE mission concept.

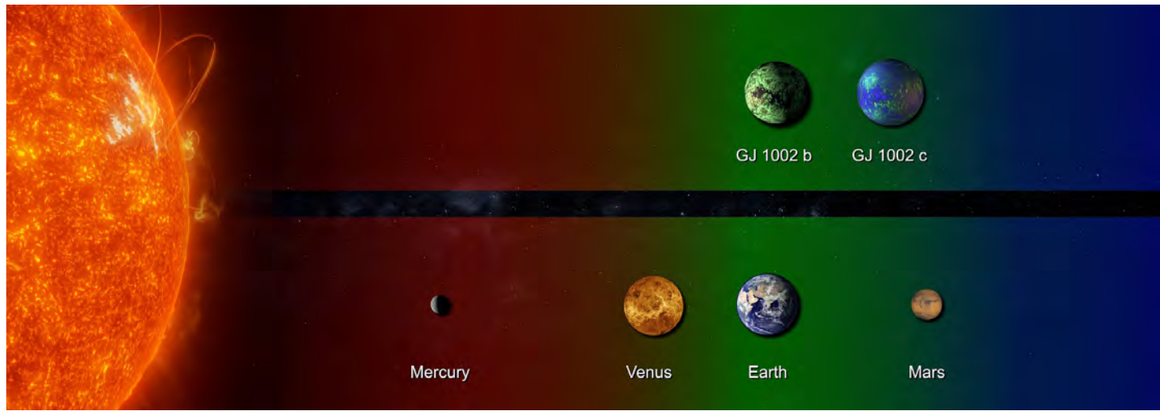

Figure 19: The infographic compares the planet positions, scaled to the habitability zone, with those of the Solar System.

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Scientific Highlights

WEAVE spectrograph begins its study of the galaxy formation and evolution

More than 500 astronomy professionals from all over Europe, including IEEC members, have designed and planned a total of five years of operations for this instrument recently installed at the Canary Islands Observatory.

WEAVE is a powerful new generation multifibre spectrograph in the William Herschel Telescope (WHT) at the Roque de los Muchachos Observatory (La Palma, Canary Islands) which has recently started its observations and is already generating high-quality data. First light observations were presented in late 2022 and targeted NGC 7318a and NGC 7318b, two galaxies at the centre of Stephan's Quintet, a group of interacting galaxies. This group had already been observed with the Hubble, Spitzer and Chandra telescopes, among others, and also more recently with the James Webb Space Telescope (JWST). Its galaxies, four of which are 280 million light-years from Earth, are colliding with each other, providing an excellent "close-up" laboratory for studying the consequences of galaxy collisions and subsequent evolution. The speeds obtained by WEAVE indicate that the NGC 7318b galaxy is entering the group from behind at about 800 km/s.

The observations of the first light were carried out with the so-called Large Integral Field Unit (LIFU) fibre array, one of WEAVE's three fibre systems. The other two modes, the Multi-Object Spectrograph (MOS, with 950 individual fibres) and mini Integral Field Unit (mIFU, with 20 fibre bundles) are currently being commissioned. Two resolutions are available, a low resolution mode covering the entire visible spectra at around R~5000 and a high resolution mode at R~20000.

Astronomers from all over Europe have planned eight surveys for observation with WEAVE, including studies of stellar evolution, the Milky Way, the galaxy evolution and cosmology. In line with the European Space Agency's Gaia satellite, WEAVE will be used to obtain spectra of several million stars in the disc and halo of our Galaxy, enabling the archaeology of the Milky Way. Nearby and distant galaxies will be studied to discover the history of their growth. And quasars will be used as indications to map the spatial distribution and interaction of gas and galaxies when the universe was only about 20% of today's age.

This project involves scientists from the Institute for Space Studies of Catalonia (IEEC). From the beginning of the project, they have worked on the definition of the scientific objectives, and they have key roles in the selection and preparation of the objects to be observed, from stars in various evolutionary phases to star clusters, in addition to quasars, which are extremely bright and very distant active galactic nuclei.

Figure 20: The WEAVE instrument mounted at the top ring of the William Herschel Telescope. The fibre positioner system is located at the black box, and fibres transfer light into the Nashmidth platform at the side of the telescope. Credit: Javier Méndez.

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Short News

Catalonia participates in the IAC 2022, the most important international congress of the space sector

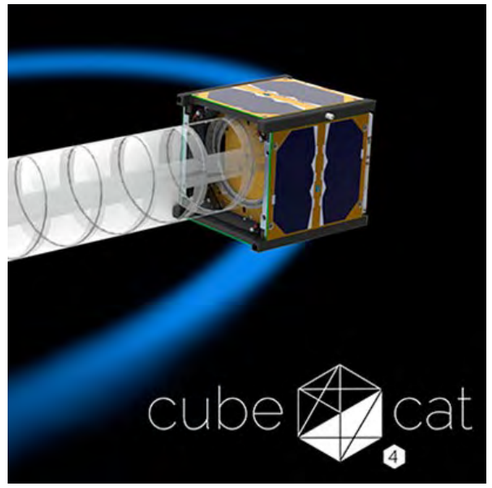
Catalonia participated for the first time with its own pavilion in the International Astronautical Congress (IAC). With 250 exhibitors and 6,500 participants from all over the world, the IAC staged its 73rd edition from 18 to 22 September at the Paris Convention Centre.

The 'NewSpace Catalonia' pavilion hosted 11 companies from the Catalan space ecosystem (Compoxi, Fregata Space, Gutmar, isardSAT, Lobelia Earth, Kreios Space, Pangea Aerospace, Sateliot, Satellogic, SpaceSUR and Telstar) and the 4 promoting entities of the NewSpace Strategy of Catalonia: the Government of Catalonia, the IEEC, the i2CAT Foundation and the Institut Cartogràfic i Geològic de Catalunya (ICGC).

The 11 Catalan companies taking part had the opportunity to engage in networking activities and established international contacts as part of an innovative ecosystem. Furthermore, the Catalan delegation organised other complementary activities at the NewSpace Catalonia booth, such as meetings with delegations, agencies and companies from other countries, and networking events to connect the global ecosystem with the participating companies.

The IEEC and the Barcelona Chamber of Commerce will collaborate to promote NewSpace in Catalonia

The IEEC and the Barcelona Chamber of Commerce have signed a collaboration agreement to promote the space sector, in particular the 'NewSpace Economy', as a driver for the generation of business opportunities and the transfer of knowledge and technology to other business sectors. The agreement includes joint initiatives to support the NewSpace sector in Catalonia and develop a competitive ecosystem to help the sector grow through knowledge transfer and awareness-raising activities, such as conferences, webinars and space dissemination sessions.



NanoSat Lab's 3Cat-4 selected by ESA for the inaugural flight of the new Ariane6 launchers

The 3Cat-4 nanosatellite from the NanoSat Lab of the Universitat Politècnica de Catalunya · BarcelonaTech (UPC) has been selected by the European Space Agency (ESA), in close collaboration with the companies ArianeGroup and Arianespace, as a candidate payload to potentially fly in the inaugural flight of the new generation of Ariane 6 launchers, which will take place from the European Spaceport Centre (in French Guiana).

Short News

First use case of the nanosatellite Enxaneta in a real environment

On 2 February, the results of the first use case in a real environment obtained by Enxaneta, the first nanosatellite that the Catalan Government put into orbit in the framework of the Catalan NewSpace Strategy, were presented in Tremp (Pallars Jussà, Catalonia). The first use case consisted of measuring physical and environmental parameters of the soil in vineyards via an Internet of Things (IoT) connection with the nanosatellite. The pilot test was developed by the Catalan Ministry of the Vice-presidency and Digital Policies and Territory in collaboration with the IEEC, the Institut Cartogràfic i Geològic de Catalunya (ICGC), the i2CAT Foundation and Sateliot.

The IEEC participates in the Mobile World Congress 2022

The IEEC participated in the Mobile World Congress (MWC 2022, 28 February - 3 March), the most important international trade fair in the technology, digital and business sectors, as one of the three leading centres of the NewSpace Strategy of Catalonia. The NewSpace Strategy booth showcased innovation and R&D activities and projects demonstrating the use of space technology for the benefit of the NewSpace ecosystem, linked to technologies such as Earth Observation, IoT/5G and Global Navigation Satellite Systems (GNSS). Furthermore, the first use case in a real environment of the nanosatellite Enxaneta was presented to the audience at the congress.

Minister of Research and Universities Gemma Geis visits the Montsec Observatory

On 2 March, the Minister of Research and Universities, Gemma Geis, visited the Montsec Observatory (OdM) located in Sant Esteve de la Sarga (Pallars Jussà). During the visit, Geis announced that on the occasion of the centenary of the birth of the illustrious scientist Dr Joan Oró, born in Lleida, the Department of Research and Universities will announce two research calls with his name, aimed at the recruitment of pre-doctoral research staff in training and the foundation of scientific culture.

DCA NewSpace Community Conference: Opportunities for global IoT-5G connectivity

On 29 March, the Digital Catalonia Alliance (DCA) NewSpace Community held the conference entitled “Opportunities for Global IoT-5G Connectivity”, aimed at organisations and professionals interested in the subject, with a special focus on the Internet of Things (IoT) and NewSpace sectors. During the session, the technologies that allow the application of IoT by means of 5G satellite connection were presented, as well as examples of IoT applications that benefit from the 5G-NS network infrastructure in priority NewSpace sectors.

Michel Mayor, 2019 Nobel Prize in Physics, talks about other worlds in the Universe at CosmoCaixa

On 11 May, “La Caixa” Foundation, in collaboration with the Consulate General of Switzerland in Barcelona and the IEEC, presented the lecture ‘Other worlds in the Cosmos and perhaps with life!’, given by Michel Mayor, one of the astrophysicists who in 1995 detected the first exoplanet. This discovery led to Dr. Mayor being awarded the Nobel Prize in Physics in 2019, together with his research partner Didier Queloz. The event took place at CosmoCaixa (Barcelona), and was moderated by Dr. Ignasi Ribas, director of the IEEC and researcher at the Institute of Space Sciences (ICE-CSIC).

One hundred students take part in the Catalan final of #CanSat, organised by the UPC in collaboration with the IEEC

One hundred students, with ages ranging from 14 to 19, took part in the national qualifying phase in Catalonia of the #CanSat competition, which was held at the Igualada-Òdena Aerodrome on 7 May. The contest was organised by the School of Industrial, Aerospace and Audiovisual Engineering of Terrassa (ESEIAAT) of the Universitat Politècnica de Catalunya · BarcelonaTech (UPC), in collaboration with the IEEC. The initiative, promoted by the European Space Agency (ESA), aims to foster vocations for space, technology and STEM disciplines among young people, and consists of designing, building and launching satellites the size of a soft drink can that have a scientific or technological purpose. A team from the secondary school Institut de Terrassa won both the Catalan and national stages, and defended its CanSat in the European final.

The IEEC and the Chamber of Commerce of Barcelona organise a workshop on funding opportunities for the space sector

On 11 May, the IEEC and the Chamber of Commerce of Barcelona organised the Innovation Workshop ‘CASSINI: Downstream funding opportunities’, intended for companies and entrepreneurs with solutions related to the space sector and the NewSpace Economy. The aim of the initiative was to raise awareness of the funding opportunities offered by the European CASSINI programme for projects framed in the downstream of the space sector (processing and treatment of satellite data to turn them into products or services). The event received the collaborative support of the Department of the Vice-Presidency and Digital Policies and Territory of the Catalan Government, the KIMbcn Foundation, and the European Union Agency for the Space Programme (EUSPA).

New edition of the series “Tandems of scientific couples: public and private entities”

The IEEC has organised a new edition of the series ‘Tandems of scientific couples: public and private entities’. Entitled “Large-scale missions in astronomical and aerospace research”, the conversation could be followed live on the IEEC’s YouTube channel. Dr. Miquel Nofrarias, researcher at the Institute of Space Sciences (ICE-CSIC) and IEEC member, and Joan Manel Casalta, director of the Science Department of SENER-Aerospace, participated in the colloquium, which was moderated by Mireia Colina, manager of the space sector in Leaf Space and leader of the local group of Women in Aerospace (WiA Europe - Barcelona). Among other topics, they talked about the current status of large astronomical and aerospace missions, as well as the future prospects of large-scale missions versus the boom in missions at a much lower level (such as nanosatellites).

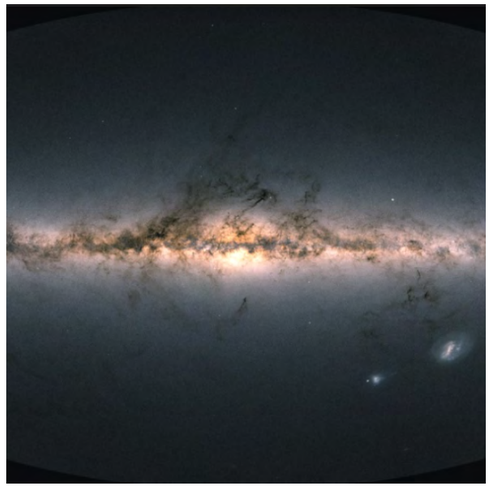
Short News

The IEEC celebrates its 4th Forum with more than 100 attendees

On 2 June, the IEEC 2022 Forum was held at the Centre de Cultura Contemporània de Barcelona (CCCB). This year's Forum was the first major face-to-face event to be organised by the Institute since the COVID pandemic. Bringing together more than 100 attendees, it consisted of lectures on scientific and technological topics, including a presentation of the latest news about the James Webb Space Telescope. In the new section 'Elevator Pitches', very short presentations were made to the audience, especially by young researchers showing their work. Another new feature was the opportunity to present posters. The event concluded with the round table 'Professional career development', in which the participants talked about the difficulties of pursuing a professional career related to the space field, both from an academic and business point of view.

The second nanosatellite of the NewSpace Strategy of Catalonia will be called 'Menut' (small)

On 13 June, the new name of the second nanosatellite that the Catalan Government will put into orbit within the framework of the 'NewSpace Strategy of Catalonia' was announced at CosmoCaixa (Barcelona). The name was chosen by means of a contest organised by the Department of the Vice-Presidency and Digital and Territorial Policies, the IEEC, and the Catalan Audiovisual Media Corporation (CCMA), and it was announced on 'InfoK', a TV programme for youngsters on TV3. Menut (small, in Catalan) was the final name chosen from the 256 proposals sent in by the viewers. The event featured the IEEC's director, Ignasi Ribas, among other personalities. Menut will be dedicated to Earth observation to help control and combat the effects of the climate crisis.



Release of the 3rd catalogue of data from Gaia

The European Space Agency (ESA) made public the Gaia Data Release 3 (Gaia DR3), the 3rd catalogue of data from the Gaia mission, on 13 June. This data release contained, for the first time, the light spectra of 220 million stars, as well as information about more than 33 million stars with determinations of their radial velocities (i.e. the speed at which they move away from or closer to us). Also new in this data set was the largest catalogue yet of binary stars (more than 800,000 systems). Gaia DR3 also contained information on thousands of Solar System objects such as asteroids and moons of planets, and millions of galaxies and quasars outside the Milky Way. The IEEC Gaia group at the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB) prepared a whole series of acts to share this historic event with the scientific community and the general public.

The IEEC joins Eurisy, the association that bridges space and society

The transversality that space is acquiring, together with the digitalisation of society, is paving the way for new methodologies and technologies that generate the multidisciplinary knowledge needed to address multiple current challenges. Within this framework, our Institute is expanding its frontiers to establish new alliances and collaborations with the aim of harnessing space-related sciences for the benefit of society. Aligned to this purpose, the IEEC has joined the non-profit association Eurisy, which brings together European space agencies, governmental offices, and international organisations involved in space-related activities. Eurisy encourages innovative uses of satellite applications that respond to the challenges of communities and industry.

Short News

‘Science and Space’ project: research in microgravity conditions

On 27 June, CERCA (Research Centres of Catalonia) – with the collaboration of the IEEC, the Centre for Genomic Regulation (CRG) and the Institute for Bioengineering of Catalonia (IBEC) – organised the exploratory day ‘Science and Space - Research in microgravity conditions’, whose main objective was to explore the interest present in the Catalan research ecosystem in carrying out experiments in microgravity conditions for genomics, life sciences and materials science projects, as well as the capabilities of the CERCA centres in relation to this topic.

Our institute becomes a new member of the NEREUS network

The Network of European Regions Using Space Technologies (NEREUS) approved the membership of the IEEC in July 2022. NEREUS represents the interests of European regions that use space technologies whilst simultaneously highlighting the regional dimension of European space policy and programmes. This network is the only European association of its kind in which the responsibilities for governing the network lie with the regions that comprise its membership. As a unique thematic network for matters of regional space uses, its key mission is to explore the benefits of space technologies for European Regions and their citizens, as well as to promote the use of space and its applications.

Jocelyn Bell speaks at the third conference dedicated to the Athena X-ray Observatory at CosmoCaixa

Under the title “Exploring the Hot and Energetic Universe”, the third scientific conference of the European Space Agency (ESA) dedicated to the Athena X-ray Observatory was held on 7-10 November at CosmoCaixa. At this conference, Prof. Jocelyn Bell Burnell gave a public lecture on the discovery of pulsars. During her talk, Dr. Bell told us the story behind what is one of the most relevant discoveries in Physics.

The IEEC attends the Space Tech Expo Europe

Space Tech Expo Europe (15-17 November, 2022) is the largest dedicated space technology trade fair in Europe. The free-to-attend exhibition and high-level conference is Europe’s meeting place for space business, technology & innovation, showcasing the latest from technical designers, sub-system suppliers, manufacturers and components through to systems integrators for civil, military and commercial space. The IEEC attended the three-day event, which also included a B2B matchmaking initiative to get in touch with potential partners for future collaborations. Engineers, industry leaders, buyers, manufacturers and global decision makers gathered to discuss design, manufacturing and testing of spacecraft, satellites, launch vehicles and space-related technologies.

MedaWeek Barcelona 2022: moderating a roundtable with NASA, small companies and Aerospace associations

The Mediterranean Week of Economic Leaders (MedaWeek Barcelona), the conference dedicated to promoting the Mediterranean region worldwide, took place from 16 to 18 November, endorsing the key economic sectors and the cultural values of this region through a wide variety of forums. On 17 November, the second edition of the Mediterranean Space Forum brought together the public and private sector, Science and Research, Space Agencies from the Mediterranean and European countries, as well as members of International Space Organizations. IEEC members contributed to this event by moderating a roundtable with NASA, small and medium enterprises (SMEs) and Aerospace associations, showcasing how space assets can contribute and impact Mediterranean society and its economy.

Awards

The SafetyIoT-5G project receives the ‘Innovative FP Project’ award

SafetyIoT-5G, a project for innovation and applied research and knowledge transfer in professional training (FP, in its Spanish acronym), received the ‘Innovative FP Project’ award at the Advance Factories congress held in Barcelona from 29 to 31 March 2022. SafetyIoT-5G, in which the IEEC participates, was recognised as an innovative dual professional training project in the industrial sector.

Gemma Busquet, IEEC researcher at ICCUB, awarded 2022 Leonardo Grant in Physics

The IEEC researcher at the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB) Gemma Busquet received one of the five 2022 Leonardo Grants in Physics given by the BBVA Foundation. This was a special award this year, as part of the BBVA Foundation’s support programme for Researchers and Cultural Creators.

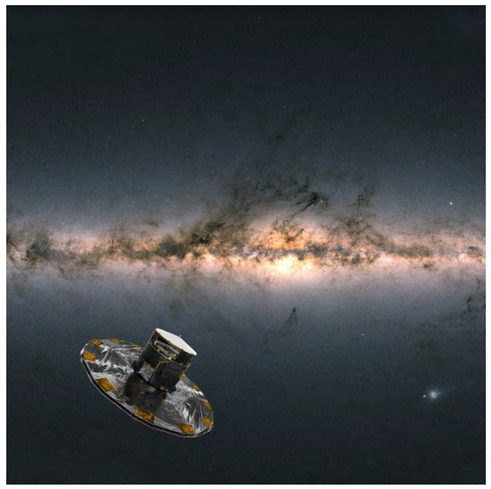
Awards

The short film ‘Pulsars: A Tale of Cosmic Clocks’ wins the first prize in the ‘Science in Action’ competition

The short film ‘Pulsars: A tale of Cosmic Clocks’, created by the astrophysicist Nanda Rea, IEEC researcher at the Institute of Space Sciences (ICE-CSIC), received the 1st Ex Aequo Prize for Short Science Films in the ‘Short Science Films’ category of the 23rd edition of the ‘Science in Action 2022’ competition.

The MOSAiC expedition is awarded the Arctic Circle Prize 2022

Arctic Circle is the largest network of international dialogue and cooperation on the future of the Arctic. It consists of governments, organisations, corporations, universities, think tanks, environmental associations and indigenous communities, among others, that seek to delve into the status and functioning of this remote enclave on Earth. IEEC researchers at the Institute of Space Sciences (ICE-CSIC), together with experts from the Institute of Marine Sciences (ICM-CSIC) and other international research centres, participated in MOSAiC between 2019 and 2020.



The Gaia collaboration receives the 2023 Berkeley Prize

The Gaia collaboration, which is responsible for the spacecraft that is currently creating the largest and most precise three-dimensional map of our galaxy, received the 2023 Lancelot M. Berkeley – New York Community Trust Prize for Meritorious Work in Astronomy. The distinction recognizes its key role in enabling the creation of a transformative, multidimensional map of the Milky Way. Several IEEC astronomers and engineers at the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB) have been collaborating in this mission, launched by the European Space Agency (ESA) in 2013.

The Hi-SIDE project is awarded the Innovation in Space Award 2022

The Hi-SIDE (High-Speed Integrated Satellite Data System) project, in which researchers of the IEEC at the Centre of Space Studies and Research (CERES) of the Universitat Autònoma de Barcelona participate, has received the Innovation in Space Award 2022, in recognition of the contribution and impact that an organisation or project has had on the space industry and on society. The Hi-SIDE project’s aim is to develop and demonstrate satellite data-chain technologies to advance on-board data handling and support high-speed data transfer for future Earth Observation missions.

The researcher Adriano Camps is awarded the Duran Farell Prize for Technological Research 2022

Professor Adriano Camps, director of the NanoSat Lab of the Universitat Politècnica de Catalunya - BarcelonaTech (UPC) and member of the IEEC, has won the 13th Duran Farell Prize for Technological Research, awarded by the UPC Social Council, with the support of Naturgy Energy Group. Dr. Camps has been recognised for his role in the project 'FSSCat: the 1st CubeSat-based ESA Third Party Mission contributing to the Copernicus programme to Monitor Essential Climate Variables of the Water Cycle'. The project has created the first maps of soil moisture, concentration, extent, and thickness of polar ice, as well as salinity in the Arctic, generated by data provided by two nanosatellites from the CubeCat family.

Meetings, Schools and Training

4th Symposium on Space Educational Activities staged in Barcelona

Last April, the 4th Symposium on Space Educational Activities (SSEA 2022), held in Barcelona, was a resounding success: it was attended by more than 500 delegates from 34 different countries around the world. Promoted by the European Space Agency (ESA) and locally organised by the Universitat Politècnica de Catalunya · BarcelonaTech (UPC), the event was held with the collaboration of the IEEC and the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB). The IEEC also supported the SSEA 2022 as a partner and one of the leading centres in the coordination of the 'NewSpace Strategy of Catalonia'. The Institute hosted a stand in collaboration with the Vice-presidency and Digital Policies and Territory Department, the i2CAT Foundation, and the Institut Cartogràfic i Geològic de Catalunya (ICGC).

Space for the financial world: the IEEC co-organises the 4th CASSINI Hackathon in Barcelona

The 4th CASSINI Hackathon was held simultaneously in 10 European locations. The local edition in Barcelona, with more than 40 students (on site and in virtual format) was co-organised by the IEEC, the Knowledge Innovation Market Foundation and the Barcelona Chamber of Commerce; it also received collaborative support from the Castelldefels School of Telecommunications and Aerospace Engineering (EETAC), the Mediterranean Science and Technology Park, and the Universitat Politècnica de Catalunya · BarcelonaTech (UPC). The final projects sought to respond to three challenges from the financial world to activate green and sustainable investment, to make innovative financial tools and technologies, and to advance global financial intelligence, using data from Copernicus, Galileo and EGNOS.

More than 400 people attend the NewSpace Economy Congress held in Barcelona

On 19 and 20 October, Barcelona hosted the NewSpace Economy Congress 2022, an event organised by the Barcelona Chamber of Commerce and the Generalitat de Catalunya (Catalan Government) which attracted more than 40 experts in the space sector from companies, institutions, universities and research centres, and more than 400 visitors. The event presented key initiatives of the NewSpace Strategy of Catalonia, such as the launch of the Enxaneta and Menut nanosatellites, and the reactivation of the ESA BIC Barcelona incubator. During the congress, the Catalonia Space Office was announced, a new structure within the IEEC to coordinate and collaborate in the execution of space activities in Catalonia for the development of the NewSpace Strategy.

PhD Theses

Author: **Santiago Serrano**
Department/Institute: Universitat Autònoma de Barcelona. Department of Physics
Title: Data mining and precision simulations of Cosmic Surveys
Date: 28 January 2022
Directors: Enrique Gaztañaga and Francisco Castander

Author: **Qi Liu**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Department of Physics
Title: GNSS-based global ionospheric maps : real-time combination, time resolution and applications on space weather monitoring
Date: 14 April 2022
Director: Manuel Hernández Pajares

Author: **Zujia Lu**
Department/Institute: Universitat de Barcelona. Department of Quantum Physics and Astrophysics
Title: The Dynamical State of Star-forming Regions, from Molecular Clouds to Massive Clumps
Date: 26 April 2022
Directors: Paolo Padoan and Veli-Matti Pelkonen

Author: **Martí Mañosas Caballú**
Department/Institute: Universitat Autònoma de Barcelona. Department of Telecommunications and Systems Engineering
Title: Contributions to Array Processing: Beamforming, Synchronization and Localization
Date: 6 May 2022
Director: Gonzalo Seco-Granados

Author: **Carles García Palau**
Department/Institute: Universitat de Barcelona. Department of Quantum Physics and Astrophysics
Title: Statistical detection of tidal streams generated by globular clusters and their application to measure the axis ratio of the Milky Way dark matter halo
Date: 12 May 2022
Director: Jordi Miralda Escudé

PhD Theses

Author: **Chen Gao**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Department of Physics
Title: Dynamics and control for continuous low-thrust spacecraft near collinear libration points
Date: 18 May 2022
Directors: Josep Masdemont Soler, Gerard Gómez Muntané and Jianping Yuan

Author: **Gerard Portal González**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Department of Signal Theory and Communications
Title: Synergistic optical and microwave remote sensing approaches for soil moisture mapping at high resolution
Date: 27 May 2022
Directors: Mercedes M. Vall-Llossera Ferran and María P. Piles de la Fuente

Author: **Marc Oncins Fernández**
Department/Institute: Universitat de Barcelona. Department of Quantum Physics and Astrophysics
Title: Observational consequences of Black holes in the Universe: From Dark Matter candidates to Quasars
Date: 3 June 2022
Director: Jordi Miralda Escudé

Author: **Mariona Caixach**
Department/Institute: Universitat Autònoma de Barcelona. Department of Physics
Title: Gamma emission from Type Ia Supernovae: simulation, analysis and detection
Date: 8 June 2022
Director: Jordi Isern

Author: **Laura Alemany Juvanteny**
Department/Institute: Universitat Autònoma de Barcelona. Department of Chemical, Biological and Environmental Engineering
Title: Mathematical modelling of bioreactors in the MELiSSA regenerative life support system
Date: 4 July 2022
Directors: Francesc Gòdia and Carolina Arnau

Author: **Glòria Montaña**
Department/Institute: Universitat de Barcelona. Department of Quantum Physics and Astrophysics
Title: Effective-theory description of heavy-flavoured hadrons and their properties in a hot medium
Date: 8 July 2022
Directors: Àngels Ramos and Laura Tolós

Author: **Christoph Josef Herbert**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Department of Signal Theory and Communications
Title: Advanced methods for earth observation data synergy for geophysical parameter retrieval
Date: 15 July 2022
Directors: Mercedes M. Vall-Llossera Ferran, and Adriano J. Camps Carmona

Author: **Samuel Brieden**
Department/Institute: Universitat de Barcelona. Department of Quantum Physics and Astrophysics
Title: From the Precision Era towards the Accuracy Era of Cosmology with DESI
Date: 14 September 2022
Directors: Licia Verde and Héctor Gil

Author: **Roselena Rubino**
Department/Institute: Universitat Politècnica de Catalunya · BarcelonaTech. Department of Signal Theory and Communications
Title: Deriving vertical total electron content maps from SMOS full polarimetric data to compensate the Faraday rotation effect
Date: 16 September 2022
Directors: Núria Duffo Ubeda and Veronica González Gambau

Author: **Ahmed Ismail Abdelghafar Ismail**
Department/Institute: Universitat Autònoma de Barcelona. Department of Telecommunications and Systems Engineering
Title: Multi-Chord (P2P) Approach for Integrated Satellite IoT Networks
Date: 16 December 2022
Director: Ángeles Vázquez

Outreach

Open Day at NanoSat Lab

On 3 February, the NanoSat Lab, coordinated by the Universitat Politècnica de Catalunya · BarcelonaTech (UPC), organised a virtual open day to present a number of its projects and to introduce visitors to the facilities of the laboratory.

Celebration of the International Day of Women and Girls in Science

On 11 February, the IEEC and its Research Units joined the celebration of International Day of Women and Girls in Science, organising and participating in several activities which sought to further women and girls' full and equitable access to and involvement in the field of science, and to recognize their role as agents of change.

The IEEC celebrates the International Women's Day

On 8 March, the IEEC added its support to the celebration of International Women's Day once again, recognising all our women researchers who challenge the frontiers of knowledge, in general, and space sciences and technologies, in particular.

'Astronuclear Nibbles' videos

The video series 'Astronuclear Nibbles', a nuclear astrophysics outreach project funded by COST Action and coordinated by the researcher of the Universitat Politècnica de Catalunya · BarcelonaTech (UPC) and IEEC member Jordi José, has been released on YouTube.

TOC-TOC talk: 'L'espai al cinema: ficció i realitat'

The director of the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB) and IEEC member Xavier Luri participated in the series of talks 'TOC-TOC: Xerrades divulgatives d'investigadors de la UB', which the UB organises to make science accessible to all. He gave the talk 'L'espai al cinema: ficció i realitat' ('Space in cinema: fiction and reality').

'L'H 6.0 una ciutat connectada' closing session

Màrius Montón, project manager at the IEEC of the Enxaneta nanosatellite, participated in the closing session of the conference 'L'H 6.0 una ciutat connectada' ('L'H 6.0, a connected city'), organised to coincide with the Mobile World Congress 2022, where he spoke about the digital economy, space technology and the applications of IoT and 5G in the fight against climate change.

Round table about space research and technology in Catalonia

Pep Colomé, head of the IEEC Knowledge Transfer Office, participated in a round table about space research and technology in Catalonia organised by the Real Acadèmia de les Ciències i les Arts de Barcelona (RACAB), at which he talked about the transversality of the space sector and its value chain in Catalonia.

Photography exhibition 'El llegat del Telescopi Espacial Hubble abans del James Webb'

Josep Maria Trigo, researcher at the Institute of Space Sciences (ICE-CSIC) and IEEC member, commented on a series of photographs taken by the Hubble Space Telescope at the exhibition entitled 'El llegat del Telescopi Espacial Hubble abans del James Webb' ('The legacy of the Hubble Space Telescope before James Webb').

'Virtual Frontiers of Sciences VI'

The IEEC researcher at the Institute of Space Sciences (ICE-CSIC) Josep Maria Trigo gave a talk about early protoplanetary disk chemistry using a xenolith discovered inside a carbonaceous chondrite meteorite at the 'Virtual Frontiers of Sciences VI' science-in-society meeting sponsored by the Network for Researchers on the Chemical Evolution of Life (NoRCEL).

Video release of an ESA's GNSS experiment

A video about an experiment funded by the European Space Agency (ESA) to investigate reflectometry at low angles using GNSS signals reflected in the sea has been released. The project aims to measure the topography of the sea surface very precisely. IEEC researchers Estel Cardellach (PI), Serni Ribó and Weiqiang Li from the Earth Observation Group of the Institute of Space Sciences (ICE-CSIC) participated in the experiment.

MEMEnginy22: the UAB's most high-profile technology fair

On 21 April, MEMEnginy – the most important technology fair organised by the Universitat Autònoma de Barcelona (UAB) – was held at the UAB's Engineering School, with the presence of more than 35 companies, some 15 talks and workshops, and more than 200 interviews. The IEEC participated with a stand and with several talks given by IEEC researchers.

'Finestres a l'univers', introductory astronomy course

On 26 April, IEEC researcher and technical director of the Montsec Observatory (OdM-IEEC) Kike Herrero participated in the introductory astronomy course 'Finestres a l'univers' (Windows to the Universe), organised by the CosmoCaixa Museum. He gave a talk entitled 'Photographing the Universe', in which he spoke about the special characteristics of astronomical photography.

Moon Observation at the International Symposium on Electronic Art 2022

On 6 May, high school students from the 'Institut Vapor del Fil', together with the artist Martí Madaula, had the opportunity to observe the moon with telescopes from the roof of the Museu de Ciències Naturals de Barcelona. The activity was led by IEEC researcher and technical director of the Montsec Observatory (OdM-IEEC) Kike Herrero, and formed part of the 'En residència' programme of the 27th International Symposium on Electronic Art (ISEA) (10-16 June).

Guided tours to the Montsec Observatory are back

This year, Montsec Observatory opened its doors once again to visitors, offering the opportunity to learn about the Observatory's infrastructure and its science. Visits were available to the three robotic telescopes – the Joan Oró telescope, the Fabra-ROA Montsec telescope and the XO-Montsec telescope – as well as the Satellite Ground Station, installed and managed by the Universitat Politècnica de Catalunya · BarcelonaTech (UPC) and the IEEC, among other equipment and facilities.

Talk about the the most complete map of the Milky Way at 'La Xarxa'

The director of the IEEC, Ignasi Ribas, and the researcher of the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB), Josep Manel Carrasco, appeared on 28 June in the magazine programme 'Fet a mida' (Tailored) of 'La Xarxa' to talk about the publication of the most complete map of the Milky Way (Gaia DR 3), with information about 1.8 billion stars.

Josep Maria Trigo on 'Els matins de TV3'

The TV3 programme 'El matins de TV3' invited the IEEC member and researcher of the Institute of Space Sciences (ICE-CSIC), Josep Maria Trigo-Rodríguez, to talk about his book 'La Terra en Perill. L'impacte d'asteroides i cometes' (Earth in Danger. The Impact of Asteroids and Comets).

Symposium 'L'Espai a les nostres vides'

On 30 April, the local group of Women in Aerospace (WiA Europe - Barcelona), in collaboration with the IEEC, the KIMbcn foundation, and the Museu Nacional de la Ciència i la Tècnica de Catalunya (Manresa), organised the symposium 'L'espai a les nostres vides' ('Space in our lives'), aimed at families, young people and children. The day included a round table and three workshops, in which several IEEC researchers took part.

The project ‘Ciutat Augmentada’

The IEEC researcher at the Institute of Space Sciences (ICE-CSIC) Nanda Rea provided an outline of the research under way at the ICE-CSIC and IEEC as part of the ‘Ciutat Augmentada’ project, led by La Mandarina de Newton and Barcelona City Council. You will find her at the first stop on the “Universe” route.

‘Objectes de la Recerca’ exhibition: bringing science closer to the public

The Catalan delegation of the Spanish Research Council (CSIC) presented the exhibition ‘Objectes de la Recerca’ (Research Objects), whose aim is to bring science closer to the public based on exceptional objects. The exhibition opened by showing a fragment of the Sikhote-Alin meteorite held by the Institute of Space Sciences (ICE-CSIC), which fell to Earth in 1947, and the IEEC researcher at the ICE-CSIC, Josep M. Trigo-Rodríguez, was one of the participants at the session.

Quantum Physics at ‘La Serenalla’ market

The Agora 4 space at ‘La Serenalla’ market was the setting for the conversation ‘Quantum physics: what it is and how it affects us. Review of the latest discoveries’. The director of the IEEC and researcher at the Institute of Space Sciences (ICE-CSIC), Ignasi Ribas, was among the speakers at this event.

Communicating crisis in the SSP-ISU 2022 programme

“Crisis communication and media training” was the title of the hands-on workshop instructed on 2 August by Ana Montaner, head of the Communication Office, at the Space Studies Program 2022 (held at Oeiras, Portugal). This intensive nine-week interdisciplinary course, organised by the International Space University (ISU) since 1987, was attended by 107 participants. The programme is designed for young graduates and professionals focused on space-field studies.

Involving children in science at the IV STEM Day in Space

The STEM Day in Space aims to present information of interest and learning tools related to space. The Day is held every two years and is directed in particular towards elementary and middle school teachers, so that they may start to involve children in science and promote their STEM skills (science, technology, engineering, and mathematics). This year, IEEC astronomer Kike Herrero gave us a tour of the Montsec Observatory (OdM) and showed us how we can use the computer to make an astronomical observation of the sky using open source apps like Stellarium.

Science Week in secondary schools

To mark the occasion of Science Week, astrophysicist Carme Jordi, IEEC researcher at the Institute of Cosmos Sciences of the Universitat de Barcelona (ICCUB), gave a talk to a very participative audience made up of 3rd-year secondary school students at the Institut Pau Claris in Barcelona. The discussion focused on how stars are born, live and die.

Talk on exoplanets in La Pobla de Claramunt

The Town Council of La Pobla de Claramunt opened the second ‘km 0’ Conference Cycle with a talk entitled ‘Exoplanetes, què són i com es troben’ (Exoplanets, what they are and how they are found), given by Juan Carlos Morales, IEEC researcher at the Institute of Space Sciences (ICE-CSIC).

The NewSpace strategy in the media

Josep Colomé, director of the Catalonia Space Office – a new structure within the IEEC to coordinate and collaborate in the execution of space activities for the development of the NewSpace Strategy – was interviewed by Espai.Mèdia, a digital newspaper focused on the Catalan space sector. He talked about the NewSpace Strategy of Catalonia, the reactivation of the ESA Business Incubation Centre in Barcelona and other related topics.

Outreach

Discussion about the Christmas star on Catalunya Ràdio

IEEC researcher at the Institute of Space Sciences (ICE-CSIC) Guillem Anglada participated in 'La nit dels ignorants', a radio show on Catalunya Ràdio. The conversation focused on the Christmas star, the star said to have guided the Three Wise Men to Bethlehem. A discussion took place about various theories and possibilities regarding what kind of phenomenon might have occurred.

Life and research career of Ignasi Ribas on Canal Taronja

The director of the IEEC, Ignasi Ribas, was interviewed on the programme 'Molt personal', a series of in-depth conversations aimed at capturing the personality of guests broadcast on Canal Taronja (a local television channel in Central Catalonia). Ribas and his host talked about his life and research career, but also about current space-related topics.

This Hubble Space Telescope view shows one of the most dynamic and intricately detailed star-forming regions in space, located 210,000 light-years away in the Small Magellanic Cloud (SMC), a satellite galaxy of our Milky Way. At the centre of the region is a brilliant star cluster called NGC 346. A dramatic structure of arched, ragged filaments with a distinct ridge surrounds the cluster.

Credit: NASA, ESA and A. Nota (ESA/STScI, STScI/AURA)

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