Annual Report 2020
Memoria Anual

CENTRO DE ASTROBIOLOGÍA · CAB

ASOCIADO AL NASA ASTROBIOLOGY PROGRAM

EXCELENCIA MARÍA DE MAEZTU

CSIC Consejo Superior de Investigaciones Científicas

INTA

Centro de Astrobiología (CSIC-INTA)

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Playa de La Lobera. Dos lobos marinos con los Fuelles de Neptuno y la Punta Fildes al fondo.
• Crédito: Comandante Eduardo Insignares Serrano

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Tapetes de algas en las rocas del cauce del Río Tinto.

Crédito: J. Segura

Introduction
Introducción

El Centro de Astrobiología (CAB) se fundó en 1999 como un Centro Mixto entre el Consejo Superior de Investigaciones Científicas (CSIC) y el Instituto Nacional de Técnica Aeroespacial (INTA). Localizado en el campus del INTA en Torrejón de Ardoz (Madrid), el CAB se convirtió en el primer centro fuera de los Estados Unidos asociado al recién creado NASA Astrobiology Institute (NAI), convirtiéndose en miembro formal en el año 2000 y actualmente miembro asociado al Programa de Astrobiología de NASA. Durante el año 2020, el CAB fue cofundador y una de las organizaciones principales del recientemente creado Instituto Europeo de Astrobiología (EAI).

The Centro de Astrobiología (CAB) was founded in 1999 as a joint centre between the National Research Council (CSIC) and the National Institute for Aerospace Technologies (INTA). Located within the INTA campus in Torrejón de Ardoz (in Madrid), CAB became the first astrobiology organization outside the United States to be associated with the NASA Astrobiology Institute (NAI), formally becoming an associate partner in the year 2000, and currently associate member of the NASA Astrobiology Program. During the year 2020, CAB became also a co-founder and one of the core organizations of the recently created European Astrobiology Institute (EAI).

La Astrobiología considera la vida como una consecuencia natural de la evolución del Universo, y en el CAB trabajamos para estudiar el origen, evolución, distribución y futuro de la vida en el Universo, mediante investigaciones en la Tierra como en entornos extraterrestres. La aplicación del método científico a la Astrobiología requiere la combinación de teoría, simulación, observación y experimentación. Esta aplicación de la Ciencia fundamental a las cuestiones de la Astrobiología es el principal método de trabajo en el CAB. La organización multi- y transdiciplinar del Centro fomenta la interacción de los ingenieros con investigadores experimentales, teóricos y observacionales de varios campos: astronomía, geología, bioquímica, biología, genética, teledetección, ecología microbiana, ciencias de la computación, física, robótica e ingeniería de las comunicaciones.

La investigación en el CAB aborda la sistematización de la cadena de eventos que tuvieron lugar entre el *Big Bang* inicial y el origen de la vida, incluyendo la autoorganización del gas interestelar en moléculas complejas y la formación de sistemas planetarios con ambientes benignos para el florecimiento de la vida. La consecuencia lógica de esa cadena de eventos es la universalización, en el sentido más amplio, de la vida y su presencia en otras partes. El objetivo final es investigar la posible existencia de procesos biológicos en otros mundos, reconociendo biosferas diferentes de la terrestre, para ayudarnos en la comprensión del origen y distribución de la vida. El camino será todavía largo, pero la meta está cada vez más próxima, y el Centro de Astrobiología sin duda estará en la vanguardia del conocimiento.

No podemos dejar de mencionar la especial dificultad por la que hemos tenido que pasar durante el año 2020. La irrupción de COVID-19 en toda la actividad humana ha condicionado sin duda nuestras actividades científicas. A pesar de ello, y gracias al esfuerzo de todas las personas que hacemos del CAB un gran Centro, hemos sido capaces de mantener una actividad de gran calidad y productiva. A destacar, por ejemplo, el lanzamiento de la misión Mars2020 de NASA en la que el Centro de Astrobiología tiene un papel relevante con el instrumento MEDA (Mars Environmental Dynamics Analyzer). MEDA es una estación medioambiental compuesta por una serie de sensores que se encargarán de medir las condiciones ambientales del lugar de aterrizaje, el cráter Jezero, y estudiar el fino polvo marciano que es importante para la exploración humana en el futuro. En concreto, MEDA consta de sensores para medir la dirección y velocidad del viento, la temperatura del suelo y del aire, la humedad relativa, la presión atmosférica, la radiación solar ultravioleta, infrarroja y visible, las propiedades del polvo en suspensión y, además, cuenta con una cámara para tomar imágenes del cielo marciano y estudiar las nubes. MEDA es el tercer instrumento español enviado a Marte, y es (en el momento de escribir estas líneas) la tercera estación medioambiental liderada por el Instituto Nacional de Técnica Aeroespacial - Centro de Astrobiología (CAB, CSIC-INTA) que funciona en el planeta rojo junto a REMS (*Rover Environmental Monitoring Station*) en operación desde agosto de 2012 a bordo del rover Curiosity; y TWINS (*Temperature and Wind for InSight*), que aterrizó en 2018 a bordo de la misión InSight.

Mencionar, entre otras, contribuciones relevantes durante 2020 como: la detección por primera vez de urea fuera de una región de formación estelar, o el descubrimiento de una segunda galaxia con erupciones cuasi periódicas de rayos X por el mismo equipo del CAB que describió este fenómeno por primera vez; la contribución de los sensores TWINS en los primeros resultados científicos de la misión InSight en Marte; o el descubrimiento del planeta LHS1140 b, situado en la zona de habitabilidad, que parece tener un gran océano de agua líquida, lo que lo convierte en un objetivo ideal para la búsqueda de biomarcadores. En esta memoria presentamos las contribuciones más destacadas dentro de los distintos departamentos y grupos de investigación del CAB.

Finalmente, y como cierre a los diferentes actos y eventos relativos al vigésimo aniversario del CAB, en septiembre de 2020 la revista líder en el campo, *Astrobiology*, dedicó su portada al CAB junto con cuatro artículos científicos de relevancia y una pequeña revisión histórica (https://www.liebertpub.com/toc/ast/20/9).

El Centro de Astrobiología (CAB) se fundó en 1999 como un Centro Mixto entre el Consejo Superior de Investigaciones Científicas (CSIC) y el Instituto Nacional de Técnica Aeroespacial (INTA).

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Astrobiology considers life as a natural consequence of the evolution of the Universe, and CAB aims to study the origin, evolution, distribution, and future of life in the Universe, through investigations on Earth and in extraterrestrial environments. Application of the scientific method to astrobiology requires the combination of theory, simulation, observation and experimentation. This application of fundamental science to the questions of astrobiology is the most important goal for CAB. The multi- and transdisciplinary setting available at CAB allows engineers to interact with experimental, theoretical and observational scientists from various fields: astronomy, geology, bio-geochemistry, biology, genetics, remote sensing, microbial ecology, computer science, physics, robotics and communications engineering.

The research at CAB relates to the systematization of the chain of events that took place between the Big Bang and the origin and evolution of life, including the self-organisation of the interstellar gas into complex molecules and the formation of planetary systems with benign conditions fostering the flourishing of life. The final aim is to investigate the possibility of life on other worlds, recognizing biospheres that might be different from that on Earth, to help us understanding the origin of life. It will be still a long way, but the destination is becoming closer and closer and the Center for Astrobiology will undoubtedly be at the forefront of knowledge.

We should mention the special difficulty that we have had to go through in 2020. The emergence of COVID-19 in all human activity has undoubtedly conditioned our scientific activities. Despite this, and thanks to the efforts of all the people who make CAB a great Center, we have been able to maintain a high-quality and productive activity. To highlight, for example, the launch of NASA's Mars2020 mission in which the Center has a relevant role with the MEDA (Mars Environmental Dynamics Analyzer) instrument. MEDA is an environmental station made up of a series of sensors that will be in charge of measuring the environmental conditions of the landing site, the Jezero crater, and studying the fine Martian dust which is important to assess the risks for human exploration in the future. Specifically, MEDA consists of a set of sensors to measure the direction and speed of the wind, soil and air temperature, relative humidity, atmospheric pressure, UV, infrared and visible solar radiation, the properties of dust in suspension and, in addition, has a camera to take images of the Martian sky and study the clouds. MEDA is the third Spanish instrument sent to Mars, and it is (at the time of writing) the third environmental station led by the INTA-CAB operating on the red planet, together with REMS (Rover Environmental Monitoring Station) in operation since August 2012 aboard the Curiosity rover; and TWINS (Temperature and Winds for InSight), which landed in 2018 aboard the InSight lander.

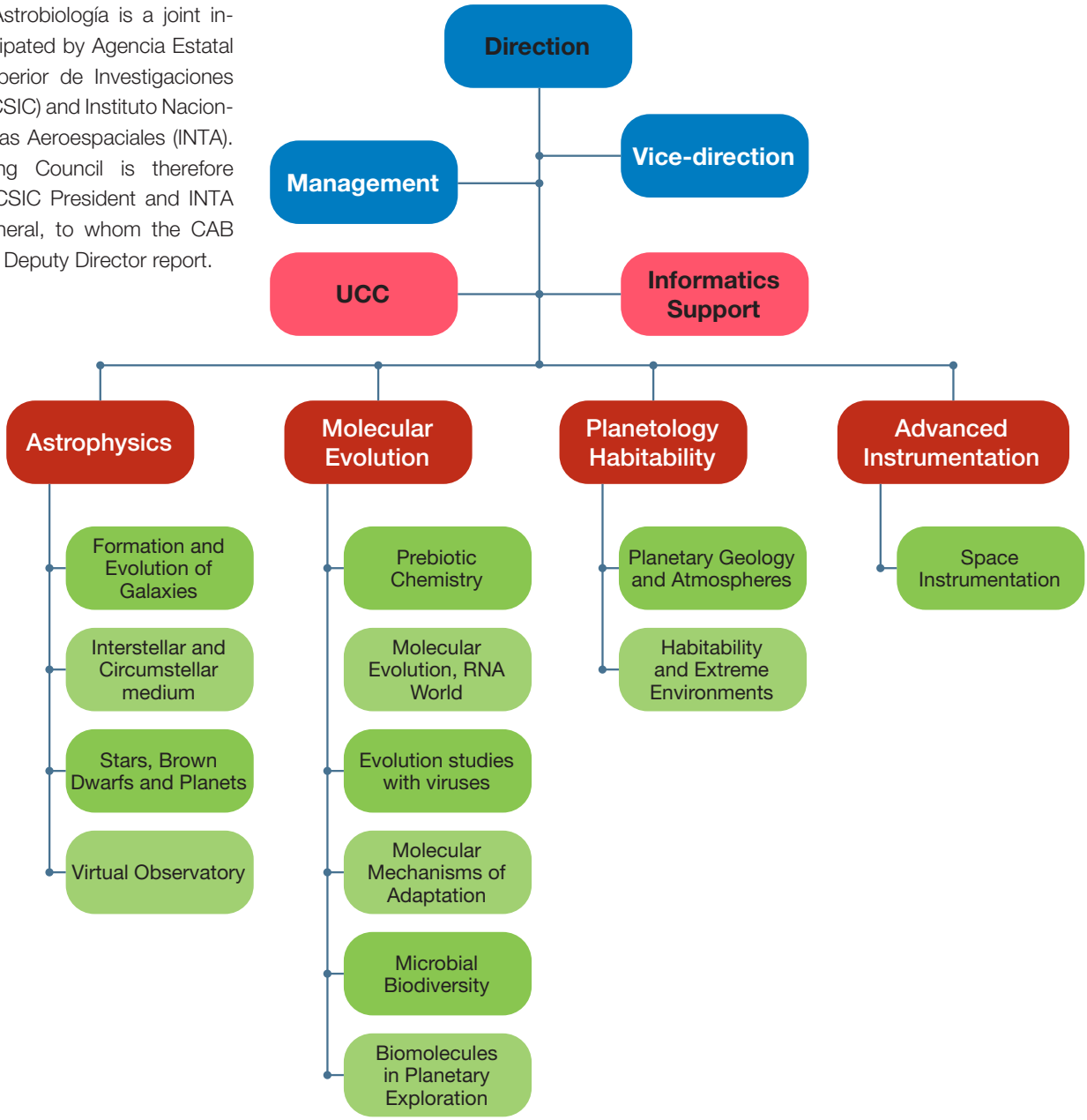
Mention, among others, relevant contributions during 2020 such as the detection for the first time of urea outside a star formation region; the discovery of a second galaxy with quasi-periodic X-ray eruptions by the same CAB team that described this phenomenon for the first time; the contribution of TWINS sensors to the first scientific results of the InSight mission on Mars; or the discovery of the planet LHS1140 b, located in the habitable zone, which appears to have a large ocean of liquid water, which makes it an ideal target for the search for biomarkers. In this report we present the most outstanding contributions within the different departments and research groups of the CAB.

Finally, and as a closing to the different acts and events related to the twentieth anniversary of CAB, in September 2020 the leading journal in the field, *Astrobiology*, dedicated its cover to CAB along with four relevant scientific articles and a historical review

(https://www.liebertpub.com/toc/ast/20/9).

Center organization

Centro de Astrobiología is a joint institute participated by Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC) and Instituto Nacional de Técnicas Aeroespaciales (INTA). Its Governing Council is therefore chaired by CSIC President and INTA Director General, to whom the CAB Director and Deputy Director report.



Organization of Centro de Astrobiología in 2020. Centro de Astrobiología was organized in four Research Departments (red), each of them having different research groups (green). Additional units such as the Unidad de Cultura Científica (UCC), the Informatics Support, or the DNA Sequencing service, provide the required support for the operations of CAB. The departments operate a number of laboratories and facilities covering the very different areas of activities.

Members of the Governing Council 2020

D. Rafael Rodrigo Montero,
Secretario General de Coordinación de Política Científica, Ministerio de Ciencia e Innovación

Dña. Esperanza Casteleiro LLamazares,
Secretaria de Estado de Defensa, Ministerio de Defensa.

Dña. Rosa Menéndez,
Presidenta Agencia Consejo Superior de Investigaciones Científicas (CSIC)

D. Jesús Marco de Lucas,
Vicepresidente de Investigación Científica y Técnica (CSIC)

D. José María Salom Piqueres,
Director General, Instituto Nacional de Técnica Aeroespacial (INTA)

D. Julio Ayuso Miguel,
Subdirector General de Coordinación y Planes, INTA

D. Victorino Parro García,
Director, Centro de Astrobiología (CAB)

Advisory board

The former Directors of CAB constitute its Advisory Board:

Prof. Juan Pérez Mercader (CSIC):
1999-2008

Prof. Álvaro Giménez Cañete (CSIC):
2008-2010

Dr. Javier Gómez Elvira (INTA):
2010-2015

Dr. Miguel Mas Hesse (CSIC):
2015-2019

External scientific advisory board

Paola Caselli,
Director and Scientific Member at the Max Planck Institute for Extraterrestrial Physics, Garching, Germany)

Muriel Gargaud,
CNRS Research Director, Laboratoire d'Astrophysique de Bordeaux, Université de Bordeaux, France

Rosaly Lopes,
Directorate Scientist, NASA's Jet Propulsion Laboratory (JPL), Pasadena, CA, USA)

Michel Mayor,
University of Geneva, Geneve. Nobel Prize in Physics 2019

Christopher McKay,
Space Science Division - NASA Ames Research Center, USA

Gian Gabriele Ori,
Universita d'Annunzio, Pescara, Italy - Ibn Battuta Centre, Marrakech

Direction and Center
executive board

Victorino Parro García

Francisco Najarro de la Parra

Name	Position
Victorino Parro García	Director
Francisco Najarro de la Parra	Deputy Director
Sagrario Salado Rey	Administrative Manager
Miguel Mas Hesse/Pablo G. Pérez González	Head of Astrophysics
Felipe Gómez Gómez	Head of Planetology and Habitability
Ester Lázaro Lázaro	Head of Molecular Evolution
Eduardo Sebastián Martínez	Head of Advanced Instrumentation
Benjamín Montesinos Comino	Researcher
Ángeles Aguilera Bazán	Researcher
Consuelo Moncayo Ortega	Administration

Management and support

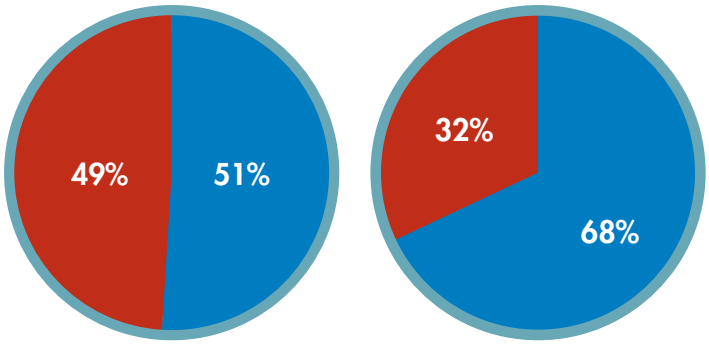
Name	Position
Sagrario Salado Rey	Administrative Manager
Margie Guitart Martín	Administration
Consuelo Moncayo Ortega	Administration
Esther Bermúdez Castillo	Technical management
Virginia Suarez Marsá	Technical management
Miguel Ángel Alonso Valdivielso	Library services

external support in 2020

María Pilar Alonso del Val	Technical support
Rosa del Olmo Andrés	Technical management
Tatiana Fraile Noriega	Technical management
Inmaculada García Climent	Technical management
María Teresa García Martín	Technical management
Macarena Gutiérrez Ortega	Technical management
Carmen Martínez de Llera	Technical management
Antonio Parras Rico	Computing support
Sergio Suarez Carrasco	Computing support
Juan Ángel Vaquerizo Gallego	Outreach support

Personnel

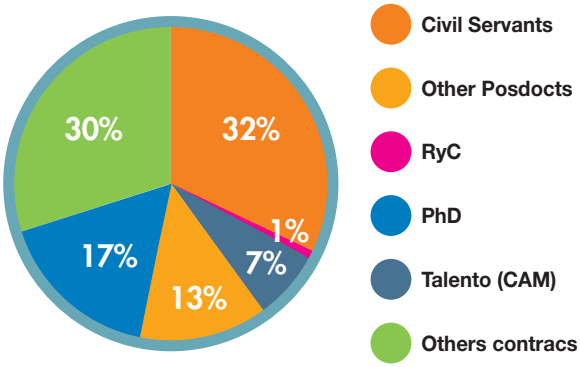
by gender



Gender Balance: (left) Total, (right) Scientific scales.

Women Men

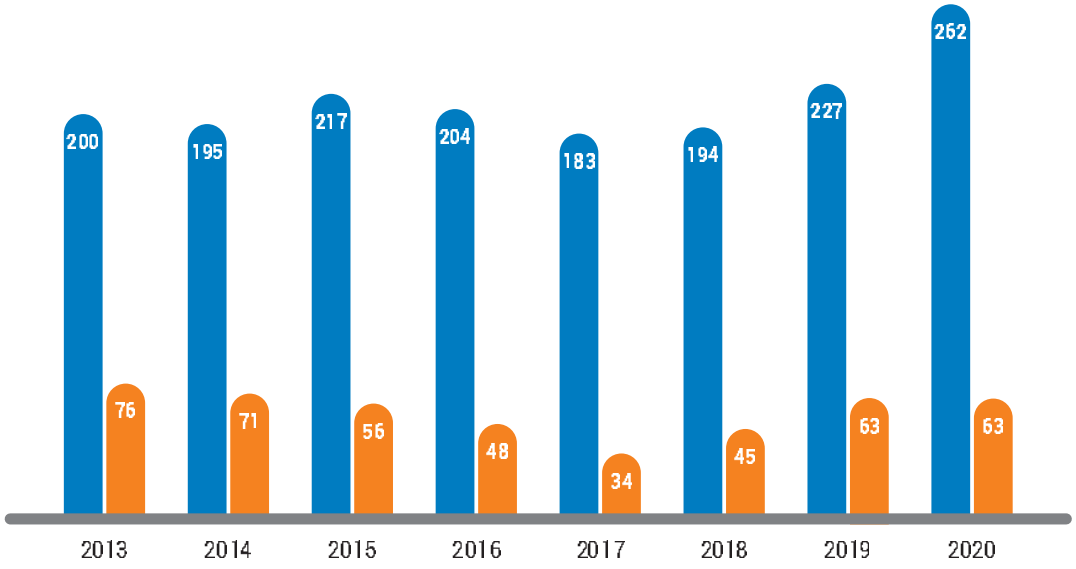
by type of contract



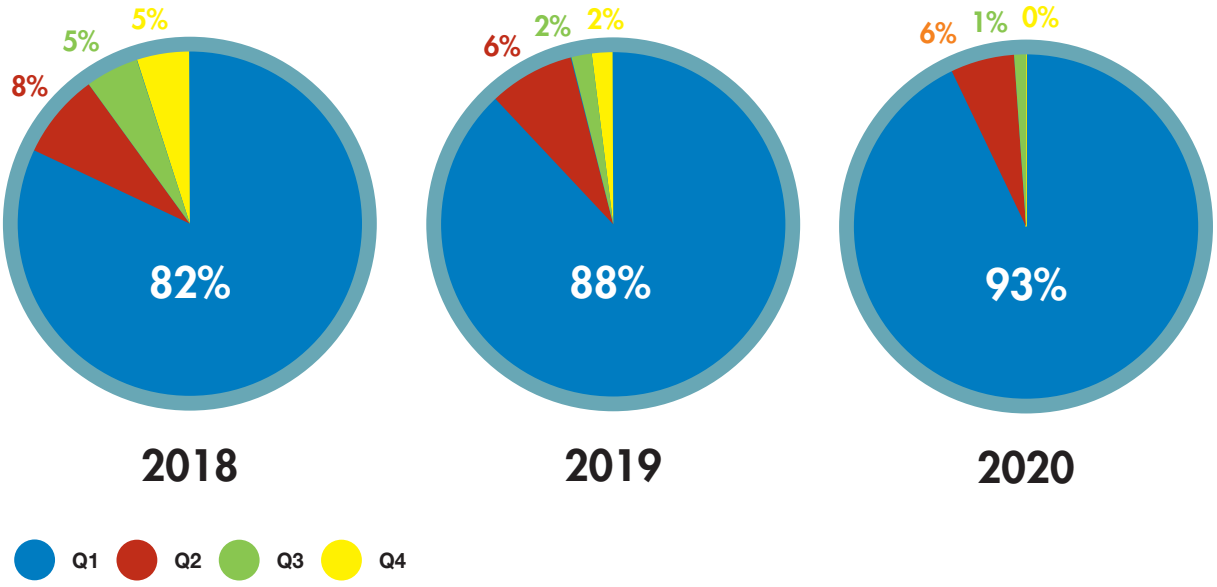
Scientific Production

research articles

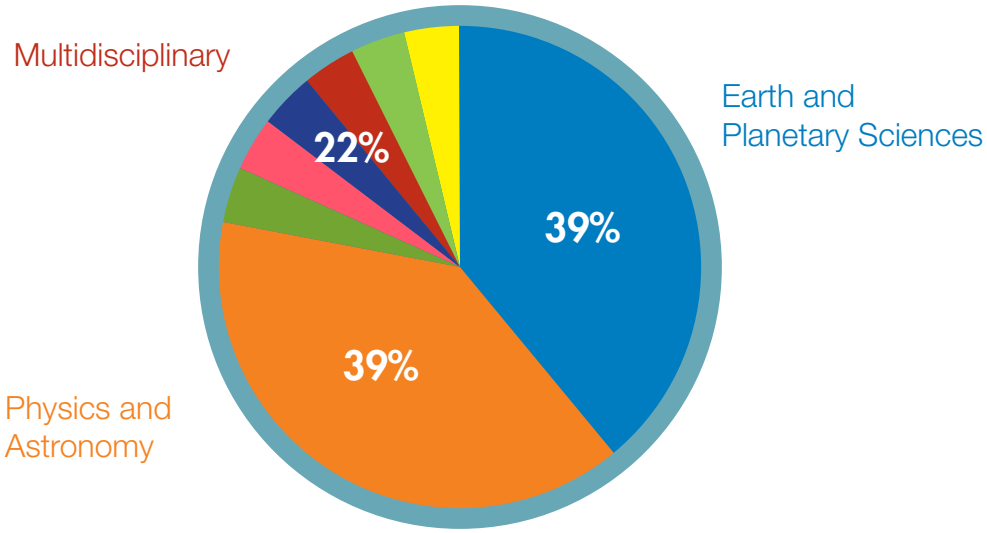
Papers



by quartile



by subject area



El espejo primario del futuro Extremely Large Telescope
Crédito: ESO/L. Calçada/ACe Consortium

El futuro Extremely Large Telescope
Crédito: ESO/L. Calçada/ACe Consortium

Astrophysics department of

Heads of Department:

Pablo G. Pérez González (January - September 2020)
J. Miguel Mas Hesse. (October - December 2020)

Research by the Astrophysics Department at CAB includes a large number of topics, from those directly related to Astrobiology *per se* to others that, while not so closely related, contribute as well to the advance on our knowledge of the Cosmos and to the development of technology, placing CAB at the forefront of knowledge.

Throughout the history of the Universe, generations of stars have created in their interior all the elements heavier than helium that we know. The atoms of these chemical elements formed molecules, dust grains and ice sheets in the interstellar and intergalactic medium to condense into planetary systems with rocky planets. Many of them orbit their host stars within their so-called habitable zone, where liquid water can survive on their surfaces providing the boundary the conditions in which life arose more than 3.5 billion years ago on Earth. A process that could have been repeated in a large number of planetary systems all over the Cosmos.

We investigate key processes that were necessary for the appearance and evolution of life in the Universe such as: the formation of chemical elements in the interior of the stars and the formation and evolution of the galaxies that house them, processes of planet formation around new stars, the formation and evolution of chemical compounds of a range of complexity in the interstellar space, or the search for new extrasolar planets.

The Astrophysics Department has a strong participation and leadership in technological activities associated with future astronomical instrumentation, both in space and on the ground. Further, the department is also heavily involved in the scientific exploitation of ground and space facilities, which are currently under operation and basically cover the whole electromagnetic range, from gamma-rays to radio wavelengths.

During 2020, despite the restrictions to physical meetings imposed by the COVID-19 pandemia, we have continued our research on the physico-chemical processes that play a significant role in interstellar and circumstellar environments, which are rich in chemical species crucial for appearance of life. Within the field of stellar astrophysics, we have carried out studies across all the evolutionary stages, seeking to understand the formation and evolution from high to very low mass stars, including protoplanetary discs and exoplanets. At larger scales we have investigated massive star-formation in both nearby and distant luminous star-forming galaxies, as well as its relation with the presence of massive black holes in their nuclei. Finally, our Virtual Observatory group has been very successful in the improvement of the CAB Data Centre, providing support to other Spanish data centres. It has also actively continued with the development of VO standards and tools related with data mining combined with education and outreach activities.

The Department is organized in 4 Research Groups:

- Galaxies Formation and Evolution
- Interstellar and Circumstellar Medium
- Formation and Evolution of Stars, Brown Dwarfs and Planets
- Virtual Observatory Group: Scientific exploitation of astronomical archives

In the following sections we summarize some of the most relavant results achieved by the researchers in the different groups.

Galaxies Formation and Evolution

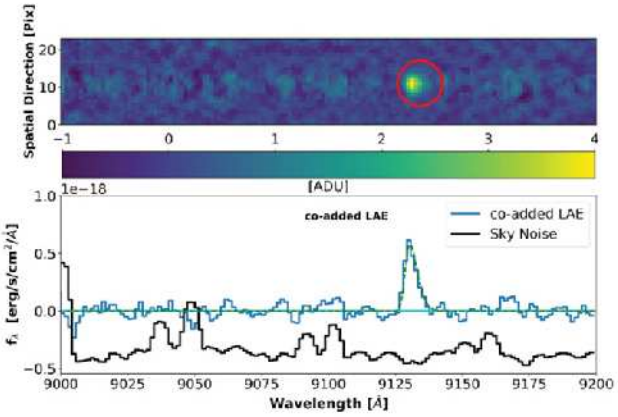
Coordinator: Giovanni Miniutti

Members	Category
Alonso Herrero, Almudena	Investigadora Científica de OPI (CSIC)
Álvarez Márquez, Javier	Postdoc
Annunziatella, Marianna	Postdoc
Arribas Mocoroa, Santiago	Profesor de Investigación de OPI (CSIC)
Bellocchi, Enrica	Postdoc
Catalán Torrecilla, Cristina	Postdoc
Cerviño Saavedra, Miguel Antonio	Científico Titular de OPI (CSIC)
Colina Robledo, Luis	Profesor de Investigación de OPI (CSIC)
Costantin, Luca	Atracción de Talento 2 (Com. de Madrid)
Crespo Gomez, Alejandro	PhD student
Estrada Piqueras, Alberto	Ingeniero
Giustini, Margherita	Atracción de Talento 1 (Com. de Madrid)
Gorgues Valenciano, Alejandro	Programa de Empleo Joven MICINN
Labiano, Álvaro	Atracción de Talento 1 (Com. de Madrid)
Lamperti, Isabella	Postdoc
Martínez Martín, Cecilia	Contrato garantía juvenil CSIC
Mas Hesse, J. Miguel	Investigador Científico de OPI (CSIC)
Mérida González, Rosa María	PhD student
Miniutti, Giovanni	Científico Titular de OPI (INTA)
Peralta de Arriba, Luis	Postdoc
Pereira Santaella, Miguel	Atracción de Talento 1 (Com. de Madrid)
Pérez García, Ana María	Postdoc
Pérez González, Pablo Guillermo	Investigador Científico de OPI (INTA)
Perna, Michele	Atracción de Talento 2 (Com. de Madrid)
Piqueras Lopez, Javier	Postdoc
Rodríguez Del Pino, Bruno	Postdoc
Sánchez García, María	PhD student
Sanz Fernández de Córdoba, Lourdes	Científica Superior de la Defensa
Villar Martín, Montserrat	Científica Titular de OPI (CSIC)
Vives Arias, Héctor	Postdoc

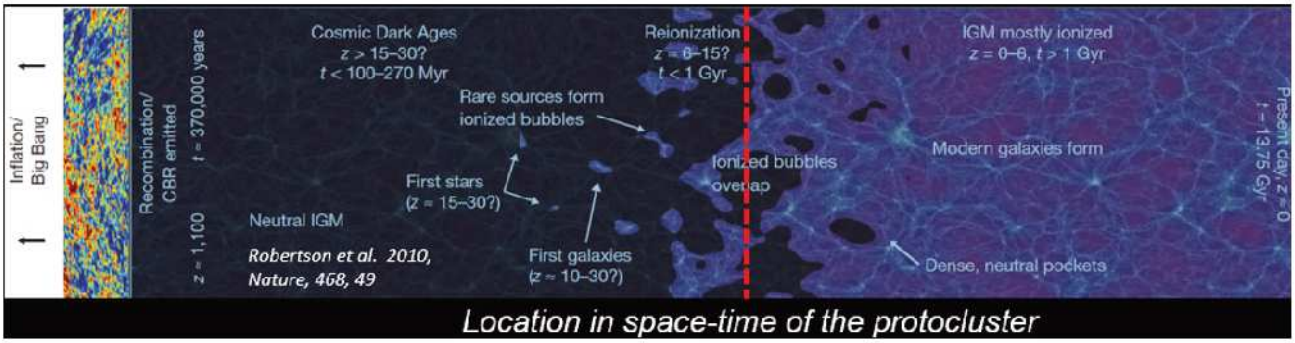
Scientific Highlights

Reionization of the Primordial Universe

We have detected a proto-cluster of Lyman alpha emitting galaxies at redshift z ~ 6.5 (12.8 Gyr back in time). For the 10 sources we have spectroscopically confirmed with the OSIRIS instrument on the GTC, we have determined their Lyman alpha emission line luminosities as well as their intrinsic ionising photon fluxes. We find that the sources in the proto-cluster produce sufficient Lyman continuum photons to ionise a very large bubble around them in the Intergalactic Medium. We conclude that there are sufficient ionising photons to not only ionise the volume occupied by the whole proto-cluster, but even a larger ionised super-bubble that increases its volume with time. Therefore we claim that we have discovered a large ionised bubble such as those that through percolation completed the re-ionization of the Universe by z ~ 6, when it was only ~1 Gyr old (~1.000 millions of years).



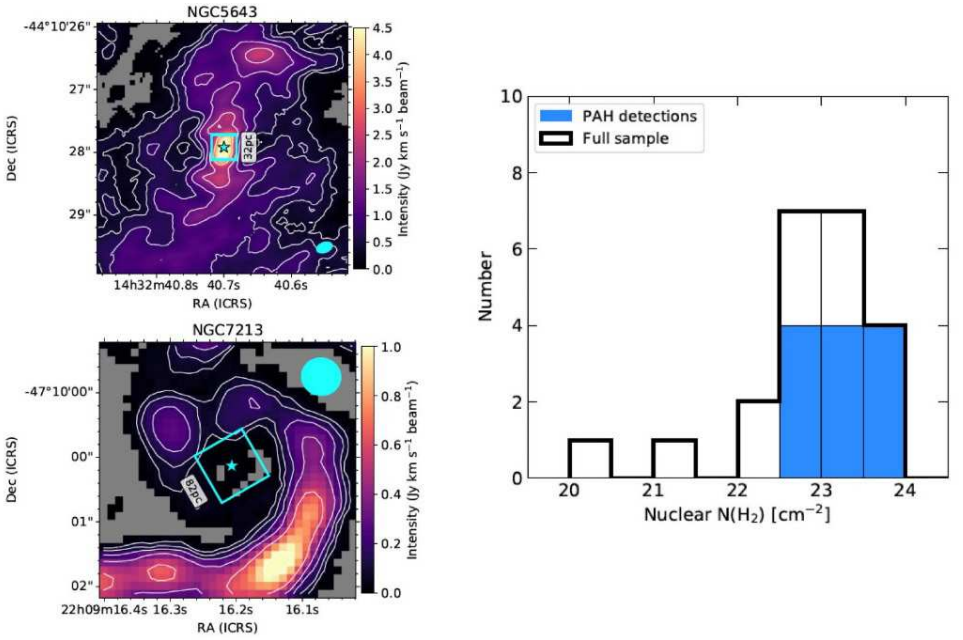
Co-added spectra of of the Lyman alpha emitting galaxies in the protocluster at z~6.5 (J.M. Rodríguez Espinosa, J.M. Mas-Hesse, E. Salvador-Solé, et al., 2020).



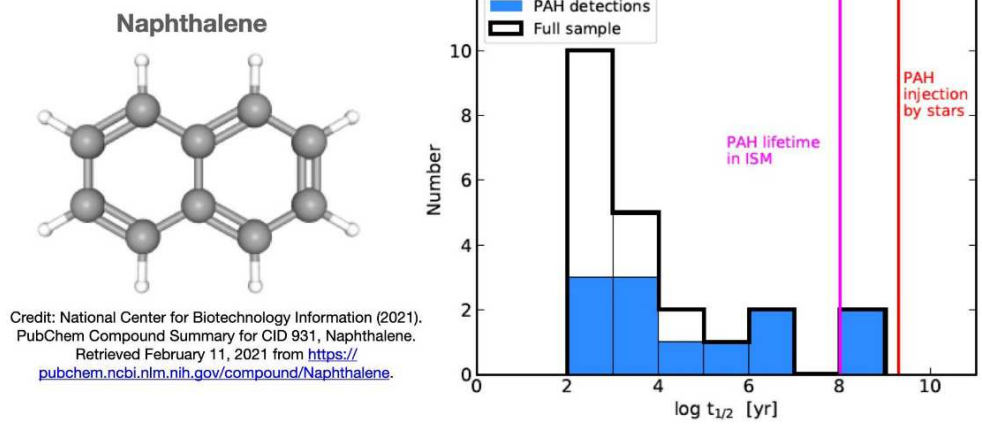
Sketch showing the process of reionization of the Universe and the position in time of the protocluster we have identified.

Cold molecular gas and PAH emission in the nuclear regions of Seyfert galaxies

We investigated the relation between the detection of the 11.3μm polycyclic aromatic hydrocarbon (PAH) feature in the nuclear regions of nearby Seyfert galaxies and the properties of the cold molecular gas using ALMA and NOEMA observations of the CO(2-1) transition. Galaxies with a nuclear detection of the 11.3μm PAH feature contain more CO(2-1) and have higher column densities (median $N(H_2) = 2x10^{23}$ cm^{-2}) in their nuclear regions. This suggests that molecular gas plays a role in shielding the PAH molecules in the harsh environments of Seyfert nuclei. Choosing the PAH molecule naphthalene as an illustration, we estimated shorter half-lives in nuclei without a 11.3μm PAH detection than in those with a detection when exposed to 2.5keV hard X-ray photons.



Left: Examples of ALMA CO(2-1) images of the central regions of two Seyferts in our sample with a nuclear detection of the 11.3μm PAH (NGC5643) and without (NGC7213). Right: Histogram of the estimated nuclear column densities. (A. Alonso-Herrero et al., 2020).



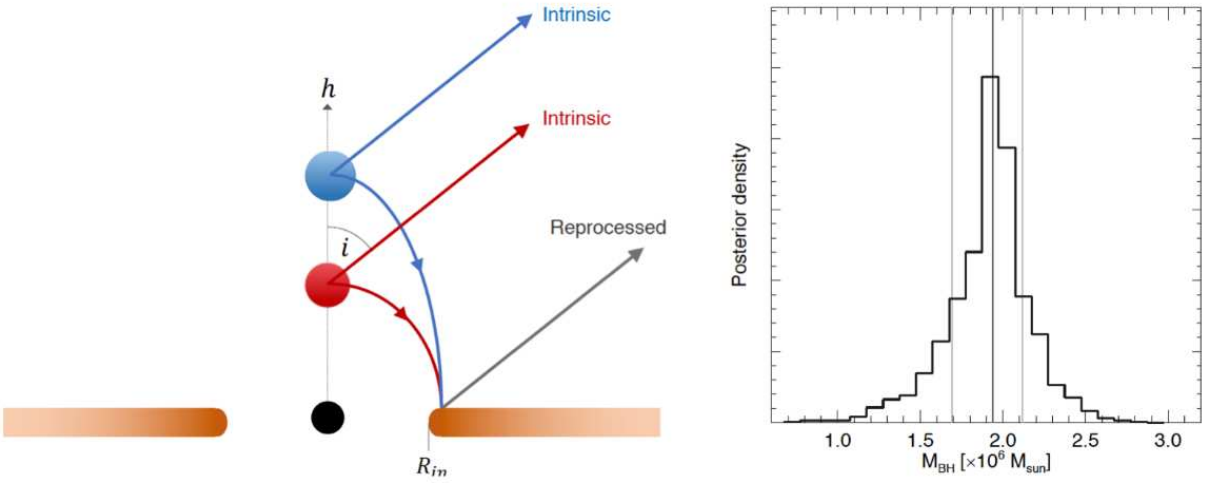
Credit: National Center for Biotechnology Information (2021). PubChem Compound Summary for CID 931, Naphthalene. Retrieved February 11, 2021 from https://pubchem.ncbi.nlm.nih.gov/compound/Naphthalene.

Right: Estimated lifetimes for the naphthalene molecule in the nuclear regions of our sample of Seyfert galaxies (A. Alonso-Herrero et al., 2020).

A dynamic black hole corona

We have analysed a large XMM-Newton X-ray data set on the active galactic nucleus (AGN) IRAS 13224–3809 for a total exposure time of ~ 2 Ms (or ~ 556 hours). The source is one of the most X-ray variable objects in the sky with fast and large amplitude variation on timescales as short as minutes. Observations of AGN have revealed the presence of a hot "corona" of electrons close to the black hole that accounts for a significant fraction of the overall AGN X-ray luminosity. The structure, nature, and geometry of the corona is still largely unknown, but we know that it irradiates the accretion flow and that radiation is reprocessed there before being directed toward the observer in the form of an "X-ray reflection component", as schematically shown in the left panel of the Figure below.

The physical separation between the corona and the reprocessing accretion disc implies that a distant observer will detect a time delay (an echo) between the intrinsic (corona) and the reflection (disc) components. We were able to follow these X-ray echoes as the source varied widely. One of the unexpected results of our analysis was that the corona size/structure was changing incredibly fast. As the corona size changed, so did the light echoes much like the echoes of a voice would do in a room with moving walls and ceiling. By tracking and modelling these changes, we were able to have a view of the highly dynamical black hole immediate environment. As a bonus, we obtained accurate measurements of the black hole mass and spin. This study opens up a new window to explore the innermost regions of the accretion flow around supermassive black holes with the final goal of understanding the complex interplay between the different physical structures (e.g. corona, accretion flow, spacetime geometry …) and the emitted radiation in AGN.

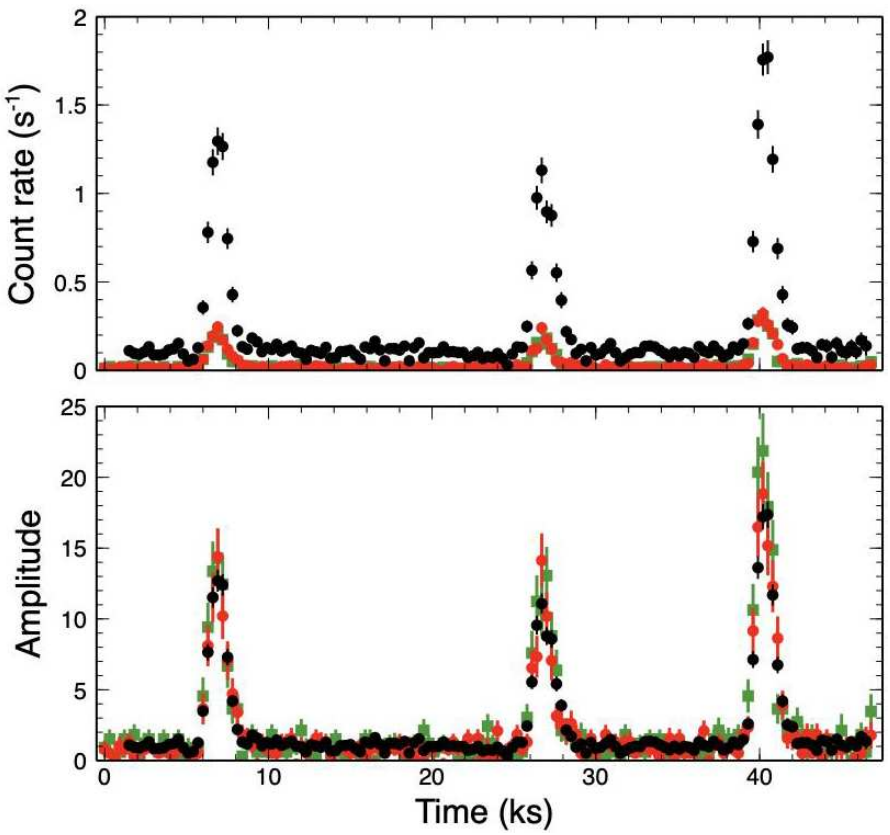


The left panel shows a schematic representation of the X-ray corona at two different heights above the disc (blue and red), and of the delayed reprocessed component from the accretion disc (echo), with a longer time delay for a larger corona-disc separation. The right panel shows the posterior distribution for the black hole mass of IRAS 13224-3809 from our modelling, with median and 68% regions shown in grey (W.N. Alston et al. 2020, Nature Astronomy, 4, 597). For more information see also a corresponding ESA press release.

Discovery of X-ray quasi-periodic eruptions in the galaxy RX J1301.9+2747

Following the recent discovery of X-ray quasi-periodic eruptions (QPEs) coming from the nucleus of the galaxy GSN 069 by Miniutti et al. 2019 (Nature 573, 381), we discovered QPEs in the nucleus of a second galaxy, named RX J1301.9+2747. QPEs are high-amplitude, recurrent X-ray flares over a generally stable flux level (quiescent level) associated with supermassive black hole (SMBH) accretion. In GSN 069, QPEs last about one hour and recur about every nine hours, with a subtle alternating pattern of long-short recurrence times and strong-weak amplitudes.

Thanks to a new 12.5 hours-long XMM-Newton observation performed in May 2019, three strong X-ray QPEs have been detected also in the nucleus of RX J1301.9+2747 (Giustini, Miniutti & Saxton 2020, A&A 636, 2). As in GSN 069, there is an alternate pattern of short-long recurrence times between QPEs in RX J1301.9+2747: the first two QPEs are separated by a longer recurrence time (about 5.5 hours) compared to the second and third (about 3.5 hours). This pattern is consistent with the alternating long-short recurrence times of the GSN 069 QPEs, although the difference between the consecutive recurrence times is significantly smaller in GSN 069. The duration of the QPEs in RX J1301.9+2747 is also significantly shorter than the ones of GSN 069, lasting only about half an hour. The X-ray spectral properties of GSN 069 and J1301.9+2747 are remarkably similar both in quiescence and during QPEs, making us confident we are witnessing the same physical phenomenon in the two galaxies.

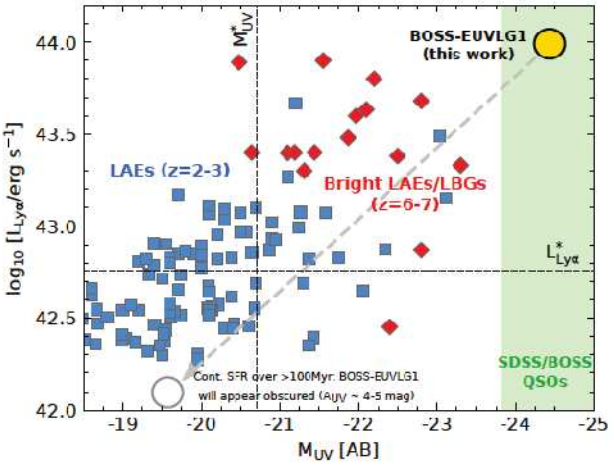


X-ray light curves of the nucleus of the galaxy RX J1301.9+2747 observed in May 2019 with the three EPIC cameras on board XMM-Newton: EPIC-pn data in black, EPIC-MOS1 in red, EPIC-MOS2 in green. Three strong QPEs are detected about 6.5 ks, 26 ks, and 40 ks after the beginning of the observation. The top panel reports the observed X-ray counts per second, while the bottom panel reports the ratio between the observed X-ray count rate and the average quiescent level, highlighting the strong QPE amplitudes.

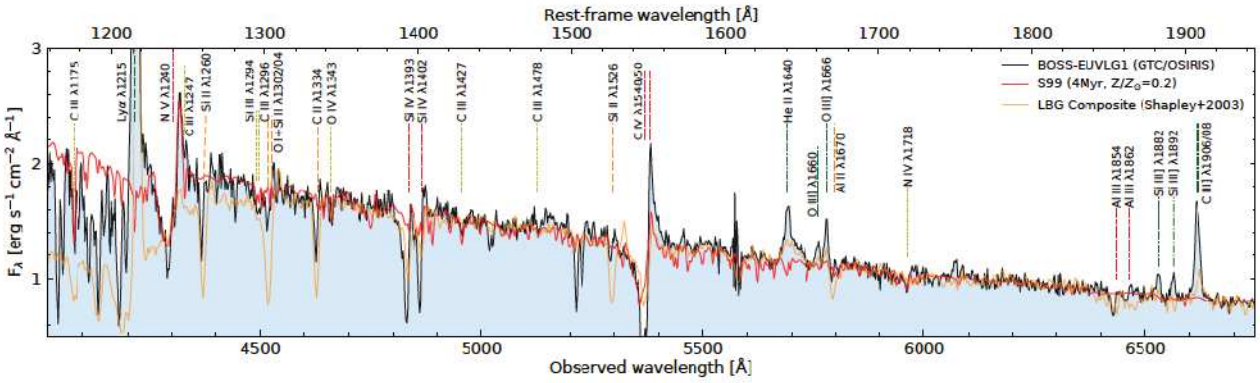
QPEs are a new phenomenon whose physical origin is under investigation: they might be related, among other possibilities, to radiation- or magnetic-pressure instabilities of the inner accretion flow around the central SMBH, or to the orbital motion of a secondary body. The detection of QPEs from a second galaxy rules out contamination by a Galactic source in both cases, assessing QPEs as a novel extragalactic phenomenon associated with supermassive accreting black holes.

The discovery of the most UV-Lyalpha luminous star-forming galaxy: a young, dust- and metal-poor starburst with QSO-like luminosities

We report the discovery of BOSS-EUVLG1 at z = 2,469, by far the most luminous, almost un-obscured star-forming galaxy known at any redshift. First classified as a QSO within the Baryon Oscillation Spectroscopic Survey, follow-up observations with the Gran Telescopio Canarias reveal that its large luminosity, Muv= -24.40 and Lyalpha luminosity of 1E+44 erg/s, is due to an intense burst of star-formation, and not to an AGN or gravitational lensing. BOSS-EUVLG1 is a compact (reff ~ 1.2 kpc), young (4-5 Myr) starburst with a stellar mass of 1E+10 solar masses and a prodigious star formation rate of 1000 solar masses per year. However, it is metal- and dust-poor (12+log(O/H)=8.13, E(B-V)= 0.07), indicating that we are witnessing the very early phase of an intense starburst that has had no time to enrich the ISM. BOSS-EUVLG1 might represent a short-lived (<100 Myrs), yet important phase of star-forming galaxies at high redshift that has been missed in previous surveys. Within a galaxy evolutionary scheme, BOSS-EUVLG1 could likely represent the very initial phases in the evolution of massive quiescent galaxies, even before the dusty star-forming phase (Marques-Chaves, Álvarez-marquez, Colina et al., 2020).



Ly_alpha luminosity and UV absolute magnitude of BOSS-EUVLG1 (yellow) and other LAEs/LBGs Horizontal and vertical dashed lines represent the typical Ly_alpha and UV luminosities of z~2-3 LAEs and LBGs (figure from Marques-Chaves+ 2020)



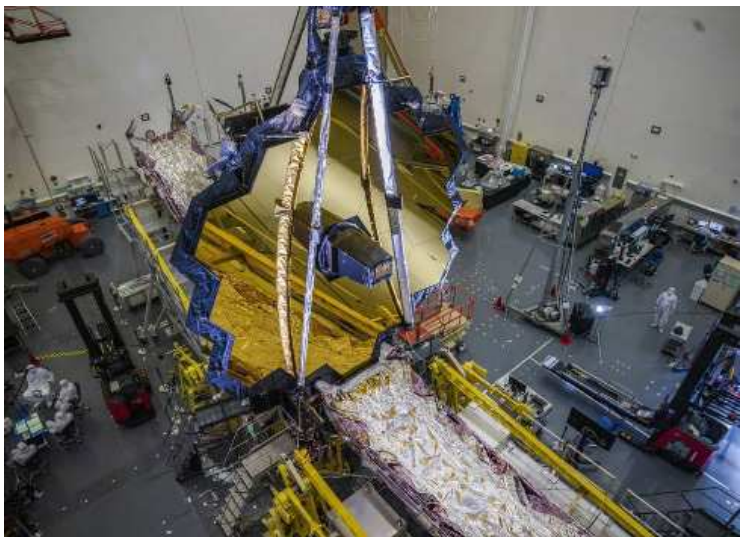
GTC rest-frame UV spectra of BOSS-EUVLG1. Ticks mark the positions of main features associated with stellar P-Cygni wind lines (red) and photospheric absorption (yellow), nebular emission (green) and ISM absorption (orange). The best-fit S99 model with age of 4 Myr and metallicity 0.2 solar is shown in red. The z~ 3 LBG composite at the redshift of BOSS-EUVLG1 is shown in orange. (Figure taken from Marques-Chaves+ 2020).

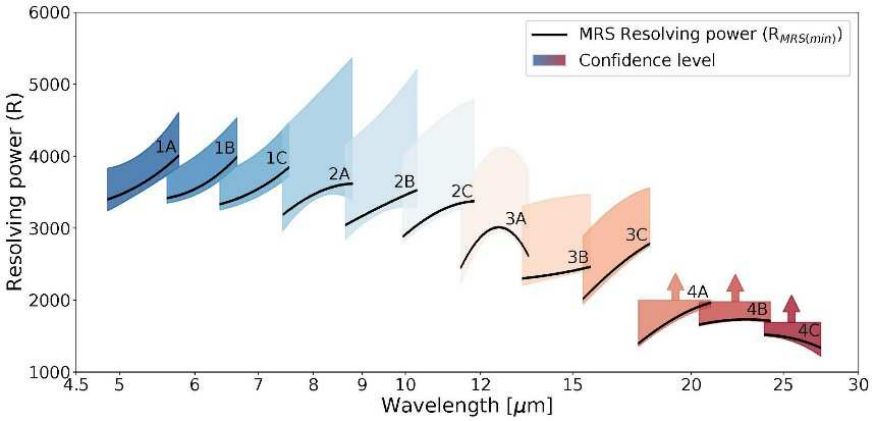
The James Webb Space Telescope (JWST)

JWST is the most ambitious and powerful space telescope ever built. It will fundamentally change our knowledge of the Universe. It has been developed within a joint NASA-ESA-CSA collaboration, it will be launched by the end of 2021. Its scientific payload consists of four instruments: 3 dedicated to explore the near-infrared wavelengths, and one, MIRI for the mid-infrared range. On the one hand MIRI includes an imager, a coronagraph, a long-slit and an integral field spectrometer (the Medium Resolution Spectrometer, MRS). It was developed by a consortium of European and US institutes over a period of more than ten years, including INTA and CAB. On the other hand NIRSpec is a multi-object (MOS) and integral field (IFS) spectrograph, operating through the whole 0.6–5mm spectral range. It is also equipped with a set of 5 slits. CAB researchers have provided science support during the development phase of this instrument, and they are now contributing to its commissioning campaign, as well as to the preparations of Cycle 1 science exploitation.

MIRI: During 2020, the MIRI CAB team has led all activities involving the MRS calibration and commissioning preparation, including coordination of the European team, commissioning rehearsals, support to the software, pipeline, operations and calibration teams, development of MRS analysis tools, delivery of calibration data products, measurement and definition of Point (PSF) and Line Spread Functions (LSF), spectral and spatial characterisation of the detectors and scientific products, definition and planning of commissioning observations, analysis activities, and science verification criteria, development of analysis tools, and support to the scientific community on best use and proposal preparations for the general observe call.

MIRI CAB scientists are involved in the planning, definition and exploitation of more 300 hours of NIRSpec and MIRI



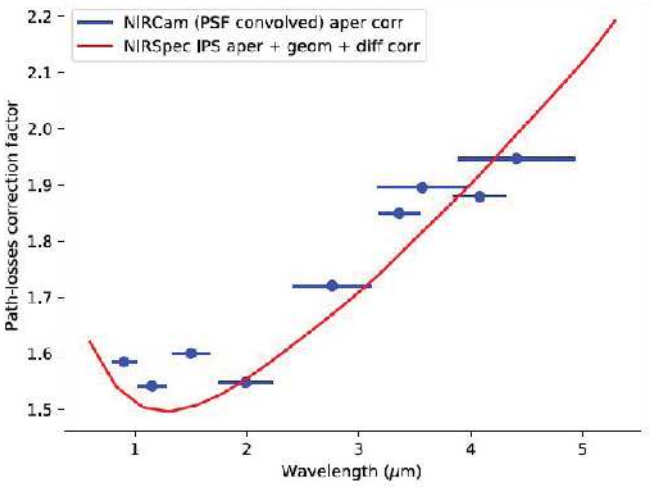


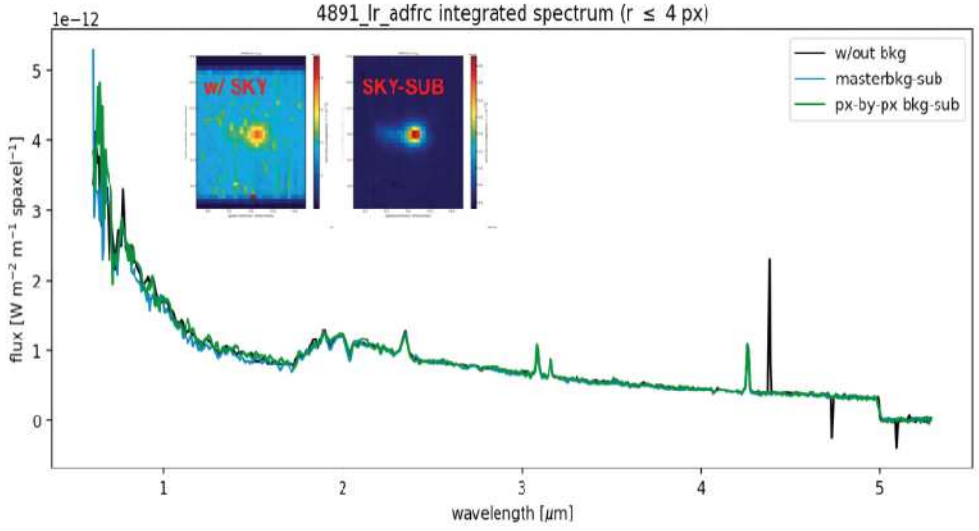
Left: the JWST, fully assembled, on the Northrop-Grumman facilities, ready to undergo the final rounds of pre-flight testing. MIRI and the near-IR instruments lay behind the primary mirror inside the Integrated Science Instrument Module (ISIM). The ISIM also harbors the cooling mechanism electronics and data handling subsystems. Right: resolving power of the MRS, measured by CAB scientists as part of the MRS spectral characterization (Labiano et al A&A submitted, Argyriou+20). Black lines show the median MRS resolving power for each MRS band. The colored area +1σ confidence levels, based on the ground test campaigns. The arrows define a lower limit for the confidence level in channel 4 of the MRS.

Guaranteed Time Observations (GTO), including local and high redshift Universe, as well as several Early Release Science (ERS) programs. Both GTO and ERS programs had to be updated during 2020 to account for the launch delay, and include the latest calibration and characterisation results.

NIRSpec: During the past year NIRSpec CAB team has been actively working on several tasks aimed at characterising the performance of the instrument, as well as at supporting the commissioning and the on-orbit verification campaign. Specifically, through a contract signed with ESA, they are responsible for several analyses to determine the performance of the Integral Field and Multi-object spectroscopic modes, as well as the dithering commissioning activity. These studies provide key information to optimise science operations of the instrument. NIRSpec CAB researchers have also led and /or participated in several working groups for data processing and simulations of both the MOS and the IFS modes.

NIRSpec CAB scientists have been deeply involved in the Cycle 1 GTO programs, which are mainly focused on observing the Early Universe using over 1000h of JWST time. On the one hand, the GA-IFS (270h) have required several updates following the technical revisions by the STScI. On the other hand the JADES (a collaboration with NIRCam involving 800h prime + 800h parallel) + WIDE surveys have involved a number of activities, mainly associated to data processing and simulations.





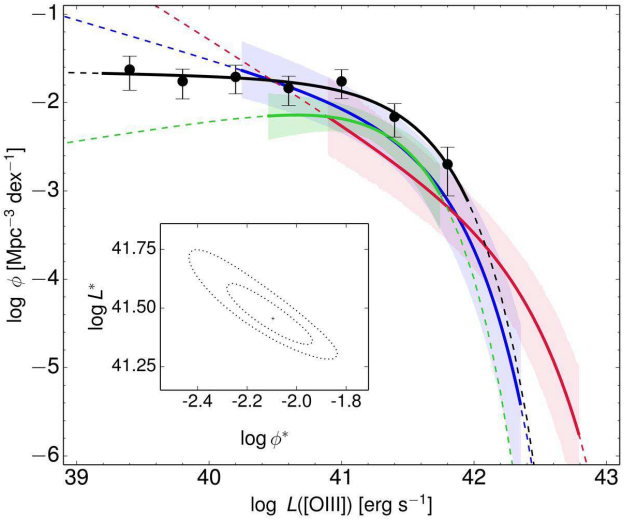
Left: Correction for recovering light loss as a consequence of the slit effect for the NIRSpec-MOS mode (B. Rodriguez del Pino) Right: Simulated spectra of a LBG at $z = 3.70$, to test the data analysis strategies for the sky subtraction (M. Perna).

Scientific exploitation of OTELO survey: the faint end of the [O III] emission line luminosity function at z ~0.8 and the mass-metallicity relation at z~0.4

The OSIRIS Tunable Filter Emission Line Object (OTELO) survey is a very deep, blind exploration of a selected region of the Extended Groth Strip. The observations provide a ~300 Å width pseudo-spectrum around 9000 Å which allows to find different emission line sources at different redshift windows down to a detectable line flux of ~5 × 10–19 erg s–1 cm^2 and equivalent widths of ~6 Å. In particular, the [N II] doublet and Hα lines are seen for objects at z~0.4 and the 4959+5000 [O III] doublet is seen for objets at z~0.83.

During this year we have exploit the results of the survey being able to obtain the faint-end properties of the luminosity function of the [O III] sample at a mean redshift of z ~ 0.83 (Bongiovanni et al. 2020, A&A 635A, 35B, including, M. Cerviño & A. M. Pérez García). This LF reaches values that are approximately ten times lower than those from other surveys, and 87% of this sample is comprised of galaxies with stellar masses of M⋆ < 1010 M⊙ (see Figure 1).

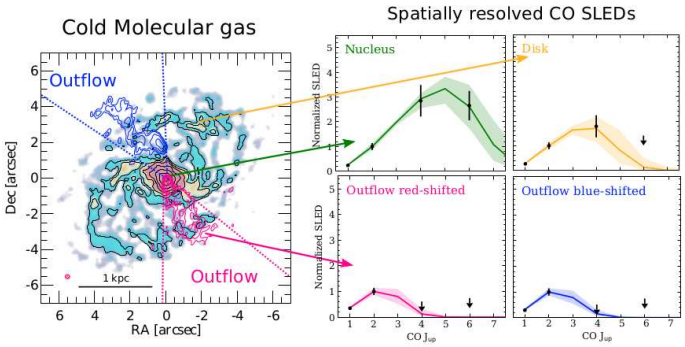
In addition, we have explore the mass-metallicity relation (MZR) for galaxies at z~0.4 (i.e. galaxies with Hα emission) in Nadolny et al. 2020, A&A 636A, 84N finding no evidence for an MZR evolution from comparing our very low-mass sample with local Star Forming Galaxies from the Sloan Digital Sky Survey.



[O III] luminosity functions at at {z}~0.8 from the recent literature (blue, green, and red) and OTELO survey data (black). In each case, the solid line extends over the sampled luminosities in each survey, while the dashed line is the extrapolation of the corresponding best fit. The inset shows the 68% and 90% confidence contours for the [O III] luminosity function obtained by OTELO. (Bongiovanni et al. 2020)

Excitation and acceleration of the molecular outflows on 200 pc scales

We report the first spatially resolved study of the molecular outflow properties in a luminous starburst (Pereira-Santaella et al. 2020). We used high-resolution ALMA observations of four CO transitions (1-0, 2-1, 4-3, and 6-5). The outflowing molecular gas is less excited than the nuclear and disk regions of the host galaxy (see Figure). Radiative transfer models indicate that the outflow gas temperature is very low (~9 K) and that the outflowing clouds are not bound by self-gravity. This suggests that the life-cycle (formation, collapse, dissipation) of the outflow and disk molecular clouds is very different and, therefore, star-formation in the outflow results unlikely. We also found that the survival of cold molecular gas up to 2kpc away from the disk could be favored by the inefficient heating of the molecular gas by the hotter ionized outflow phase. The 0.8 km/s/pc velocity gradient of the molecular gas up to a distance of 600 pc suggests that ram pressure might play a relevant role in the acceleration of outflows at these scales.



(left) The background image and black contours show the cold molecular gas emission (CO 2-1) of the local LIRG ESO 320-G030 obtained with ALMA. The blue and red contours present the extended high-velocity (> 200 km/s) outflow emission. (right) CO spectral line energy distribution (SLED) from four different regions: nucleus (green); disk (yellow); red-shifted outflow (red); and blue-shifted outflow (blue). The outflow gas is clearly less excited than the nucleus and disk as indicates the non-detection of high-velocity CO(4-3) and CO(6-5) emission.

Formation And Evolution Of Stars, Brown Dwarfs And Planets

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de la Fuente Guillén, Diego	Postdoc
García Castro, Miguel	Technical
García García, Miriam	Postdoc
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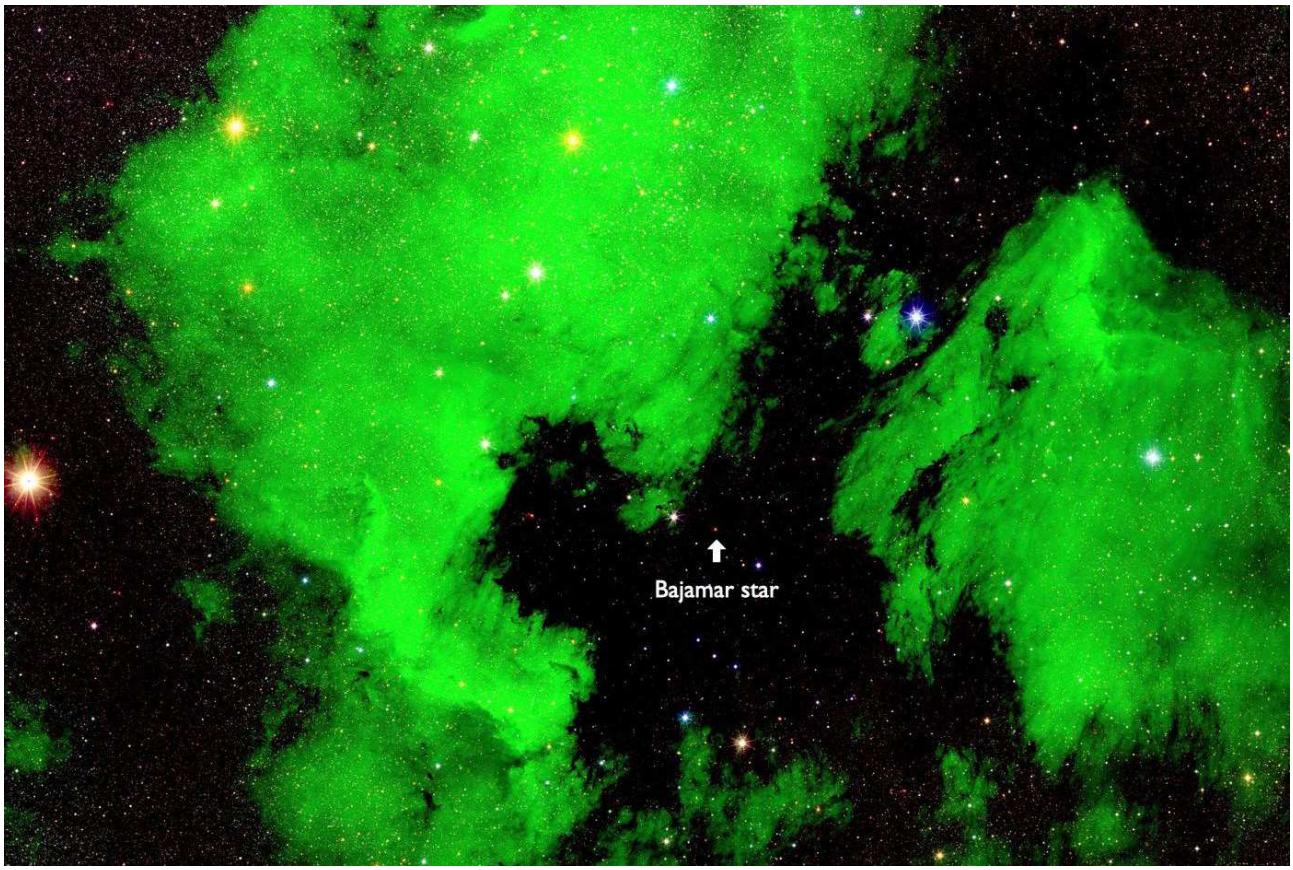
Discovery of the first very broad interstellar absorption band in the visible spectrum

Despite a century of studies, many interstellar bands in the visible spectrum remain unidentified. The plot has thickened even further this year when a team from CAB led by Jesús Maíz Apellániz has discovered yet another example, much broader in wavelength than any other interstellar band in that part of the spectrum and similar to others previously known in the ultraviolet and the infrared. The new band was hidden behind a telluric (atmospheric) absorption band and was first discovered in Hubble Space Telescope spectra and then found in ground-based data after the telluric line was carefully subtracted. The band is present in most interstellar sight lines where dust is also seen but is conspicuously depleted (or even absent) in dense clouds rich in diatomic molecular carbon, despite the high amount of dust present in such clouds. This is an indication that the band originates in a carbon-based carrier that requires low/intermediate-density regions exposed to ultraviolet light and that such compound disappears in higher density regions shielded from ultraviolet light. Further studies are planned that will correlate the intensity of the absorption band with other interstellar species in order to better ascertain the characteristics of its carrier.

For more information:
http://adsabs.net/abs/2021MNRAS.501.2487M

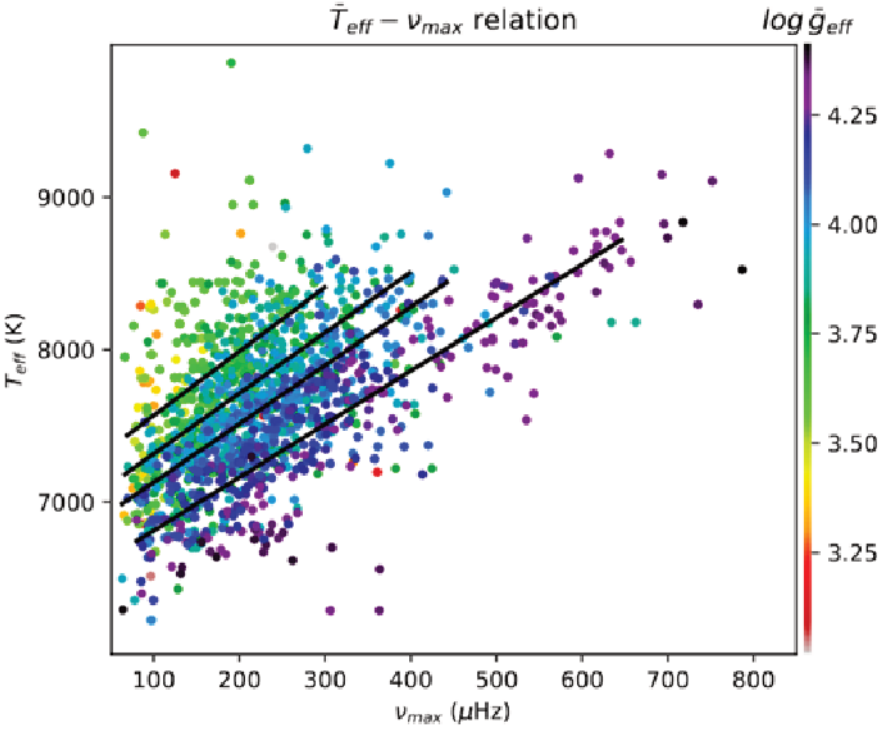


The North America and Pelican nebulae as observed by the GALANTE project. The Bajamar star is located behind the thick molecular cloud that gives its shape to the “Atlantic Ocean” and the “Gulf of Mexico” and is responsible for the ionizing photons that produce the nebular emission of the nebulae (in green). Despite the vast amounts of dust located between the Bajamar star and us, the new band is barely visible in its spectrum.

Unveiling the power spectra of δ Scuti stars with TESS. The temperature, gravity, and frequency scaling relation

Thanks to long-duration high-cadence light curves from TESS space mission, we analysed more than two thousand δ Scuti stars. In that way, we propose the frequency at maximum power (ν_{max}) as a proper seismic index since it is directly related with the intrinsic temperature, mass and radius of the star. This parameter seems not to be affected by rotation, inclination or extinction unlike photometric and spectroscopic techniques. Thus, it is possible to improve their distance, age, and habitable zone estimations for this kind of stars.

Furthermore, we can constrain rotation and inclination using the departure of temperature produced by the gravity-darkening effect. This is especially feasible for fast rotators as most of δ Scuti stars appear to be. More details in Barceló Forteza + 2020, A&A, V638, A59.



Temperature and frequency scaling relation for each group of δ Scuti stars with different values of their surface gravity. From Barceló Forteza et al., 2020.

Centro de Astrobiología celebrates the 7th Iberian Meeting on Asteroseismology (7th I+):

The 1st Iberian Meeting on Asteroseismology (2008) was born in the dawn of the space missions CoRoT and Kepler, both dedicated to stellar characterisation and exoplanet research. These meetings were created to boost the asteroseismic spanish-portuguese institutions within the international scientific community. The I+ continued up to the 6th edition (2013) due to the effects of the Great Recession that put at risk the continuity of the different working groups.

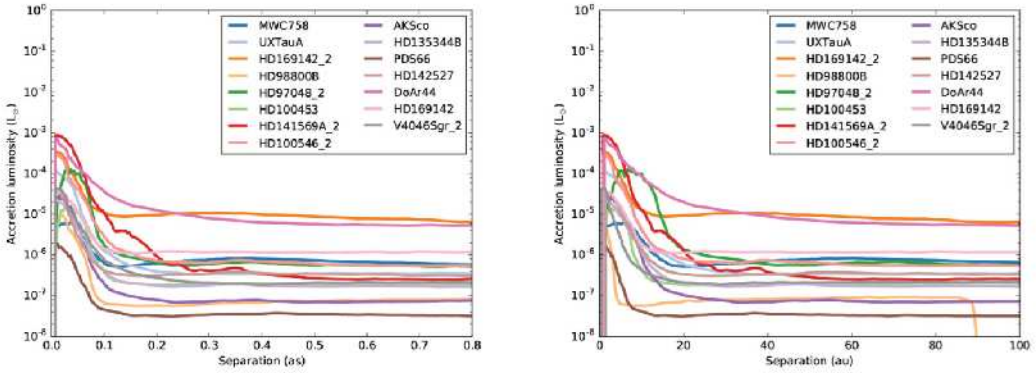
Now, in the age of TESS and CHEOPS space missions and the new ground-based telescopes SONG and CARMENES, the iberian community wishes to start and/or renew solid collaborations. This is of special importance to prepare the future ESA mision PLATO2.0. For that reason, CAB led the 7th I+ jointly with Instituto de Astrofísica de Andalucía and Universidad de Granada. Eleven different projects were proposed to work on site.

This edition was the first one celebrated online due the pandemic restrictions. However, 42 scientists from portuguese/spanish institutions and also other european researchers attended the most multitudinous meeting of the series, managing to be one of the biggest asteroseismic communities of Europe.

Searching for the youngest planets through observations in accretion tracers

Planets are formed in the disks surrounding young stars. At the earliest stages of their formation, thay are expected to gather material and form their own circumplanetary disks. Different planet formation theories predict that planets can accrete material from both the circumstellar and the circumplanetary disks and, as a result, they can emit in accretion tracers like, e.g. the Hα emission line. This scenario has been already confirmed in one young planetary system: PDS70ab (Haffert et al. 2019)

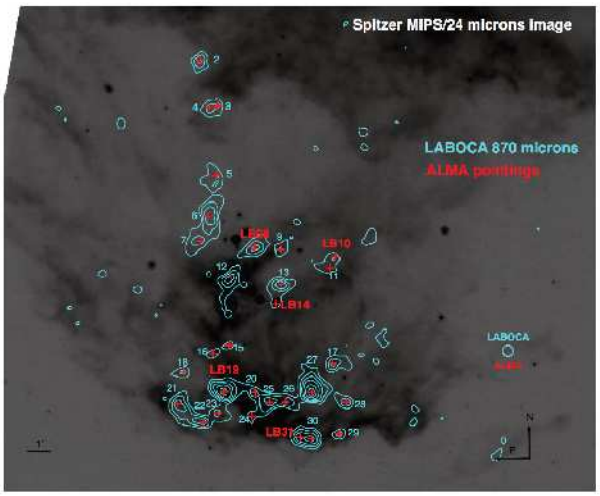
To further test this hypothesis, we have participated in the largest survey to detect accreting protoplanets around young stars (Zurlo et al. 2020, incl. N. Huélamo). To do so, we have used high angular resolution observations obtained with the instrument SPHERE at the VLT, reaching unprecedented sensitivity and angular resolution (see Figure below). As a result, we have not detected any accreting protoplanet, and the mean accretion luminosity limit is $10^{-6}\,L_{\odot}$ at a separation of 0.″2 from the host. There are different scenarios to explain these non-detections: either protoplanets have accretion luminosities fainter than the ones achieved on our observations, or they show episodic accretion and we have observed them in a quiescent phase. Another possibility is that the dust from the disks (circumstellar and circumbinary) is producing a large extinction of the Hα emission.



Accretion luminosity limits for all the targets of the sample versus angular separation (left) and physical separation (right).

A database of substellar objects at the earliest evolutionary stages: SUCANES

Brown dwarfs (BDs) are abundant in star forming regions and the field. However, their formation mechanism is still a matter of debate.The fact that young (~1-10 Myr) BDs show properties similar to young late-type stars (e.g. presence of disks and jets), suggests that they form in the same way. However, BD masses are smaller than the Jean masses estimated for molecular clouds, so their formation cannot be simply explained as a scaled-down version of low-mass stars. Moreover, there are other mechanisms that can form BDs like e.g. disk fragmentation or ejection from multiple protostellar systems.



Spitzer 24 μm image of the Barnard 30 cloud. The field of view is ~23′ × 18′. The cyan contours represent single-disk APEX/LABOCA detections at 870 μm associated with substellar dust clumps. The red crosses represent ALMA Band 7 (~880 μm) detections of five of these clumps. Three of them are classified as pre-BD candidates.

Since stars and BDs evolve very rapidly during the first million years, a way to understand BD formation is to study the properties of BDs at the earliest stages of their evolution, when they are still embedded in their parental clouds. At this stage, and by analogy with low-mass protostars and prestellar cores, they are called proto- and pre-BDs. There are several studies that have identified pre- and proto-BD candidates in different star forming regions (see the Figure for an example). All these studies show different observational approaches, and a comprehensive study comparing the properties of all the candidates is needed to shed light on the BDs formation mechanism. That is the main reason to build the Substellar Candidates at the Earliest stages (SUCANES) database (A.M. Pérez García, N. Huélamo). The objective of SUCANES is to compile all the data available for objects identified as pre- and proto-BDs in the literature. The database includes all the relevant information of each object, like e.g. photometry/fluxes from the optical to the centimeter wavelength range. In the near future, it will also include visualization tools and scripts to deliver relevant physical quantities like e.g. the internal luminosity, bolometric temperature and total luminosity.

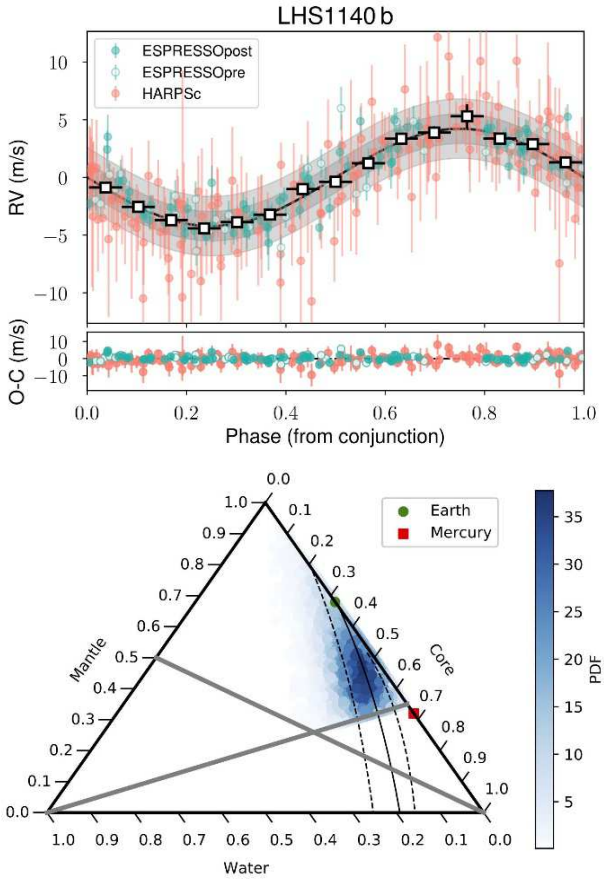
Focused search and characterization of extrasolar planets

The large number of extrasolar planets known to date (more than 4300) now allows us to classify planets according to their main bulk properties. The high precision instrumentation available in both space and ground allows a deep characterization of these worlds. Along 2020, several studies led by CAB researchers have pushed the limits of this exploration towards different directions.

We have led studies on the precise determination of planet properties in different planetary systems, which allowed to estimate the internal structure of other worlds with astrobiological interest. This is the case, for instance, of the iconic system LHS1140, with two known planets, one in the habitable zone of this cold star (LHS 1140 b). By using data from an intensive campaign with the state-of-the-art ESPRESSO instrument, we could determine in Lillo-Box et al. (2020) the rocky nature of the two planets and unveil that the habitable zone planet contains a large water fraction (potentially between 5 and 80 times the amount of water on Earth). Besides, an international team lead by the Center for Astrobiology (PI: J. Lillo-Box) was granted a Legacy Program at the Calar Alto Observatory. The team will develop between 2021-2023 the KOBE experiment (K-dwarfs Orbited By habitable Exoplanets) with the aim to scrutinize a set of 50 late type K-dwarfs to look for temperate planets around these quite stars that could potentially be the optimal environments for life.

Some members of our Department also belong to the ESPRESSO consortium making use of the ESPRESSO Guaranteed Time Observations. Some highlights from the ESPRESSO GTO published in 2020 are the following:

- Nightside condensation of iron in an ultrahot giant exoplanet (Ehrenreich et al. 2020, Nature, 580, 597).
- An independent confirmation of the 11-d planet orbitin Proxima (Suárez Mascareño et al. 2020, A&A, 639, 77).
- The discovery of one of the densest planets discovered to date (Toledo Padrón et al. 2020, A&A, 641, 92).
- A precise and 3D view of the pi Mensae planetary system (Damasso et al. 2020, A&A, 642, 31), where the precise ESPRESSO radial velocities were combined with Gaia astrometry.
- The finding of a resonant planetary system orbiting a very old, low metallicity star (Mortier et al. 2020, MNRAS, 499, 500).



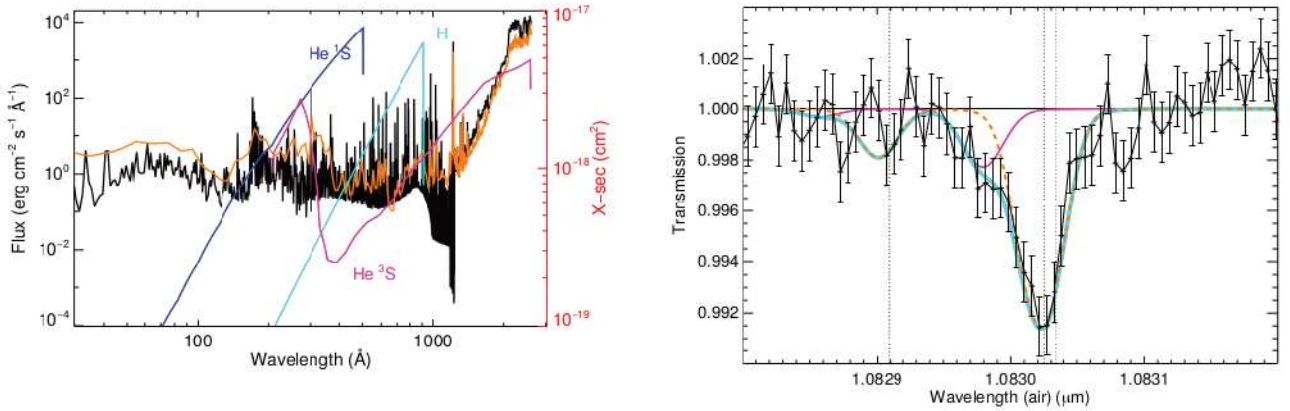
Left: radial velocity signal induced by the extrasolar planet LHS1140b obtained with the HARPS (red symbols) and ESPRESSO (blue symbols) instruments. Right: Sampled 2D marginal posterior distribution for the core mass fraction and water mass fraction of LHS1140 b. the color code displays the probability density function. The solid and dashed black lines represent the isoradius curves for the central value of the radius and its 1σ confidence interval limits, respectively. The gray lines delimit the areas we excluded from our sampling.

Research on exoplanets atmospheres

The research on exoplanets is reaching the study of their atmospheres using space and ground-based instrumentation. J. Sanz Forcada has participated in 7 papers studying the exoplanet atmospheres. Main participation is through the modelling of stellar high energy radiation, and the evaluation of the level of contamination of planetary spectra due to stellar activity. The most novel result is the modelling of the observed He I 10830 line triplet in the atmosphere of the exoplanet HD 209458b (Lampón et al. 2020, see Fig. below). The use of this line gives important clues on exoplanet atmospheric escape: close-in exoplanets subjected to strong high energy irradiation suffer from atmospheric escape, i.e., loss of atmospheric gases due to photoevaporation. Up to 2018 only the Lyman alpha line was used to detect planetary atmospheric escape. But the use of this line is limited to the nearest stars, because of interstellar medium absorbing the line. Our collaboration within the CARMENES consortium brought a new line, the He I 10830A triplet, that can be used to measure the atmospheric escape, and it is rarely affected by interstellar absorption. This line has an unusual formation process in which it strongly depends on the incoming XUV stellar irradiation. The theoretical modelling is very useful in determining also the escape regime that yields the observed line. There are currently three escape regimes identified, with different efficiency of the photoevaporation processes.

Other studies on exoplanet atmospheres include the evolution of the atmosphere of GJ 357b (Modirrousta-Galian et al. 2020), the He I 10830 line in the GJ 3470b atmosphere (Palle et al. 2020), and the research of the atmospheric spectra of three exoplanets within the PanCET collaboration: WASP-79b, WASP-52b, HAT-P-32Ab (Sotzen et al., Bruno et al., Alam et al. 2020).

Using HoRUS on the GTC, Tabernero et al. (2020, MNRAS, 498, 4222) were able to set the most restrictive upper limit on the presence of sodium in the atmosphere of one of the warmest super-Earths known in our Galaxy. In addition, this was the first scientific paper of HoRUS, and it demonstrated the utility of this spectrograph for the studies of exoplanetary atmospheres.

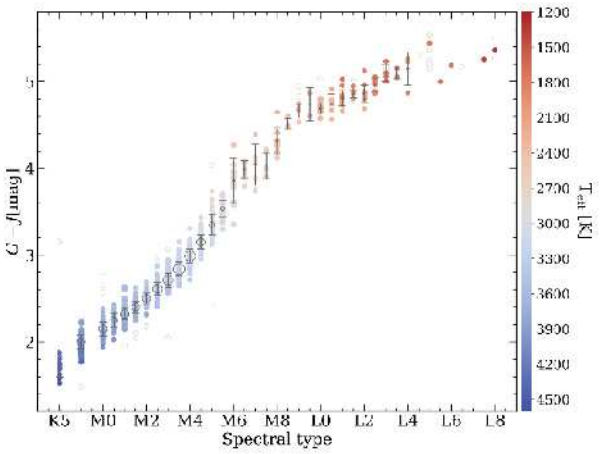


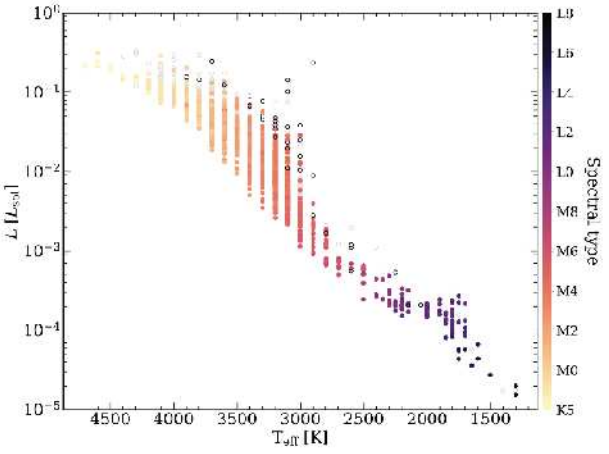
Left: Stellar SED (black) based on coronal model (built with X-rays + UV data). Right: He I triplet modeled (blue) matching the actual planet atmosphere signal.

Knowing the most common type of star: luminosities, colours and spectral energy distributions of M dwarfs

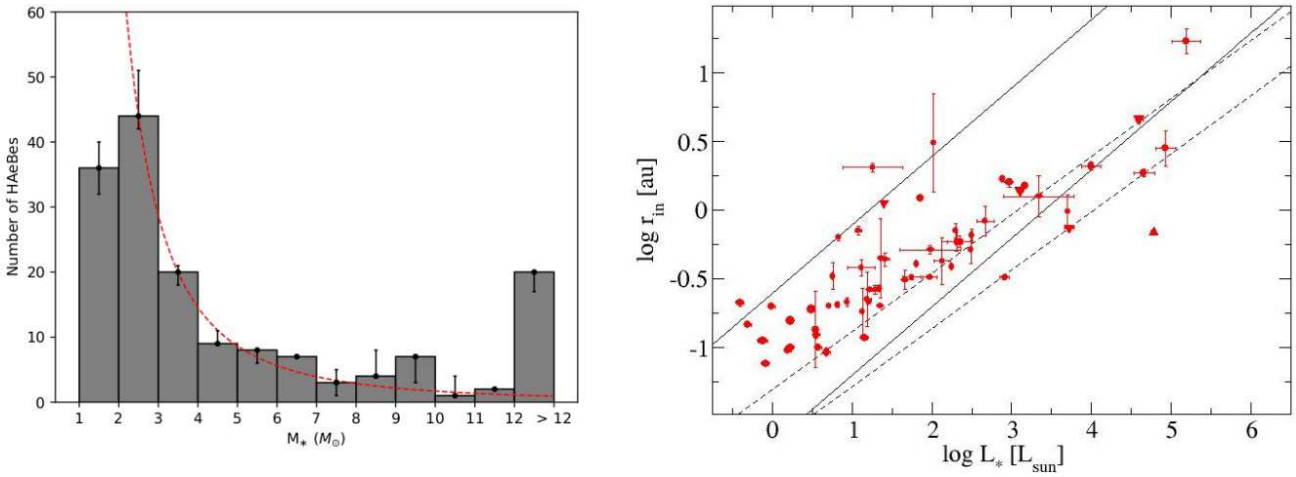
When searching for planets outside the solar system that resemble our own, M dwarfs are very appreciated targets for many reasons. Firstly, they are extraordinarily abundant: we estimate their fraction in the Milky Way to be as high as 70%. Secondly, they are remarkably long-living stars, to the extent that our Universe is still young in comparison. Thirdly, it is much easier to detect perturbations in their movement caused by planetary companions. These qualities are a consequence of their intrinsic properties. Namely, they are smaller, cooler and fainter than our Sun. State-of-the-art instrumentation can detect radial movements in a star of this kind caused by one or more planets that are comparable to the speed of a person walking. CARMENES (Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Echelle Spectrographs, Quirrenbach et al. 2014), is an instrument specifically designed for this purpose. It is mounted in the 3.5-m telescope at the Calar Alto Observatory in Almería, Spain.

When describing the kind of worlds that instruments like CARMENES encounter, we always do so referring to the host star. For instance, we can estimate the mass of the planet because we have constrained the mass of the star. The better we characterise the star, the more detailed will be our picture of the planet. Light can reveal much more about a star than its only apparent brightness. If we observe the light emitted by a star along the spectrum (i.e. broadband photometry), we can obtain colours and bolometric luminosities. In Cifuentes et al. (2020) we combined this photometric analysis with the latest astrometry provided by *Gaia*, and with the BT-Settl CIFIST grid of theoretical spectra. We derived empirical relations that allow the derivation of fundamental properties of M dwarfs (e.g. luminosities, masses, radii, effective temperature) from the observed ones (e.g. apparent and absolute magnitudes, colours).





Left: G-J colour as a function of spectral type of the star (OBAFGKMLT). The grey empty circles mark the mean value and its standard deviation. Right: bolometric luminosity as a function of effective temperature. Empty black circles represent young stars, which are known to be overluminous. From Cifuentes et al. (2020).



(Left, from Guzmán-Díaz et al. 2021): The stellar mass distribution of all known Herbig Ae/Be stars follow the initial mass function (red line), except for the not well sampled boundaries. (Right, from Marcos-Arenal et al. 2021): Correlation between stellar luminosity and size of inner dust disk observed in Herbig Ae/Be stars. Dotted and dashed lines indicate different accretion mechanisms.

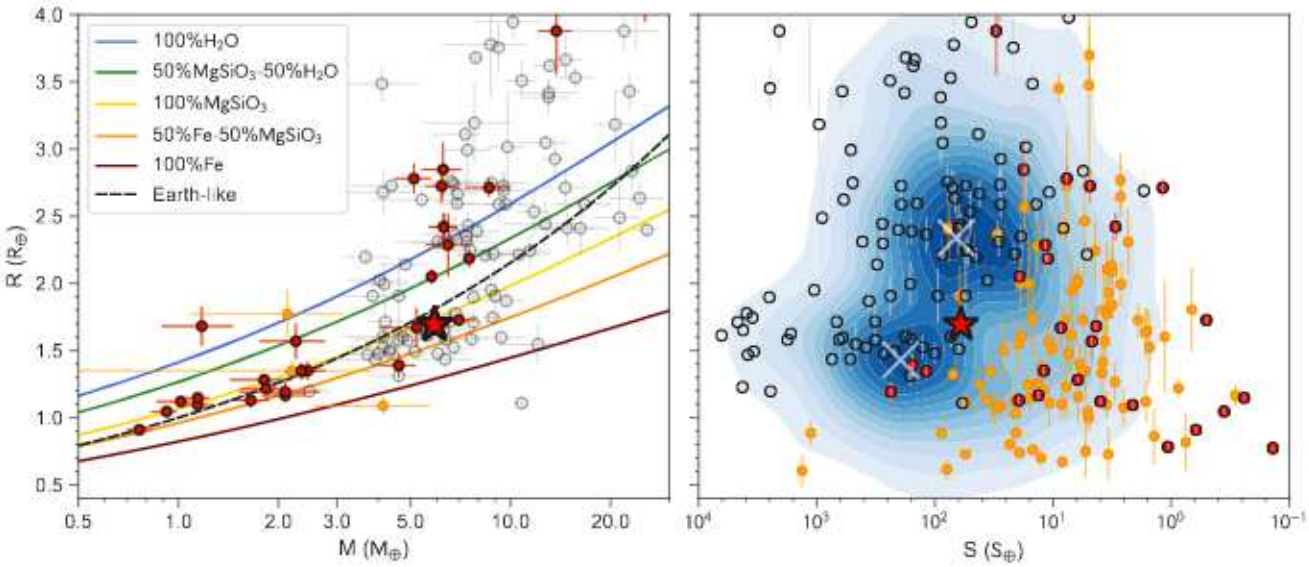
Characterization of protoplanetary disks around intermediate-mass young stars

Young stars are surrounded by circumstellar disks, which are the sites where planets form. Our lack of knowledge about young stars and their protoplanetary disks increases with the stellar mass. The main reason is that low-mass stars (< 2 M⊙) are more frequent and thus easier to study at closer distances. Although massive stars (> 10 M⊙) are scarce, they have a major role dominating the kinematic feedback and chemical enrichment on large scales. However, the mechanism driving the formation of massive stars is still the subject of debate. The fact that massive young stellar objects are optically invisible, remaining embedded in their natal envelopes during the whole pre-main sequence phase, makes their study even more difficult. Young, Herbig Ae/Be stars have stellar masses in between both previous regimes (2 ≲ M*/M⊙ ≲ 10). Being relatively abundant and showing an optically visible pre-main sequence phase, **Herbig Ae/Be stars are key to understand the transition between the formation mechanisms of low- and high-mass stars.** Recently, the CAB team led by I. Mendigutía has provided major results concerning Herbig Ae/Be stars. First, an invited review paper on the formation mechanisms of Herbig Ae/Be stars has been published (Mendigutía, 2020). Second, building on a collaboration with astronomers from the University of Leeds (UK) and ESA-ESAC (Madrid), thousands of new potential Herbig Ae/Be stars have been discovered combining Gaia DR2 distances and machine learning (Vioque et al. 2020). Third, the largest characterization to date of the stellar and circumstellar parameters of all known Herbig Ae/Be stars has been done based on the most recent Gaia EDR3 distances and photometry (Guzmán-Díaz et al. 2021). The associated archive is online, thanks to a collaboration with the VO-team at CAB. Last but not least, the most complete analysis of the empirical correlation between the sizes of the inner disks and the stellar luminosities of Herbig Ae/Be stars has been carried out, based on interferometric data taken with the instrument GRAVITY/VLTI (Marcos-Arenal et al. 2021, submitted to A&A). **These works probably represent the most important reference for future studies of intermediate-mass young stars.**

Mass and radius determination of transiting sub-Neptunes and super-Earths: a fruitful CARMENES-TESS collaboration

CARMENES is the high-precision radial-velocity spectrograph at the 3.5 m Calar Alto telescope, especially designed, built and operated for the search of low-mass planets around M dwarfs, which are the most frequent stars in the solar neighbourhood. TESS is the Transiting Exoplanet Survey Satellite, a NASA space mission aimed to discover transiting planets, also especially around M dwarfs. Radial-velocity surveys yield only minimum planet masses, while transit surveys yield planet radii and orbit inclinations. Thus, for determining both planet masses and radii and, therefore, bulk densities, from which infer their composition and internal composition, one needs data from the two surveys. Prior 2020, there were only a handful of transiting planets around M dwarfs. These faint stars, because of their small mass and radius, are the only ones that ease the detection of planets of a few Earth masses.

Within the TESS Follow-up Observing Program (TFOP), the Spanish-German CARMENES consortium, including a number of CAB astronomers, and TESS agreed in collaborating for determining masses and densities of some of the transiting planets for which TESS had measured only radii. This collaboration was very fruitful in 2020, with the publication of four joint referred papers, all CARMENES-led and with CAB astronomers among the first authors: TOI-1235 b (a planet in the radius gap between super-Earths and sub-Neptunes; Bluhm et al. 2020), LTT 3780 b and c (two planets on the opposite sides of the radius gap; Nowak et al. 2020), GJ 3473 b and c (a hot, transiting, Earth-sized planet and a second temperate, non-transiting planet; Kemmer et al. 2020), and LP 714-47 b (a planet on the hot Neptune desert; Dreizler et al. 2020).



Mass-radius (left) and insolation-radius (right) in Earth units (from Bluhm et al. 2020).In the two panels, open circles are transiting planets around F-, G-, and K-type stars with mass and radius measurement better than 30% from the TEPCat database of well-characterized planets, filled red circles are planets around M dwarfs with mass and radius measurement, filled yellow circles are planets around M dwarfs with mass determinations lower than 30% or without mass constraints at all (right panel only), and the red star is TOI-1235 b, whose radius and mass are determined with accuracies of 5% and 10%, respectively.

Looking for exocomets around A-type stars

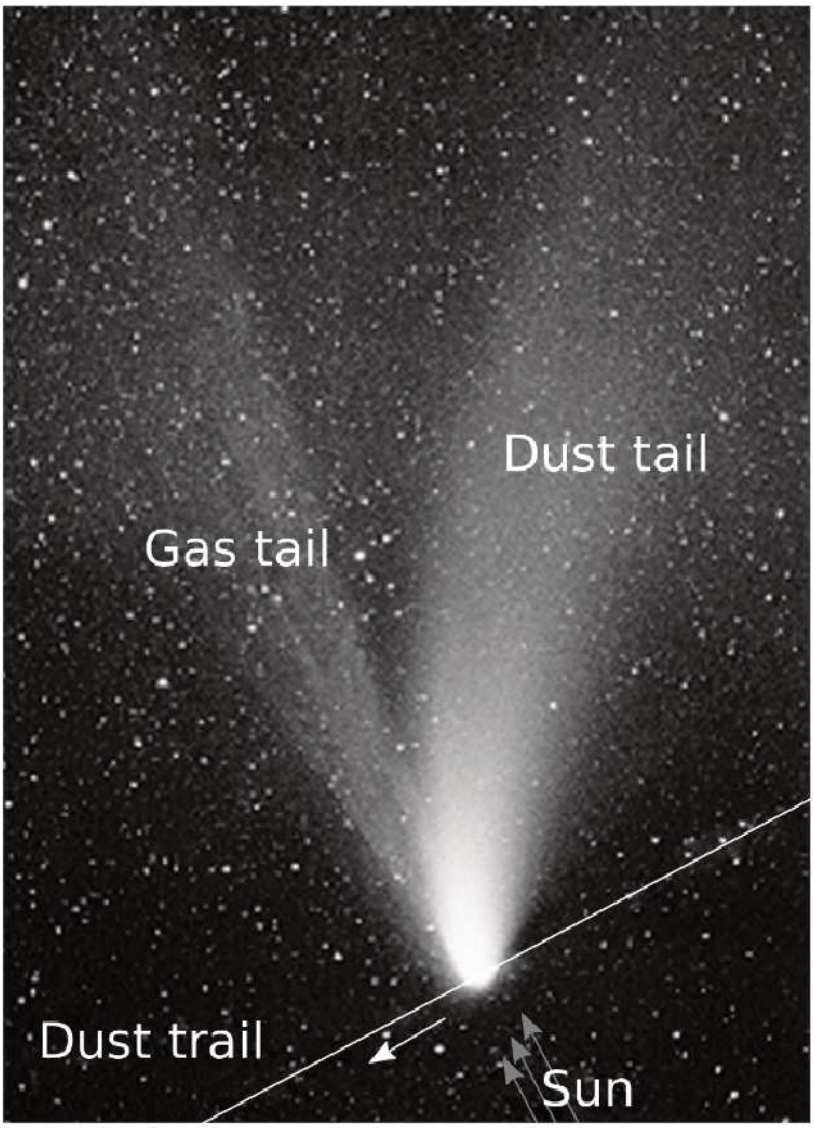
In addition to exoplanets, which are now routinely detected around late-type stars, small objects, similar to the comets in our Solar System, must play an important role in the architecture of (exo)planetary systems.

During the last five years we have been carrying out a spectroscopic monitoring of a sample of some 120 main-sequence A-type stars, following the pattern of β Pic, the prototypical object where the extreme variability observed in the Ca II K line profile has been interpreted for decades as originated by comet-like objects within the so-call "falling evaporating bodies" (FEB) scenario. These objects would fall onto the star, sublimating and ejecting -circumstellar- gas which is observed as narrow, variable absorption features superimposed on the Ca II and other photospheric lines.

More than 2000 high-resolution spectra were obtained in campaigns with FIES/NOT, HERMES/Mercator, and HARPS-n/TNG (Roque de los Muchachos, La Palma), CARMENES/CAHA 3.5-m, at Calar Alto (Almería) , and FEROS/MPIA 2.2-m (La Silla). Spectral signatures potentially linked to the presence of exocometary events were observed in six stars, adding these objects to the sample of around 20 stars where this kind of events had been already reported.

However, a word of caution should be explicitly written: the deep analysis of one of the stars of the sample, HR 10 (HD 256), using our observations, plus spectra retrieved from archives, building a 30-year time series of spectra proved that the variability of this object, that had been attributed to exocomets, is actually caused by a peculiar architecture: the star is a binary, with both components harbouring a circumstellar shell, the orbital motion originating the variability observed. The bottom line is that in some cases, a long time span of spectroscopic observations is required to confirm or discard the exocometary scenario.

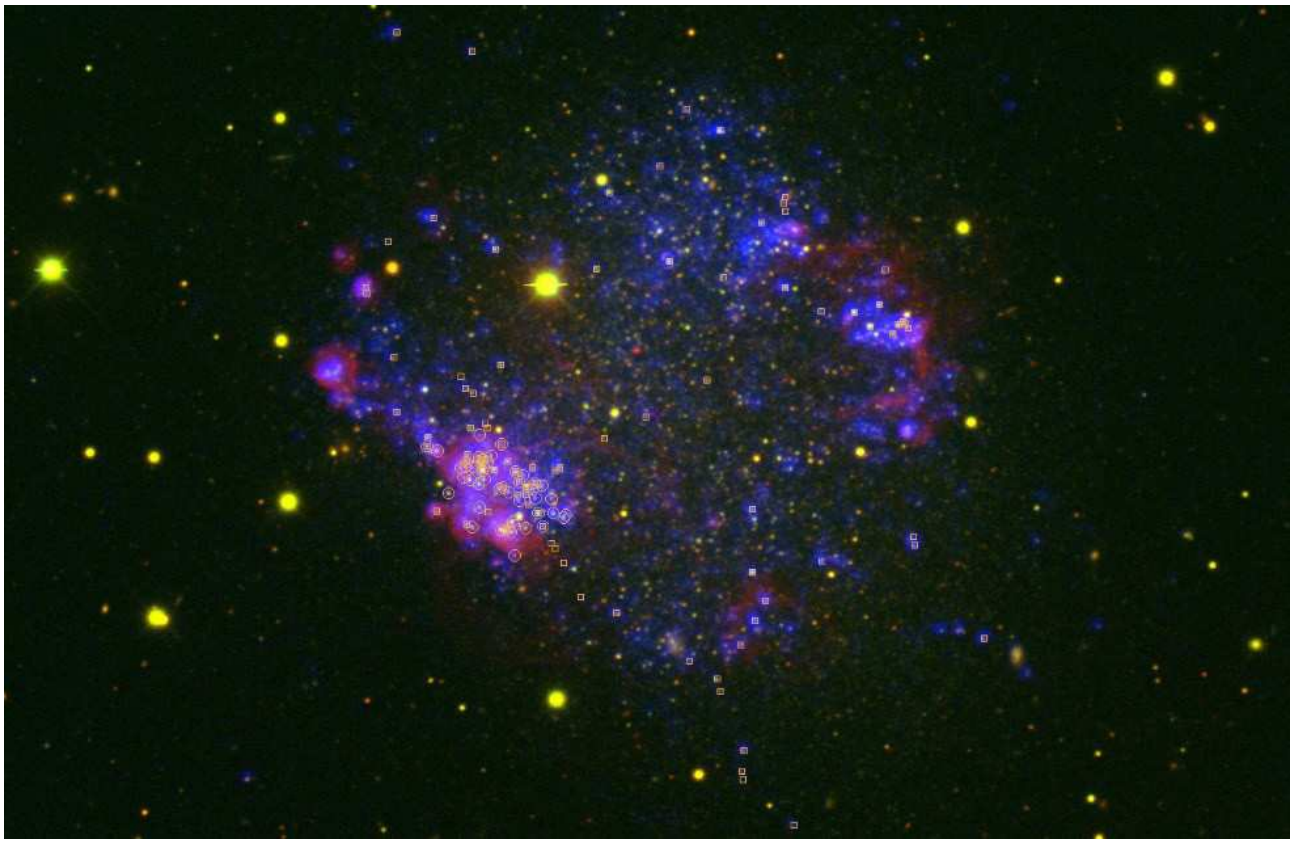
Members of the group involved in this research are Benjamín Montesinos, Eva Villaver, Ignacio Mendigutía and Jorge Lillo. The results of these extensive survey and subsequent analysis were compiled in the PhD thesis by Isabel Rebollido "Exocomets: A study of the gaseous environment of A-type main sequence stars" (2020, Universidad Autónoma de Madrid, supervised by Eva Villaver and Benjamín Montesinos), and in the paper "Exocomets: A spectroscopic survey" (Rebollido et al., 2020, Astronomy and Astrophysics, 639A, 11R).



CAB continues expanding the catalog of very metal-poor massive stars

Massive stars are the most powerful stellar-size sources of ionizing photons and kinetic energy within a galaxy. These characteristics make them important ingredients for chemo-dynamical simulations and synthetic populations, where past epochs of the history of the Universe are usually represented by a very low content of metals. Very metal-poor massive stars are fundamental to understanding the reionization epoch and the early evolution of galaxies, but the interest in these objects has been further increased as of recent. On the one hand the incoming data from gravitational wave experiments and, on the other, the observations of extreme nebular HeII emission in starburst systems at various redshifts, have inspired the development of novel channels of evolution of single and binary very metal-poor massive stars.

During the last decade, the team of massive stars at CAB has been working to provide an observational sample to support and constrain the models of evolution at the metal-poor regime. With about 100 entries, our catalog in the galaxy Sextans A is the largest sample of massive stars with poorer metal content than the SMC to date. It is the core of the low-metallicity sample of the HST DDT program ULLYSES (https://ullyses.stsci.edu/), devoted to building a legacy UV-library for studies of star-forming galaxies. Our sample will help address questions that have arisen with the new theoretical scenarios such as what is the frequency of binary stars, stripped binaries, or chemically homogeneous evolution. We are also working to answer long-standing questions such as whether metal-poor environments can lead to a top-heavy initial mass function (Lorenzo, Garcia, & Najarro 2020, XIV.0 Scientific Meeting of the Spanish Astronomical Society, 56). To this aim, we recently carried out a successful observing campaign of 42 hours with GTC, which we used to mine the most active star-forming region of Sextans-A looking for very massive stars.



The dwarf irregular galaxy Sextans-A with red/green/blue coding H-alpha/V-band/UV photometry. Squares mark massive stars confirmed by our previous spectroscopic programs and circles mark the targets of the latest observing run, focused on the region with the largest HII shells.

New models for the winds of massive stars

Radiation-driven winds are one of the stellar properties that most strongly impact the evolution of massive stars. The removal of mass alters the conditions at the stellar center, determining the mass and size of the He-burning core, the post-main sequence stages, the type of supernova at the end of the evolution (if any) and ultimately the neutron star or black hole remnant. For many years the codes that model the atmospheres of massive stars failed to launch the wind starting from the parameters at the stellar photosphere, and had to rely on assumptions for a hydrodynamic structure. Moreover, the wind recipes implemented in the models of stellar evolution have long been suspected to overestimate mass loss rates.

The team of massive stars has continued working to improve the characterization of the winds of massive stars. In collaboration with J. Sundqvist (former Marie Curie fellow at CAB), a self-consistent solution for the atmosphere equation of motion, independent on any assumption on the line force responsible for the wind driving, has finally been achieved (Sundqvist et al. 2019, A&A, 632, A126; Björklund et al 2021, A&A, 648, A36, both including F. Najarro). The code FASTWIND has been updated to extend its applicability to the UV range and to include an advanced description of X-ray emission from wind-embedded shocks (Puls, Najarro, et al. 2020, A&A, 646, A172). We have also finished a description of the radial distribution of wind-inhomogeneities (clumping) in the atmospheres, made from the multiwavelength analysis of a sample of Galactic massive stars. These results, that will contribute to narrow down the mass loss rates of massive stars, are presented in the PhD thesis by María del Mar Rubio Díez (UAM, 2021).

Updates from the Galactic Center

The Center of the Milky Way (GC) provides an unique laboratory to understand the physics governing the formation of circum-nuclear star-bursts and their contribution both to the galactic energy budget and ecology. Such star-bursts are prominent in many other galaxies, but only our Galactic Center allows to resolve individually its stars. Given that the mean temperature, density, pressure and velocity dispersion of the molecular material at the GC is significantly greater than the values obtained for the disk, one would expect star formation processes to proceed differently in both regions.

Our group has actively participated in several collaborations seeking to determine the star formation history of GC as well as the massive star population in this region. Nogueras Lara et al. 2020, Nat. Ast. 4,377 (including F. Najarro) found that the bulk of the stars in this region formed at least 8Gyrs ago and, after a long period of quiescence, a starburst event followed about 1 Gyr ago which may have likely been one of the most energetic events in the history of the Milky Way.

Following a series of papers characterizing the massive star population of the Arches and Quintuplet clusters at the GC, we performed a thorough study (Clark, et al., incl F. Najarro arXiv:2102.08126) of the isolated massive stars in the region, which number was, at least, comparable to that of the known clusters which clearly demonstrates the great impact of massive stars in the energetics and evolution of the Galactic Center region.

Interestelar And Circunstelar

Coordinator: Guillermo Muñoz Caro

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García de la Concepción, Juan	Postdoc
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Megías Toledano, Andrés	Predoc
Muñoz Caro, Guillermo Manuel	Investigador Científico de OPI/INTA
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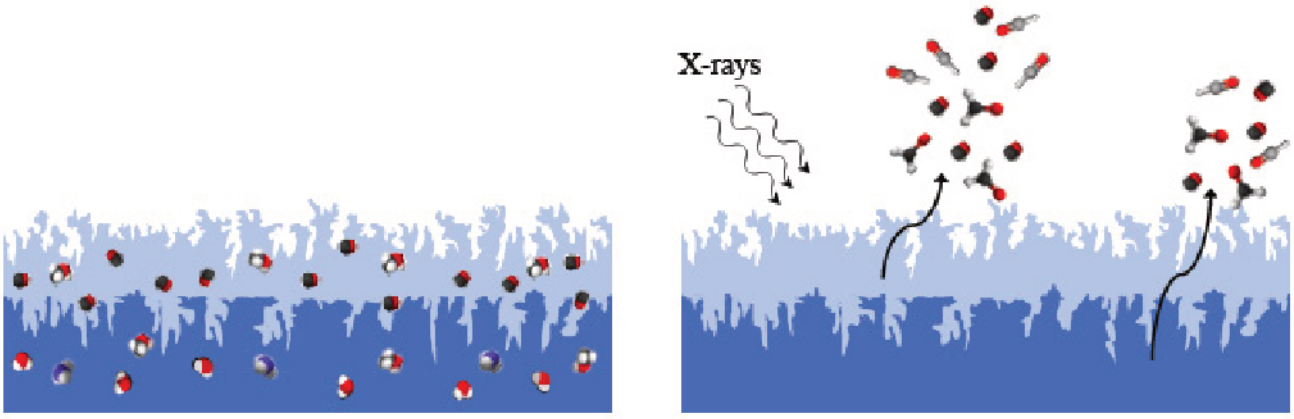
X-ray processing of a realistic ice mantle can explain the gas abundances in protoplanetary disks

The Atacama Large Millimeter Array (ALMA) has allowed a detailed observation of molecules in protoplanetary disks, which can evolve toward solar systems like our own. While CO, CO2, HCO, and H2CO are often abundant species in the cold regions of the disk, CH3OH or CH3CN are only found in a few regions, and more complex organic molecules (COMs) were not observed.

To approach this astrophysical scenario, we simulated experimentally the X-ray processing of more realistic ice mantles that cover dust grains in disks. The ice is composed of a layer with mixed H2O, CH4 and NH3 covered by another layer made of CH3OH and CO. The photoproducts found to desorb from the ice to the gas during the X-ray irradiation converge with those detected in higher abundances in the gas phase of protoplanetary disks, providing important insights on the non-thermal processes that drive the chemistry in these objects. Also in line with the lack of COMs in the gas observations of protoplanetary disks is that some of these species are formed in the ice, but they did not desorb during irradiation.

For more information:

Ciaravella, A.; Muñoz Caro, G. M.; Jiménez-Escobar, A.; Cecchi-Pestellini, C.; Hsiao, L.-C.; Huang, C.-H.; Chen, Y.-J. X-ray processing of a realistic ice mantle can explain the gas abundances in protoplanetary disks. PNAS, 117, Issue 28, 116149.



Sketch of the two layers ice experiment. Left: the bottom layer of H2O:CH4:NH3 (1:0.5:0.5) mixture covered by a layer of CO:CH3OH (3:1) mixture. Right: X-ray irradiation of the ice induced a very fast destruction of CH3OH due to formation of new species rather than photo-desorption. During the irradiation a negligible desorption of CH3OH has been detected while CO and products such as HCO, H2CO and CO2 had the most intense intense desorption signals. Desorption from the bottom layer species, after diffusion in the top layer, was also detected.

UV irradiation of methane ice can explain the hydrocarbon gas-phase abundances in transneptunian objects

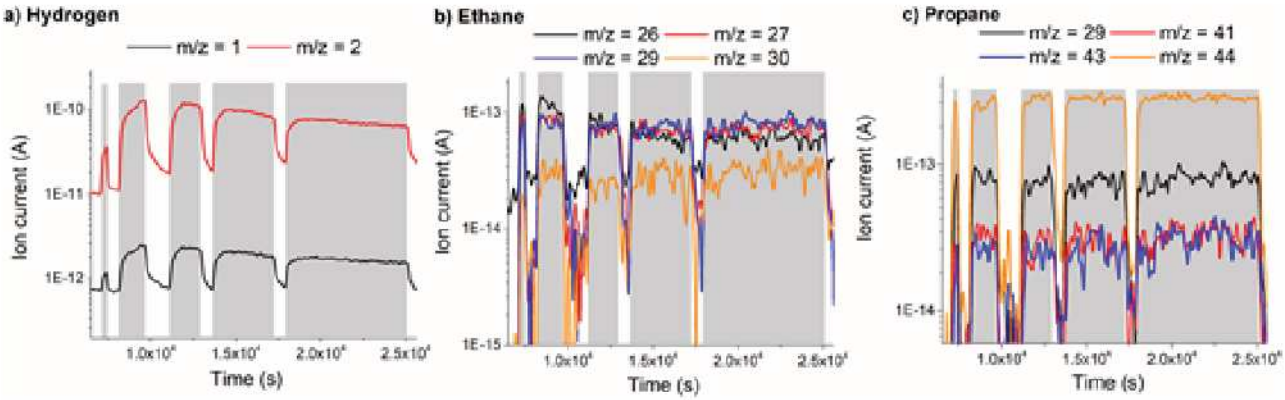
Hydrogenation of C atoms on dust grain surfaces is expected to produce CHx radicals and, ultimately, methane, CH4. At the low temperatures found in the interior of dense clouds and circumstellar regions, along with H2O, CO, CO2, or CH3OH, the IR features of CH4 have been observed on icy dust grains. Ultraviolet (UV) photons induce different processes in ice mantles, affecting the molecular abundances detected in the gas-phase.

Pure CH4 ice samples were simulated and submitted to UV irradiation. We studied photon-induced processes for the different photoproducts arising in the ice upon UV irradiation. Photochemidesorption is a mechanism first detected in our group that accounts for inmediate ejection to the gas of photoproducts formed on the ice surface.

Direct photodesorption of pure CH4 was not observed. UV photons form CHx and H radicals, leading to photoproducts like H2, C2H2, C2H6, and C3H8. Evidence for the photodesorption of C2H2 and photochemidesorption of C2H6 and C3H8 is found, the latter species is so far the largest molecule found to photochemidesorb. The relative photon-induced desorption of these hydrocarbons in our experiment can explain their abundances measured in Pluto's atmosphere.

For more information:

Carrascosa, H; Cruz-Díaz, G.A.; Muñoz Caro, G. M.; Dartois, E.; Chen, Y.-J.; Photon-induced desorption of larger species in UV-irradiated methane ice. MNRAS, 493, 821-829 (2020).



Ion current measured by quadrupole mass spectrometry during the irradiation of a pure CH4 ice sample, proportional to the gas-phase abundance at any time, for the three main photoproducts formed from UV irradiation of CH4: hydrogen (H2), ethane (C2H6) and propane (C3H8). The constant rate measured for ethane and propane is indicative of a photochemidesorption mechanism. Grey areas represent the time lapse when the UV-lamp is turned on.

Thermal conductivity of salt-bearing ice analogs in Jovian moons to support future JUICE mission

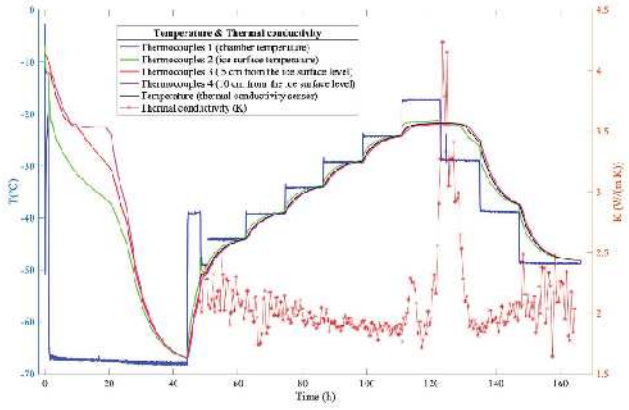
The future missions JUpiter ICy moons Explorer (JUICE, from ESA) and Europa Clipper (NASA) will be launched in the upcoming years to make detailed observations of the giant gaseous planet Jupiter and three of its largest moons: Ganymede, Callisto, and Europa. Thermal properties of frozen salt solutions are important to interpret the data from these missions due to the shortage of experimental measurements.

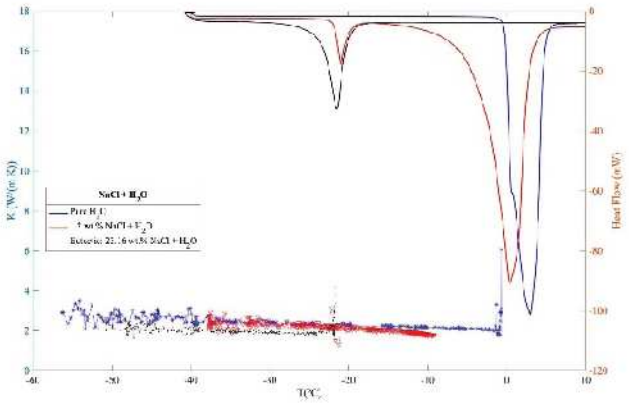
Consequently, we have conducted a set of experiments to measure and study the thermal conductivity and calorimetry of macroscopic frozen salt solutions as analogs of the Jovian moon surfaces, including Na-chloride (NaCl), Mg-sulphate ($MgSO_4$), Na-sulphate (Na_2SO_4), and Mg-chloride ($MgCl_2$).

A climatic chamber has been used to mimic the cryogenic conditions in the Jovian Icy Moons. Measurements were performed at atmospheric pressure and temperatures from 0 to -70ºC. Temperature and thermal conductivity were measured during the course of the experiments. A side effect of these measurements is that they served to spot phase changes in the frozen salt solutions. A small sample of the liquid salt-water solution was set aside for the calorimetry measurements.

These experiments and the measurements of thermal conductivity and calorimetry will be valuable to constrain the chemical composition, physical state, and temperature of the upper layers of the icy crusts of Ganymede, Callisto, and Europa. For more information: González-Díaz et al., 2020.

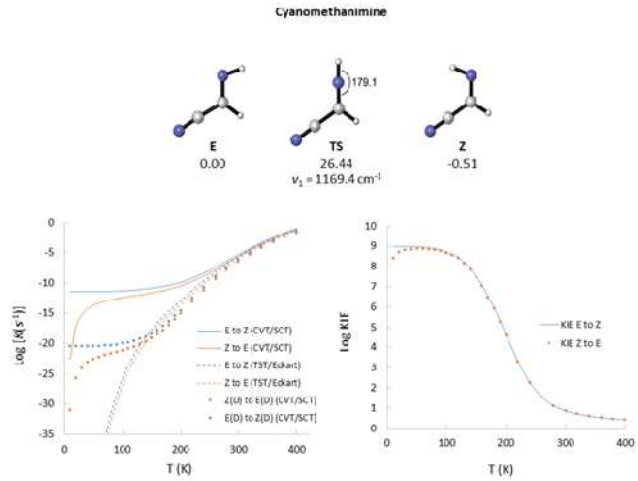
Left: Thermal conductivity and temperature values measured by thermocouples and thermal conductivity meter for eutectic (23.16 wt.%) NaCl + H2O ice as a function of time. Right: Thermal conductivities of water (H2O) and sodium-chloride (NaCl) with different molarities or concentration.





The origin of the E/Z isomer ratio of imines in the Interstellar Medium

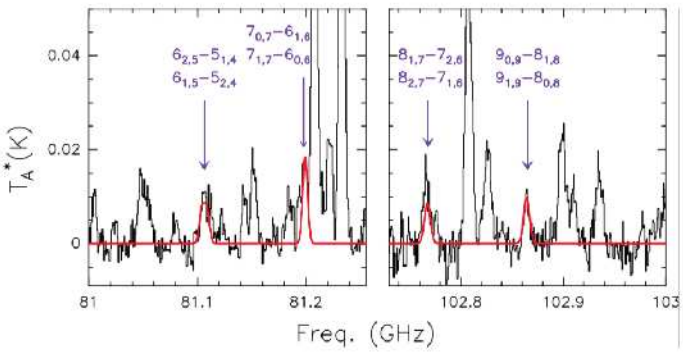
Recent astronomical observations of both isomers E and Z of imines such as cyanomethanimine, ethanimine and 2-propyn-1-imine, have revealed that the abundances in the ISM of these isomers differ by factors of ~3-10. Several theories have been proposed to explain the observed behavior, but none of them successfully explains the [E]/[Z] ratios. We investigated the kinetics of the one-step E-Z isomerization reactions of cyanomethanimine, ethanimine and 2-propyn-1-imine under interstellar conditions (in the 10-400 K temperature range). This reaction was previously thought to be non-viable in the ISM due to its associated high-energy barrier (about 13,000 K). We show that considering the multidimensional small curvature tunneling approximation, the tunneling effect enables the isomerization even at low temperatures. This is due to the fact that the representative tunneling energy lies in the vibrational ground state of the least stable isomer up to approximately 150 K, making the reaction constants of the isomerization from the least stable to the most stable isomer basically constant. The predicted [E]/[Z] ratios are almost the same as those reported from the astronomical observations for all imines observed. This study demonstrates that the [E]/[Z] ratio of imines in the ISM strongly depends on their relative stability. For more information: García de la Concepción et al. (in press).



Optimized geometries of the E, Z and TS stationary points for the cyanomethanimine. Plots of Log K(T) (rate constants) against T(K) for the E to Z isomerization (blue lines) and Z to E (orange lines) with the CVT/SCT (solid lines) and TST/Eckart (dashed lines). Dotted curves are Log K(T) against T(K) for the deuterated isotopologes of the imine. Plot of the kinetic isotope effect (KIE) against T (K) is also shown (down right).

Toward the RNA-World in the Interstellar Medium: Detection of Urea and Search of 2-Amino-oxazole and Simple Sugars

In the past decade, astrochemistry has witnessed an impressive increase in the number of detections of complex organic molecules. Some of these species are of prebiotic interest such as glycolaldehyde, the simplest sugar, or aminoacetonitrile, a possible precursor of glycine. In this study, we present deep and high-sensitivity observations toward two of the most chemically rich sources in the galaxy: a giant molecular cloud in the center of the Milky Way (G+0.693-0.027) and a proto-Sun (IRAS16293-2422 B). Our aim is to explore whether the key precursors considered to drive the primordial RNA-world chemistry are also found in space. Our high-sensitivity observations reveal that urea is present in G+ 0.693-0.027 with an abundance of ~5 × 10-11. This is the first detection of this prebiotic species outside a star-forming region. Urea remains undetected toward the proto-Sun IRAS16293-2422 B (upper limit to its abundance of ≤2 × 10-11). Other precursors of the RNA-world chemical scheme such as glycolaldehyde or cyanamide are abundant in space, but key prebiotic species such as 2-amino-oxazole, glyceraldehyde, or dihydroxyacetone are not detected in either source. Future more sensitive observations targeting the brightest transitions of these species will be needed to disentangle whether these large prebiotic organics are certainly present in space. For more information: Jiménez-Serra et al. 2020.



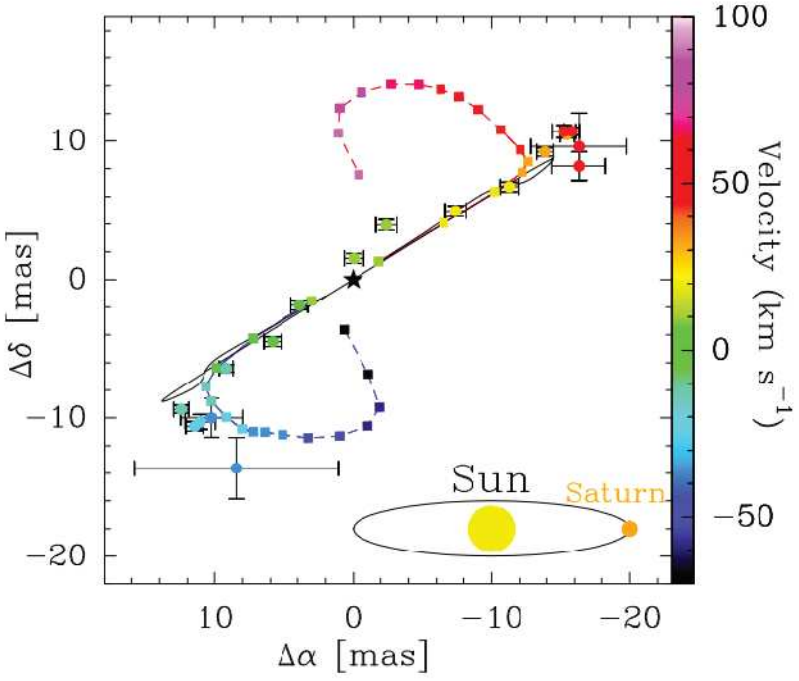
Clean rotational transitions of urea detected toward G+0.693-0.027 (in black). Red line indicates the spectrum of urea simulated with MADCUBA for a column density of (6.3±0.1)x1012 cm-2 , Tex=8K, Δv=20 km s-1 and VLSR=69 km s-1.

The Ionized Warped Disk and Disk Wind of the Massive Protostar Monoceros R2-IRS2 Seen with ALMA

Theories of massive star formation predict that massive protostars accrete gas through circumstellar disks. Although several cases have been found already thanks to high angular-resolution interferometry, the internal physical structure of these disks remains unknown, in particular whether they present warps or internal holes, as observed in low-mass protoplanetary disks. Here, we report very high angular-resolution observations of the H21α radio recombination line carried out in Band 9 with the Atacama Large Millimeter/submillimeter Array (beam of 80 mas × 60 mas, or 70 au × 50 au) toward the IRS2 massive young stellar object in the Monoceros R2 star-forming cluster. The H21α line shows maser amplification, which allows us to study the kinematics and physical structure of the ionized gas around the massive protostar down to spatial scales of ~1-2 au. Our ALMA images and 3D radiative transfer modeling reveal that the ionized gas around IRS2 is distributed in a Keplerian circumstellar disk and an expanding wind. The H21α emission centroids at velocities between -10 and 20 km s-1 deviate from the disk plane, suggesting a warping for the disk. This could be explained by the presence of a secondary object (a stellar companion or a massive planet) within the system. The ionized wind seems to be launched from the disk surface at distances ~11 au from the central star, consistent with magnetically-regulated disk wind models. This suggests a similar wind-launching mechanism to that recently found for evolved massive stars such as MWC349A and MWC922.

For more information:

Jiménez-Serra, I., Báez-Rubio, A., Martín-Pintado, J., Zhang, Q., Rivilla, V. M. 2020, ApJ Letters, 897L, 33J



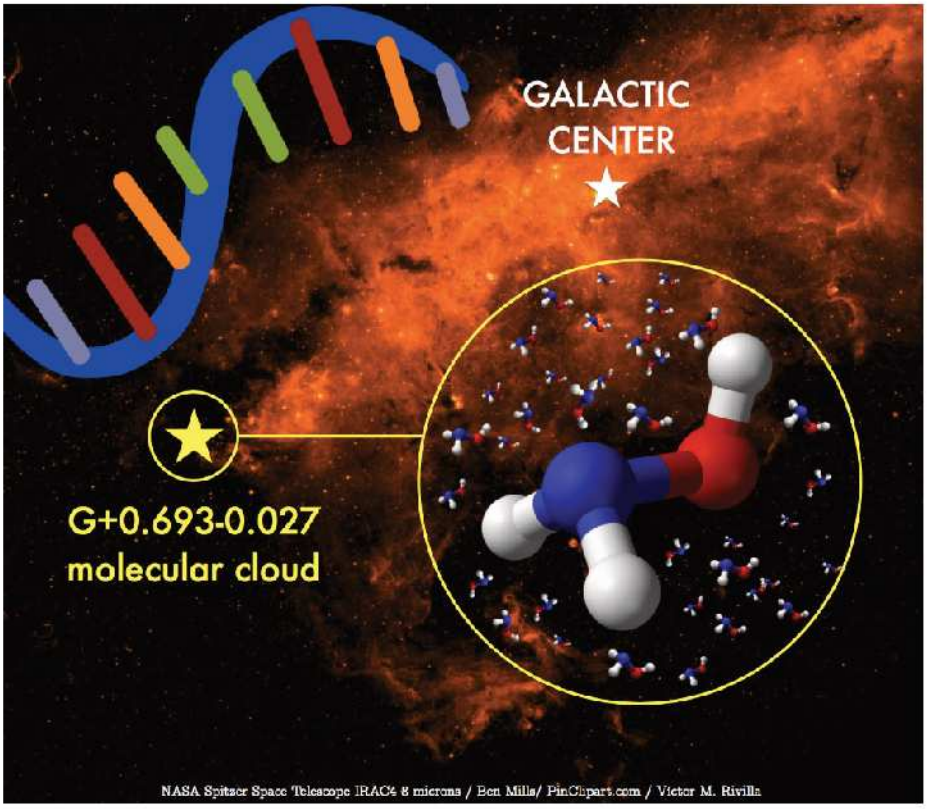
Centroid map of the H21alpha emission observed with ALMA toward the massive protostar MonR2-IRS2. The exquisite accuracy achieved with this technique allows us to unveil the physical structure of the source with an ionized warped disk and an ionised wind being launched from the disk.

Prebiotic Precursors of the Primordial RNA World in Space: Detection of NH2OH

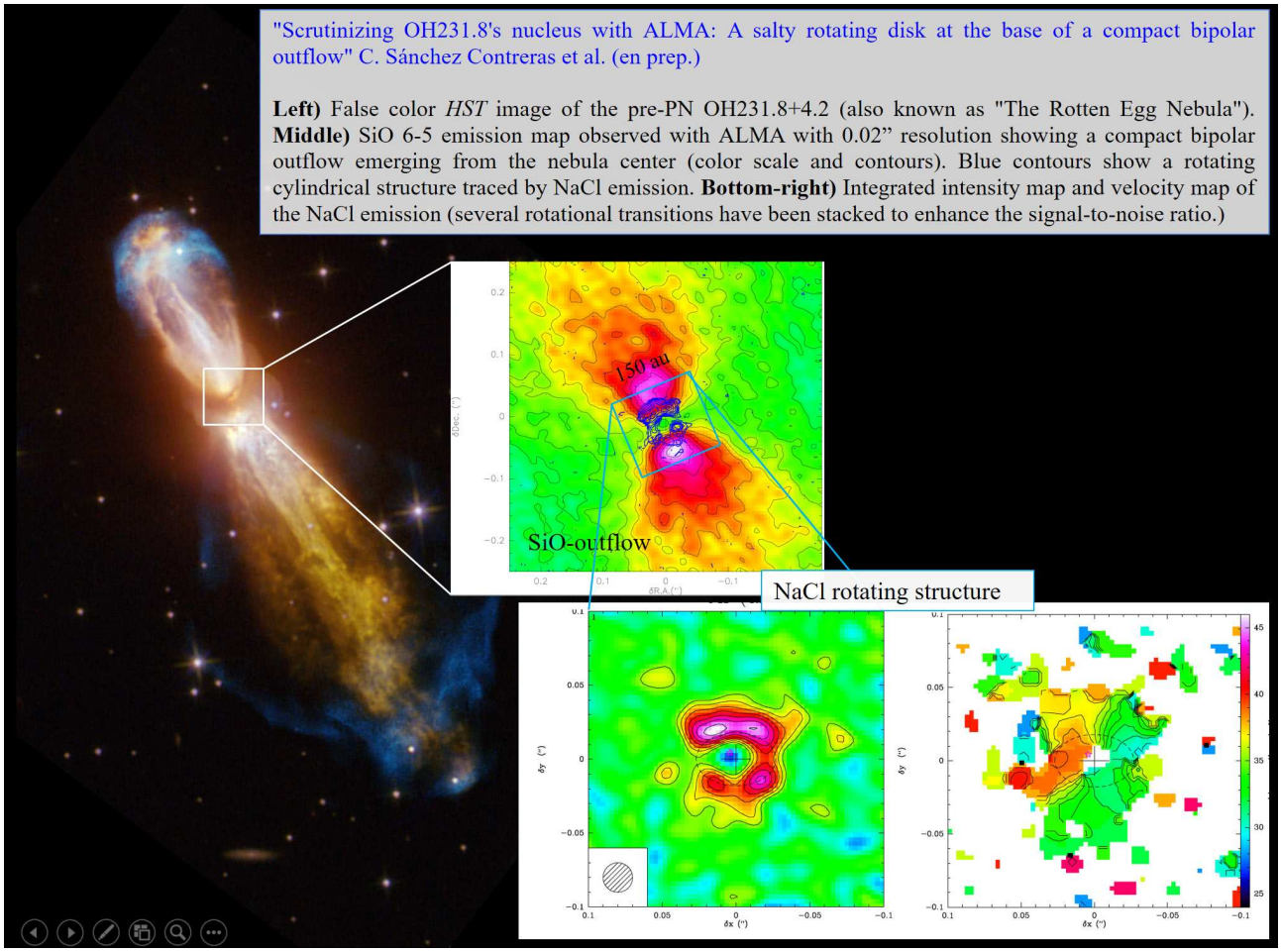
One of the proposed scenarios for the origin of life is the primordial RNA world, which considers that RNA molecules were likely responsible for the storage of genetic information and the catalysis of biochemical reactions in primitive cells, before the advent of proteins and DNA. In the last decade, experiments in the field of prebiotic chemistry have shown that RNA nucleotides can be synthesized from relatively simple molecular precursors, most of which have been found in space. An important exception is hydroxylamine, NH2OH, which, despite several observational attempts, it has not been detected in space yet. Here we present the first detection of NH2OH in the interstellar medium toward the quiescent molecular cloud G+0.693-0.027 located in the Galactic Center. We have targeted the three groups of transitions from the J = 2-1, 3-2, and 4-3 rotational lines, detecting five transitions that are unblended or only slightly blended. The derived molecular abundance of NH2OH is (2.1 ± 0.9) × 10^(-10). From the comparison of the derived abundance of NH2OH and chemically related species, with those predicted by chemical models and measured in laboratory experiments, we favor the formation of NH2OH in the interstellar medium via hydrogenation of NO on dust grain surfaces, with possibly a contribution of ice-mantle NH3 oxidation processes. Further laboratory studies and quantum chemical calculations are needed to completely rule out the formation of NH2OH in the gas phase.

For more information:

Rivilla, Víctor M.; Martín-Pintado, Jesús; Jiménez-Serra, Izaskun; Martín, Sergio; Rodríguez-Almeida, Lucas F.; Requena-Torres, Miguel A.; Rico-Villas, Fernando; Zeng, Shaoshan; Briones, Carlos, The Astrophysical Journal Letters, Volume 899, Issue 2, id.L28, 10.3847/2041-8213/abac55



Discovery of hydroxylamine (NH2OH), considered one of the essential building blocks of RNA ribonucleotides, towards the molecular cloud G+0.693-0.027. The background image was obtained with the Spitzer space telescope. Credits: Nasa Spitzer Space Telescope, camera IRAC4 (8 micron) / Ben Mills / PinClipart.com / Victor M. Rivilla (Centro de Astrobiología de Madrid, INTA-CSIC).



Scrutinizing OH231.8's nucleus with ALMA: A salty rotating disk at the base of a compact bipolar outflow"

We present maps of high angular resolution (~20mas) obtained with the ALMA interferometer of the molecular emission of the fast bipolar outflow OH231.8 + 4.2, a key object to understand the remarkable changes in nebular morphology and dynamics that take place during the brief transition between the AGB and the planetary nebula (PN) phase. Previous maps with ALMA of this object (Sánchez Contreras et al. 2018) revealed an extravagant variety of substructures that prompted us to reconsider the nebular formation scenarios proposed to date and improve the characterization of its central regions, where it is expected that the wind collimation mechanisms operate.

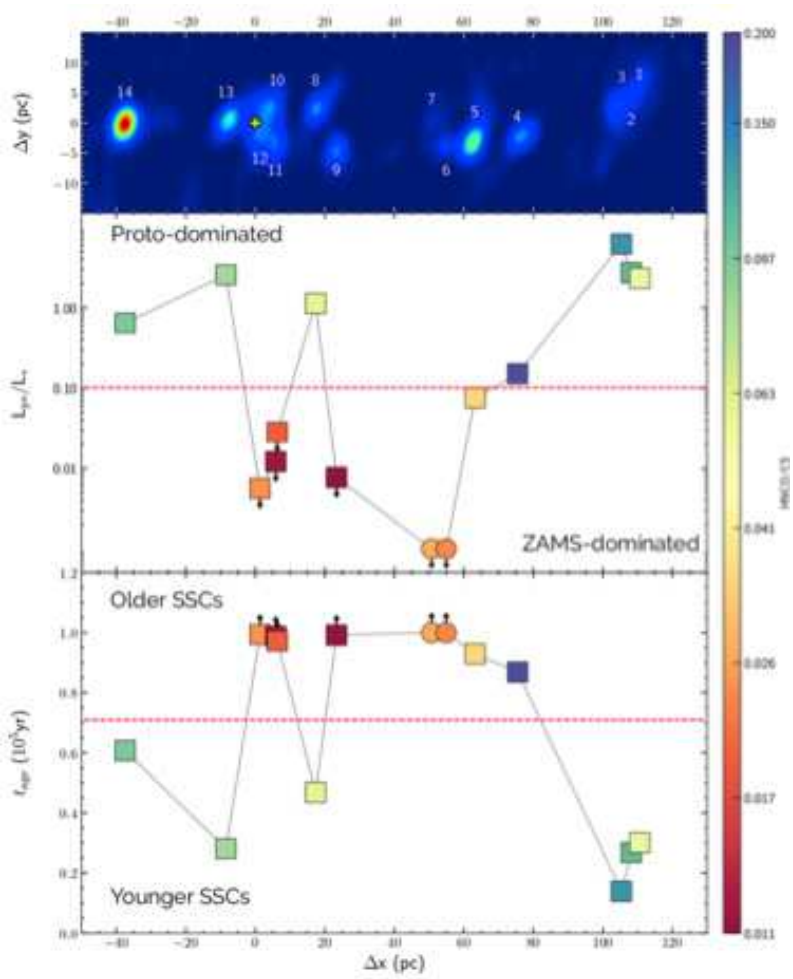
Our new ALMA observations, of the highest possible angular resolution with current instrumentation at (sub) millimeter frequencies, allow us to scrutinize the innermost circumstellar zones, ~30-100AU from the central Mira star, never mapped before. At the core, right at the base of a young bipolar jet (~ 50-100yr old), we have discovered and solved spatially and spectrally a rotating (and expanding) cylindrical structure. This constitutes the first direct observation of rotation in a 'standard' or pre-PN. This rotating structure is "invisible" in the maps of most of the observed species, and is only traced by salts (NaCl, KCl) and water, which indicates that these species are optimal (and so far unique) tracers of the much sought after, but elusive, rotating discs in pre-PNs with bipolar jets.

Super Hot Cores in NGC 253: Witnessing the formation and early formation of super star clusters

Using 0.2" ALMA images of HC3N vibrationally excited emission (HC_3N^*) we have revealed the presence of 8 unresolved Super Hot Cores (SHCs) in the inner 160 pc of the starburst galaxy NGC 253. Our LTE and non-LTE modelling of HC_3N^* indicate that the SHCs have high dust temperatures of 230-350 K and high IR luminosities of 0.2-2 x108 , all associated with young super star clusters (SSCs). Using the ratio between the luminosities derived from HC_3N^* (proto-star phase) and those derived from free-free emission (Zero Age Main Sequence phase, ZAMS phase) we have been able to establish the evolutionary sequence of the forming SSCs, finding that the most evolved SSCs are located, in projection, closer to the center of the galaxy than the younger proto-SSCs, suggesting an inside-out SSC formation scenario.

For more information:

Rico-Villas, F., Martín-Pintado, J., González-Alfonso, E., Martín, S., and Rivilla, V. M., MNRAS, vol. 491, no. 3, pp. 4573-4589, 2020, doi:10.1093/mnras/stz3347



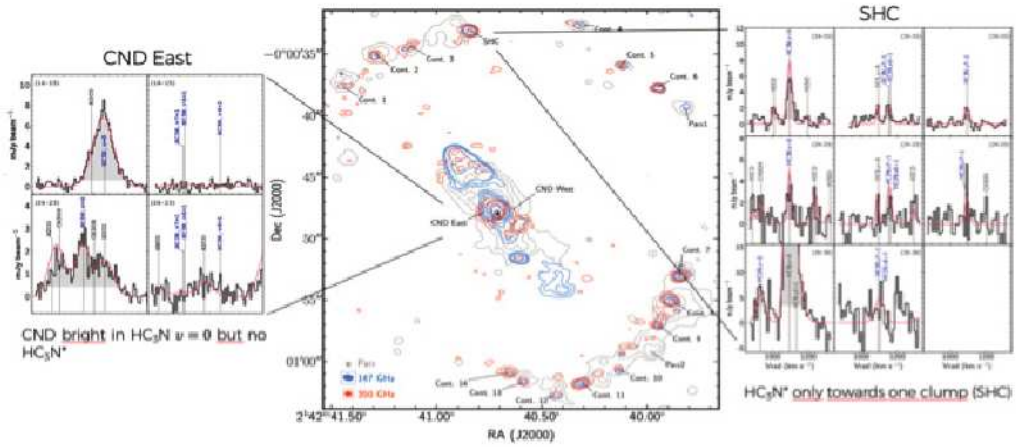
The top panel shows the rotated NGC 253 218 GHz continuum emission, with the numbers indicating the position of the SSCs. The middle panel shows the proto/ZAMS star luminosity ratio. The lower panel shows the age estimation for the SSCs.

HC_3N vibrationally excited emission as a tracer of star formation activity in NGC1068

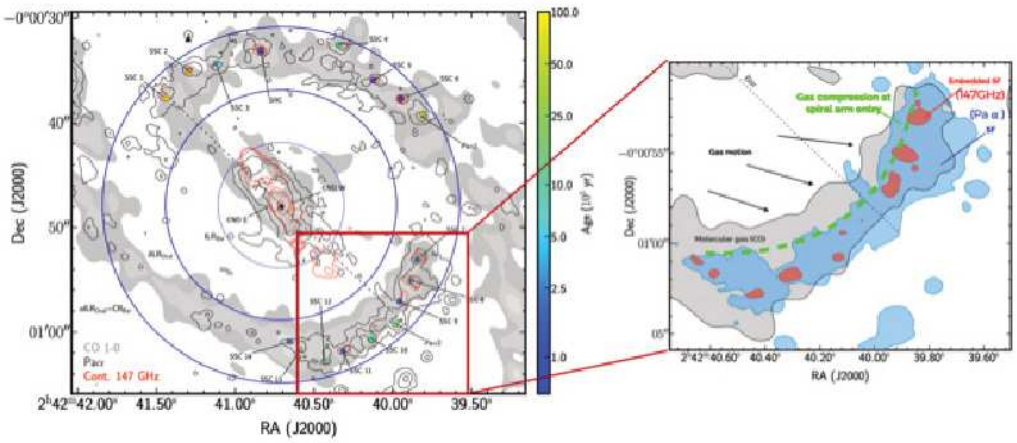
Using publicly available data from the ALMA archive, we have studied the HC_3N emission in the starburst ring (SB ring) and the circumnuclear disc (CND) of the SB/AGN composite Seyfert 2 galaxy NGC 1068. We have detected emission from vibrationally excited HC3N (HC_3N^*) in one of the clumps of the SB ring, revealing the presence of a Super Hot Core (SHC) where massive star formation is taking place. From our LTE and non-LTE modelling of the HC_3N^* emission we obtain a dust temperature of ~250 K in the SHC. For the other regions of the SB ring, the observations lack the sensitivity to detect HC_3N^*, where HC_3N column densities are ~1014 and dust temperatures of ~180-230 K. Remarkably , despite of intense HC3N emission from the vibrational ground state in the CND, no HC3N* emission was detected. We use the continuum emissions at 147 and 350 GHz, with CO and Pa α, to estimate the ages of another 14 SSCs in the SB ring, finding that the youngest SSCs are associated with the nuclear bar, supporting the scenario of sequential star formation triggered by gas inflow towards the bar. For the CND, our analysis yields Td ≤ 100 K. The very different dust temperatures found for the CND and the proto-SSC indicates that, while the dust in the proto-SSC is being efficiently heated from the inside by the radiation from massive stars, the CND is mainly heated externally by the AGN, which in the optically thin case can only heat the dust up to 56 K. We finally discuss the implications of the non-detection of HC3N * near the luminous AGN in NGC1068 on the interpretation of the HC3N * emission observed in the SB/AGN composite galaxies NGC 4418 and Arp 220.

For more information:

Rico-Villas, F., Martín-Pintado, J., González-Alfonso, E., Rivilla, V. M., Martín, S., García-Burillo, S., Jiménez-Serra, I., and Sánchez-García, M., MNRAS, vol. 502, no. 2, pp. 3021-3034, 2021, doi: 10.1093/mnras/stab197



Central region of NGC 1068. The continuum and Pa α brightest clumps are indicated in the central panel along the SHC position. Blue and red contours indicate the 147 and 350 GHz continuum emission and grey contours the Pa α emission. The left panel shows the spectra (in black) and LTE model (in red) for the CND East position, with no HC3N* emission. The right panel shows the spectra (in black) and LTE model (in red) for the SHC position.



The left panel shows the continuum 147GHz emission (in red), the Pa α emission (in black) and the CO 1-0 emission (in grey) in NGC 1068. The colored circles indicate the position and estimated age of the SSCs in the SB ring. The right panel shows the expected star formation sequence inside corotation: the molecular gas enters the spiral arm, where it starts to be accumulated and compressed and then star formation is triggered, with the youngest star formation still embedded inside their natal molecular clouds.

Virtual Observatory: Scientific Exploitation Of Astronomical Archives

Coordinator: Enrique Solano Márquez

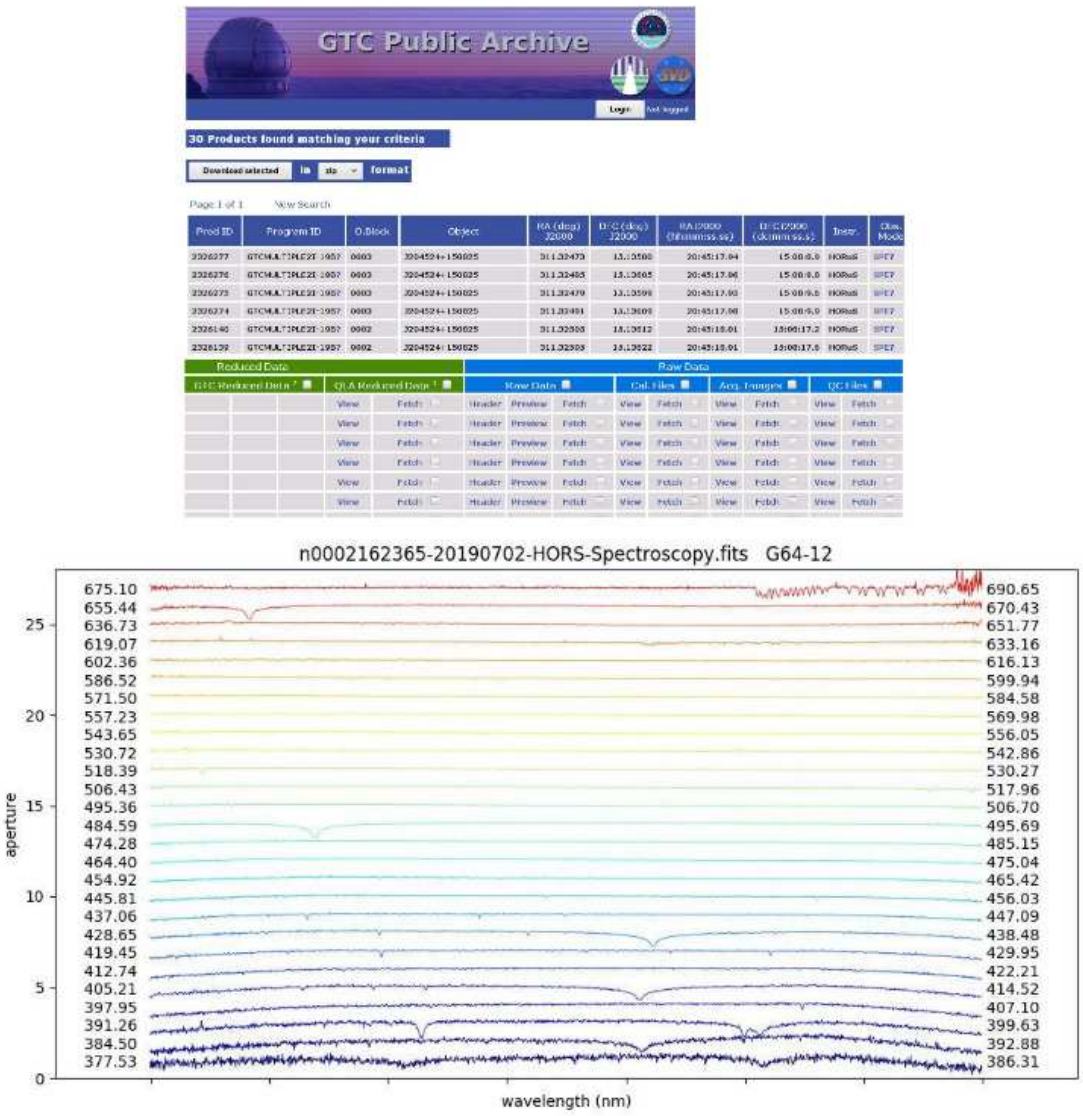
Members	Category
Alacid Polo, José Manuel	ISDEFE
Aller Egea, Alba	Contratada "Atracción de Talento" CAM
Cortés Contreras, Miriam	Contratada proyecto H2020 ESCAPE
Cruz Gamba, Patricia	Contratada "Atracción de Talento" CAM
García Almudena	ISDEFE
Jiménez Esteban, Francisco	Contratado proyecto H2020 ESCAPE
López Martí, Belén	Contratada EXPRO ESA (since Jun 2020)
Rizzo, Ricardo	ISDEFE
Rodrigo Blanco, Carlos	Contratado
Solano Márquez, Enrique	Investigador Científico OPI/INTA
Velasco Trasmonte, Almudena	ISDEFE

Generation of high level data products for VO compliant archives

The long-term activity of integrating science-ready data in the VO archives developed and maintained at CAB has been significantly boosted in 2020, as is detailed below.

GTC Archive:

• Implementation of the HORuS pipeline and the subsequent reduction of more than 700 HORuS observations.



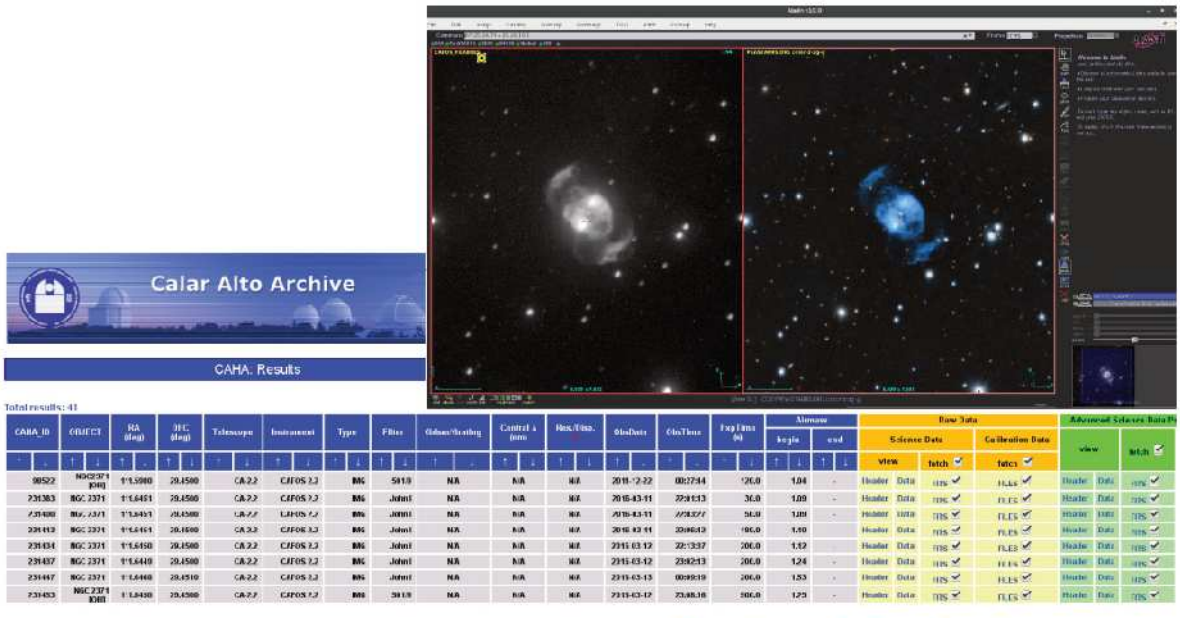
Visualisation an HORuS reduced spectra available from the GTC archive.

Calar Alto Archive:

• First release of CAFE reduced spectra: More than 3600 spectra covering the period 2013-2019 are now available from the Calar Alto archive. The spectra were reduced using the pipeline developed by Lillo-Box et al. (2020). The pipeline is now part of the archive so that new CAFE observations are

Result of a query in the Calar Alto archive. Access to CAFE reduced spectra is given in the columns in green.

• Implementation of the FILABRES pipeline. More than 40000 instrumentally and astrometrically corrected images taken with the CAFOS instrument from 2008 to 2019 are now available at the Calar Alto archive.



Result of query in the Calar Alto archive showing a reduced CAFOS image.

Virtual Observatory tools

In 2020 our group has continued working on the field of VO tools and services. New functionalities and data have been added to the already existing tools, and new tools have been developed.

• Implementation of new functionalities in VOSA[1] VOSA is a VO tool to estimate physical parameters of thousands of stars by comparing their spectral energy distribution with theoretical models. VOSA is a robust and well-tested tool as demonstrated by the fact that more than 2600 users have analysed almost 10 000 000 objects and have published more than 200 refereed papers making use of it. Among the new functionalities, we highlight the access to the new Gaia catalogue (EDR3, released in December 2020).

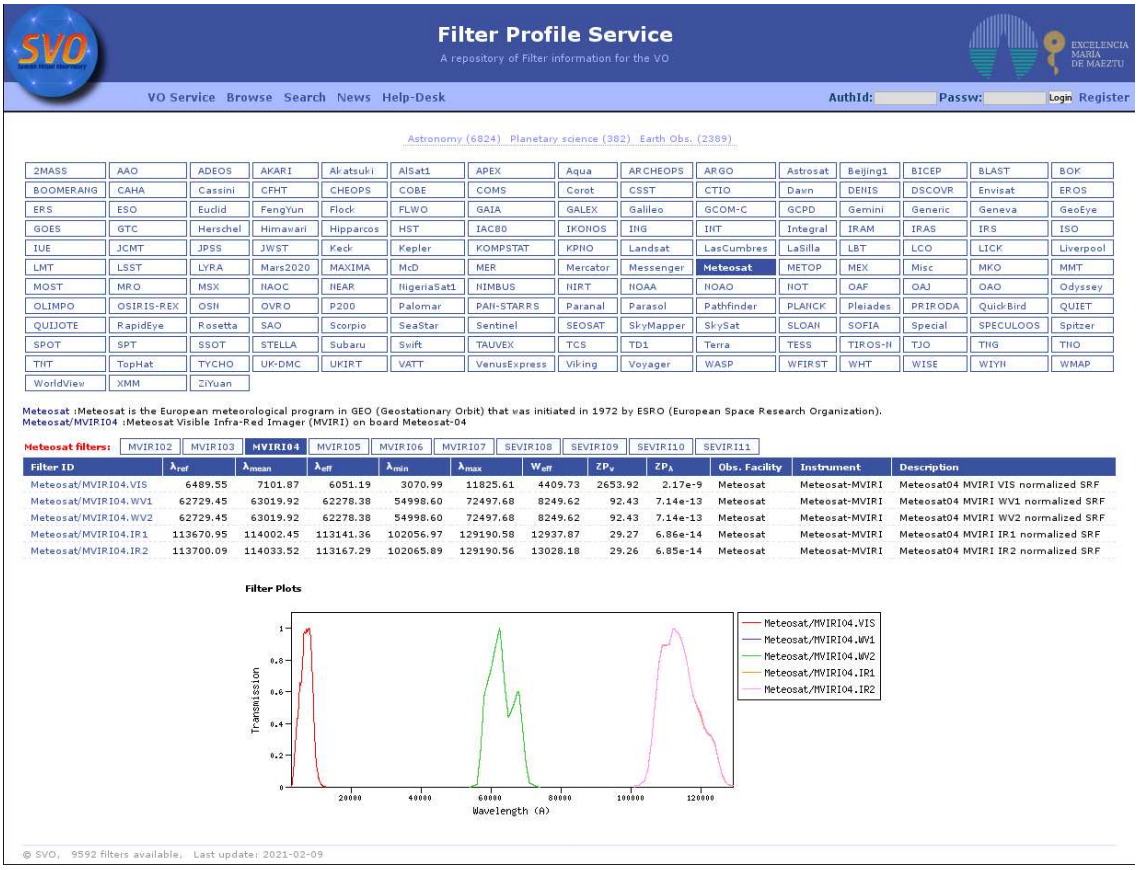
1. INTRODUCTION

In the era of database astronomy, the construction of spectral energy distributions (SEDs) from the ultraviolet to the mid-infrared for large samples of stars is straightforward, requiring little user-input or effort. Modern tools such as the VO SED Analyzer (Bayo et al. 2008) can even detect infrared excesses for thousands of candidates at a time in a completely automated fashion.

Extracted from Dennihy et al. (2020), it highlights the importance of VO tools like VOSA for the efficient management of large datasets.

• Ingestion of new filters in the SVO Filter Profile Service. In 2020, the service has been adapted to also include photometric information from planetary science and Earth observation missions. At present, the Filter Profile Service provides access to 9595 filters (6824 for astronomy, 382 for solar system and 2389 for Earth observation).

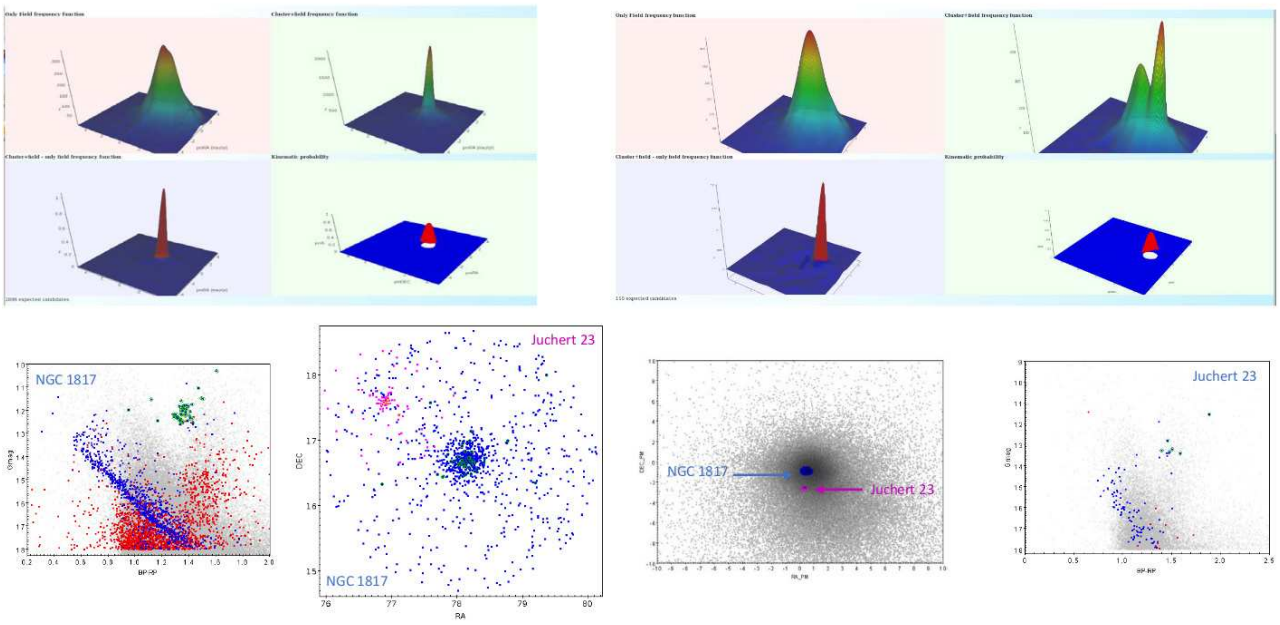
Screenshot of the information available at the Filter Profile Service on the Meteosat filters



• New release of SVOCat. SVOCat is an application intended to simplify the process of publishing an astronomical catalogue, both as a web page and as a Virtual Observatory ConeSearch service. A new version to work with catalogues without astronomical coordinates was developed in 2020.

Template of the catalogue generated using the new version of SVOCat.

• First release of Clusterix: Clusterix is a new VO tool described in Balaguer-Núñez et al. (2020) that computes the membership probability of a list of objects to a given cluster. Its official release took place in February 2020.

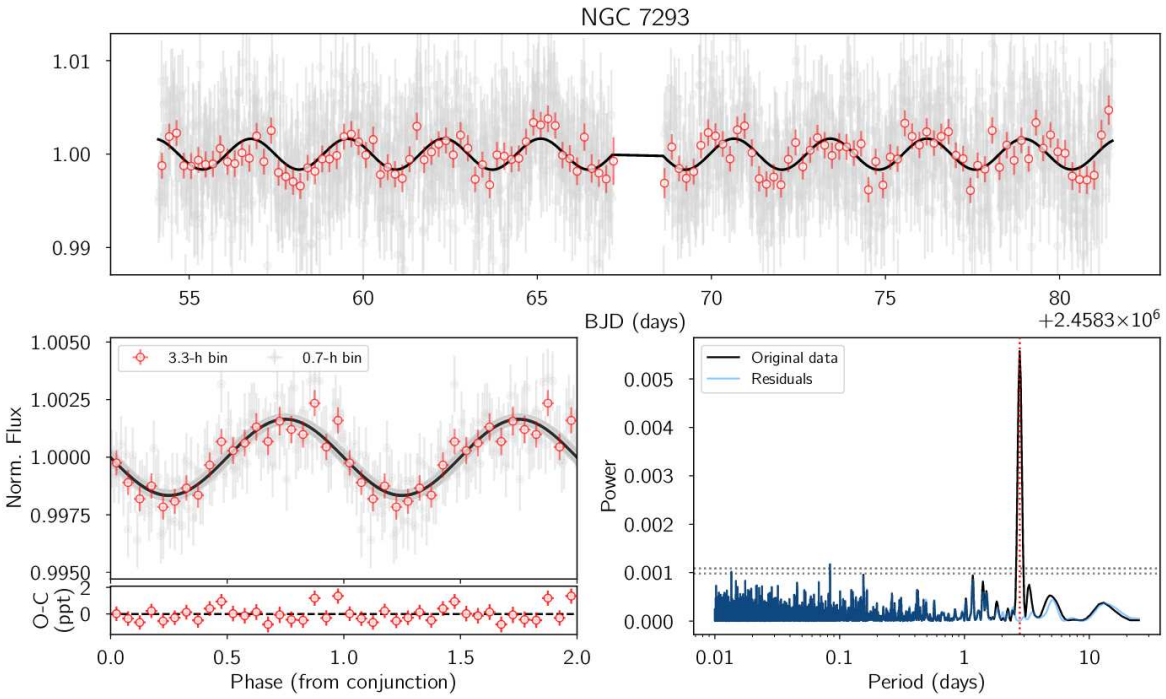


An example of the Clusterix output.

Planetary nebulae seen with TESS: Discovery of new binary central star candidates from Cycle 1. (Aller et al. 2020)

It has become clear in recent years that binarity plays a crucial role in many aspects of planetary nebulae (PNe), particularly with regard to the striking morphologies they exhibit. To date, there are nearly 60 known binary central stars of PNe (bCSPNe). However, both theory and observation indicate that this figure represents only the tip of the iceberg, with the Galactic PN population hosting orders of magnitude more stars. New discoveries of bCSPNe and their characterization carry important implications not only for understanding PN evolution but also for studying binary evolution and the common-envelope phase, which is still poorly understood.

Data from the TESS satellite were used to search for variability in eight CSPNe. All the CSPNe but one show clear signs of periodic variability. The cause of this variability can be attributed to different effects, some of them requiring the presence of a companion star. Simple sinusoidal modulations were found in several of the systems, compatible with irradiation effects. In addition, two of the central stars (PG 1034+001 and NGC 5189) also show photometric variations due to ellipsoidal variations and other signs of variability that are probably caused by star spots or relativistic Doppler-beaming. The case of the Helix Nebula is of particular interest as the variability pattern constrains the possible companion to be a very low-mass main-sequence star or a sub-stellar object.



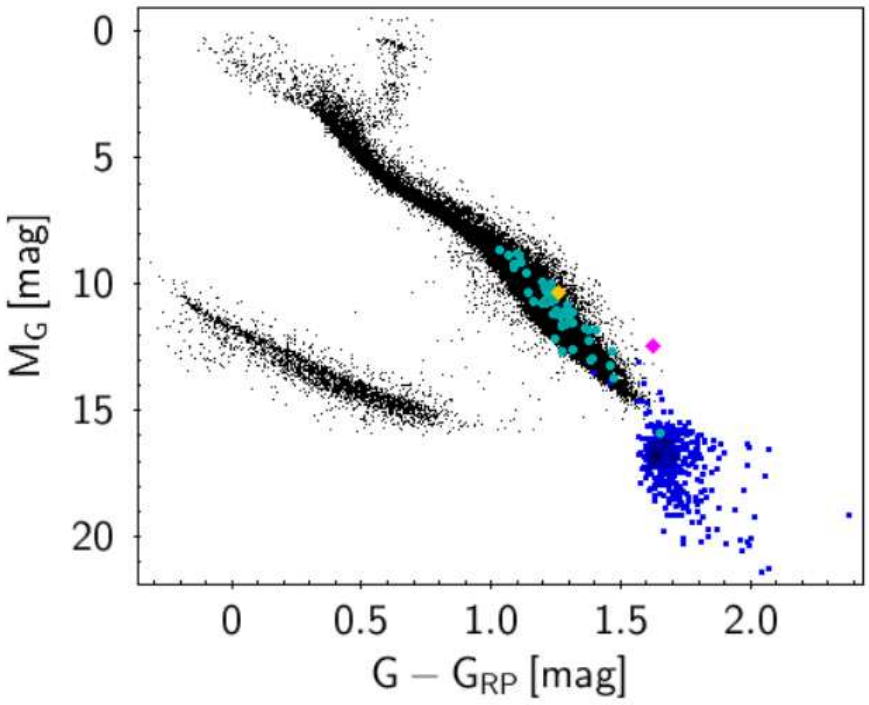
Time-flux light curve (top), phase-folded light curve (bottom left) and periodogram (bottom right) of the Helix Nebula. Two different bin sizes are shown with red and grey circles, respectively.

The Gran Telescopio Canarias OSIRIS Broad Band First Data Release

In order to optimize the scientific exploitation of the Gran Telescopio Canarias archive, the first release of the GTC OSIRIS Broad Band reduced images was made public. It includes 6788 astrometrically and photometrically images in the Sloan *griz* filters obtained between April 2009 and January 2014. The associated catalogue contains 6.23 million detections of more than 630 000 unique sources.

The catalogue contains standard PSF and Kron aperture photometry with a mean accuracy better than 0.09 and 0.15 mag, respectively. The relative astrometric residuals are always better than 30 mas and better than 15 mas in most cases. The absolute astrometric uncertainty of the catalogue is of 0.12 arcsec. This work describes the procedure followed to build the image archive and the associated catalogue, as well as the quality tests carried out for validation.

The scientific potential of the catalogue was demonstrated with two pilot projects aimed at the discovery and characterization of asteroids and cool dwarfs. 141 unknown asteroids were reported for the first time while two new K+L and M+L binary systems were also discovered.



Colour-magnitude diagram using GaiaDR2 sources with parallaxes larger than 10 mas (black dots). Light blue filled circles represent our 48 single dwarf candidates later than M0, yellow filled diamond represents the M type secondary belonging to the K+M close binary and the magenta filled diamond stand for the M+L close binary system. L and T dwarfs with Gaia Counterparts identified in Smart et al. (2017) are displayed with dark blue dots

Other results

Contract with external agencies (ESA)

• The Gaia Catalogue of OH/IR Stars

Under contract with the European Space Agency, we are currently creating a catalogue of OH/IR stars with reliable parallax measurements as provided by ESA's Gaia mission. By combining accurate distance estimations with evolutionary models of AGB stars, fundamental physical parameters, such as luminosities, mass-loss rates, and progenitor main-sequence masses can be derived. The catalogue will provide a means to test the progenitor masses of a larger sample of OH/IR stars, becoming a benchmark for further studies in the field.

The delivery of the first public version of the catalogue is foreseen by the end of March 2021. The project started in June 2020. Following the planned working schedule, the first two tasks were completed before the end of the year:

The first task was the creation of an internal version of the catalogue with the source counterparts in the AllWISE, 2MASS and Gaia DR2 catalogues. This first internal catalogue version, together with an explanatory technical note, was delivered to ESA in September 2020. The Gaia data were updated later in December 2020, when the Gaia EDR3 catalogue was released.

The second task consisted in the compilation of multi-wavelength photometry from different catalogues-publicly available through the Virtual Observatory, which was used to construct the spectral energy distributions (SED) of the stars with unprecedented coverage. Using the Gaia distance estimations, these SEDs were fitted with evolutionary models of AGB stars, in order to estimate the bolometric fluxes and luminosities of the sources. A second internal version of the catalogue, including all the additional photometry and the physical parameters, was delivered in December 2020, together with the corresponding technical note.

• Virtual Observatory schools go virtual.

Since 2009 the Spanish Virtual Observatory group has been actively participating in the organisation of Virtual Observatory (VO) schools both at national and European level. These schools have two goals: to expose participants to VO tools and services, so they can efficiently use them for their research and to gather feedback and requirements for VO tools and services and the schools themselves from the participants.

Due to the current pandemic situation, the schools were moved online. Three schools were organised in November-December 2020 with an attendance of up to 60 participants in a single school, a quite relevant number taking into account that "physical" schools were limited to 40 participants at most. All schools had an important practical component, with hands-on sessions and presentations held via Zoom. Slack was used as an asynchronous forum for questions, informal interaction among participants, and discussing other aspects of the VO and the school. We did not observe a negative impact on the follow-up of the tutorials nor the communication with the participants. On the contrary, we noticed even more interaction between students and tutors compared to a face-to-face school, perhaps because we all attempted to supply the lack of eye contact. In the three schools the participants' feedback was very positive. This challenging experience has taught us new ways of spreading the VO knowledge, opening new opportunities for dissemination and reaching a broader audience (MsC astrophysics students at national level, astronomical amateur community, contact with Latin-America universities,...). In fact, the XIX SVO school was the first school organised outside Europe.

In parallel to this, during the Spring 2020 lockdown, two online tutorials describing the use of VO tools were also conducted. these tutorial are now publicly available in the CAB YouTube channel.

Links to the schools

• XVII SVO School. Universidad Complutense. Madrid . November 2020
• XVIII SVO School. Universidad Autónoma Madrid. December 2020
• XIX SVO School. Brazilian Astronomical Society. December 2020

Links to the online tutorials

• Aladin (>600 visualisation until February 2021).

• TOPCAT (>200 visualisations until February 2021).

Education and Outreach

• Activities during the lockdown: *Astronomía desde el sofá. "Asteroides: ¿Qué son y cómo identificarlos desde casa con el Observatorio Virtual"*. Description of our citizen science projects on the discovery of near Earth asteroids in astronomical images using the VO.

• Our citizen science project on asteroids was selected by the Universidad de Valparaíso (Chile) among the activities to be carried out during the Asteroid Day.

• Women promotion in STEM

• Proyecto Astrominas (P. Cruz)

• Proyecto Girls inSpace, as part of the UNOOSA programme "Space4Women". (P. Cruz)

• Día Internacional de la mujer y la niña en ciencia. IES Joaquín Rodrigo. Vicálvaro, Madrid. 12 feb 2020. (A. Aller, M. Cortés).

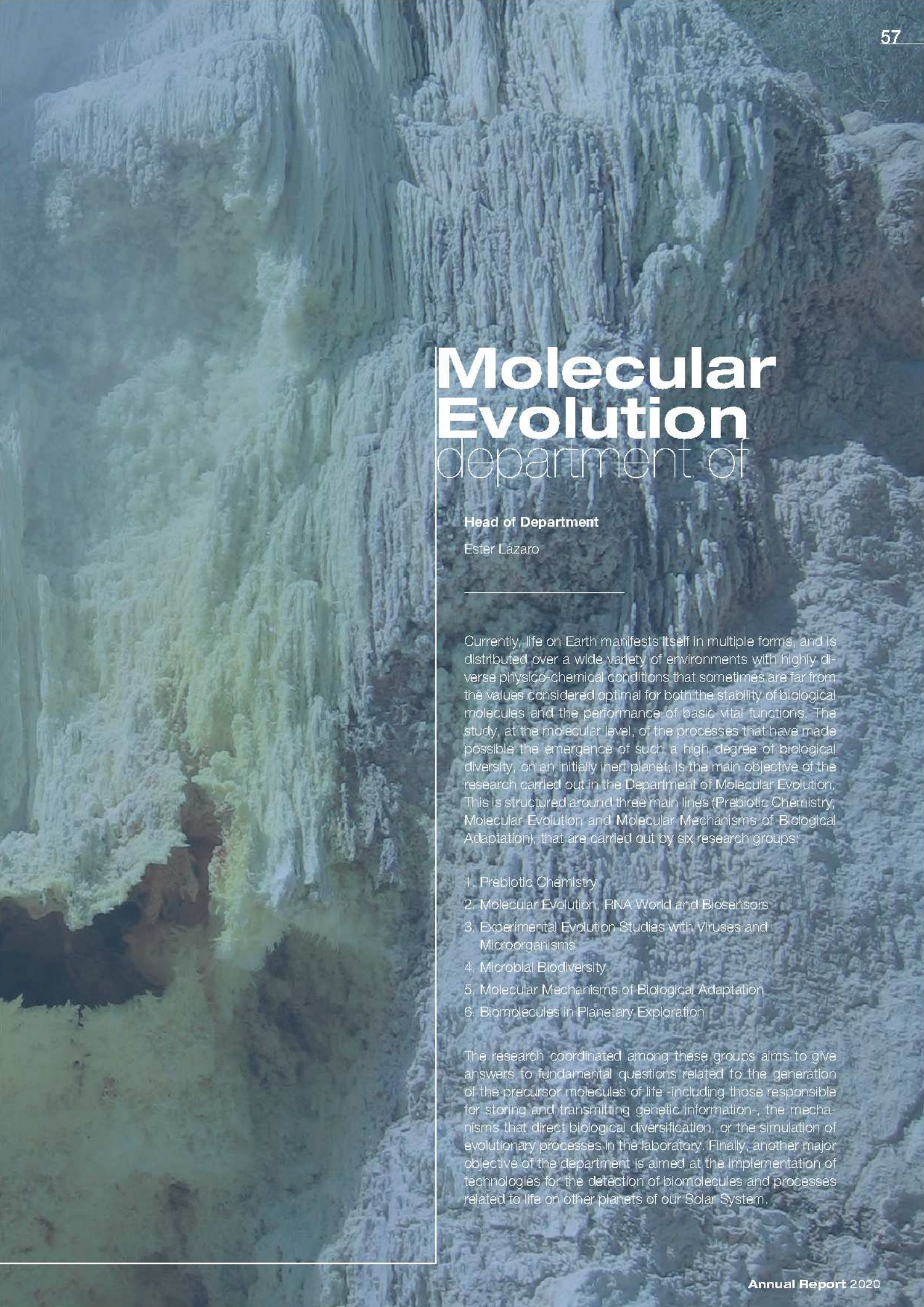
• "Chatea con una astrónoma" 20 feb 2020 (A. Aller)

• Press releases:

• *"Estudiando nebulosas planetarias con el telescopio espacial TESS"* (A. Aller)

• The Virtual Observatory on the cover of the magazine "Astronomía"

Catarata de azufre.
Crédito: Miriam García Villadangos



Molecular Evolution
department of

Head of Department

Ester Lázaro

Currently, life on Earth manifests itself in multiple forms, and is distributed over a wide variety of environments with highly diverse physico-chemical conditions that sometimes are far from the values considered optimal for both the stability of biological molecules and the performance of basic vital functions. The study, at the molecular level, of the processes that have made possible the emergence of such a high degree of biological diversity, on an initially inert planet, is the main objective of the research carried out in the Department of Molecular Evolution. This is structured around three main lines (Prebiotic Chemistry, Molecular Evolution and Molecular Mechanisms of Biological Adaptation), that are carried out by six research groups:

1. Prebiotic Chemistry
2. Molecular Evolution, RNA World and Biosensors
3. Experimental Evolution Studies with Viruses and Microorganisms
4. Microbial Biodiversity
5. Molecular Mechanisms of Biological Adaptation
6. Biomolecules in Planetary Exploration

The research coordinated among these groups aims to give answers to fundamental questions related to the generation of the precursor molecules of life -including those responsible for storing and transmitting genetic information-, the mechanisms that direct biological diversification, or the simulation of evolutionary processes in the laboratory. Finally, another major objective of the department is aimed at the implementation of technologies for the detection of biomolecules and processes related to life on other planets of our Solar System.

Prebiotic Chemistry

Coordinator: David Hochberg

Members	Category
Marta Ruiz Bermejo	Científica Titular de OPIS
Pedro Rayo Pizarroso, personal laboral	co-dirección Eva Mateo y Marta Ruiz
Jorge Vega Fernández	estudiante de grado (TFG)
Eva Mateo Martí	Investigadora Científica de OPIS
Eduardo Cueto Diaz	Postdoctoral Atracción de Talento CAM
Laura Jiménez Bonales	Postdoctoral María de Maeztu
Santos Gálvez Martínez	Estudiante Doctorado
Natalia Blanco García	Estudiante de TFG
David Hochberg	Investigador Científico de OPIS

We focus on the study of the critical aspects prior to the origin of life itself, such as the origin of biological homochirality, the first catalytic polymers, and the self-organization of biomolecules on surfaces. In our group we deal with prebiotic chemistry as the first step towards the emergence of life; as it encompasses all the natural physico-chemical processes that occur within a given planetary environment starting from its formation, up until the emergence of the first self-replicating systems upon which Darwinian evolutionary processes and selection can begin to operate.

Four main unsolved problems define the subjects of our research: (1) The abiotic origin of the important chemical precursors of life such as amino-acids and the simple sugars, and how they combine leading to abiotic oligomers and polymers with new functional properties (e.g., catalyzers, metabolic functions, etc.), (2) The origin of homochirality of all the actual bioorganic compounds (it is currently accepted that it is impossible to construct any self-replicating systems using a mixture of enantiomeric compounds, this necessarily leads to its prebiotic origin), (3) The supramolecular association of the complex molecules generated, such as vesicle formation, membranes, etc. and (4) Molecular self-assembly, interactions and reactivity on surfaces. Underlying all these topics are the theoretical/foundational aspects of prebiotic chemistry and chiral symmetry breaking and amplification. This activity is devoted to the study of autocatalytic reaction systems, chemical self-replicating systems, and chiral symmetry breaking systems, as precursors to the origin of biological homochirality. Related topics of study include the conditions imposed by non-equilibrium thermodynamics on far from equilibrium systems, and entropy production aspects of molecular mirror symmetry breaking and the general evolution criterion applied to chemical reaction networks.

Scientific Highlights

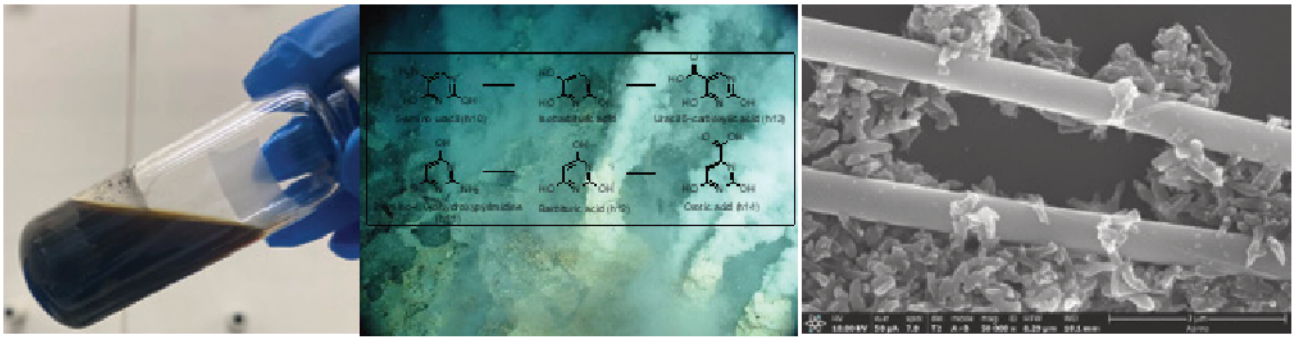
Marta Ruiz Bermejo

The HCN aqueous chemistry in hydrothermal systems and icy environments

Hydrogen cyanide, HCN, is considered a fundamental molecule in chemical evolution, being a ubiquitous compound in the Universe. HCN can be considered as a prebiotic reagent since could be available in adequate concentrations on the primitive Earth, or elsewhere, and it could lead to the formation of other more complex molecules by compatible reactions with the geochemical and geophysical constraints of a particular planetary or interstellar environment. More than fifty years ago, J. Oró claimed the first prebiotic synthesis of adenine (a nucleobase) from refluxed solutions of concentrated ammonium cyanide. Since then, HCN oligomerization/polymerization has been considered as a preferential prebiotic route for the synthesis of purines and pyrimidine derivatives. Currently, we know that the HCN-derived polymers are not only precursors of important biomonomers and related compounds but that they can have photocatalytic, anticorrosive and re-dox properties and to present 2D structures, in addition to being biocompatible compounds, which offers completely unexplored new perspectives in prebiotic chemistry but also in materials science.

On the other hand, it is widely accepted that hydrothermal systems could be excellent niches for the generation of complex organic chemistry, which ultimately triggered the appearance of ancient biochemistry on early Earth. Likewise, these hydrothermal systems have a high interest in planetary exploration as astrological objectives, given their direct relationship with the potential habitability of the frozen moons of the Solar System due to the possible existence in them of liquid water suboceans with hydrothermal activity. Nevertheless, several experiments have shown that high temperatures and pressures could be adverse to the stability of organic molecules. Thus, it is necessary to carry out systematic experiments to study the synthesis, stability and fate of organic molecules in hydrothermal scenarios. In a first work, we performed experiments focused on the stability and fate of HCN under a simple hydrothermal system scenario: the thermolysis of HCN at 100°C, at acidic and basic pH and in the presence of Mg-montmorillonite. Furthermore, we analyzed the products from HCN thermolysis and highlighted the role of these chemical species as prebiotic molecules under a hydrothermal scenario. This approximation about the role of the HCN thermolysis process in the formation of organic molecules suggests that surroundings of hydrothermal environments (<100°C), such as subaerial alkaline environments, could have been an import source of free organic compounds on early Earth. In a second work, we synthesized an HCN-derived thermal polymer simulating an alkaline hydrothermal environment (i.e., HCN (l) 0.15 M, 50 h, 100º C, pH approximately 10) and characterized its chemical structure, thermal behavior, and the hydrolysis effect. Elemental analysis and infrared spectroscopy suggest an important oxidation degree. The thermal behavior indicates that the polymer is more stable compared to other HCN-derived polymers. The mass spectrometric thermal analysis showed the gradual release of several volatile compounds along different thermal steps. The results suggest a complicate macrostructure formed by amide and hydroxyl groups, which are joined to the main reticular chain with conjugated bonds (C=O, N=O, –O-C=N). The hydrolysis treatment showed the pH conditions for the releasing of organics. In addition, a microwave reactor were used to simulated alkaline hydrothermal conditions. As a result, microwave radiation has a marked influence on NH_4CN polymerization, especially when the reactions are conducted in the absence of air, which is categorically demonstrated, as its efficiency is closely linked to the experimental conditions, probably due to relevant mechanistic variations associated with a singular kinetic behaviour. This fact leads to polymers whose structural and textural features can be tuneable, mainly according to XRD patterns and SEM analysis, when an innovative polymerization method is applied to this robust prebiotic reaction. These NH_4CN polymers have a rich organic chemistry and are precursors of several important bioorganics, such as amino acids, carboxylic acids, an elevated number of N-heterocycles, such as hydantoins, nucleobases, no canonical nucleobases of a possible *pre-RNA world*, and co-factors. Finally, their final properties indicate that they are suitable candidates for the development of new multifunctional materials. Thus, basic research in astrobiology inspires the development of novel materials and motivates the investigation of unexplored but promising HCN microwave-driven chemistry.

Beyond of the complex chemistry generated by the HCN in alkaline hydrothermal scenarios also it was proved that the HCN could increase the molecular complexity in icy environments. The effect of water freeze-thaw cycles, UV-radiation and salts on the polymerization of NH_4CN was explored as an approach to understand the possible organic chemistry of icy worlds. As a result, insoluble and soluble NH_4CN polymers, synthesized under multiple conditions, were analyzed by GC-MS. A diverse set of amino acids, carboxylic acids, and several N-heterocycles were identified. Glyoxylic acid was detected



The exploration of the aqueous HCN chemistry under simulated alkaline hydrothermal conditions lead to the generation of a widely set of organic molecules, some of them of importance in a pre-RNA worl, and also to the production of nanoparticles and nanofibers of interest for the development of multifunctional polymeric materials.

under particular reaction conditions, extending the plausible favorable conditions for the emergence of this molecule, referred to as the "glyoxylate scenario." In addition, the GC-MS results were studied by multivariate analysis, showing that the ice-water interfaces may be good places to develop complex organic chemistry from a carbon source as simple as cyanide.

Eva Mateo-Martí

Adsorption and reactivity of biomolecules on surfaces

The detailed study of molecule-substrate interactions is essential for elucidating the mechanisms in the formation of molecular structures and relevance for developing strategies to functionalize surfaces and developing organic-inorganic platforms for new devices. Mineral substrates are crucial in the prebiotic chemistry field and play a role for the preservation of molecules in planetary exploration. Therefore, iron pyrite (FeS_2) is a common mineral on Earth, which has also been found on the surface of Mars as well as on Martian meteorites. Pyrite has a highly reactive mineral surface that can catalyse reactions in chemical, geochemical and biological processes, having relevant implications for the iron-sulfur world hypothesis. In this context, we have studied the spectroscopic characterization of pyrite surfaces, modified by Ar+ ion sputtering with and without a successive annealing process, as well as its influence on the adsorption of the glycine amino-acid molecule. Ar+ ion sputtering leads to the selective sputtering of S lighter atoms by the generation of sulfur vacancies and metallic iron. We confirm that pre-treatment procedures have critical implications on the pyrite surface behavior. Annealing, sputtering and time evolution processes on the surface are crucial parameters for the resulting glycine final species adsorbed on pyrite surfaces. The defects have produced undercoordinated sites of S and Fe atoms (dangling bonds) that lead to the production of monosulfide sites and increases the molecular reactivity of the surface.

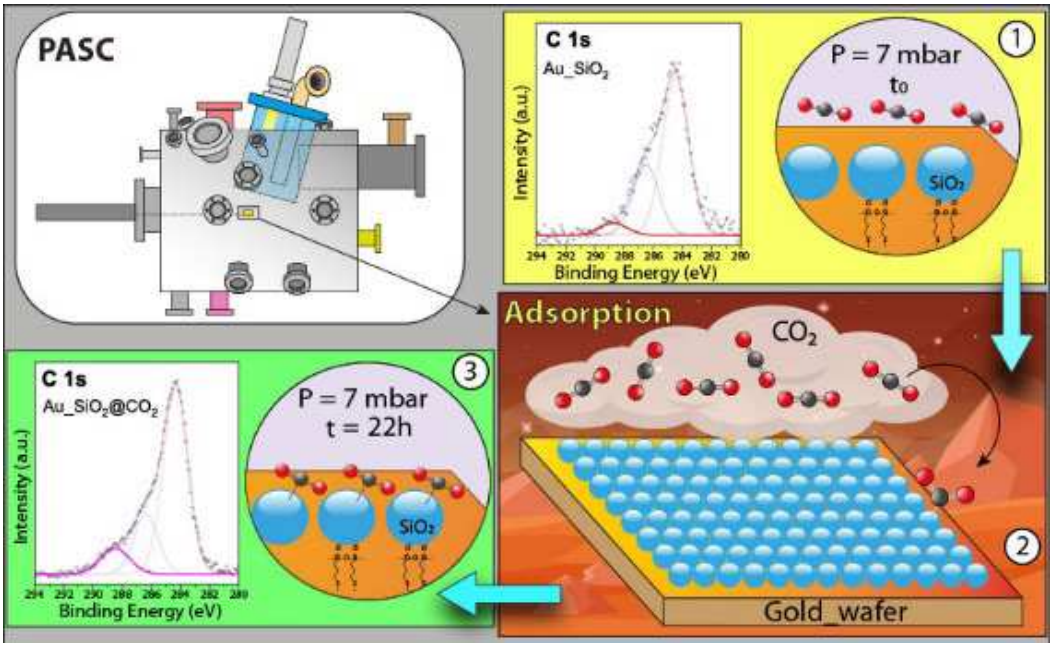
Furthermore, an XPS spectroscopy study was carried out, to understand the surface chemistry of the HCN-derived polymers on pyrite surfaces. As a result, the simulation of a plausible prebiotic alkaline hydrothermal environment led to the identification of a NH_4CN-based film with protective corrosion properties, preventing immediately the oxidation of the highly reactive pyrite surface. In addition, the effect as coating with antioxidant properties is preserved during a relatively long time and the polymeric film is undoubtedly stable against the ambient conditions. These results increase the great potential of HCN polymers for the development as a cheap and easily produced new class of multifunctional polymeric materials, but also show promising and attractive insights in prebiotic chemistry.

In addition, identifications of spectroscopic fingerprints corresponding to relevant molecular/minerals in Mars environments is a crucial search in Astrobiology. Therefore, we study the stability of $Gly.MgSO_4.5H_2O$ under Mars-like surface conditions, compared to the behaviour of epsomite and glycine. $Gly.MgSO_4.5H_2O$ has been identified as a molecule with astrobiologi-

cal interest since an amino acid and water molecules, which are essential for life, are part of its structure. Furthermore, this compound may form by interaction of sulphate minerals with glycine-bearing aqueous solutions, and both could be presents on Mars. The main analyses were performed by using *in situ* Raman spectroscopy, an upcoming ground-breaking technique for NASA and ESA Mars planetary missions. Raman spectroscopy has been set-up into the Planetary Atmosphere and Surfaces Chamber allowing us to successfully identify and compare the process occurring in molecules exposed to Mars simulated conditions: atmosphere, UV irradiation and temperature. Our results show that pressure is critical for provoking dehydration and amorphization of $Gly.MgSO_4 .5H_2O$ and release of glycine from a matrix compound; low temperature provides greater stability to $Gly.MgSO_4.5H_2O$ compared to glycine and epsomite individually. This strategy is designed to be able to evaluate by Raman spectroscopy how diverse Mars simulated environmental conditions favour or inhibit molecular preservation and their identification. Mimicking the complex Mars geochemical environment is still an enormous challenge; nevertheless, the selection of different environmental conditions could help to discriminate under which conditions molecule/mineral compounds preservation would or would not be negligible.

Finally, we show how a single layer of silica nanoparticles with an average size of 200 nm deposited on pristine gold surfaces can be used for CO_2 physisorption and chemisorption. We analyse the device, both spectroscopically and morphologically, before and after exposure to an atmosphere of 7 mbar of CO_2, inside the planetary atmospheres and surfaces simulation chamber, (PASC) mimicking Martian atmospheric conditions. Our studies demonstrate that these clusters are suitable for CO_2 detection and storage, under well controlled experimental Martian conditions. Their high sensitivity at a very low concentration of CO_2, 12.4 ppm, makes them ideal candidates in the nanosensor field. We have demonstrated that SiO_2NPs can be self-organized in a two-dimensional ordered structure, which can be fully characterized by a battery of surface science techniques as XPS, infrared, AFM and SEM. Furthermore, we have investigated the suitability of SiO_2NPs deposited in gold wafers as a tool for CO_2 recognition at standard Mars low pressures. The nanosensors could also be used for (i) atmospheric biosignatures detection if referring to the presence of one or several gas species, and (ii) surface biosignatures if detectable by their light reflection characteristics providing spectral molecular fingerprints or characteristic chemical features. Moreover, these results open the door to future studies involving the use of Mars minerals as an atmospheric trap and reservoir.

In summary, our research studies are aimed at studying the role of chemical changes of the mineral surfaces on the adsorption of a prebiotically and planetary relevant molecules.



Schematic representation of the SiO2NPs deposition onto Au wafers and the subsequent CO2 adsorption process inside the planetary simulation chamber (PASC).

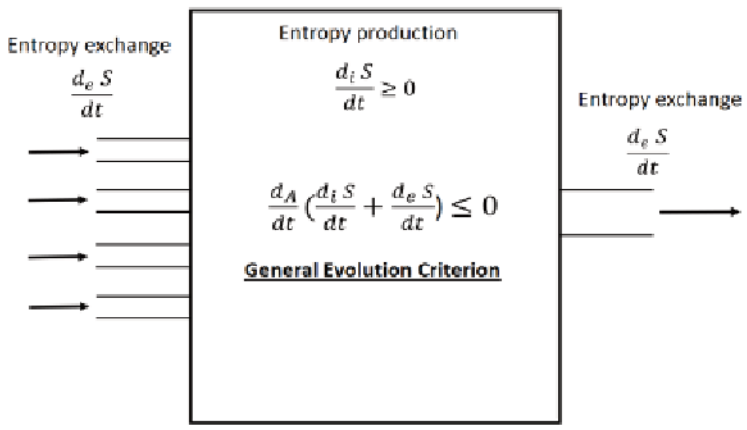
Entropic analysis of spontaneous mirror symmetry breaking in open-flow systems: entropy production, entropy exchange and the General Evolution Criterion

Spontaneous mirror symmetry breaking (SMSB) takes place in non-equilibrium thermodynamic systems open to matter flow, and/or energy exchange, and involves both the production of entropy (dissipation) and the entropy exchanged with the surroundings. The *thermodynamic evolution* of fluid flow-driven chemical reactions involves both the internal micro-reversible transformations taking place within the system volume *V*, and the matter fluxes into and out from the system (the latter are specified by the boundary conditions). The affinities, or chemical forces, must always evolve so as to minimize the sum of the internal entropy production and the entropy exchange. The set of reactions together with the input/output matter fluxes for well-mixed systems evolve *jointly* and in unison, as dictated by the General Evolution Criterion (GEC), a theorem valid in both the non-linear and linear regimes of non-equilibrium thermodynamics: see Scheme 1.

The GEC, a unifying thermodynamic evolution theorem for dissipative systems, was established originally by Glansdorff and Prigogine, who derived an inequality for the temporal changes in the entropy production valid for the entire range of macroscopic physics, and for fixed boundary conditions (**Scheme 1**). The GEC states that the temporal change of the generalized forces proceeds always in a way so as to lower the value of the entropy production. The scope of their GEC does apply, of course, to chemical reactions, but its usefulness in the chemical sciences has been limited to simplified systems lacking explicit volumetric fluid matter flows. Yet, such flows are the hallmark of continuous open-flow systems such as e.g., flow chemical reactors and also biological cells: *systems that exchange matter and energy with their environments*. Nevertheless, the clamped approximation, which assumes constant fixed concentrations for all species external to the reaction volume, has traditionally been invoked as a convenient, if unrealistic, simplification in benefit of the mathematical analysis. We have thus successively extended the validity of GEC to volumetric open-flow systems (such as found in both microfluidics and flow-reactors) which establishes an important and needed contribution to the thermodynamic understanding of far from equilibrium non-linear systems, and so aids to broaden the range of applications of GEC to non-linear chemical systems, as found for example in prebiotic chemistry.

A key result, obtained in our previous coordinated project, using stoichiometric network analysis (SNA), reveals that the *partial* entropy productions and exchanges associated with each individual irreversible (one-way) reaction and matter flow term are equi-partitioned, or shared out, among those pathways in which such reactions and flow terms jointly participate. The combined, or hybrid, entropy productions and exchanges over each reaction pathway gives insight to the mechanisms (reaction, flow) involved in chiral symmetry breaking. This result is important for linking the production of entropy and exchange entropy with the chemical pathways, and hence with network topology. Open-flow chemical systems play a privileged role regarding features of symmetry breaking in dynamical systems, as well as their clear relevance for studying biochemical and biological problems in more involved non-equilibrium situations.

Our immediate and future objectives, for the correct non-equilibrium thermodynamic interpretation of the detailed study of experiments carried out in flow reactors, will be to deduce a fully encompassing version of the GEC (**Scheme 1**), using the framework of the theory of continuous media, where we will be able to obtain the explicit velocity flow and treat the fluid velocity that generates the well-mixed solution inside the reactor (such as turbulent flows). This is important because the flow terms include some of the physical effects of mixing and diffusion, and hence comparison with the idealized (i) well-mixed and (ii) instantaneous diffusion limits will provide insights into the physical-chemical mechanisms contributing to the overall entropy production and the entropy exchange in real systems (as e.g., in real flow reactors).



Scheme 1: Schematic representation of a continuous-flow stirred tank reactor (CSTR). Species flow in at fixed concentrations (left), all species flow out with their instantaneous concentrations (right) as determined within the reactor. The internal micro-reversible reactions lead to a positive definite entropy production, while the input/output matter flows lead to entropy exchanges (these can be either positive or negative) with the surroundings. The General Evolution Criterion is the statement that the change, of the sum of the entropy production plus the total entropy exchange, with respect to the temporal derivative of the chemical affinities A, is negative semi-definite, and is strictly zero at a NESS.

Molecular Evolution, RNA World And Biosensors

Coordinator: Carlos Briones

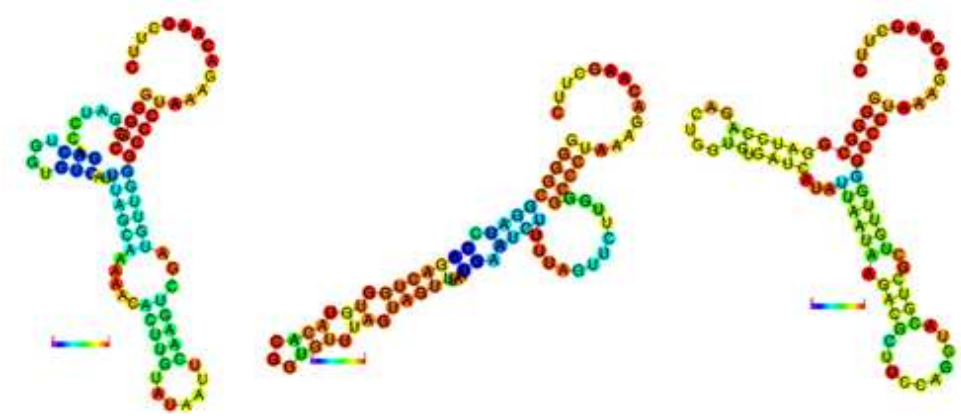
Group members in 2020

Members	Category
Beatriz Torres Vázquez	Predoctoral scientist (hired)
María Fernández Algar	Laboratory Technician (permanent position)
Almudena Náñez Cabrero	Predoctoral scientist (hired)
Yolanda Blanco López	Postdoctoral scientist (hired, María de Maeztu program)
Carlos Briones Llorente	Staff Research Scientist, Group PI

The CAB research group Molecular Evolution, RNA world and Biosensors is focused on the study of the origin and early evolution of life (including experimental and theoretical approaches to the RNA world hypothesis), *in vitro* selection and evolution of nucleic acids (RNA and ssDNA aptamers), biosensor development (DNA microarray technology, aptamer-based sensors, bionanotechnology-inspired sensor platforms), and genetic variability of RNA viruses. We also collaborate with interdisciplinary research projects devoted to the detection of molecular precursors of the RNA world in the interstellar medium, as well as to the characterization of microbial biodiversity in extreme environments.

In the field of *in vitro* evolution of nucleic acids, we have continued the selection of aptamers against molecular targets relevant in astrobiology and biochemistry. Aptamers are RNA or single-stranded DNA (ssDNA) oligonucleotides selected *in vitro* from large libraries of random oligonucleotides, using an amplification-selection method termed Systematic Evolution of Ligands by EXponential enrichment (SELEX). After 8 to 14 rounds of *in vitro* selection, including counter-selection steps, aptamers can bind with high affinity (in the nanomolar range) and specificity to any target molecule of interest.

In 2020, we have focused on *in vitro* selection and characterization of RNA and ssDNA aptamers specific for relevant proteins coded by RNA viruses, as well as for ancestral peptides with different sequences and structures. Among them, we have developed 76 nt-long RNA and ssDNA aptamers against hepatitis C virus (HCV) core protein belonging to genotypes 1 to 4, as well as against different variants of the S protein of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), being potentially useful in diagnosis and therapy (patent and articles in preparation). In parallel, the 9 to 35 aa-long ancestral peptides used for aptamer selection belong to different families of metal-binding proteins that have been preserved through evolution. The affinity and specificity of the selected aptamers are characterized using Enzyme-Linked OligoNucleotide Assay (ELONA) coupled to either real-time, quantitative PCR (qPCR, for ssDNA aptamers) or reverse transcription followed by quantitative PCR (RTqPCR, for RNA aptamers), a methodology previously developed by our group, as well as using colorimetric ELONA.

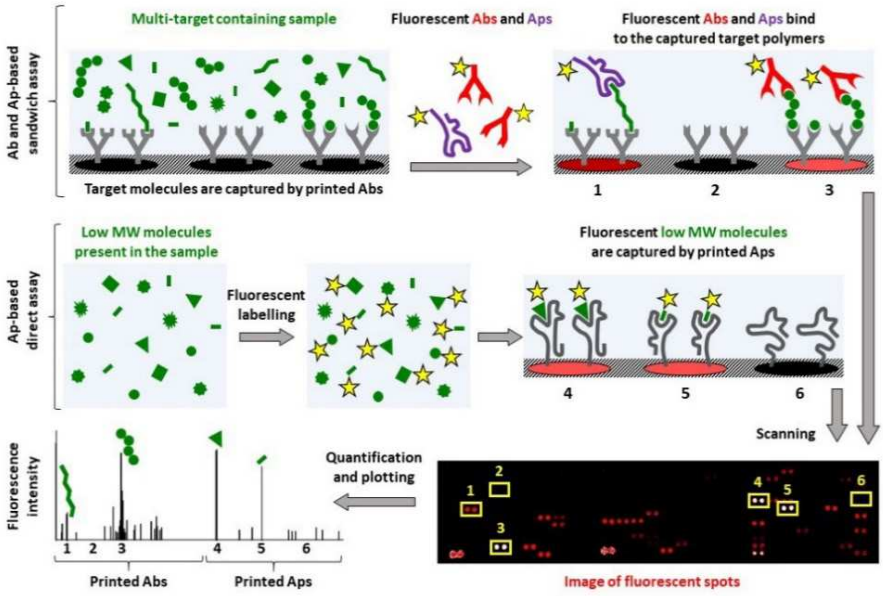


Secondary structures of three high affinity aptamers selected in this work.

Aptamers show key advantages over other bio-recognition elements used in biosensing, including antibodies. Among them, they can be chemically modified at their 5' and/or 3' ends, thus allowing their immobilization onto a large variety of solid substrates, including glass, plastics, beads, nanoparticles, activated graphene or other nanomaterials. Different assay formats can be used to detect the target molecule (which can be present in a homogeneous solution, in heterogeneous mixtures, or even in complex biological samples), including those traditionally performed with antibodies: direct, competitive and sandwich ones. As a result, aptamers are increasingly used in a number of analytical applications and have led to the development of novel aptamer-based biosensors (also called "aptasensors").

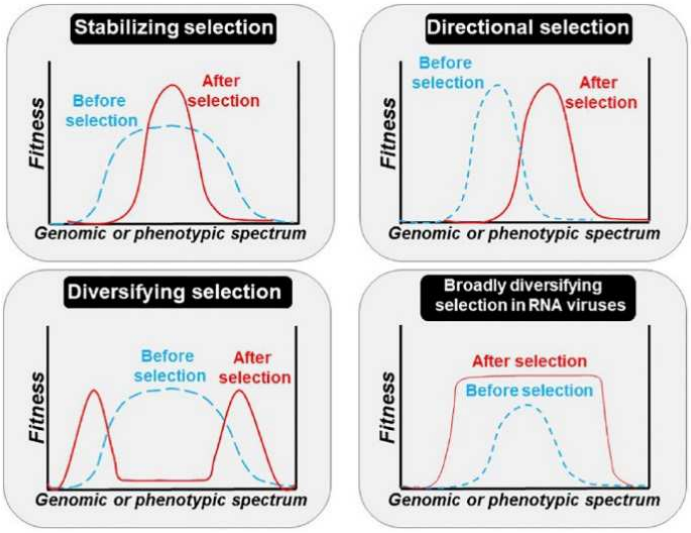
One of the anti-HCVcore ssDNA aptamers showing high affinity for its target protein has been used to develop novel graphene-based biosensors, in collaboration with researchers from the Instituto de Ciencia de Materiales de Madrid (ICMM, CSIC) and the International Iberian Nanotechnology Laboratory (INL, Braga, Portugal). This aptasensor is based on the covalent chemical functionalization of graphene with p-aminothiophenol (p-ATP), following a protocol that preserves the pristine electronic properties of graphene and allows the binding of thiol-modified aptamers useful as probe molecules. The graphene-conjugated aptamer retains the functionality required to recognize the target protein in solution, and therefore such hybrid nanostructures open a new route towards the integration of high-quality biosensing platforms (patent and articles in preparation). The applicability of this kind of graphene-based aptasensors to other astrobiologically-relevant ligands is currently being investigated.

Aptamer-based microarrays are included in the instrument suite termed "Complex Molecules Detector" (CMOLD), which has been proposed in 2020 by an interdisciplinary group of CAB and INTA scientists to search for (bio)chemical complexity on Mars and icy moons. CMOLD is devoted to determining different levels of prebiotic and biotic chemical/structural complexity, following a general approach valid for both terrestrial and non-terrestrial life. It is based on a microfluidic block that distributes a liquid suspension sample to three complementary instruments: i) a microscopy for identifying ultrastructures and cell-like morphologies, ii) Raman spectroscopy for detecting universal intramolecular complexity that leads to biochemical functionality, and iii) bioaffinity-based systems (including antibodies and aptamers as capture probes) for finding life-related and non-life-related molecular compounds. We have proposed this novel instrument suite to be included as scientific payload in future exploration missions to several astrobiologically relevant bodies in the Solar System.



Schematic representation of the microarray-based protocol to be performed with CMOLD, which combines the antibody- and aptamer-based sandwich assay (top panel) and the aptamer-based direct assay (medium panel) to detect biopolymers and low molecular weight biomolecules, respectively [Fairén et al., (2020) Astrobiology 20].

In the field of the genetic variability of RNA viruses, our group has collaborated with that of Esteban Domingo (Centro de Biología Molecular "Severo Ochoa", CBMSO, CSIC-UAM) and others in the discovery of a new adaptive feature of quasispecies dynamics: the broad diversifying selection in absence of external perturbations, which is built upon a progressive increase of the number of different genomes that dominate the population. The evidence was provided by analyses of mutant spectrum composition of two important RNA viruses, foot-and-mouth disease virus (FMDV) and HCV, after prolonged replication in their respective cell culture environment. Despite being fuelled by mutations that arise randomly and in absence of an external selective pressure, this type of selection prepares the viral population for a response to selective forces still to occur. Since broadly diversifying selection is favoured by high mutation rates and population sizes, it may also be relevant to the adaptive dynamics of other microbial populations.



Scheme of the main types of positive selection operating in RNA viruses, depicted as modifications of fitness peaks, where broadly diversifying selection can be regarded as an extension of diversifying selection [Domingo et al. (2020), Inf. Genet. and Evol. 82].

Additionally, our group has collaborated with that of Jesús Martín Pintado (CAB) and others to assess the biochemical relevance of the detection of hydroxylamine (NH_2OH) in the interstellar medium, towards the quiescent molecular cloud G+0.693-0.027 located in the Galactic Centre. Hydroxylamine is a very relevant molecule that could have been delivered to early Earth and act as a precursor for the stepwise synthesis of ribonucleotides, thus contributing to the origin of the primordial RNA world before the advent of proteins and DNA.

Experimental Evolution Studies with Viruses and Microorganisms

Coordinator: Ester Lázaro Lázaro

Group members in 2020

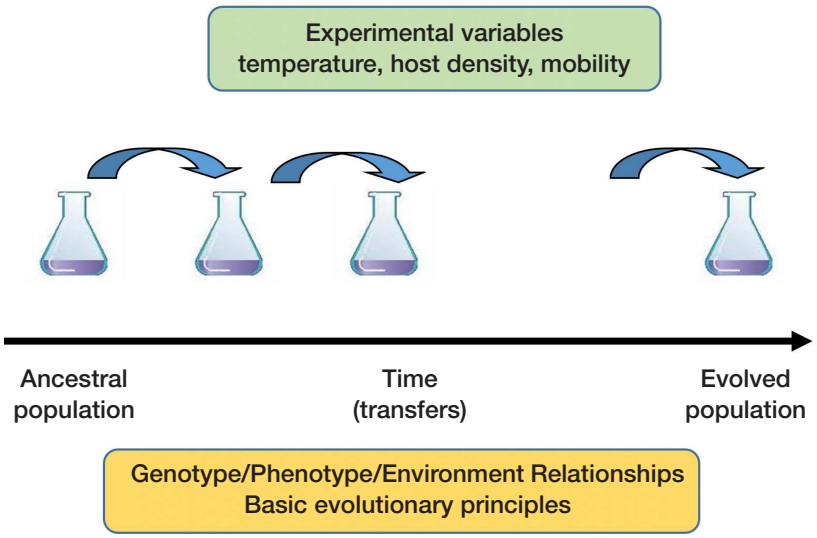
Members	Category
María Arribas Hernán	Technician (permantent position)
Elena Llorente Flores	Predoctoral scientist (hired with a Garantía Juvenil contract)
Mara Laguna Castro	Predoctoral scientist (hired with an FPI contract)
Andrea Menés Rubio	Undergraduate student (TFG)
Pilar Somovilla Crespo	Predoctoral scientist (hired with an FPI contract that lasted until February 2020)

To understand how life has diversified since its origin it is necessary to know the basic principles that drive adaptation to different environments. In this sense, the re-creation of evolutionary processes in the laboratory, using simple organisms that evolve rapidly under controlled conditions, has allowed great advances in the identification of relationships between environmental parameters, genetic changes and specific adaptations. RNA viruses meet most of the necessary requirements to be used as an experimental system in this type of studies. They have short generation times and replicate their genomes with very high error rates (between 10^{-4} and 10^{-6} errors per copied nucleotide), giving rise to large, highly heterogeneous populations, composed by a dynamic ensemble of mutants referred to as mutant spectrum, which adapts rapidly to most changes in environmental conditions.

Our experimental system is a bacteriophage, Qβ, which infects the bacterium *Escherichia coli*. It has a single-strand-

ed, positive-sense RNA genome of only 4217 nucleotides that facilitates the establishment of genotype-phenotype relationships. Evolutionary experiments carried out in our group are usually focused on analyzing the genotypic and phenotypic changes experienced by Qβ when it is propagated under the particular conditions whose influence on evolution we want to analyze (Fig. 1). Genotypic analysis includes determination of consensus sequences and characterization of the mutant spectra, whereas phenotypic analysis focuses on determination of growth rates, competitive fitness, and several parameters that determine the virus infective cycle. The variables used as selective pressures in the studies carried out in during this year were: increase in replication temperature, structure of the medium where the virus propagates, and variations in host density.

The main research lines that we have carried out in 2020 and the most relevant results obtained are summarized in the following sections:



Scheme showing the design of an experimental evolution experiment. Propagation of the virus through serial transfers under controlled variables that act as selective pressures allows the establishment of genotype/phenotype/environment relationships and the identification of basic evolutionary principles.

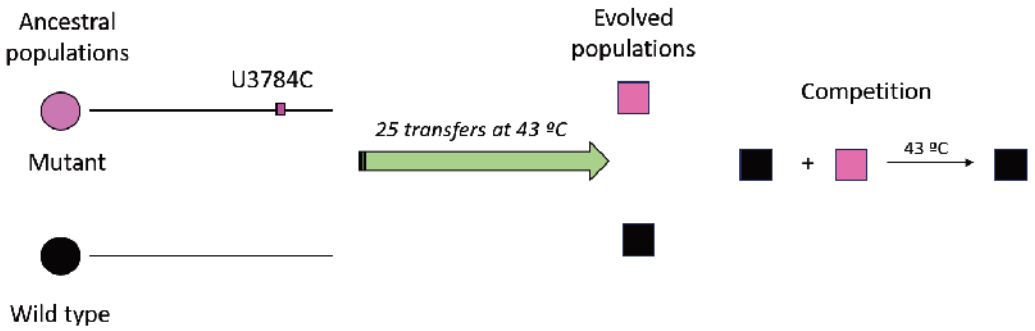
Characterization of intra-population competition during adaptation to increased temperature

In previous studies, we showed that during the process of adaptation to higher-than optimal temperature (43 ºC), Qβ populations were composed of a highly diverse mutant spectrum containing different combinations of mutations. Mutant spectra were highly dynamic, showing the rapid ascent of specific genotypes and the loss of some mutations with beneficial effects at 43 ºC. In particular, it was striking the loss of U3784C, a mutation in the replicase gene which was almost fixed at an intermediate stage of adaptation. Estimation of the growth rate of a set of virus clones showed that, although they all had higher values than the wild-type virus, there were no large differences among them that could explain the behaviour observed.

New results obtained this year indicate that competitive interactions within the mutant spectrum are leading adaptation to high temperature. The selective valour of particular mutations is being continuously modified due to the generation of new ones in the same or in different genomes. We clearly demonstrated that U3784C provided a higher beneficial effect in the genomic context of the wild-type virus than in more-fit genotypes, which is a clear example of a type of interaction among mutations known as diminishing return epistasis that could explain the loss of this mutation as adaptation progresses. In agreement with this possibility, the sequences of several sets of virus clones isolated from evolved populations at intermediate stages of adaptation showed a trend of U3784C to be present in genetic backgrounds different from the one that fixed at the last transfer.

Adaptation experiments carried out with a single mutant containing U3784C, which was built through site-directed mutagenesis, showed that the new populations generated kept U3784C, although they reached lower competitive fitness than those whose

ancestor was the wild-type virus (Fig. 2). Currently, we are using Next Generation Sequencing (NGS) methodologies to characterize the mutant spectrum of the populations, which the aim of analysing the accessible genotype networks in each case.



Competition between two 43 °C adapted populations generated from different ancestors

Characterization of the adaptive pathways followed by Qβ as a function of pre-existent genetic diversity and the pattern of environmental change

In a previous study we analysed the influence of the pre-existent genetic diversity and the pattern of environmental change on the dynamics of fitness gains and on the variation in the consensus sequences of several lineages of Qβ propagated at higher-than-optimal temperature.

To study in depth the changes produced in the mutant spectra of the different populations, we have carried out an NGS analysis of three amplicons that contain several of the positions that are frequently mutated at increased temperature. The values of the haplotype density and the minimum mutation frequency allowed to estimate the total genetic diversity contained in the populations, regardless of how abundant each mutation or each haplotype was. The haplotype frequency distributions as a function of their number of order or their Hamming distance, as well as the values of Shannon entropy, the π index, or the maximum mutation frequency with respect to the consensus sequence were used to analyse the internal structure and degree of complexity of the populations. The most relevant results obtained were:

i) The analysis of the mutant spectrum of a Qβ population propagated at optimal temperature (37 °C) shows the presence at low frequencies of some of the mutations that were responsible for virus adaptation to 43°C. These mutations, which at 37 °C were kept in low amount, could constitute the basis on which natural selection starts to act when there are changes in the environment.

ii) Adaptation to 43 °C from a diverse ancestral population produces a population bottleneck, which is probably due to the rapid selection of some minority genome with advantages at 43 °C that is present in the mutant spectrum of the initial population.

iii) Tracking of haplotypes throughout adaptation to 43°C shows the appearance of combinations of mutations that were present in separate genomes in the ancestral population. This fact is probably due to the high error rate of Qβ, which favours the recurrent appearance of the same mutations in different genomic contexts.

iv) Although there was some overlap between the mutations that were selected after gradual or sudden changes in temperature, the adaptive pathways followed were not the same, as demonstrated in the analysis of the mutations that were fixed in each case.

Adaptation to variations in the host density and the medium structure

One of the most relevant factors influencing the evolution of any biological entity is its probability of replication. In the case of viruses, this factor depends on the ease of finding susceptible hosts, which is conditioned by host concentration and mobility. The lower these two parameters, the longer the virus spends in the external environment between successive infections, thus increasing its probability of degradation due to physical-chemical variables, which ultimately could lead to its extinction. There should be a critical host density separating sustained propagation from extinction, whose value will probably be dependent on interactions between host-, virus-, and environment-derived factors. Above the critical host density, the virus spreads in the population and can select evolutionary strategies that allow it to improve its replication and/or inter-host transmission capacities under the particular selective pressures of the environment.

During last year we have initiated an experiment in which Qβ was propagated through serial transfers in liquid media containing 10^8, 10^7, 10^6, 10^5, or 10^4 bacteria/mL in duplicate. The minimal concentration of bacteria that permitted sustained propagation of Qβ in liquid medium under this condition was 10^5 bacteria/mL. All lineages evolved using 10^7, 10^6, or 10^5 bacteria/mL fixed mutation C2011A (Thr222Arg in the A1 protein), increased their growth rates and acquired a small plaque phenotype. This result is intriguing, since small plaques were also obtained during the propagation of Qβ at 43 °C in semisolid medium, although in this case the mutation responsible of the change was U830C (Val-246Ala in the A2 protein).

Evolutive Systems & Complexity In Astrobiology

Principal Investigator: Jacobo Aguirre

Students:
Marina Fernández (JAE Intro ICU, CSIC); Javier Gómez, Isabel Pérez and Miguel García (Master's Thesis students).

The main objective of the research line we are starting at CAB is to put the theoretical and applied context of the theory of complexity at the service of astrobiology, making use of the tools of complex network theory, game theory, nonlinear dynamics and the mathematical modelling of evolutionary processes. This interdisciplinary approach combining complexity and astrobiology became a fundamental pillar in the foundation of the Centro de Astrobiología, and we would like to advance in this direction. In summary, the main lines of research that we have developed during 2020 are:

Modelling the origin and early evolution of life through digital organisms and network science

In this context, we face the mathematical and numerical study of the origin and evolution of early life on Earth in a simplified manner as an interaction between complex structures. To achieve this goal:

- We have developed a computer environment named *NetWorld*, where complex networks interact following simple rules of union and division that are easy to implement and vary. This is used to simulate the chemistry in the interstellar medium and the first steps of prebiotic chemistry, giving rise to the basic building blocks of life, later used in progressively more complex biochemical reactions. From isolated nodes or very basic structures (motifs), our tool produces a rich variety of networks with different complexity and topological properties (figure 1).

- We have developed numerical algorithms to describe the evolution of the chemical compounds studied in *NetWorld*, their diversity and abundance in the different phases of the process.

- In collaboration with the *Chemical Complexity in the ISM Group* of CAB, we have started to study the chemical network of phosphorus, a critical element in the formation of monomers of relevance in biochemistry, such as ribonucleotides (necessary for the establishment of an RNA world) and energy molecules such as ATP and GTP (required in numerous metabolic reactions). The chemical network of this element is relatively small and easy to test.

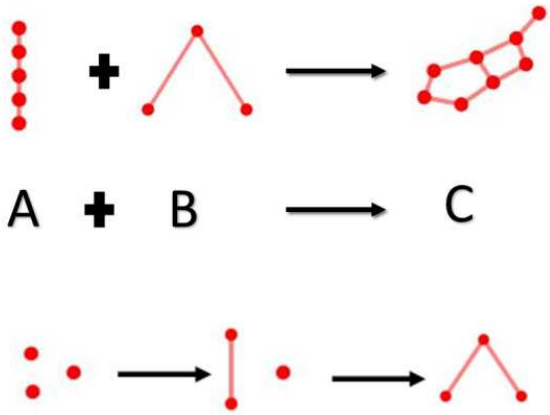


Figure 1. Isolated nodes or simple motifs interact in our computational environment to simulate a chemistry of complex networks.

Evolutionary processes on interacting complex networks

The interaction, collaboration and competition between different agents represent the main driving forces behind the evolution of the biological, sociological and technological systems that surround us. A large part of the systems that evolve in the Universe are based on cooperation and/or competition for resources that are always limited. Many of these systems are so complex that in order to represent them accurately we must use networks formed by a multitude of nodes and their interactions. This phenomenon can be seen in all scales of life: from virus dynamics to cultural and social evolution.

From this perspective, we have developed during 2020 a novel research line to shed light on a variety of challenging open problems in the study of evolutionary systems related to the origin and evolution of complexity in nature and society. We have focused on:

- The development of a formal theory to study complex processes that can be modelled as different networks that interact and evolve in a complex manner.

- The analysis of the infection of a human cell by *Epstein-Barr* virus in different times after contagion. We have focused on two different network models: protein-protein interaction networks and host-virus protein co-expression networks.

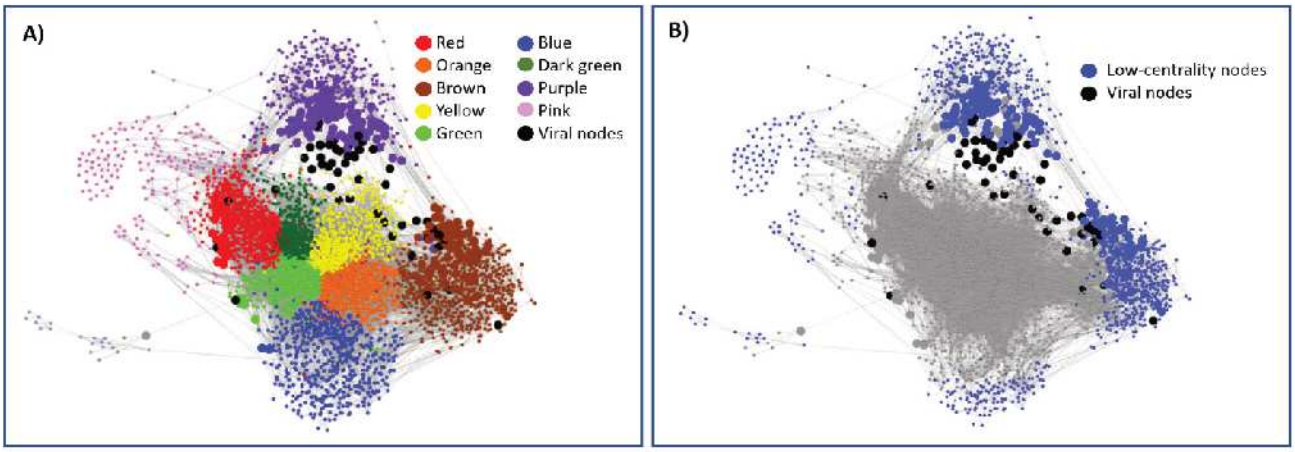


Figure 2. Viral nodes in the human - EBV virus co-expression network interact with functionally enriched modules. Viral nodes are highlighted in black.

- The study of the basic mechanisms that lead to the creation of complex socioeconomic structures, which up to now remain poorly understood. Our analytical and numerical findings are compatible with the interconnection dynamics observed in real-world networks.

- The study of a stochastic *SEIR* model to describe COVID-19 propagation during a football competition. We proposed a variety of strategies to minimise the probability that COVID-19 propagated in case the season of *Spanish football league* was re-started after the 2020 lock-down. The results were discussed with *La Liga and were used to achieve a safe development of the remaining 11 fixtures in June-July 2020.*

Complex networks in biotechnology and molecular biomarkers

We collaborated with the *Biomolecules in Planetary Exploration Group* at the Department of Molecular Evolution in the development of an antibody microarray with 20 polyclonal antibodies to detect perchlorate-reducing bacteria strains and two highly conserved enzymes involved in perchlorate respiration. Perchlorate anions are produced by chemical industries and are important contaminants in certain natural ecosystems. Furthermore, they are especially abundant on the surface of Mars. In particular, our contribution to this work consisted on applying a deconvolution method based on graph theory to discriminate between specific signals and cross-reactions from related microorganisms.

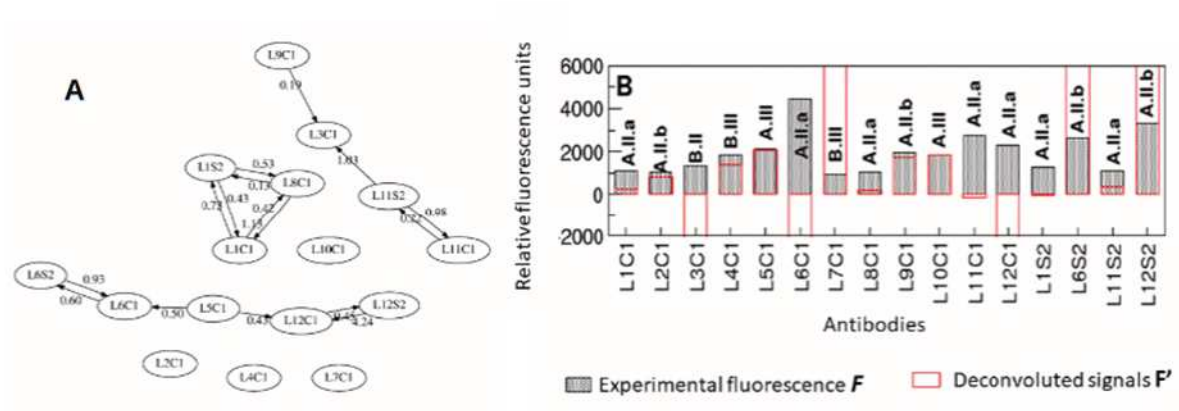


Figure 3. (A) Antibody graph associated with the antibody microarray. Each node represents one antibody and links represent cross-reactivities. (B) Deconvolution method applied to one complex natural sample. Analysing the experimental and deconvoluted signals associated with each antibody we obtain reliable information about its existence or not in the sample.

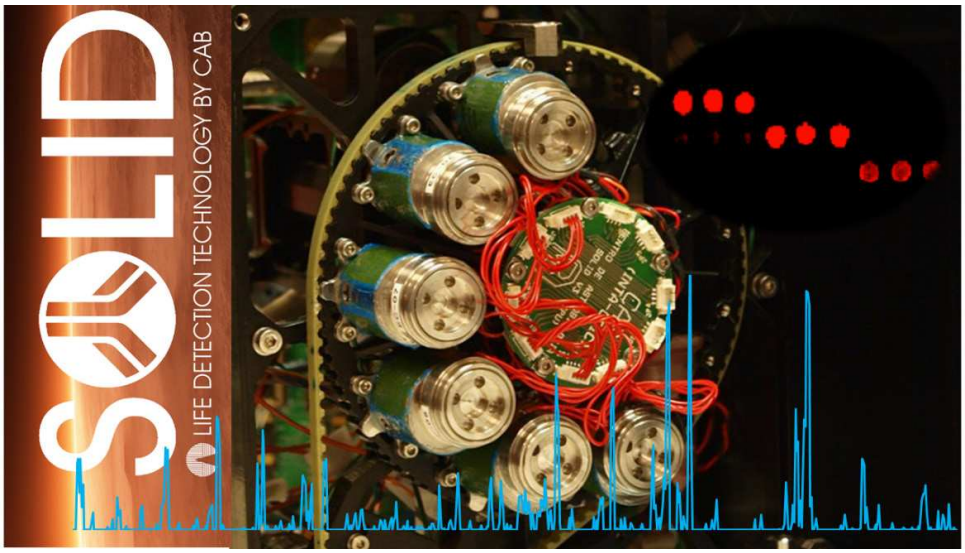
Biomolecules in Planetary Exploration

Coordinator: Victor Parro García

Group members in 2020

Members	Category
Mercedes Moreno Paz	Researcher
Laura Sánchez García	Researcher RyC
David Ruano Gallego	Presearcher (Atracción Talento CAM)
Ángeles Lezcano Vega	Posdoct researcher (Juan de la Cierva)
Rita Sofía dos Santos Severino	PhD contract
Pedro Mustieles del Ser	PhD contract
Miriam García Villadangos	Lab technicien
Miguel Ángel Lominchar	Lab technicien (PTA)
Juan Manuel Manchado Ortega	Hired engineer
Carolina Díaz Ibáñez	Undergraduate student, TFG
Valentine Megevand	Graduate student, thesis of master

Multidisciplinary group with biologists, chemists, engineers, technicians and students of different levels (training, Ph.D., degree) whose goal is to understand the microbial metabolic potential and the preservation of molecular biomarkers (in space and time) in terrestrial analog environments to other found in other planetary bodies. The objective is to achieve an integrative vision about the feasibility of life in other planets as well as to design methods and strategies for its detection in planetary exploration missions.



SOLID-LDChip instrument. The sample preparation unit showing 6 out of 10 extraction cells, a representative immunogram with peaks of fluorescence units revelaing positive immunodetections (blue). Red spots correspond to positive immunodetections on LDChip in triplicate pattern.

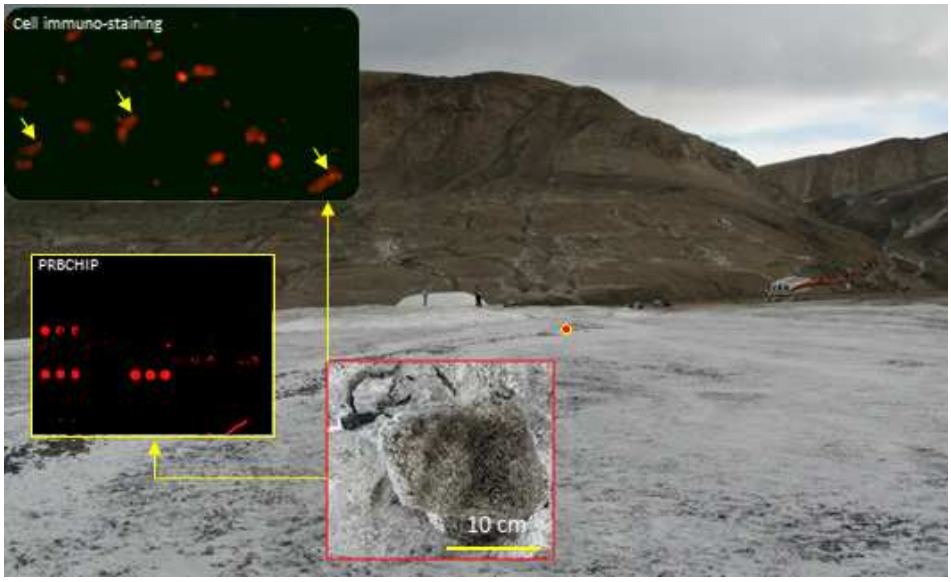
We study the metabolic potential, the presence of molecular biomarkers and their preservation, as well as the inferred ecological patterns, in changing extreme environments: salty deserts, icy deserts, Arctic and Antarctic Permafrost, deep continental subsurface, or extremely acidic waters. We have developed a unique immunological biosensor LDChip (Life Detector Chip) based on microdispensing technology, and the SOLID (Signs Of LIfe Detector) instrument for remote and autonomous in situ sample analysis for detecting microbial biomarkers in planetary exploration.

During 2020 we have carried on several research activities aimed to implement LDChip and SOLID instrument by increasing LDChip capabilities and technical maturing of SOLID in field studies. At the same time, an array of analytical techniques has been deployed for thorough characterization of molecular biomarkers in the laboratory.

Implementing LDChip with a Set of Antibodies for Detecting Perchlorate-Reducing Bacteria for Environmental Monitoring and Planetary Exploration.

Since the discovery of perchlorate salts on Mars, the presence of hydrated salt in the so called Recurrent Slope Lineae (RSL), and the possibility of brines in the martian subsurface, microorganisms capable of respiring perchlorate are being considered as components of a hypothetical Martian microbiota. Alternatively, the potential microbes living on Mars might have to deal with the poisonous concentration of perchlorate derivatives as chorite. In both cases, we could expect similar biochemical mechanisms or structural components with terrestrial microorgansisms dealing with perchlorate reduction and chlorite detoxification.

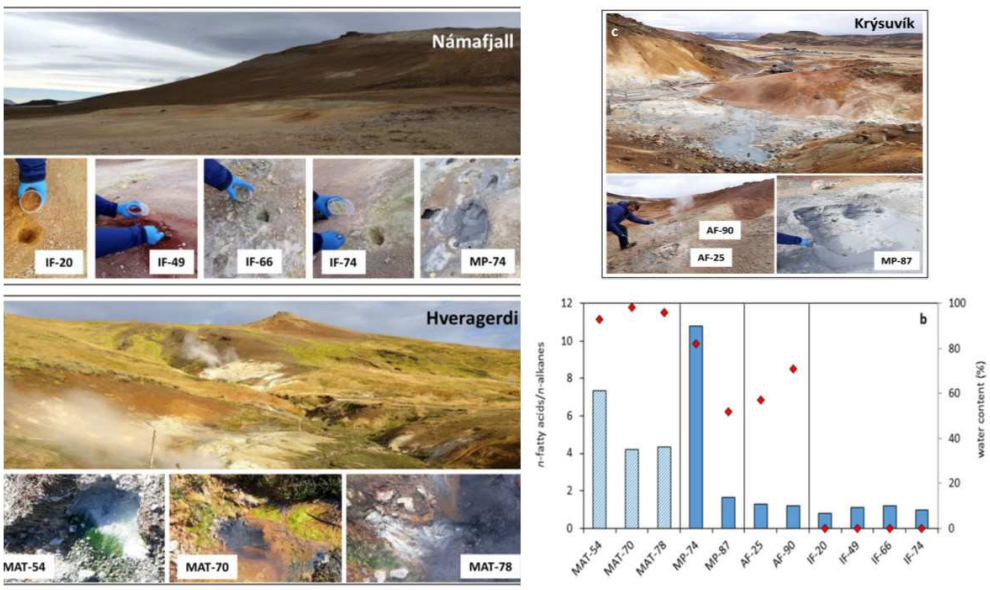
On Earth, perchlorate anions are produced by chemical industries and are important contaminants in certain natural ecosystems. Perchlorate also occurs in some natural and uncontaminated environments such as the Atacama Desert, the high Arctic or the Antarctic Dry Valleys, and is especially abundant on the surface of Mars. As some bacterial strains are capable of using perchlorate as an electron acceptor under anaerobic conditions, their detection is relevant for environmental monitoring on Earth as well as for the search for life on Mars. We have developed an antibody microarray with 20 polyclonal antibodies to detect perchlorate-reducing bacteria (PRB) strains and two crucial and highly conserved enzymes involved in perchlorate respiration: perchlorate reductase and chlorite dismutase. The PRB detecting chip (PRBCHIP) allowed us to detect and classify environmental isolates as well as to detect similar strains by using crude extracts obtained from 0.5 g even from soils with low organic-matter levels (<10^3 cells/g of soil). Our results demonstrated that PRBCHIP is a valuable tool for sensitive and reliable detection of perchlorate-reducing bacteria for research purposes, environmental monitoring and planetary exploration.



Detecting Perchlorate reducing bacteria and proteins in the sulfate and chloride rich salts from perennial springs in the Canadian High Arctic with PRBCHIP (triplicate red spots) and by immunostaining enriched cultures with anti-chlorite dismutase antibodies. Arroheads point to stained cells.

Fingerprinting molecular and isotopic biosignatures on different hydrothermal scenarios of Iceland, an acidic and sulfur-rich Mars analog.

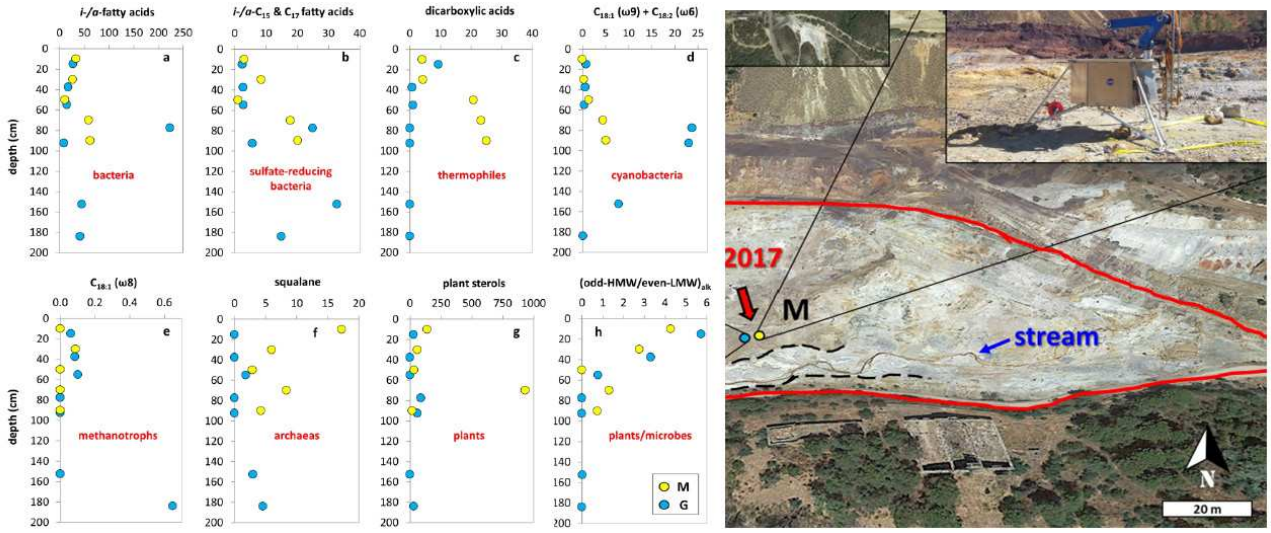
Detecting signs of potential extant/extinct life on Mars is challenging because the presence of organics on that planet is expected to be very low and most likely linked to radiation-protected refugia and/or preservative strategies (e.g., organo-mineral complexes). With scarcity of organics, accounting for biomineralization and potential relationships between biomarkers, mineralogy, and geochemistry is key in the search for extraterrestrial life. Here we explored microbial fingerprints and their associated mineralogy in Icelandic hydrothermal systems analog to Mars (i.e., high sulfur content, or amorphous silica), to identify potentially habitable locations on that planet. The mineralogical assemblage of four hydrothermal substrates (hot springs biofilms, mud pots, and steaming and inactive fumaroles) was analyzed concerning the distribution of biomarkers. Molecular and isotopic composition of lipids revealed quantitative and compositional differences apparently impacted by surface geothermal alteration and environmental factors. pH and water showed an influence (i.e., greatest biomass in circumneutral settings with highest supply and turnover of water), whereas temperature conditioned the mineralogy that supported specific microbial metabolisms related with sulfur. Raman spectra suggested the possible coexistence of abiotic and biomediated sources of minerals (i.e., sulfur or hematite). These findings may help to interpret future Raman or GC–MS signals in forthcoming Martian missions.



Icelandic geothermal areas investigated in this work throughout the Mid-Atlantic Ridge traversing the island: Námafjall (top left), Hveragerdi (bottom left), and Krýsuvík (top right). The numbers in the sample names indicate the discrete temperature recorded in situ at the time of collection. (bottom right) biological activity degree (blue bars) relative to the sample water content (red diamonds) in the four hydrothermal substrates; hot spring biofilms (MATs), mud pots (MPs), active (AFs) and inactive (IFs) fumaroles. The extent of freshness or biological activity was assessed based on the relative abundance of functional groups (i.e. carboxylic acids) over saturated straight-chain (normal) alkanes (i.e. the n-fatty acids/n-alkanes ratio).

Simulating Mars drilling mission for searching for life: ground-truthing lipids and other complex microbial biomarkers in the iron-sulfur rich Rio Tinto analog.

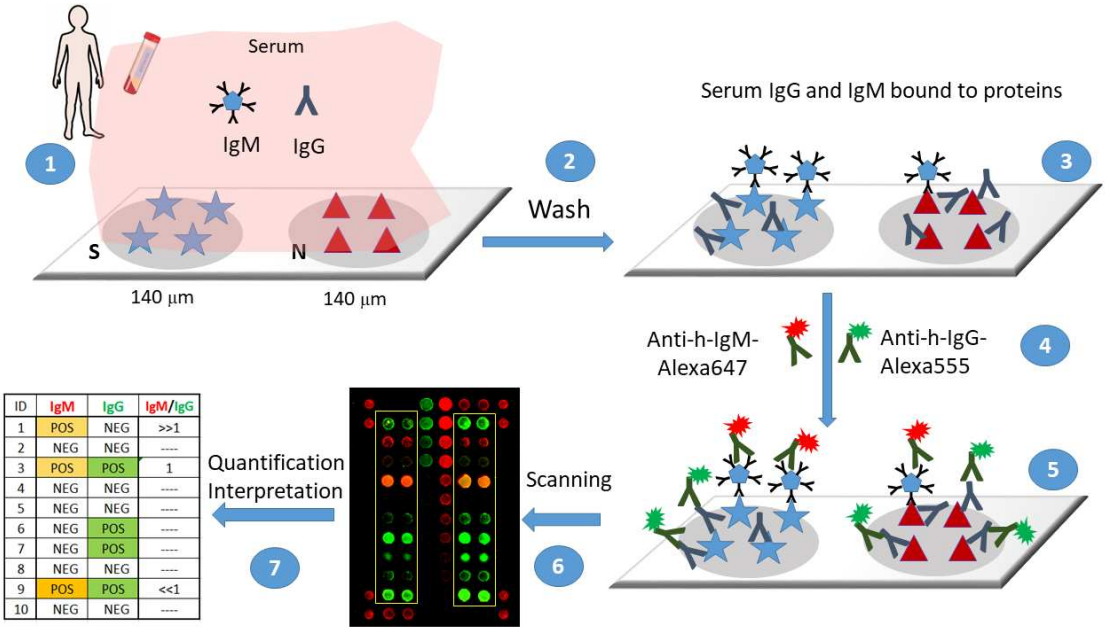
Sulfate and iron oxide deposits in Río Tinto (Southwestern Spain) are a terrestrial analog of early martian hematite-rich regions. Understanding the distribution and drivers of microbial life in iron-rich environments can give critical clues on how to search for biosignatures on Mars. We simulated a robotic drilling mission searching for signs of life in the martian subsurface, by using a 1m-class planetary prototype drill mounted on a full-scale mockup of NASA's Phoenix and InSight lander platforms. We demonstrated fully automated and aseptic drilling on iron and sulfur rich sediments at the Río Tinto riverbanks, and sample transfer and delivery to sterile containers and analytical instruments. As a ground-truth study, samples were analyzed in the field with the life detector chip immunoassay for searching microbial markers, and then in the laboratory with X-ray diffraction to determine mineralogy, gas chromatography/mass spectrometry for lipid composition, isotope-ratio mass spectrometry for isotopic ratios, and 16S/18S rRNA genes sequencing for biodiversity. A ubiquitous presence of microbial biomarkers distributed along the 1m-depth subsurface was influenced by the local mineralogy and geochemistry. The spatial heterogeneity of abiotic variables at local scale highlights the importance of considering drill replicates in future martian drilling missions. The multi-analytical approach provided proof of concept that molecular biomarkers varying in compositional nature, preservation potential, and taxonomic specificity can be recovered from shallow drilling on iron-rich Mars analogues by using an automated life-detection lander prototype, such as the one proposed for NASA's IceBreaker mission proposal.



Depth distribution of lipid biomarkers along the Mars robotic drill (yellow) and manual coring drill (blue) profiles. Right, site Drilling and study in the Río Tinto basin (Southwestern Spain) where the LMAP-2017 drilling and sampling campaign was conducted. Insert, top right, a close-up views of the Mars robotic drill performed in collaboration with NASA-Ames Research Center using a mock-up of the IceBreaker mission concept proposal and a robotic drill and a sample distribution robotic arm.

Development of SCOVAM (SARS-Cov2 Antigen Microarray), a multiplex fluorescence antigen microarray for serological test and monitoring COVID-19 seroprevalence.

The year 2020 will be forever the year of the COVID-19 pandemic. SARS-Cov2 coronavirus stroke to the humanity provoking millions of deaths. In an attempt to give a hand and contribute to fight against it, we used our know-how on microarray-based immunosensors like LDChip for developing a highly sensitive and ease to escalate serological assay for COVID-19. By the end of May 2020 we had already set up a multiplex antigen microarray capable to simultaneously detect IgG and IgM antibodies against SARS-Cov2 with high sensitivity by using as little as 1 uL of serum from a fingertip drop blood. We used several antigens (proteins S, N, main protease) from the virus to capture the antibodies, what makes the system one of the most reliable serological tests for COVID. SCOVAM is easily scalable because we can print in 3x8 microarrays per microscope slide, and four slides can be processed in parallel as a 96 well microtitter plate and scanned for fluorescence. In an appropriate platform it is possible to analyze thousands of sample per day in a single service unit. During 2020 we analyzed more than 3000 samples and validated SCOVAM.

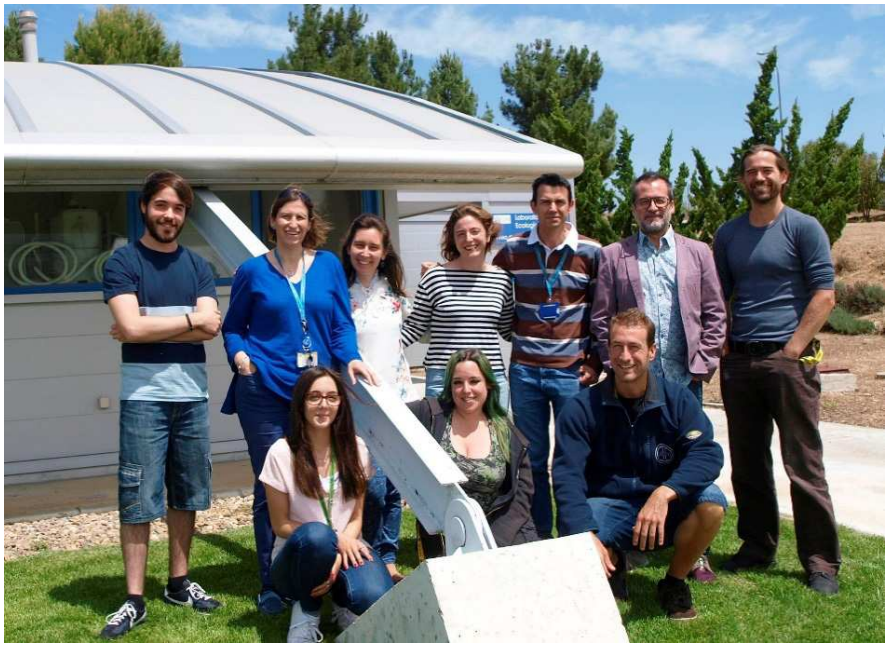


ID	IgM	IgG	IgM/IgG
1	POS	NEG	>>1
2	NEG	NEG	----
3	POS	POS	1
4	NEG	NEG	----
5	NEG	NEG	----
6	NEG	POS	----
7	NEG	POS	----
8	NEG	NEG	----
9	POS	POS	<<1
10	NEG	NEG	----

Chart showing the procedure and the principles behind SCOVAM serological assay. 1) 50 uL with 1/100 serum dilution are incubated with one SCOVAM microarray; 2) after a wash out; 3) specific IgG and/or IgM bound to the printed proteins of the virus are retained; 4) a mixture of fluorescently labeled Goat-anti-human IgG (green) and Goat-anti-human IgM (red) were incubated with SCOVAM to bind to the previously retained antibodies 5); After a final wash out, an image showing fluorescent spots after scanning for fluorescence with two lasers (6) is quantified (7) to reveal positive detection of specific IgG and IgM for COVID. Internal calibration curves can be run simultaneously.

Molecular Mechanisms of Biological Adaptation

Coordinator: José Eduardo González Pastor



Group members in 2020

Members	Category
Carolina González de Figueras	Technician (permanent position)
María Lamprecht Grandío	Postdoctoral researcher
Patricia de Francisco Martínez	Postdoctoral researcher
Joseph White	Postdoctoral researcher
Jon Ochoa de Eribe	Postdoctoral researcher
Macarena Benguigui de la Cámara	PhD student (FPU fellowship)
Sara Gómez de Frutos	PhD student (INTA fellowship)
Jorge Díaz-Rullo	PhD student (FPI fellowship)
Ruymán Alonso Ravelo	PhD student (INPhINIT Retaining fellowship, Fundación La Caixa)
David Deschamps Ramos	Master student

Microorganisms that inhabit extreme environments have developed complex molecular mechanisms that allow them to survive in these conditions. In our group we are interested in discovering new adaptation mechanisms, but a major problem is that a high percentage of microorganisms cannot be cultivated or there are no molecular tools for their genetic manipulation, and therefore their study is impossible. Thus, we are using independent culture techniques, such as metagenomic sequencing, functional metagenomics and metatranscriptomics, which allow us to access the genetic information of all the microorganisms present in a certain environmental sample, and then be able to study their adaptation strategies to extreme conditions.

Currently we are interested in: i) studying the molecular mechanism of adaptation to perchlorate, salt and UV radiation in microorganisms that inhabit hypersaline environments, which are able to thrive in high salt and perchlorate concentrations and high doses of radiation; ii) investigate gene transfer mechanisms in hyperhalophilic microorganisms, such as *Haloferax volcanii*. Hypersaline environments can be considered analogous to Mars and icy satellites such as Europa (Jupiter) and Enceladus (Saturn). In addition, we have studied the effect of UV radiation on the transcriptome of the astrobiological model lichen *Circinaria gyrosa*. This work is funded by the European Project: METAFLUIDICS (H2020, GA685474) and the Coordinated Project: CGL2015_66686-C3-2 (MINECO, Spain)

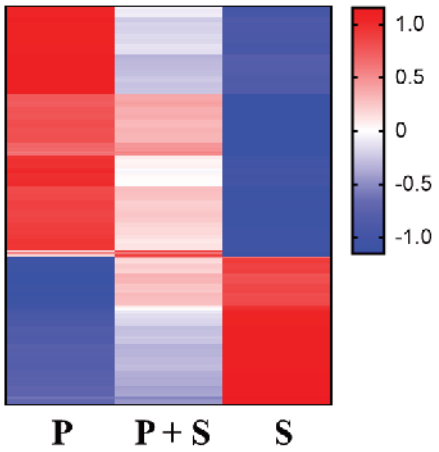


Figure 1. Heat map of differentially expressed genes (DEG). Only genes showing greater than a 1.8-fold difference in expression (FDR=0.1) were considered as DEGs. Expression is normalized by row: blue, red and white indicate minimum, maximum and midpoint expression levels, respectively. Each column indicates one of the three comparisons: NaClO4 versus NaCl (P), NaClO4 versus control (P+S), NaCl versus control (S).

Deciphering the molecular mechanisms of perchlorate resistance in *Haloferax volcanii* using transcriptional analysis

In 2008, high levels of perchlorate salts were discovered on the Martian surface. This finding has a major astrobiological interest at present due to perchlorate physical-chemical properties. Perchlorate is very hygroscopic, enhancing moisture absorbance to form liquid droplets, and it allows the presence of partially liquid salt solutions at very low temperatures (> -100ºC). Therefore, perchlorate is thought to promote the formation of perchlorate-rich salt liquid brines which could be niches for some microorganisms on Mars. The best candidates for inhabiting these environments would be hyperhalophiles, which grow under high salinity and naturally tolerate high perchlorate levels. For these reasons, the aim of this project was to study the molecular mechanisms of perchlorate resistance in the model archaeon *Haloferax volcanii* using transcriptional analysis.

Hfx. volcanii was exposed for 30 minutes to a sublethal concentration of sodium perchlorate and to a similar concentration of sodium chloride. This saline control was necessary to distinguish between the effect of the perchlorate anion and the increment in salinity due to adding the perchlorate salt to the medium. After RNA extraction, creation of cDNA libraries, sequencing and bioinformatic analysis, we studied the differences in gene expression among treatments.

We observed that perchlorate anion and salinity produced opposite effects in the transcriptome, therefore perchlorate was supposed to simulate a decrease in salinity (**Fig. 1**). Furthermore, in the presence of perchlorate, it was shown a reduction in cellular respiration and an increase in ROS elimination and DNA repair, as a response against oxidative stress and DNA damage produced by perchlorate. In addition, we observed enhanced transcription, translation and protein degradation for elimination and turnover of proteins damaged by chaotropic effects of perchlorate. Finally, we

hypothesize that modifications of tRNAs may induce changes in tRNA stability and the aminoacidic protein composition, which could help *Hfx. volcanii* to adapt to perchlorate/low-salinity conditions. Thus, *Hfx. volcanii* may tolerate high perchlorate levels not only by using general defense mechanisms but also because of its own adaption to changes in salinity.

Effect of day and night cycles on gene expression in hyperhalophilic microbial communities

The objective of this study was to assess the impact of light and dark cycles on the genetic expression of hypersaline-environment microorganisms, by employing a metagenomic and metatranscriptomic approach. For this, six samples of microorganisms were collected at different times during the day and at night from microorganisms of a salt crystallizer in the Es Trenc salterns (Mallorca). Total DNA (metagenome) and RNA (metatranscriptome) were isolated from the samples, sequenced and analysed by bioinformatics. The metagenomic data showed a very diverse taxonomic distribution, but the archaea *Haloquadratum walsbyi* and the bacterium *Salinibacter ruber* were the majority species. Metatranscriptomic distribution analyzes revealed a change in the expression pattern of these microorganisms, with increased *H. walsbyi* gene expression during the day and *S. ruber* gene expression during the night. Further studies through metatranscriptomic were accomplished to describe the main functional behaviour and mechanisms for adapting to changes in light (Fig. 2). Few *S. ruber* genes showed significant expression during the day, whereas at nigh a large increase was found in the housekeeping functions of information storage and processing, metabolism and energy production and conversion. An opposite gene transcription pattern was observed for *H. walsbyi*. Both species appear to coexist due to several adaptive mechanisms mediating inter-specific interactions and a temporal niche differentiation event. Additional metavirome-based studies of the same samples and further experiments using pure laboratory cultures of *S. ruber* are being carried out.

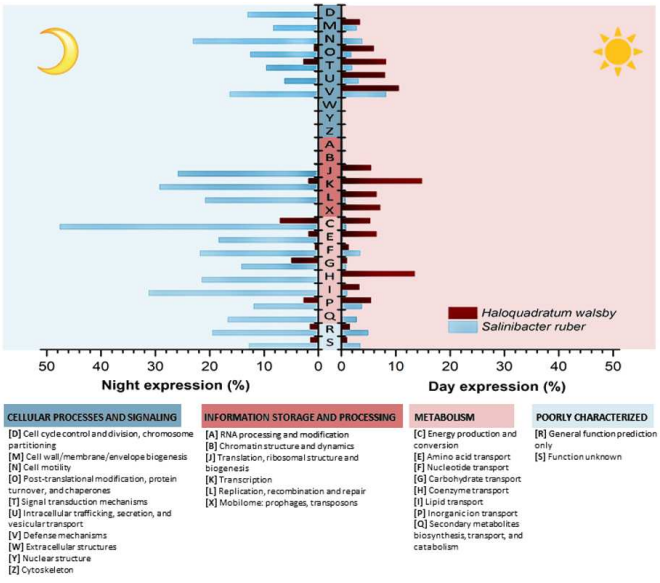


Figure 2. Functional profile of day and night induced genes in *Salinibacter ruber* and *Haloquadratum walsbyi* based on COG categories. Data represented as a percentage of significantly induced genes out of the total genes of each functional category.

Characterization of DNA vesicles produced by *Haloquadratum walsbyi* cultures

Haloquadratum walsbyi is a hyperhalophilic archaeon first discovered in the early 1980s in a coastal brine of the Sinai Peninsula (Egypt). This novel organism has been reported as the most abundant microorganism in these extreme hypersaline habitats and its square cell shape is really characteristic. Analyzing cultures of *H. walsbyi* growing at 42°C under light-dark cycles (12h/12h), we have detected, at specific cell densities (OD values between 0.16 and 0.26), the production of very small spherical particles that contain DNA. This phenomenon, undescribed until now for *Haloquadratum*, seems to be related to cell density and we have detected it in both a natural strain isolated from Santa Pola salterns and in a collection strain (DSM 16790). We are currently characterizing these extracellular vesicles (EVs). EVs are spherical particles that are enclosed by a lipid bilayer and cannot auto-replicate. Although the biological relevance of EVs was initially controversial, numerous recent studies highlight its involvement in multiple processes such as cell defense against virus, development of microbial communities that are resistant to

different antibiotics and horizontal gene transfer processes, among other.

We have developed protocols for isolating these extracellular vesicles from *Haloquadratum* cultures and for extracting its DNA content. Our preliminary analyses suggest that they contain large molecules of > 10 kb. We will now proceed with its sequencing in order to check whether they contain whole genomes or specific regions of it. In addition, we have recently analyzed these particles by fluorescent microscopy and by transmission electron microscopy, observing spherical vesicles with a diameter of around 30-40 nm (Fig. 3).

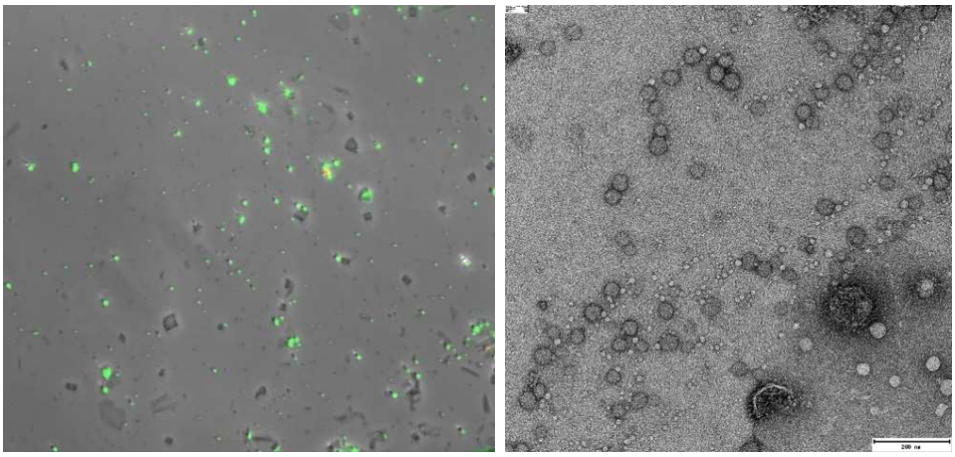


Fig. 3. Left: Fluorescent microscopy image of *Haloquadratum walsbyi* (DSM 16790) cells and vesicles labelled with Life/Dead staining. DNA from live cells and vesicles (small fluorescent dots) were labelled in green. Right: Transmission electron microscopy image of vesicles isolated from the culture.

Study of effect of UV radiation on gene expression of the astrobiological model lichen *Circinaria gyrosa*

The main purpose of this research has been to study the effect of extreme UV space radiation effect in *Circinaria gyrase*, a species of vagrant lichen used as an astrobiological model system due to its high resistance and survival observed in the space missions and we are specifically interested in identifying the genes involved in adaptation to high doses of UV radiation. *C. gyrase* samples were exposed at 300 J/cm^2 of UV-C and UV-B radiation for 30h, RNA was isolated and sequenced by Illumina HiSEq. Sequence reads were annotated taxonomically (Blast) and functionally (UNIPROT database). Changes in gene expression were analyzed in UV-exposed samples compared to untreated ones. In the case of the genes of the algae that make up the lichen, a very high percentage of repressed genes was observed in almost all functional categories, including metabolism and genes related to the storage and processing of genetic information. These results indicated that the algae were severely damaged by the high UV radiation dose. On the other hand, the fungal component of the lichen seems to react positively to UV radiation, since overexpressed genes were observed mainly for RNA processing and modification and for translation, ribosomal structure and biogenesis (both from information storage and processing) and intracellular traffic, secretion and vesicular transport.

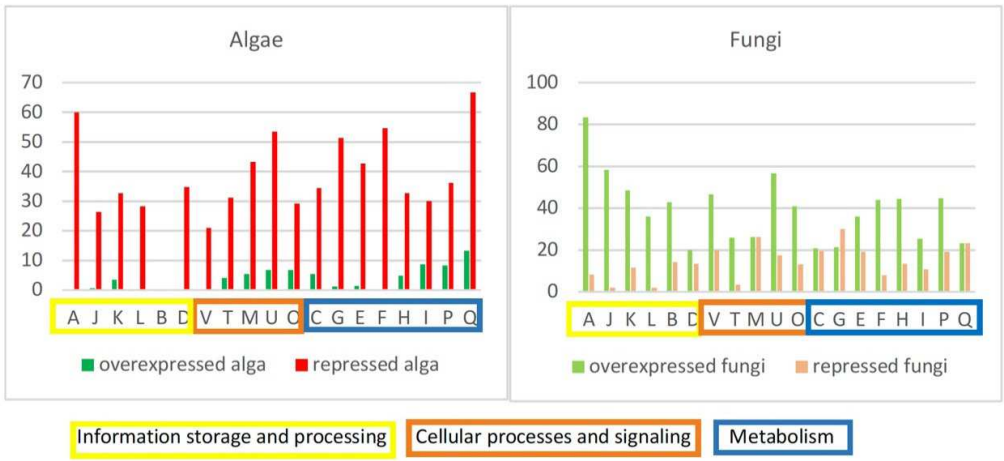
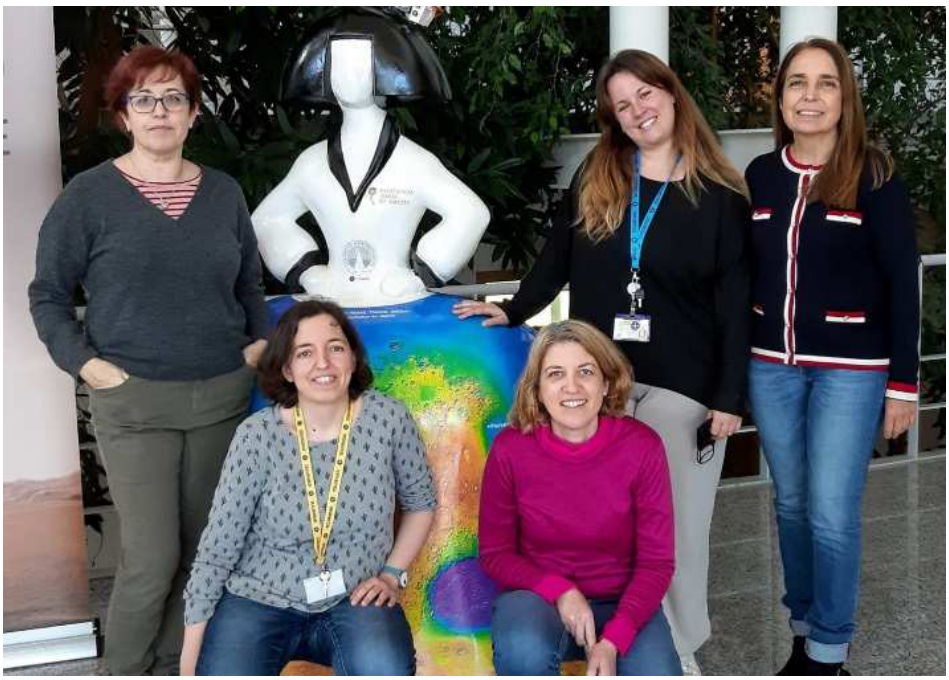


Figure 4. Functional profile of the algal and fungal components of the Circinaria gyrosa lichen based on COG categories. Data represented as a percentage of significantly induced genes out of the total genes of each functional category.

Microbial Biodiversity

Coordinator: Ángeles Aguilera



Group members in 2020

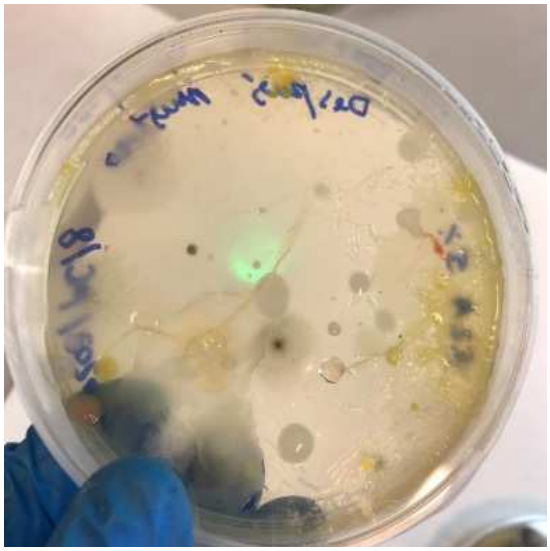
Members	Category
Ángeles Aguilera Bazán	Researcher
Cristina Cid Sánchez	Researcher
Elena González-Toril	Researcher
Eva García López	Predoctoral
Graciela de Diego Castilla	Postdoctoral

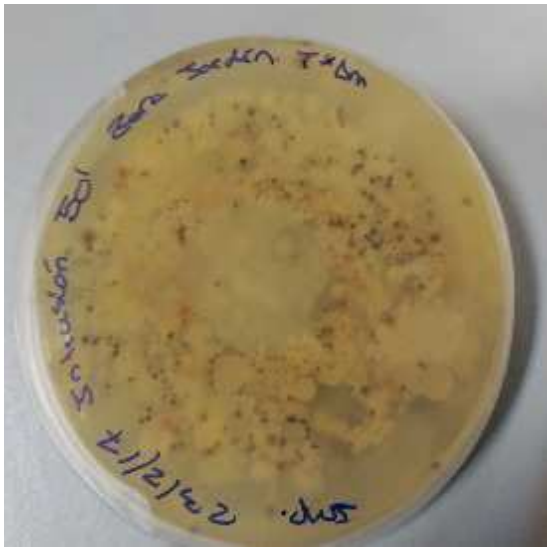
Elena González-Toril and Cristina Cid Sánchez

The cycle of aerosols on Mars and Earth, a comparative study. Implications for life and planetary protection. (CAMELIA_MICRO)

The purpose of this project is to investigate the atmospheric dispersal of mineral aerosols, organics and bioburden through the atmosphere of Mars, and then also on the atmosphere and surface of Earth, to provide an analogy case. Specific goals are: a) Study of the biodiversity and microbial dispersion associated to Saharan dust intrusions, b) Molecular mechanisms of resistance to ultraviolet radiation. Analysis of the potential protective role of dust. Molecular mechanisms activated when exposed to Martian conditions on Mars and space environment Simulation Chambers, c) Isolation of microorganisms from clean rooms of spacecraft assembly. Molecular mechanisms activated when exposed to Martian conditions on Mars and space environment Simulation Chambers.

We already produce a database of the atmospheric microbial diversity obtained from sampling in different meteorological situations, and seasons of Saharan intrusion and non-intrusion. In addition, we have a culture collection of microorganisms isolated during Saharan intrusions, isolates from clean rooms and isolates from the stratosphere. The resistance of the microorganisms to different extreme conditions, including those of the Martian atmosphere, are being carried out.



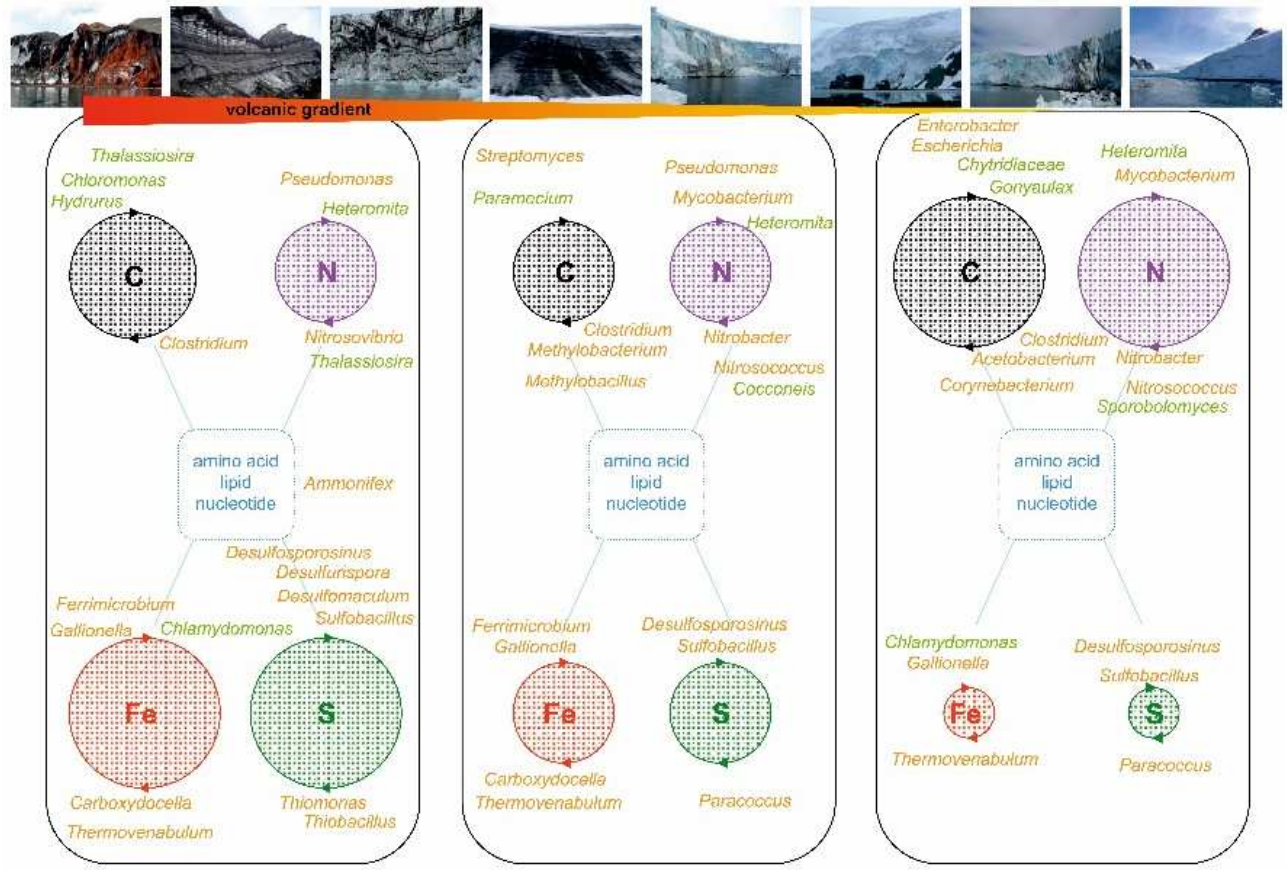


Cristina Cid Sánchez and Eva García López

Microbial community structure driven by volcanic gradients in Antarctic glaciers (POLAR_BIOSENSOR)

It has been demonstrated that the englacial ecosystem in volcanic environments is inhabited by active bacteria. To know whether this result could be extrapolated to other Antarctic glaciers, a study was performed using ice samples from eight glaciers in the South Shetland archipelago. The identification of microbial communities of bacteria and microeukaryotes using 16S rRNA and 18S rRNA high throughout sequencing showed a great diversity when compared with microbiomes of other Antarctic glaciers or frozen deserts. Even the composition of the microbial communities identified in the glaciers from the same island was different, which may be due to the isolation of microbial clusters within the ice. A gradient in the abundance and

diversity of the microbial communities from the volcano (west to the east) was observed. Additionally, a significant correlation was found between the chemical conditions of the ice samples and the composition of the prokaryotic populations inhabiting them along the volcanic gradient. The bacteria that participate in the sulfur cycle were those that best fit this trend. Furthermore, on the eastern island a clear influence of human contamination was observed on the glacier microbiome.

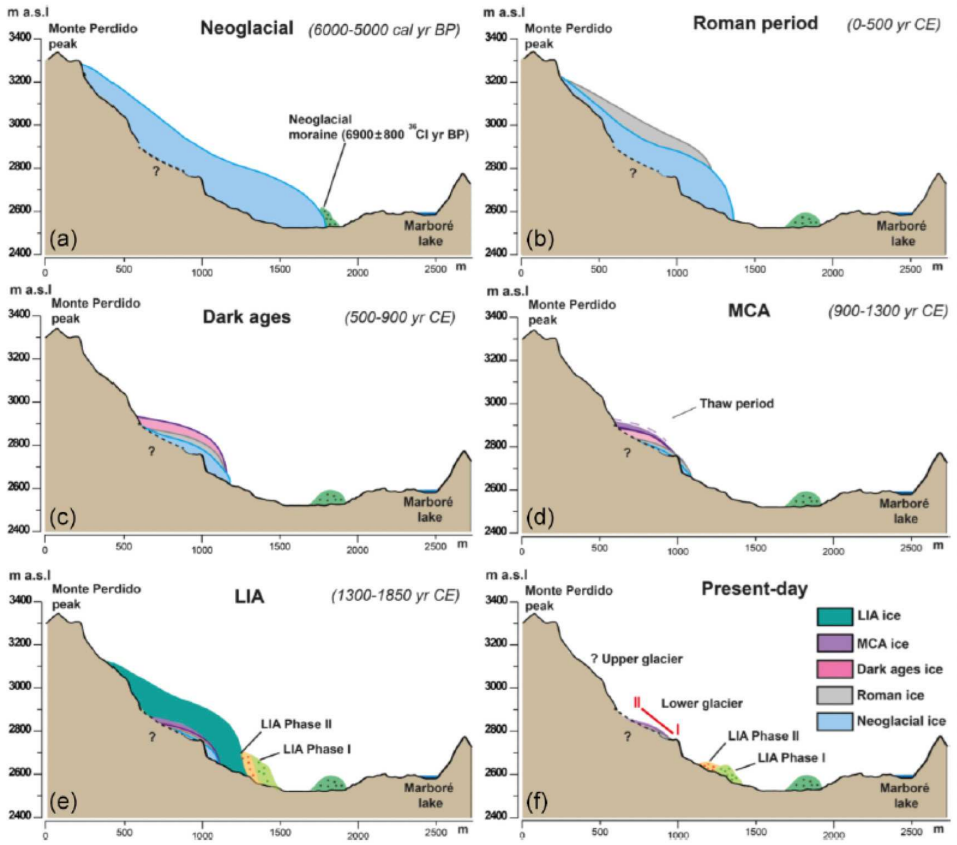


Cristina Cid Sánchez and Eva García López. Collaboration with IPE (CSIC)

Southern European glaciers which survived Roman and medieval warm periods but are disappearing under recent warming (PALEO-ICE)

Mountain glaciers have generally experienced an accelerated retreat over the last three decades as a rapid response to current global warming. However, the response to previous warm periods in the Holocene is not well-described for glaciers of the of southern Europe mountain ranges, such as the Pyrenees. The situation during the Medieval Climate Anomaly (900-1300 CE) is particularly relevant since it is not certain whether the glaciers just experienced significant ice loss or whether they actually disappeared. We present here the first chronological study of a glacier located in the Central Pyrenees (N Spain), the Monte Perdido Glacier (MPG), carried out by different radiochronological techniques and their comparison with geo-chemical proxies with neighboring paleoclimate records. The result of the chronological model proves that the glacier endured during the Roman Period and the Medieval Climate Anomaly. The lack of ice from last

600 years indicates that the ice formed during the Little Ice Age has melted away. The analyses of the content of several metals of anthropogenic origin, such as Zn, Se, Cd, Hg, Pb, appear in low amounts in MPG ice, which further supports our age model in which the record from the industrial period is lost. This study confirms the exceptional warming of the last decades in the context of last two millennia. We demonstrate that we are facing an unprecedented retreat of the Pyrenean glaciers which survival is compromised beyond a few decades.



Ángeles Aguilera and Elena González-Toril

Microbiological Control in the Formation of Mineral Deposits (MINLIFE)

The study of the Deep Biosphere is one of the most novel and promising unexplored topics of research due to its relevant implications on studies regarding the origin of life, life in extreme environments, its control over surface lithologies, the formation of low temperature mineral deposits and for the search for life in other planets. In this regard, MINLIFE proposes the study of one of the most interesting mineral deposits from the metallogenic and geomicrobiological point of view, Las Cruces (SW, Spain), in an attempt to know how microorganisms can control the processes of mineral formation and the dissolution and precipitation of metals. The project is aimed at studying mineralogy, isotope geochemistry and the microbial ecology of the deposit as well as the role of the microorganisms in the mineralizing processes. Prokaryotes and, to a lesser extent, fungi play a major role in the evolution of the uppermost crust by catalyzing thermodynamic equilibrium between minerals and fluids, having a key effect on the overall cycle of several elements and bringing life to extreme dark, hot and anaerobic environments. In fact, they are involved in many sub-surficial geochemical processes with the only limitation of the upper thermal limit of life, ca. 120°C. There are more and more evidences that microbes in the deep biosphere are much more abundant and diverse than never thought before.

In fact, one of the favorite ecological niches for extremophilic life are the ore deposits, geologic systems enriched in sulphides and oxides. The formation, modification and destruction of ore deposits is related with the circulation of, usually hot, waters enriched in metals and sulphur showing extreme pH and redox conditions. Ore deposits are also large reservoirs for electron donors/acceptors which is basic for major chemolithotrophic metabolism, including minerals, gases and aqueous species in redox disequilibrium.

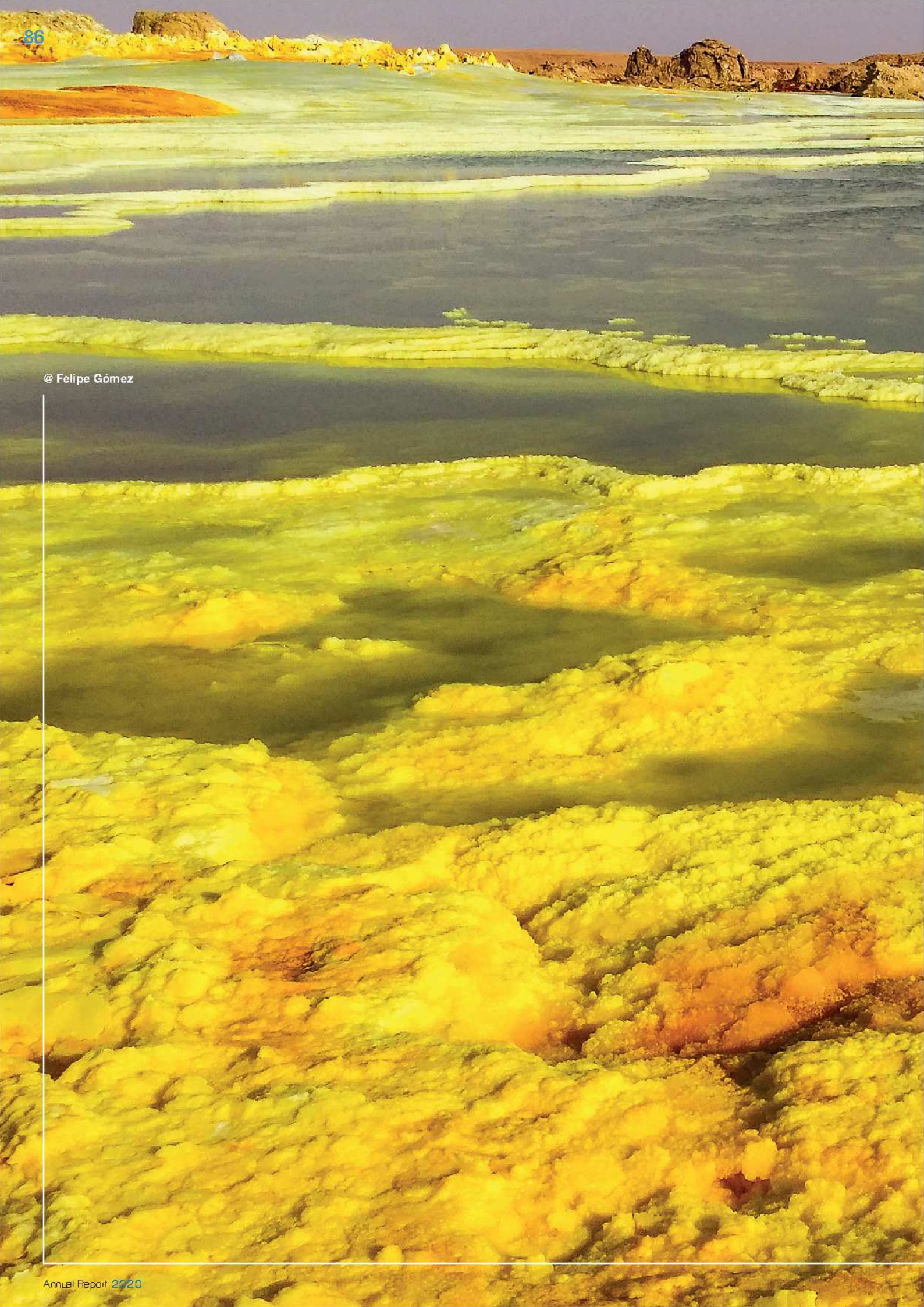
Ángeles Aguilera, Elena González-Toril and Susana Osuna

Development and implementation of sampling equipment for the study of airborne microorganisms at altitude: one stage electrostatic precipitators in Aerial Research Platforms (ELECTRO-BIOTA)

ELECTRO-BIOTA will be devoted to the study of atmospheric aerosols, using flying research platforms. At this moment, the sampling of external air is carried out by means of an isokinetic probe which will be the first thing we developed. The project has a scientific and engineering duality: the study of microbial ecology of the atmosphere and the adequacy of manned and unmanned flying platforms for the study of atmospheric microbial ecology. The main objectives are (i) Study of the microbial ecology of the atmosphere using manned and unmanned flying research platforms (ii) Correlation database by multivariate statistics and model development, (iii) Development of sampling equipment and software suitable for the proposed objectives.

Scientific working group of this project is made up of specialized researchers in microbial ecology of extreme environments and analytical chemistry. Engineering team is specialized in flying platform with an experience of more than 25 years. In summary, the combination of molecular ecology techniques, chemistry and physics, with appropriate technological support, will unveil the uniqueness of air microbial ecosystems and modeling of these interesting and little-known environments.

So far, three types of samplers have been developed (Electrostatic, Impactor, Coriolis-type liquid impregnator). Although we are collecting enough biomass, we still need to increase the efficiency of these. Also, the air intake isokinetic probe has been developed. 16S rRNA gene libraries have been developed and sequenced using Illumina. Additionally, more than 20 sampling flights using meteorological balloons were carried out during the year, sampling biomass from 20 Km to 40 Km altitude in order to recover biomass for diversity analysis and culture.



@ Felipe Gómez

Planetology and Habitability department of

Head of Department:

Dr. Felipe Gómez

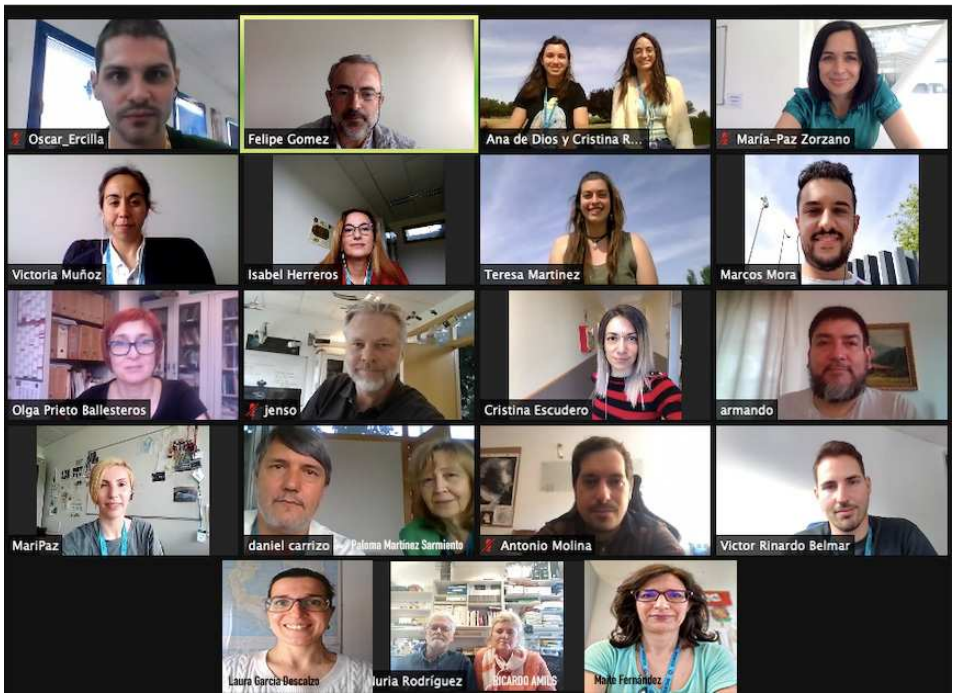
The Department of Planetology and Habitability has developed a transdisciplinary activity since its creation, a reflection of this is that it is made up of 2 Research Groups:

- Planetary Geology and Atmospheres
- Habitability and Extreme environments

Participation in space missions and international panels

The Department of Planetary Geology and Habitability has two representatives on the Planetary Protection Panel (PPP) of COSPAR (SPAce Research Committee): Scientific Commissions B - Space Studies of the Earth-Moon System, Planets and Small Bodies of Solar Systems. This year, the panel launched discussions on the Moon's planetary protection categorization. The Department also has a representative within the Mars Sample Return Scientific Management Group 2 (MSPG-2), an international panel that defines the plan to maximize the scientific return of the first samples to be brought to Earth from Mars. This plan will be an addendum to the ESA-NASA agreement for the Mars Sample Return campaign. The group also has a representative in Perseverance, as a Return Sample Science Participating Scientist (RSS-PS). As part of Perseverance operations, there are a total of 10 representatives who have been selected by NASA and 5 selected by ESA, to document procedures, select samples and provide the required on-site observations and cache samples, that the future ESA-NASA mission will bring back to Earth.

Participation in the ExoMars TGO and Curiosity science teams continues as a science team. Due to programmatic issues, the launch of the rover and the ExoMars platform was delayed from



Members
Amils Pibernat, Ricardo
Azua Bustos, Armando Javier
Carrizo Gallardo, Daniel Alejandro
De Dios Cubillas, Ana
Escudero Parada, Cristina
Fernándezsampedro, María Teresa
Garcia Descalzo, Laura
Gómez Gómez, Felipe
Gonzalez Fairen, Alberto
Herreros Cid, Maria Isabel
Lopez Jimenez, Alicia
Martin Redondo, Maria Paz
Martínez Pérez, Teresa
Martínez Sarmiento, Paloma
Molina Jurado, Antonio
Mora, Marcos
Muñoz Iglesias, Maria Victoria
Olof Ormo, Jens
Prieto Ballesteros, Olga
Rinardo Belmar, Victor Alfonso
Robas García, Cristina
Rodriguez Gonzalez, Nuria
Salese, Francesco
Vega Garcia, Sonia Maria
Zorzano Mier, Maria Paz

2020 to 2022. The group has participated in the Rover Scientific Operations Working Group (RSOWG): mapping quads for new landing ellipses at Oxia Planum , and in the rover and surface platform integration test activities with Thales Alenia (France and Italy) and Lavochkin. We have joined the team of the Raman RLS / Exomars and RAX / MMX instruments in which we have tasks related to the future scientific exploitation of the mission.

Regarding the future of the exploration of Mars, the members of this group have also been involved in the generation of several white papers of the MEPAG 2020 community as contributions to the next Decadal Study of Planetary Sciences, such as: “Towards the prediction of the climate and Martian dust storms “; “Deep Trek: Science of habitability and subsurface life on Mars” and “Deep Trek: Mission concepts to explore habitability and subsurface life on Mars”; “Knowledge gaps on planetary protection and enabling science for human missions on Mars”.

We participate in two research projects associated with planetary missions financed by MINECO: “Technical operations and scientific exploitation of ExoMars RLS data, and contribution to MMX RAX” and “Science and instrumentation for the study of biogeochemical processes on Mars”. In addition, we received funding from ESA through a contract to carry out the study “Measurements of thermal and dielectric properties of ice in support of future radar measurements of Jovian icy moons”.

ACTIVITIES REPORT OF THE HABITABILITY AND EXTREME ENVIRONMENTS GROUP:

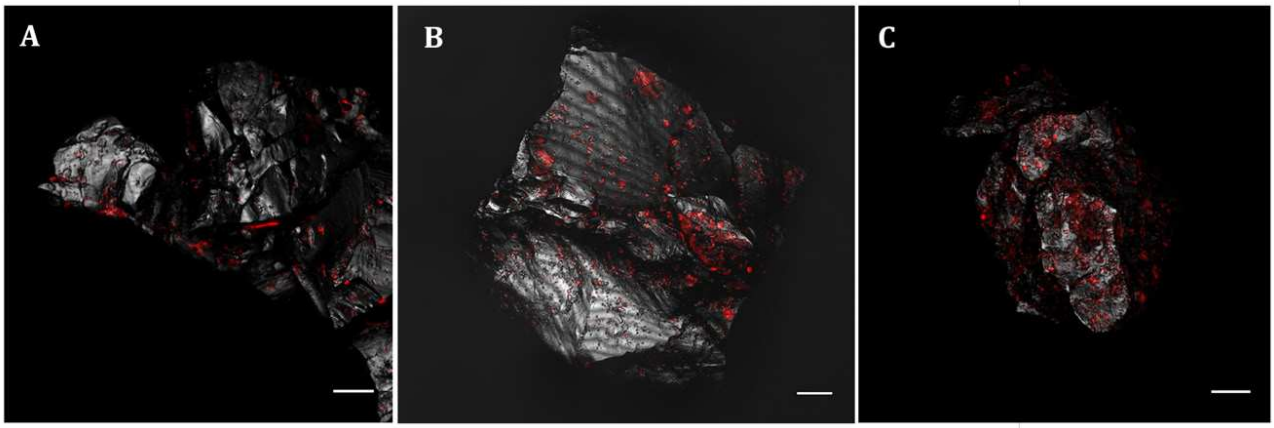
This research group is coordinated by Dr. Felipe Gómez. The research activities of the group focused during 2020 on the study of the habitability of extreme terrestrial analogs environments as well as on the study of the planet Mars. The following summary highlights some of the milestones achieved during 2020 in the research group.

Life limits and habitability studies on Earth Analogs

Visualizing Microorganism-Mineral Interaction in the Iberian Pyrite Belt Subsurface: The Acidovorax Case

Despite being considered an extreme environment, several studies have shown that life in the deep subsurface is abundant and diverse. Microorganisms inhabiting these systems live within the rock pores and, therefore, the geochemical and geohydrological characteristics of this matrix may influence the distribution of underground biodiversity.

In this study, correlative fluorescence and Raman microscopy (Raman-FISH) was used to analyze the mineralogy associated with the presence of members of the genus Acidovorax, an iron oxidizing microorganisms, in native rock samples of the Iberian Pyrite Belt subsurface. Our results suggest a strong correlation between the presence of Acidovorax genus and pyrite, suggesting that the mineral might greatly influence its subsurface distribution.

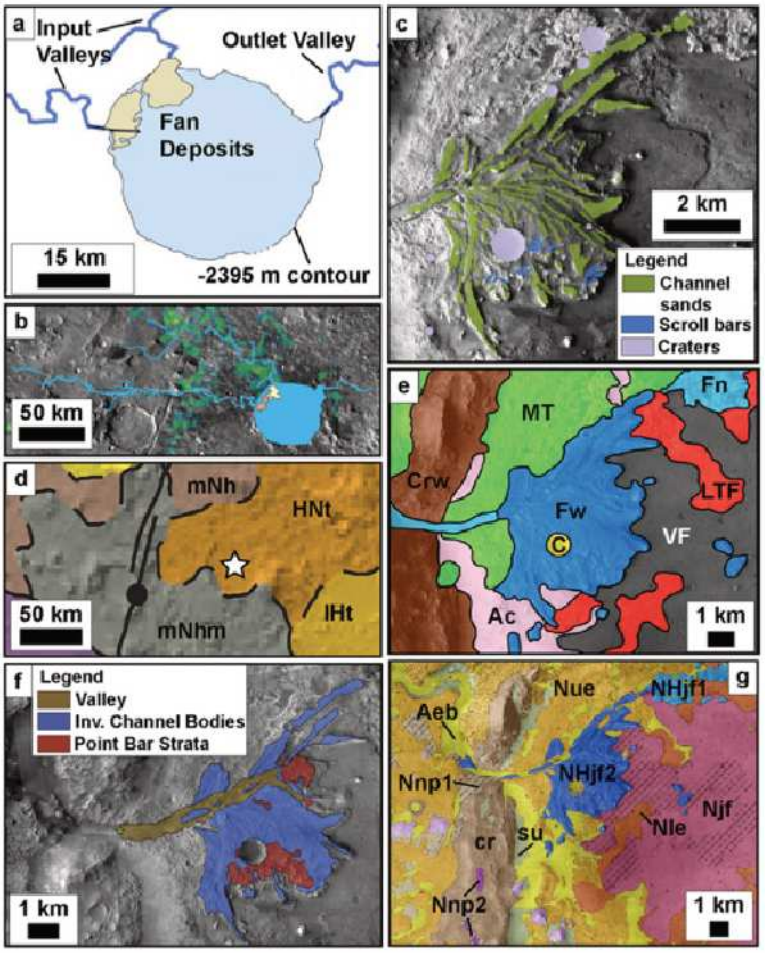


Acidovorax genus members detected by CARD-FISH in IPB subsurface rock samples at –139.4 m (A), –206.6 m (B) and –284 m (C). In red, CARD-FISH signal. In gray, reflection. Scale bars, 10 mm.

Photogeologic Map of the Perseverance Rover Field Site in Jezero Crater Constructed by the Mars 2020 Science Team

The Mars 2020 Perseverance rover landing site is located within Jezero crater, a ~50 km~50 kmdiameter impact crater interpreted to be a Noachian-aged lake basin inside the western edge of the Isidis impact structure. Jezero hosts remnants of a fluvial delta, inlet and outlet valleys, and infill deposits containing diverse carbonate, mafic, and hydrated minerals. Prior to the launch of the Mars 2020 mission, members of the Science Team collaborated to produce a photogeologic map of the Perseverance landing site in Jezero crater. Mapping was performed at a 1:5000 digital map scale using a 25 cm/pixel High Resolution Imaging Science Experiment (HiRISE) orthoimage mosaic base map and a 1 m/pixel HiRISE stereo digital terrain model. Mapped bedrock and surficial units were distinguished by differences in relative brightness, tone, topography, surface texture, and apparent roughness. Mapped bedrock units are generally consistent with those identified in previously published mapping efforts, but this study's map includes the distribution of surficial deposits and sub-units of the Jezero delta at a higher level of detail than previous studies. This study

considers four possible unit correlations to explain the relative age relationships of major units within the map area. Unit correlations include previously published interpretations as well as those that consider more complex interfingering relationships and alternative relative age relationships. The photogeologic map presented here is the foundation for scientific hypothesis development and strategic planning for Perseverance's exploration of Jezero crater.

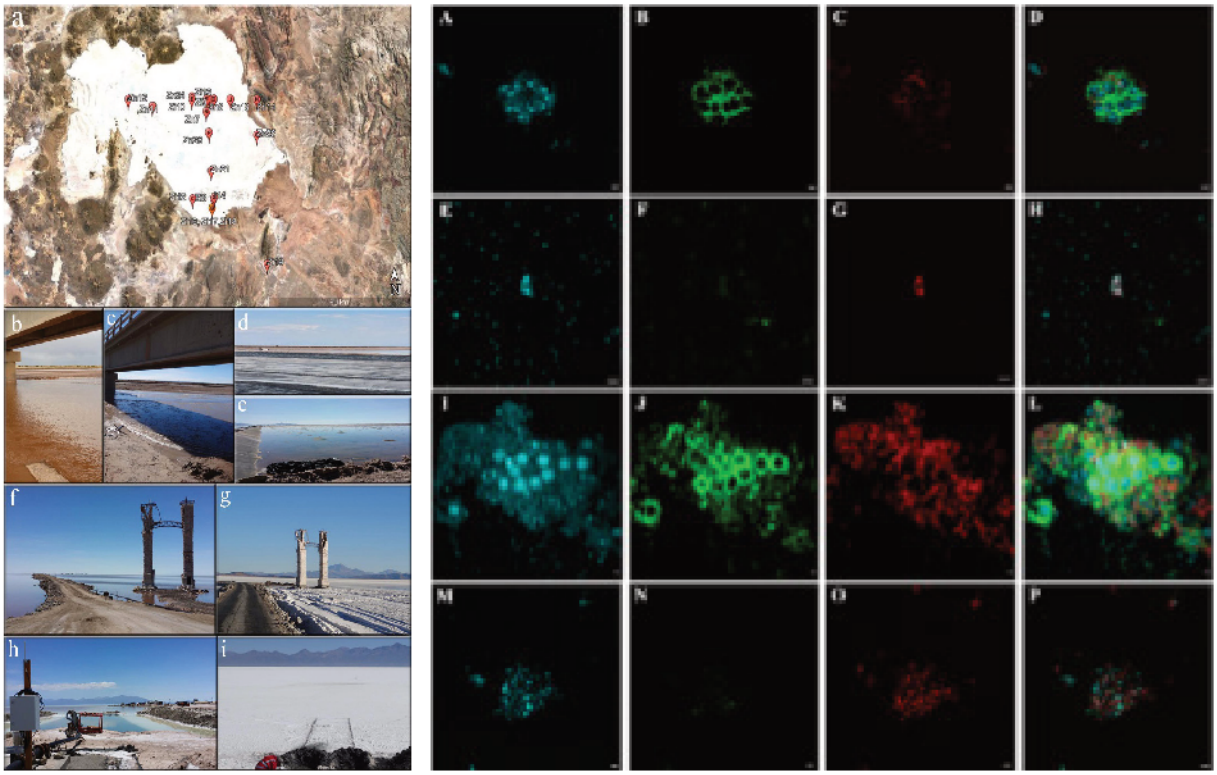


Previous mapping efforts in and around Jezero crater: (a) Inlet valleys, outlet valley, and western and northern fan deposits, modified from Fig. 1b in Fassett and Head (2005), (b) modified from Fig. 1c in Ehlmann et al. (2008); yellow is Northern delta, orange is Western delta, blue is channels and the extent of a lake if it were filled to the –2395 m contour, (c) modified from Fig. 14b in Schon et al. (2012); channel sands, scroll bars, and craters of the western Jezero delta, (d) Jezero crater (white star) mapped in Tanaka et al. (2014); HNt is Hesperian and Noachian transition unit; mNhm is middle Noachian highland massif unit; lHt is late Hesperian transition unit; mNh is middle Noachian highland unit, (e) a portion of area mapped by Goudge et al. (2015) annotated with their map unit labels; MT is mottled terrain, Fn is northern fan deposit, Fw is western fan deposit, LTF is light-toned floor unit, VF is volcanic floor unit, Ac is surficial debris cover, C is impact crater, Crw is crater rim and wall material, (f) valleys, inverted channel bodies, and point bar strata modified from Fig. 2a in Goudge et al. (2018), (g) a portion of Jezero and the surrounding area mapped in Sun and Stack (2020). Nnp1 is Noachian Nili Planum 1, Nnp2 is Noachian Nili Planum 2, Nle is Noachian lower etched, Nue is Noachian upper etched, Njf is Noachian Jezero floor, NHjf1 and NHjf2 are Noachian Hesperian Jezero fan 1 and 2, respectively, cr is crater rim, su is smooth undivided, and Aeb is Amazonian eolian bedforms

Subsurface and surface halophile communities of the chaotropic Salar de Uyuni

Salar de Uyuni (SdU) is the biggest athalosaline environment on Earth, holding a high percentage of the known world Li reserves. Due to its hypersalinity, temperature and humidity fluctuations, high exposure to UV radiation, and its elevated concentration of chaotropic agents like MgCl2, LiCl and NaBr, SdU is considered a polyextreme environment. Here, we report the prokaryotic abundance and diversity of 46 samples obtained in different seasons and geographical areas. The identified bacterial community was found to be more heterogeneous than the archaeal community, with both communities varying geographically. A seasonal difference has been detected for archaea. Sa-

linibacter, Halonotius and Halorubrum were the most abundant genera in Salar de Uyuni. Different unclassified archaea were also detected. In addition, the diversity of two subsurface samples obtained at 20 and 80 m depth was evaluated and compared with the surface data, generating an evolutionary record of a multilayer hypersaline ecosystem.



Confocal laser microscopy imaging of samples selected hybridized. In green positive signs for bacteria using probe EUB338 I-III (B, F, J, N), in Red Archaea with probe ARCH915 (C, G, K, O) and in general DAPI blue staining (A, E, I, M) for samples Zn5 (AD), Zi3 (EH), Zn25 (ILLINOIS) and i3 (M-P). D, H, L and P fused signals for Bacteria, Archaea and DAPI. Scale bar: 5 µm.

The Complex Molecules Detector (CMOLD): A Fluidic-Based Instrument Suite to Search for (Bio) chemical Complexity on Mars and Icy Moons

Organic chemistry is ubiquitous in the Solar System, and both Mars and a number of icy satellites of the outer Solar System show substantial promise for having hosted or hosting life. Here, we propose a novel astrobiologically focused instrument suite that could be included as scientific payload in future missions to Mars or the icy moons: the Complex Molecules Detector, or CMOLD. CMOLD is devoted to determining different levels of prebiotic/biotic chemical and structural targets following a chemically general approach (i.e., valid for both terrestrial and nonterrestrial life), as well as their compatibility with terrestrial life. CMOLD is based on a microfluidic block that distributes a liquid suspension sample to three instruments by using complementary technologies: (1) novel microscopic techniques for identifying ultrastructures and cell-like morphologies, (2) Raman spectroscopy for detecting universal intramolecular complexity that leads to biochemical functionality, and (3) bioaffinity-based systems (including antibodies and aptamers as capture probes) for finding life-related and nonlife-related molecular structures. We highlight our current developments to make this type of instruments flight-ready for upcoming Mars missions: the Raman spectrometer included in the science payload of the ESAs Rosalind Franklin rover (Raman Laser Spectrometer instrument) to be launched in 2022, and the biomarker detector that was included as payload in the NASA Icebreaker lander mission proposal (SOLID instrument). CMOLD is a robust solution that builds on the combination of three complementary, existing techniques to cover a wide spectrum of targets in the search for (bio)chemical complexity in the Solar System.

Constraining the preservation of organic compounds in Mars analog nontronites after exposure to acid and alkaline fluids

The presence of organic matter in lacustrine mudstone sediments at Gale crater was revealed by the Mars Science Laboratory Curiosity rover, which also identified smectite clay minerals. Analogue experiments on phyllosilicates formed under low temperature aqueous conditions have illustrated that these are excellent reservoirs to host organic compounds against the harsh surface conditions of Mars. Here, we evaluate whether the capacity of smectites to preserve organic compounds can be influenced by a short exposure to different diagenetic fluids. We analyzed the stability of glycine embedded within nontronite samples previously exposed to either acidic or alkaline fluids (hereafter referred to as "treated nontronites") under Mars-like surface conditions. Analyses performed using multiple techniques showed higher photodegradation of glycine in the acid-treated nontronite, triggered by decarboxylation and deamination processes. In contrast, our experiments showed that glycine molecules were preferably incorporated by ion exchange in the interlayer region of the alkali-treated nontronite, conferring them a better protection against the external conditions. Our results demonstrate that smectite previously exposed to fluids with different pH values influences how glycine is adsorbed into their interlayer regions, affecting their potential for preservation of organic compounds under contemporary Mars surface conditions.

Deposits from giant floods in Gale crater and their implications for the climate of early Mars

This study reports in-situ sedimentologic evidence of giant floods in Gale crater, Mars, during the Noachian Period. Features indicative of floods are a series of symmetrical, 10 m-high gravel ridges that occur in the Hummocky Plains Unit (HPU). Their regular spacing, internal sedimentary structures, and bedload transport of fragments as large as 20 cm suggest that these ridges are antidunes: a type of sedimentary structure that forms under very strong flows. Their 150 m wavelength indicates that the north-flowing water that deposited them was at least 24 m deep and had a minimum velocity of 10 m/s. Floods waned rapidly, eroding antidune crests, and re-deposited removed sediments as patches on the up-flow limbs and trough areas between these ridges forming the Striated Unit (SU). Each patch of the SU is 50–200 m wide and long and consists of 5–10 m of south-dipping layers. The strike and dip of the SU layers mimic the attitude of the flank of the antidune on which they were deposited. The most likely mechanism that generated flood waters of this magnitude on a planet whose present-day average temperature is – 60 °C was the sudden heat produced by a large impact. The event vaporized frozen reservoirs of water and injected large amounts of CO_2 and CH_4 from their solid phases into the atmosphere. It temporarily interrupted a cold and dry climate and generated a warm and wet period. Torrential rainfall occurred planetwide some of which entered Gale crater and combined with water roaring down from Mt. Sharp to cause gigantic flash floods that deposited the SU and the HPU on Aeolis Palus. The warm and wet climate persisted even after the flooding ended, but its duration cannot be determined by our study.

Extraformational sediment recycling on Mars

Extraformational sediment recycling (old sedimentary rock to new sedimentary rock) is a fundamental aspect of Earth's geological record; tectonism exposes sedimentary rock, whereupon it is weathered and eroded to form new sediment that later becomes lithified. On Mars, tectonism has been minor, but two decades of orbiter instrument–based studies show that some sedimentary rocks previously buried to depths of kilometers have been exposed, by erosion, at the surface. Four locations in Gale crater, explored using the National Aeronautics and Space Administration's Curiosity rover, exhibit sedimentary lithoclasts in sedimentary rock: At Marias Pass, they are mudstone fragments in sandstone derived from strata below an erosional unconformity; at Bimbe, they are pebble-sized sandstone and, possibly, laminated, intraclast-bearing, chemical (calcium sulfate) sediment fragments in conglomerates; at Cooperstown, they are pebble-sized fragments of sandstone within coarse sandstone; at Dingo Gap, they are cobble-sized, stratified sandstone fragments in conglomerate derived from an immediately underlying sandstone. Mars orbiter images show lithified sediment fans at the termini of canyons that incise sedimentary rock in Gale crater; these, too, consist of recycled, extraformational sediment. The recycled sediments in Gale crater are compositionally immature, indicating the dominance of physical weathering processes during the second known cycle. The observations at Marias Pass indicate that sediment eroded and removed from craters such as Gale crater during the Martian Hesperian Period could have been recycled to form new rock elsewhere. Our results permit prediction that lithified deltaic sediments at the Perseverance (landing in 2021) and Rosalind Franklin (landing in 2023) rover field sites could contain extraformational recycled sediment.

Inhabited subsurface wet smectites in the hyperarid core of the Atacama Desert as an analog for the search for life on Mars

The modern Martian surface is unlikely to be habitable due to its extreme aridity among other environmental factors. This is the reason why the hyperarid core of the Atacama Desert has been studied as an analog for the habitability of Mars for more than 50 years. Here we report a layer enriched in smectites located just 30 cm below the surface of the hyperarid core of the Atacama. We discovered the clay-rich layer to be wet (a phenomenon never observed before in this region), keeping a high and constant relative humidity of 78% (aw 0.780), and completely isolated from the changing and extremely dry subaerial conditions characteristic of the Atacama. The smectite-rich layer is inhabited by at least 30 halophilic species of metabolically active bacteria and archaea, unveiling a previously unreported habitat for microbial life under the surface of the driest place on Earth. The discovery of a diverse microbial community in smectite-rich subsurface layers in the hyperarid core of the Atacama, and the collection of biosignatures we have identified within the clays, suggest that similar shallow clay deposits on Mars may contain biosignatures easily reachable by current rovers and landers.

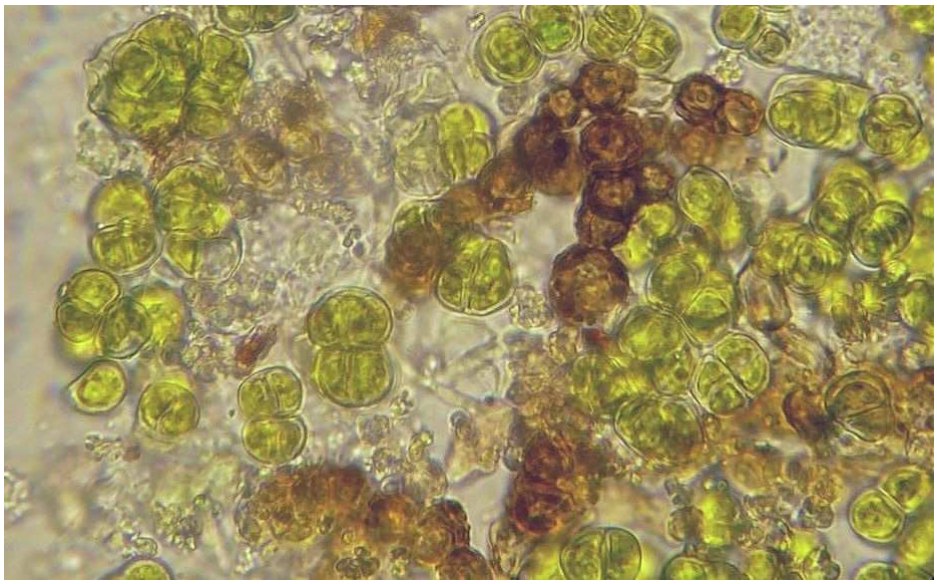
The site of Yungay, where inhabited clays have been found under its surface.

Can Halophilic and Psychrophilic Microorganisms Modify the Freezing/Melting Curve of Cold Salty Solutions? Implications for Mars Habitability

We present the hypothesis that microorganisms can change the freezing/melting curve of cold salty solutions by protein expression, as it is known that proteins can affect the liquid-to-ice transition, an ability that could be of ecological advantage for organisms on Earth and on Mars. We tested our hypothesis by identifying a suitable candidate, the well-known psycrophile and halotolerant bacteria Rhodococcus sp. JG3, and analyzing its response in culture conditions that included specific hygroscopic salts relevant to Mars—that is, highly concentrated magnesium perchlorate solutions of 20wt % and 50wt % Mg(ClO4)2 at both end members of the eutectic concentration (44 wt %)—and subfreezing temperatures (263 K and 253 K). Using a combination of techniques of molecular microbiology and aqueous geochemistry, we evaluated the potential roles of proteins over- or underexpressed as important players in different mechanisms for the adaptability of life to cold environments. We recorded the changes observed by micro-differential scanning calorimetry. Unfortunately, Rhodococcus sp. JG3 did not show our hypothesized effect on the melting characteristics of cold Mg-perchlorate solutions. However, the question remains as to whether our novel hypothesis that halophilic/psychrophilic bacteria or archaea can alter the freezing/melting curve of salt solutions could be validated. The null result obtained after analyzing just one case lays the foundation to continue the search for proteins produced by microorganisms that thrive in very cold, high-saline solutions, which would involve testing different microorganisms with different salt components. The immediate implications for the habitability of Mars are discussed.

Can the microalgae Dunaliella form a borderline lichen with Hortaea werneckii?

Lichenized fungi usually develop complex, stratifiedmorphologies through an intricately balanced living togetherwith their algal partners, but several species are known to form only more or less loose associations with algae. These borderline lichens are still little explored although they could inform us about early stages of lichen evolution.We studied the association of the extremely halotolerant fungus Hortaea werneckii with the alga Dunaliella atacamensis, discovered in a cave in the Atacama Desert (Chile), and with D. salina, common inhabitant of saltern brines. D. atacamensis forms small colonies, in which cells of H. werneckii can be frequently observed, while such interaction has not been observed with D. salina. As symbiotic interactions between Dunaliella and Hortaea have not been reported, we performed a series of co-cultivation experiments to inspect whether these species could interact and develop more distinct lichen-like symbiotic structures.We set up co-cultures between axenic strains of Hortaea werneckii (isolated both from Mediterranean salterns and from the Atacama cave) and isolates of D. atacamensis (from the Atacama cave) and D. salina (isolated from Mediterranean salterns). Although we used different growth media and cultivation approaches, bright field and SEM microscopy analyses did not indicate any mutual effects in these experiments.We discuss the implications for fungal algal interactions along the transition from algal exploiters to lichen symbioses.



The close association between the microalgae *Dunaliella* and the *fungi Hortae*

Metabolomics as an Emerging Tool in the Search for Astrobiologically-Relevant Biomarkers

It is now routinely possible to sequence and recover microbial genomes from environmental samples. To the degree it is feasible to assign transcriptional and translational functions to these genomes, it should be possible, in principle, to largely understand the complete molecular inputs and outputs of a microbial community. However, gene-based tools alone are presently insufficient to describe the full suite of chemical reactions and small molecules that compose a living cell. Metabolomic tools have developed quickly and now enable rapid detection and identification of small molecules within biological and environmental samples. The convergence of these technologies will soon facilitate the detection of novel enzymatic activities, novel organisms, and potentially extraterrestrial life-forms on solar system bodies. This review explores the methodological problems and scientific opportunities facing researchers who hope to apply metabolomic methods in astrobiology-related fields, and how present challenges might be overcome. Acknowledgments: All the research carried out in this last section has been possible thanks to the support of the Human Frontiers Science Program grant No. RGY0066 / 2018 and ERC Consolidator Grant No. 818602.

Planetary Geology And Atmospheres Group

Coordinator: Dr. Olga Prieto-Ballesteros

The activities carried out during 2020 are included within the main objectives that define this group, namely: 1) participation in planetary exploration missions to obtain astrobiological data, 2) determination of the influence of geology and atmospheres in current extreme environments and terrestrial paleo-environments that may be analogous to those of other planets, 3) the characterization of planetary material in relation to habitability, and 4) the understanding of geological and atmospheric processes that affect the evolution of planets and satellites through experimental and computational simulation.

Gender Balance in Mars Exploration: Lessons Learned from the Mars Science Laboratory

There is, recently, a global concern about the gender gap in Science, Technology, Engineering, and Mathematics (STEM) areas, starting from education role models, student applications, through the academic, industrial and management career progression. Given the high visibility and popularity of all subjects related to space exploration, female participation in this field may be used to change the existing stereotypes and provide role models to the younger generations, thus having a positive influence on education while also demonstrating to other organizations how to promote diversity in the working environment. Previous studies on spacecraft science teams, considering only principal and co-Investigators, PIs and co-investigators (CoIs), respectively, show that the percentage of women in the role of investigators has remained flat at 15.8% since 2000. The NASA Mars Science Laboratory (MSL) mission is taken here as an example to perform a statistical analysis of the gender profile for the period 2004–2018. The results are compared with: (1) data from the US National Science Foundation (NSF) about gender distribution in STEM postdoctoral profiles and faculty members; (2) the trend of planetary exploration team profiles; (3) research and innovation statistics in Europe; (4) proposals of the EU FP6 funding program; and (5) the percentage of female researchers from the Elsevier status report. This analysis shows that the process of continually holding open calls for Participating Scientists based on individual merit and the application of a flat working structure have allowed gender balance within the MSL team to improve naturally while maximizing individual and team performance. Women represent approximately 30.6% of the team, in agreement with the current percentage of female planetary exploration researchers and senior faculty members in academia. Interestingly, the percentage of female-led articles has been above the MSL women percentage trend. While the percentage of women in planetary science appears to be increasing, their role on the proposing teams is still low. As in other STEM fields, attention should be paid to secure the adequate promotion of younger generations to achieve the United Nation's Sustainable Development Goal 5 of achieving gender equality and empowering all women and girls by 2030.

PACKMAN – A portable instrument to investigate space weather

PACKMAN (PArticle Counter k-index Magnetic ANomaly) is an autonomous, light and robust space weather instrument for operation within the subsurface, surface and atmosphere (as payload in stratospheric balloons) of the Earth. It has been designed using Commercial Off-The-Shelf (COTS) components to reduce the cost of each unit and to allow to have multiple units monitoring simultaneously at different sites and also incorporate an open-access citizen science approach. The hardware-core of each PACKMAN units, weights around 600 g and consumes about 500 mA of current at 12 V. PACKMAN has been deployed at multiple latitudes and altitudes ranging from stratospheric heights (corroborating its TRL8 maturity) to subsurface depths of around 1 km. The data from PACKMAN have been compared with the state-of-the-art ground-based observatories, and satellites and scientific observations have been documented. A 3-D network of PACKMAN units operating continuously around the globe, from the subsurface to the stratosphere, would help to improve the understanding of the space weather phenomena, and its implications on the climate and infrastructures. PACKMAN is also an excellent tool for education and outreach. This article outlines the building instructions of two types of PACKMAN units: PACKMAN-S for ground-based measurements and PACKMAN-B for stratospheric measurements aboard high-altitude balloons.

Development of a wind retrieval method for low-speed low-pressure flows for ExoMars

Forced convective heat transfer from three horizontally inclined rectangular-based cylinders (rods) has been studied experimentally under representative Martian near-surface air flows in the Aarhus Wind Tunnel Simulator (AWTS), Denmark. The testing campaign was developed for the HABIT (Habitability: Brines, Irradiation and Temperature) instrument, European payload on board the ExoMars 2022 Kazachok surface platform. The average heat transfer coefficient was determined from steady CO_2 flows at a pressure of 9.9 mbar, an ambient temperature of ~25 °C, and for horizontal free-stream velocities between 0.8 and 12 m/s. A retrieval algorithm to derive the wind speed from the average heat transfer coefficient estimated at each of the three HABIT Air Temperature Sensors (ATS) rods was calibrated within the AWTS. The ATS rods are placed one at the front of the instrument structure (ATS2) and two on the sides (ATS1 and ATS3); and under Martian atmospheric conditions these rods serve as cooling fins. Several relationships between the Nusselt number and the Reynolds and Prandtl numbers reported in the literature were evaluated to model convective heat transfer from the ATS rods. Where needed, corrections to account for radiative heat transfer within the AWTS were implemented. The final retrieval method demonstrated that wind speed can be retrieved for frontal winds in the range of 0–10 m/s, with an error of ±0.3 m/s, using the cooling profile of the ATS rod 3, and for lateral winds in the range of 0–6 m/s, with an error of ±0.3 m/s, using the ATS rod 2 cooling profile.

Pressure Optimized PowEred Respirator (PROPER): A miniaturized wearable cleanroom and biosafety system for aerially transmitted viral infections such as COVID-19

The supply of Personal Protective Equipment (PPE) in hospitals to keep the Health Care Professionals (HCP) safe taking care of patients may be limited, especially during the outbreak of a new disease. In particular, the face and body protective equipment is critical to prevent the wearer from exposure to pathogenic biological airborne particulates. This situation has been now observed worldwide during the onset of the COVID-19 pandemic. As concern over shortages of PPE at hospitals grows, we share with the public and makers' community the Pressure Optimized PowEred Respirator (PROPER) equipment, made out of COTS components. It is functionally equivalent to a Powered Air Purifying Respirator (PAPR). PROPER, a hood-based system which uses open source and easily accessible components is low-cost, relatively passive in terms of energy consumption and mechanisms, and easy and fast to 3D print, build and assemble. We have adapted our experience on building clean room environments and qualifying the bioburden of space instruments to this solution, which is in essence a miniaturized, personal, wearable cleanroom. PROPER would be able to offer better protection than an N95 respirator mask, mainly because it is insensitive to seal fit and it shields the eyes as well. The PROPER SMS fabric is designed for single-use and not intended for reuse, as they may start to tear and fail but the rest of the parts can be disinfected and reused. We provide a set of guidelines to build a low-cost 3D printed solution for an effective PAPR system and describe the procedures to validate it to comply with the biosafety level 3 requirements. We have validated the prototype of PROPER unit for air flow, ISO class cleanliness level, oxygen and carbon-dioxide gas concentrations during exhalation, and present here these results for illustration. We demonstrate that the area inside the hood is more than 200 times cleaner than the external ambient without the operator and more than 175 times with the operator and in an aerosol exposed environment. We also include the procedure to clean and disinfect the equipment for reuse. PROPER may be a useful addition to provide protection to HCPs against the SARS-CoV-2 virus or other potential future viral diseases that are transmitted aerially.

The HABIT (HabitAbility: Brine Irradiation and Temperature) environmental instrument for the ExoMars 2022 Surface Platform

The HABIT (HabitAbility: Brine Irradiation and Temperature) instrument is a European payload of the ExoMars 2022 Surface Platform *Kazachok* that will characterize the present-day habitability at its landing place in Oxia Planum, Mars. HABIT consists of two modules: (i) EnvPack (Environmental Package) that monitors the thermal environment (air and ground), the incident ultraviolet radiation, the near-surface winds and the atmospheric dust cycle; and (ii) BOTTLE (Brine Observation Transition To Liquid Experiment), an In-situ Resource Utilization instrument to produce liquid water for future Mars exploration. BOTTLE will be used also to investigate the electrical conductivity properties of the martian atmosphere, the present-day atmospheric-ground water cycle and to evaluate if liquid water can exist on Mars in the form of brines, and for how long. These variables measured by HABIT are critical to determine the present and future habitability of the martian surface. In this paper, we describe in detail the HABIT instrument and sensors, together with the calibration of its Flight Model (FM) and the Engineering Qualification Model (EQM) versions. The EnvPack module has heritage from previous missions operating on the surface of Mars, and the environmental observations of its sensors will be directly comparable to those delivered by those missions. HABIT can provide information of the local temperature with ±0.2 °C accuracy, local winds with ±0.3 m/s, surface brightness temperature with ±0.8 °C, incident UV irradiance with 10% error of its absolute value in the UV-A, UV-B, UV-C ranges, as well as in the total UV-ABC range, and two additional wavebands, dedicated to ozone absorption. The UV observations can be used to derive the total opacity column and thus monitor the dust and ozone cycles. BOTTLE can demonstrate the hydration state of a set of four deliquescent salts, which have been found on Mars (calcium chloride, ferric sulphate, magnesium perchlorate and sodium perchlorate) by monitoring their electric conductivity (EC). The EC of the air and the dry salts under Earth ambient, clean room conditions is of the order of 0.1 μScm–1. We have simulated HABIT operations, within an environmental chamber, under martian conditions similar to those expected at Oxia Planum. For dry, CO2 atmospheric conditions at martian pressures, the air EC can be as low as 10–8 μScm–1, however it increases with the relative humidity (RH) percentage. The laboratory experiments show that after an increase from 0 to 60% RH within a few hours, the EC of the air increased up to 10–1 μScm–1, magnesium perchlorate hydrated and reached values of 10 μScm-1, whereas calcium chloride deliquesced forming a liquid state with EC of 102 μScm–1. HABIT will operate with a regular cadence, through day and night. The Electronic Unit (EU) is protected with a heater that is activated when its temperature is below –33 °C and disabled if the temperature of the surface platform rises above –30 °C. Additionally, the heaters of the BOTTLE unit can be activated to dehydrate the salts and reset the experiment. HABIT weighs only 918 g. Its power consumption depends on the operation mode and internal temperature, and it varies between 0.7 W, for nominal operation, and 13.1 W (when heaters are turned on at full intensity). HABIT has a baseline data rate of 1.5 MB/sol. In addition to providing critical environmental observations, this light and robust instrument, will be the first demonstrator of a water capturing system on the surface of Mars, and the first European In-Situ Resource Utilization in the surface of another planet.

Atmospheric composition of exoplanets based on the thermal escape of gases and implications for habitability

The detection of habitable exoplanets is an exciting scientific and technical challenge. Owing to the current and most likely long-lasting impossibility of performing *in situ* exploration of exoplanets, their study and hypotheses regarding their capability to host life will be based on the restricted low-resolution spatial and spectral information of their atmospheres. On the other hand, with the advent of the upcoming exoplanet survey missions and technological improvements, there is a need for preliminary discrimination that can prioritize potential candidates within the fast-growing list of exoplanets. Here we estimate, for the first time and using the kinetic theory of gases, a list of the possible atmospheric species that can be retained in the atmospheres of the known exoplanets. We conclude that, based on our current knowledge of the detected exoplanets, 45 of them are good candidates for habitability studies. These exoplanets could have Earth-like atmospheres and should be able to maintain stable liquid water. Our results suggest that the current definition of a habitable zone around a star should be revisited and that the capacity of the planet to host an Earth-like atmosphere to support the stability of liquid water should be added.

Fully Interactive and Refined Resolution Simulations of the Martian Dust Cycle by the MarsWRF Model

The MarsWRF model is set up with fully interactive dust at 5° × 5° and 2° × 2 resolution. The latter allows for a better representation of topography and other surface properties. An infinite reservoir of surface dust is assumed for both resolutions. For 5° × 5°, surface dust lifting by wind stress takes place over broad areas, occurring in about 20% of the model's grid cells. For 2° × 2°, it is more spatially restricted, occurring in less than 5% of the grid cells, and somewhat reminiscent of the corridors Acidalia-Chryse, Utopia-Isidis, and Arcadia-West of Tharsis. The onset times of major dust storms—large regional storms or global dust storm events (GDEs)—do not exhibit much interannual variability, typically occurring at around *Ls* 260°. However, their magnitude does show significant interannual variability—with only small regional storms in some years, large regional storms in others, and some years with GDEs—owing to the interaction between major dust lifting regions at low latitudes. The latter is consistent with observed GDEs having several active dust lifting centers. The agreement between the model›s surface dust distribution and observation-based dust cover index maps is potentially better for 2° × 2°. For the latter, there is also significant surface dust lifting by wind stress in the aphelion season that is largely confined to the Hellas basin. It has a recurring time pattern of 2–7 sols, possibly resulting from the interaction between midlatitude baroclinic systems and local downslope flows.

Wind retrieval from temperature measurements from the Rover Environmental Monitoring Station/Mars Science Laboratory

This work presents a novel method for the real-time retrieval of wind speed on the surface of Mars that uses temperature measurements from the Rover Environmental Monitoring Station (REMS) instrument onboard the Curiosity rover of the Mars Science Laboratory (MSL) mission. After final failure of the Wind Sensor (WS) in sol 1491, REMS has not been providing wind data. The new wind retrieval approach that we propose may eventually be able to supply MSL with wind values for contextualizing the rover's operations and for meteorological studies on the surface of Mars. The new method is based on forced convection modeling of the Air Temperature Sensors (ATS) of REMS as thin rods immersed in the extreme low-pressure and high-radiating atmospheric conditions of the Martian thermal boundary layer at a height of m from the surface. A preliminary validation of the possibilities and limitations of this retrieval has been performed using comparative analysis with existing REMS wind field-site data for the same sols that are available at the Planetary Data System (PDS). We have developed both a "coarse" approach, in which wind speed is determined with no regard to wind direction, and a "refined" method, in which it is attempted to determine both wind speed and direction. Assuming the previously reported WS retrieval errors of 20% for the wind speed, we report an agreement to the WS values of wind speed ranging from 36.4% to 77% of the acquisition time for the "coarse" approach, depending on the sol examined. These promising results are limited to only evening extended acquisitions from 18:00 to 21:00 local mean solar time (LMST). This method could be applied to daytime conditions. The results suggest a new optimal orientation for wind speed retrieval of +60°clockwise with respect to the forward direction of the Curiosity rover, although the technique is not yet ready to be considered for planning of the Curiosity rover operations. This method could extend the wind characterization of the Gale Crater for future Curiosity rover data acquisitions by recycling air temperature measurements and provide the scientific community with a data set for future comparative analysis with the Temperature and Wind Sensors for InSight (TWINS)/InSight, the HabitAbility: Brines, Irradiation and Temperature (HABIT)/ExoMars 2022, and the Mars Environmental Dynamics Analyzer (MEDA)/Mars 2020 rover instruments.

Implementing bioburden reduction and control on the deliquescent hydrogel of the HABIT/ExoMars 2022 instrument

The HabitAbility: Brines, Irradiation and Temperature (HABIT) instrument will be part of the ExoMars 2022 mission (ESA/Roscosmos) and will be the first European In-situ Resource Utilization (ISRU) instrument capable of producing liquid water on Mars. HABIT is composed by two modules: Environmental Package (EnvPack) and Brine Observation Transition To Liquid Experiment (BOTTLE). EnvPack will help to study the current habitability conditions on Mars investigating the air and surface thermal ranges and Ultraviolet (UV) irradiance; and BOTTLE is a container with four independent vessels housing deliquescent salts, which are known to be present on Mars, where the liquid water will be produced after deliquescence. In order to prevent capillarity of deliquescent or hydrated salts, a mixture of deliquescent salts with Super Absorbent Polymer (SAP) based on polyacrylamide is utilized. This mixture has deliquescent and hydrogel properties and can be reused by applying a thermal cycle, complying thus with the purpose of the instrument. A High Efficiency Particulate Air (HEPA) grade filter made of polytetrafluroethylene (PTFE) porous membrane sandwiched between spunbounded non-woven fabric stands as a physical barrier allowing interaction between the gaseous molecules of the Martian atmosphere and the salt mixtures, and at the same time preventing the passage of any potential biological contamination from the cells to the outside or vice-versa. In addition to the physical barrier, a strict bioburden reduction and analysis procedure is applied to the hardware and the contained salt mixtures adhering to the European Cooperation for Space Standardization protocol of microbial examination of flight hardware (ECSS-Q-ST-70-55C). The deliquescent salts and the SAP products need to be properly treated independently to adhere to the planetary protection protocols. In this manuscript, we describe the bioburden reduction process utilized to sterilize the salt mixtures in BOTTLE and the assays adopted to validate the sterilization. We also describe the construction of a low-cost, portable ISO 7 cleanroom tent, exclusively designed for planetary protection tests. The sterilization process involves Dry Heat Microbial Reduction (DHMR) of the deliquescent salts and the SAP mixtures. The performance of SAP after DHMR is validated to ensure its working efficiency after sterilization. A slightly modified version of the standard swab assay is used in the validation process and a comparison is made between samples exposed to a thermal shock treatment and those without thermal shock, to determine the best assay to be applied for future space hardware utilizing such salt mixtures for planetary investigation and In-Situ Resource Utilization (ISRU). The demonstration of the compatibility of these products with the processes commonly required for space applications has implications for the future exploration of Mars.

Space Environmental Chamber for Planetary Studies

We describe a versatile simulation chamber that operates under representative space conditions (pressures from < 10–5 mbar to ambient and temperatures from 163 to 423 K), the SpaceQ chamber. This chamber allows to test instrumentation, procedures, and materials and evaluate their performance when exposed to outgassing, thermal vacuum, low temperatures, baking, dry heat microbial reduction (DHMR) sterilization protocols, and water. The SpaceQ is a cubical stainless-steel chamber of 27,000 cm3 with a door of aluminum. The chamber has a table which can be cooled using liquid nitrogen. The chamber walls can be heated (for outgassing, thermal vacuum, or dry heat applications) using an outer jacket. The chamber walls include two viewports and 12 utility ports (KF, CF, and Swagelok connectors). It has sensors for temperature, relative humidity, and pressure, a UV–VIS–NIR spectrometer, a UV irradiation lamp that operates within the chamber as well as a stainless-steel syringe for water vapor injection, and USB, DB-25 ports to read the data from the instruments while being tested inside. This facility has been specifically designed for investigating the effect of water on the Martian surface. The core novelties of this chamber are: (1) its ability to simulate the Martian near-surface water cycle by injecting water multiple times into the chamber through a syringe which allows to control and monitor precisely the initial relative humidity inside with a sensor that can operate from vacuum to Martian pressures and (2) the availability of a high-intensity UV lamp, operating from vacuum to Martian pressures, within the chamber, which can be used to test material curation, the role of the production of atmospheric radicals, and the degradation of certain products like polymers and organics. For illustration, here we present some applications of the SpaceQ chamber at simulated Martian conditions with and without atmospheric water to (i) calibrate the ground temperature sensor of the Engineering Qualification Model of HABIT (HabitAbility: Brines, Irradiation and Temperature) instrument, which is a part of ExoMars 2022 mission. These tests demonstrate that the overall accuracy of the temperature retrieval at a temperature between –50 and 10 °C is within 1.3 °C and (ii) investigate the curation of composite materials of Martian soil simulant and binders, with added water, under Martian surface conditions under dry and humid conditions. Our studies have demonstrated that the regolith, when mixed with super absorbent polymer (SAP), water, and binders exposed to Martian conditions, can form a solid block and retain more than 80% of the added water, which may be of interest to screen radiation while maintaining a low weight.

Small Lava Caves as Possible Exploratory Targets on Mars: Analogies Drawn from UAV Imaging of an Icelandic Lava Field

Volcanic-aeolian interactions and processes have played a vital role in landscape evolution on Mars. Martian lava fields and associated caves have extensive geomorphological, astrobiological, and in-situ resource utilization (ISRU) implications for future Mars missions which might be focused on subsurface exploration. Although several possible cave "skylights" of tens to >100 m diameter have been spotted in lava fields of Mars, there is a possibility of prevalence of meter-scale features which are an order of magnitude smaller and difficult to identify but could have vital significance from the scientific and future exploration perspectives. The Icelandic volcanic-aeolian environment and fissure volcanoes can serve as analogs to study lava flow-related small caves such as surface tubes, inflationary caves, liftup caves, and conduits. In the present work, we have tried to explore the usability of unmanned aerial vehicle (UAV)-derived images for characterizing a solidified lava flow and designing a sequential methodology to identify small caves in the lava flow. In the mapped area of ~0.33 km^2, we were able to identify 81 small cave openings, five lava flow morphologies, and five small cave types using 2 cm/pixel high-resolution images. The results display the usefulness of UAV imaging for such analogous research, and also highlight the possibility of the widespread presence of similar small cave openings in Martian lava fields. Such small openings can facilitate optimal air circulation within the caves while sheltering the insides from physical weathering and harmful radiations. Using the available best resolution remote sensing images, we extend the analogy through the contextual and geomorphological analysis of several possible pit craters in the Tharsis region of Mars, in a region of extremely vesicular and fragile lava crust with pahoehoe-type morphology. We report two possible pit craters in this region, with diameters as small as ~20 m. The possibility that such small cave openings can lead to vast subterranean hollow spaces on Mars cannot be ruled out considering its low gravity.

DFT study of the reduction reaction of calcium perchlorate on olivine surface: Implications to formation of Martian's regolith

Perchlorates have been found widespread on the surface of Mars, their origin and degradation pathways are not understood to date yet. We investigate here, from a theoretical point of view, the potential redox processes that take place in the interaction of Martian minerals such as olivine, with anhydrous and hydrated perchlorates. For this theoretical study, we take as mineral substrate the (1 0 0) surface of forsterite and calcium perchlorate salt as adsorbate. Our DFT calculations suggests a reduction pathway to chlorate and chlorite. When the perchlorate has more than 4 water molecules, this mechanism, which does not require high-temperature or high energy sources, results in parallel with the oxidation of the mineral surface, forming magnesium peroxide, MgO_2, and in the formation of ClO_3, which through photolysis is known to form $ClO\text{-}O_2$. Because of the high UV irradiance that reaches the surface of Mars, this may be a source of O_2 on Mars. Our results suggest that this process may be a natural removal pathway for perchlorates from the Martian regolith, which in the presence of atmospheric water for salt hydration, can furthermore lead to the production of oxygen. This mechanism may thus have implications on the present and future habitability of the Martian surface.

The BepiColombo Mercury Imaging X-Ray Spectrometer: Science Goals, Instrument Performance and Operations

The Mercury Imaging X-ray Spectrometer is a highly novel instrument that is designed to map Mercury's elemental composition from orbit at two angular resolutions. By observing the fluorescence X-rays generated when solar-coronal X-rays and charged particles interact with the surface regolith, MIXS will be able to measure the atomic composition of the upper ~10-20 μm of Mercury's surface on the day-side. Through precipitating particles on the night-side, MIXS will also determine the dynamic interaction of the planet's surface with the surrounding space environment.

MIXS is composed of two complementary elements: MIXS-C is a collimated instrument which will achieve global coverage at a similar spatial resolution to that achieved (in the northern hemisphere only – i.e. ~ 50 – 100 km) by MESSENGER; MIXS-T is the first ever X-ray telescope to be sent to another planet and will, during periods of high solar activity (or intense precipitation of charged particles), reveal the X-ray flux from Mercury at better than 10 km resolution. The design, performance, scientific goals and operations plans of the instrument are discussed, including the initial results from commissioning in space.

Subsurface robotic exploration for geomorphology, astrobiology and mining during MINAR6 campaign, Boulby Mine, UK: part I (Rover development)

Autonomous exploration requires the use of movable platforms that carry a payload of instruments with a certain level of autonomy and communication with the operators. This is particularly challenging in subsurface environments, which may be more dangerous for human access and where communication with the surface is limited. Subsurface robotic exploration, which has been to date very limited, is interesting not only for science but also for cost-effective industrial exploitation of resources and safety assessments in mines. Furthermore, it has a direct application to exploration of extra-terrestrial subsurface environments of astrobiological and geological significance such as caves, lava tubes, impact or volcanic craters and subglacial conduits, for deriving in-situ mineralogical resources and establishing preliminary settlements. However, the technological solutions are generally tailor-made and are therefore considered as costly, fragile and environment-specific, further hindering their extensive and effective applications. To demonstrate the advantages of rover exploration for a broad-community, we have developed KORE (KOmpact Rover for Exploration); a low-cost, re-usable, rover multi-purpose platform. The rover platform has been developed as a technological demonstration for extra-terrestrial subsurface exploration and terrestrial mining operations pertaining to geomorphological mapping, environmental monitoring, gas leak detections and search and rescue operations in case of an accident. The present paper, the first part of a series of two, focuses on describing the development of a robust rover platform to perform dedicated geomorphological, astrobiological and mining tasks. KORE was further tested in the Mine Analogue Research 6 (MINAR6) campaign during September 2018 in the Boulby mine (UK), the second deepest potash mine in Europe at a subsurface depth of 1.1 km, the results of which will be presented in the second paper of this series. KORE is a large, semi-autonomous rover weighing 160 kg with L × W × H dimensions 1.2 m × 0.8 m × 1 m and a payload carrying capacity of 100 kg using 800 W traction power that can power to a maximum speed of 8.4 km h–1. The rover can be easily dismantled in three parts facilitating its transportation to any chosen site of exploration. Presently, the main scientific payloads on KORE are: (1) a three-dimensional mapping camera, (2) a methane detection system, (3) an environmental station capable of monitoring temperature, relative humidity, pressure and gases such as NO_2, SO_2, H_2S, formaldehyde, CO, CO_2, O_3, O_2, volatile organic compounds and particulates and (4) a robotic arm. Moreover, the design of the rover allows for integration of more sensors as per the scientific requirements in future expeditions. At the MINAR6 campaign, the technical readiness of KORE was demonstrated during 6 days of scientific research in the mine, with a total of 22 h of operation.

Winding down the Chicxulub impact: The transition between impact and normal marine sedimentation near ground zero

The Chicxulub impact led to the formation of a ~ 200-km wide by ~1-km deep crater on México's Yucatán Peninsula. Over a period of hours after the impact the ocean re-entered and covered the impact basin beneath several hundred meters of water. A suite of impactites were deposited across the crater during crater formation, and by the resurge, tsunami and seiche events that followed. International Ocean Discovery Program/International Continental Scientific Drilling Program Expedition 364 drilled into the peak ring of the Chicxulub crater, and recovered ~130 m of impact deposits and a 75-cm thick, fine-grained, carbonate-rich "Transitional Unit", above which normal marine sedimentation resumed. Here, we describe the results of analyses of the uppermost impact breccia (suevite) and the Transitional Unit, which suggests a gradual waning of energy recorded by this local K-Pg boundary sequence.

The dominant depositional motif in the upper suevite and the Transitional Unit is of rapid sedimentation characterized by graded bedding, local cross bedding, and evidence of oscillatory currents. The lower Transitional Unit records the change from deposition of dominantly sand-sized to mainly silt to clay sized material with impact debris that decreases in both grain size and abundance upward. The middle part of the Transitional Unit is interrupted by a 20 cm thick soft sediment slump overlain by graded and oscillatory current cross-laminated beds. The uppermost Transitional Unit is also soft sediment deformed, contains trace fossils, and an increasing abundance of planktic foraminifer and calcareous nannoplankton survivors. The Transitional Unit, as with similar deposits in other marine target impact craters, records the final phases of impact-related sedimentation prior to resumption of normal marine conditions. Petrographic and stable isotopic analyses of carbon from organic matter provide insight into post-impact processes. δ13Corg values are between terrestrial and marine end members with fluctuations of 1–3‰.

Timing of deposition of the Transitional Unit is complicated to ascertain. The repetitive normally graded laminae, both below and above the soft sediment deformed interval, record rapid deposition from currents driven by tsunami and seiches, processes that likely operated for weeks to potentially years post-impact due to subsequent continental margin collapse events. Highly siderophile element-enrichment at the top of the unit is likely from fine-grained ejecta that circulated in the atmosphere for several years prior to settling. The Transitional Unit is thus an exquisite record of the final phases of impact-related sedimentation related to one of the most consequential events in Earth history.

Transition from a Subaerial to a Subnival Permafrost Temperature Regime Following Increased Snow Cover (Livingston Island, Maritime Antarctic)

The Antarctic Peninsula (AP) region has been one of the regions on Earth with strongest warming since 1950. However, the northwest of the AP showed a cooling from 2000 to 2015, which had local consequences with an increase in snow accumulation and a deceleration in the loss of mass from glaciers. In this paper, we studied the effects of increased snow accumulation in the permafrost thermal regime in two boreholes (PG1 and PG2) in Livingston Island, South Shetlands Archipelago, from 2009 to 2015. The two boreholes located c. 300 m apart but at similar elevation showed different snow accumulation, with PG2 becoming completely covered with snow all year long, while the other remained mostly snow free during the summer. The analysis of the thermal regimes and of the estimated soil surface energy exchange during the study period showed the effects of snow insulation in reducing the active layer thickness. These effects were especially relevant in PG2, which transitioned from a subaerial to a subnival regime. There, permafrost aggraded from below, with the active layer completely disappearing and the efficiency of thermal insulation by the snowpack prevailing in the thermal regime. This situation may be used as an analogue for the transition from a periglacial to a subglacial environment in longer periods of cooling in the paleoenvironmental record.

Frozen ground and snow cover monitoring in Livingston and Deception islands, Antarctica: preliminary results of the 2015-2019 PERMASNOW project

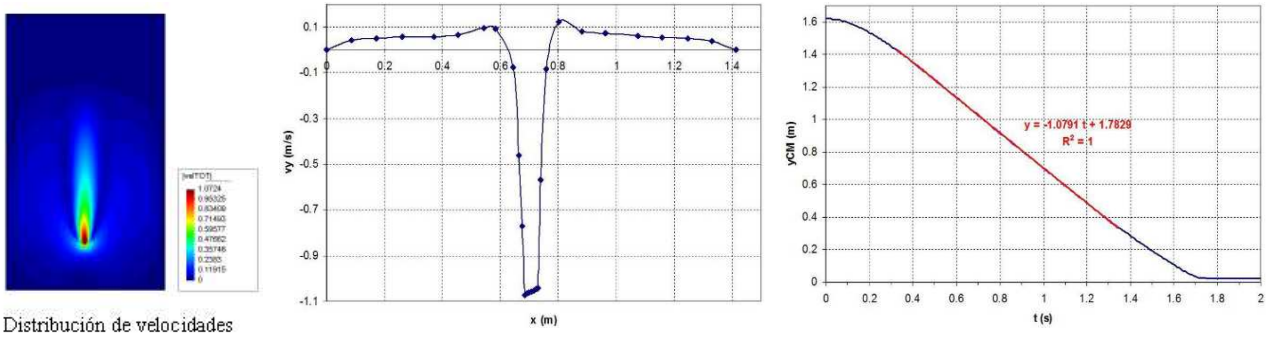
Since 2006, our research team has been establishing in the islands of Livingston and Deception, (South Shetland archipelago, Antarctica) several monitoring stations of the active layer thickness within the international network Circumpolar Active Layer Monitoring (CALM), and the ground thermal regime for the Ground Terrestrial Network-Permafrost (GTN-P). Both networks were developed within the International Permafrost Association (IPA). In the GTN-P stations, in addition to the temperature of the air, soil, and terrain at different depths, the snow thickness is also monitored by snow poles. Since 2006, a delay in the disappearance of the snow layer has been observed, which could explain the variations we observed in the active layer thickness and permafrost temperatures. Therefore, in late 2015 our research group started the PERMASNOW project (2015-2019) to pay attention to the effect of snow cover on ground thermal This project had two different ways to study the snow cover. On the first hand, in early 2017 we deployed new instrumentation, including new time lapse cameras, snow poles with high number of sensors and a complete and complex set of instruments and sensors to configure a snow pack analyzer station providing 32 environmental and snow parameters. We used the data acquired along 2017 and 2018 years with the new instruments, together with the available from all our already existing sensors, to study in detail the snow cover. On the other hand, remote sensing data were used to try to map the snow cover, not only at our monitoring stations but the entire islands in order to map and study the snow cover distribution, as well as to start the way for future permafrost mapping in the entire islands. MODIS-derived surface temperatures and albedo products were used to detect the snow cover and to test the surface temperature. Since cloud presence limited the acquisition of valid observations of MODIS sensor, we also analyzed Terrasar X data to overcome this limitation. Remote sensing data validation required the acquirement of in situ ground-true data, consisting on data from our permanent instruments, as well as ad hoc measurements in the field (snow cover mapping, snow pits, albedo characterization, etc.). Although the project is finished, the data analysis is still ongoing. We present here the different research tasks we are developing as well as the most important results we already obtained about the snow cover. These results confirm how the snow cover duration has been changing in the last years, affecting the ground thermal behavior.

Rigid body motion in viscous flows using the finite element method

A new model for the numerical simulation of a rigid body moving in a viscous fluid flow using the finite element method is presented. One of the most interesting features of this approach is the small computational effort required to solve the motion of the rigid body, comparable to a pure fluid solver.

The model is based on the idea of extending the fluid velocity inside the rigid body and solving the flow equations with a penalty term to enforce rigid motion inside the solid. In order to get the velocity field in the fluid domain, the Navier–Stokes equations for an incompressible viscous flow are solved using a fractional-step procedure combined with the two-step Taylor–Galerkin algorithm for the fractional linear momentum. Once the velocity field in the fluid domain is computed, calculation of the rigid motion is obtained by averaging translation and angular velocities over the solid. One of the main challenges when dealing with the fluid–solid interaction is the proper modeling of the interface that separates the solid moving mass from the viscous fluid. In this work, the combination of the level set technique and the two-step Taylor–Galerkin algorithm for tracking the fluid–solid interface is proposed. The characteristics exhibited by the two-step Taylor–Galerkin, minimizing oscillations and numerical diffusion, make this method suitable to accurately advect the solid domain, avoiding distortions at its boundaries and, thus, preserving the initial size and shape of the rigid body. The proposed model has been validated against empirical solutions, experimental data, and numerical simulations found in the literature. In all tested cases, the numerical results have shown to be accurate, proving the potential of the proposed model as a valuable tool for the numerical analysis of the fluid–solid interaction.

Rigid body motion in viscous fluids is a hot issue and it is paramount to understand several natural processes of relevance in Geosciences, Planetary Sciences and Astronomy. The presented model allows the study of geological processes such as marine impacts, rock avalanches, formation and propagation of tsunamis and the transport and sedimentation of particles in different media. We hope this work will open the path to a new way of approaching the solid-fluid interaction, without the need for extremely fine meshes and days/weeks of computational time.



Distribución de velocidades

Detection of Potential Lipid Biomarkers in Oxidative Environments by Raman Spectroscopy and Implications for the ExoMars 2020-Raman Laser Spectrometer Instrument Performance

The aim of the European Space Agency's ExoMars rover mission is to search for potential traces of present or past life in the swallow subsurface (2 m depth) of Mars. The ExoMars rover mission relies on a suite of analytical instruments envisioned to identify organic compounds with biological value (biomarkers) associated with a mineralogical matrix in a highly oxidative environment. We investigated the feasibility of detecting basic organics (linear and branched lipid molecules) with Raman laser spectroscopy, an instrument onboard the ExoMars rover, when exposed to oxidant conditions. We compared the detectability of six lipid molecules (alkanes, alkanols, fatty acid, and isoprenoid) before and after an oxidation treatment (15 days with hydrogen peroxide), with and without mineral matrix support (amorphous silica rich vs. iron rich). Raman and infrared spectrometry was combined with gas chromatography–mass spectrometry to determine detection limits and technical constraints. We observed different spectral responses to degradation depending on the lipid molecule and mineral substrate, with the silica-rich material showing better preservation of organic signals. These findings will contribute the interpretation of Raman laser spectroscopy results on cores from the ExoMars rover landing site, the hydrated silica-enriched delta fan on Cogoon Vallis (Oxia Planum).

Identification of microplastics in wastewater samples by means of polarized light optical microscopy

Many reports state the potential hazards of microplastics (MPs) and their implications to wildlife and human health. The presence of MP in the aquatic environment is related to several origins but particularly associated to their occurrence in wastewater effluents. The determination of MP in these complex samples is a challenge. Current analytical procedures for MP monitoring are based on separation and counting by visual observation or mediated with some type of microscopy with further identification by techniques such as Raman or Fourier-transform infrared (FTIR) spectroscopy. In this work, a simple alternative for the separation, counting and identification of MP in wastewater samples is reported. The presented sample preparation technique with further polarized light optical microscopy (PLOM) observation positively identified the vast majority of MP particles occurring in wastewater samples of Montevideo, Uruguay, in the 70–600 µm range. MPs with different shapes and chemical composition were identified by PLOM and confirmed by confocal Raman microscopy. Rapid identification of polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) were evidenced. A major limitation was found in the identification of MP from non-birefringent polymers such as PVC (polyvinylchloride). The proposed procedure for MP analysis in wastewater is easy to be implemented at any analytical laboratory A pilot monitoring of Montevideo WWTP effluents was carried out over 3-month period identifying MP from different chemical identities in the range 5.3–8.2 × 10^3 MP items/m^3.

Molecular and isotopic biogeochemistry on recently-formed soils on King George Island (Maritime Antarctica) after glacier retreat upon warming climate

Maritime Antarctica is a climate-sensitive region that has experienced a continuous increase of temperature over the last 50 years. This phenomenon accelerates glacier retreat and promotes the exposure of ice-covered surfaces, triggering physico-chemical alteration of the ground and subsequent soil formation. Here, we studied the biogeochemical composition and evolution extent of soil on three recently exposed peninsulas (Fildes, Barton and Potter) on Southwest (SW) King George Island (KGI). Nine soil samples were analyzed for their lipid biomarkers, stable isotope composition, bulk geochemistry and mineralogy. Their biomarkers profiles were compared to those of local fresh biomass of microbial mats (n = 3) and vegetation (1 moss, 1 grass, and 3 lichens) to assess their contribution to the soil organic matter (SOM). The molecular and isotopic distribution of lipids in the soil samples revealed contributions to the SOM dominated by biogenic sources, mostly vegetal (i.e. odd HMW n-alkanes distributions and generally depleted δ13C ratios). Microbial sources were also present to a lesser extent (i.e. even LMW n-alkanes and n-alkanoic acids, heptadecane, 1-alkenes, 9-octadecenoic acid, or iso/anteiso 15: 0 and 17:0 alkanoic acids). Additional contribution from petrogenic sources (bedrock erosion-derived hydrocarbons) was also considered although found to be minor. Results from mineralogy (relative abundance of plagioclases and virtual absence of clay minerals) and bulk geochemistry (low chemical weathering indexes) suggested little chemical alteration of the original geology. This together with the low content of total nitrogen and organic carbon, as well as moderate microbial activity in the soils, confirmed little edaphological development on the recently-exposed KGI surfaces. This study provides molecular and isotopic fingerprints of SOM composition in young Antarctic soils, and contributes to the understanding of soil formation and biogeochemistry in this unexplored region which is currently being affected by thermal destabilization.

Theoretical Characterization of the High Pressure Nonclathrate CO_2 Hydrate

On the basis of results from exhaustive first-principles simulations, we report a thorough description of the recently identified high pressure phase of the CO_2 hydrate, and provide an estimation of the transition pressure from the sI low pressure phase to the C-0 high pressure (HP) phase around 0.6 GPa. The vibrational properties calculated here for the first time might be useful to detect this HP structure in extraterrestrial environments, such as the Jupiter ice moons. Interestingly, we also find that CO_2 gas molecules are quasi-free to diffuse along the helical channels of the structure, thus allowing the interchange of volatiles across a solid icy barrier. Taking into account its density and comparing it with other substances, we can estimate the naturally occurring zone of this CO_2@H_2O HP phase within a giant ice moon such as Ganymede. Other potential planetary implications that all of the found properties of this hydrate might have are also discussed.

SuperCam Calibration Targets: Design and Development

SuperCam is a highly integrated remote-sensing instrumental suite for NASA's Mars 2020 mission. It consists of a co-aligned combination of Laser-Induced Breakdown Spectroscopy (LIBS), Time-Resolved Raman and Luminescence (TRR/L), Visible and Infrared Spectroscopy (VISIR), together with sound recording (MIC) and high-magnification imaging techniques (RMI). They provide information on the mineralogy, geochemistry and mineral context around the Perseverance Rover. The calibration of this complex suite is a major challenge. Not only does each technique require its own standards or references, their combination also introduces new requirements to obtain optimal scientific output. Elemental composition, molecular vibrational features, fluorescence, morphology and texture provide a full picture of the sample with spectral information that needs to be co-aligned, correlated, and individually calibrated. The resulting hardware includes different kinds of targets, each one covering different needs of the instrument. Standards for imaging calibration, geological samples for mineral identification and chemometric calculations or spectral references to calibrate and evaluate the health of the instrument, are all included in the SuperCam Calibration Target (SCCT). The system also includes a specifically designed assembly in which the samples are mounted. This hardware allows the targets to survive the harsh environmental conditions of the launch, cruise, landing and operation on Mars during the whole mission. Here we summarize the design, development, integration, verification and functional testing of the SCCT. This work includes some key results obtained to verify the scientific outcome of the SuperCam system.

Raman Laser Spectrometer (RLS) calibration target design to allow onboard combined science between the RLS and MicrOmega instruments on the ExoMars rover

The ExoMars rover, scheduled to be launched in 2020, will be equipped with a novel and diverse payload. It will also include a drill to collect subsurface samples (from 0- to 2-m depth) and deliver them to the rover analytical laboratory, where it will be possible to perform combined science between instruments. For the first time, the exact same sample target areas will be investigated using complementary analytical methods-infrared spectrometry, Raman spectrometry, and laser desorption mass spectrometry-to establish mineralogical and organic chemistry composition. Fundamental for implementing this cooperative science strategy is the Raman Laser Spectrometer (RLS) calibration target (CT). The RLS CT features a polyethylene terephthalate disk used for RLS calibration and verification of the instrument during the mission. In addition, special patterns have been recorded on the RLS CT disk that the other instruments can detect and employ to determine their relative position. In this manner, the RLS CT ensures the spatial correlation between the three analytical laboratory instruments: MicrOmega, RLS, and MOMA. The RLS CT has been subjected to a series of tests to qualify it for space utilization and to characterize its behavior during the mission. The results from the joint work performed by the RLS and MicrOmega instrument teams confirm the feasibility of the "combined science" approach envisioned for ExoMars rover operations, whose science return is optimized when complementing the RLS and MicrOmega joint analysis with the autonomous RLS operation.

Joint Europa Mission (JEM): a multi-scale study of Europa to characterize its habitability and search for extant life

Europa is the closest and probably the most promising target to search for extant life in the Solar System, based on complementary evidence that it may fulfil the key criteria for habitability: the Galileo discovery of a sub-surface ocean; the many indications that the ice shell is active and may be partly permeable to transfer of chemical species, biomolecules and elementary forms of life; the identification of candidate thermal and chemical energy sources necessary to drive a metabolic activity near the ocean floor.

In this article we are proposing that ESA collaborates with NASA to design and fly jointly an ambitious and exciting planetary mission, which we call the Joint Europa Mission (JEM), to reach two objectives: perform a full characterization of Europa's habitability with the capabilities of a Europa orbiter, and search for bio-signatures in the environment of Europa (surface, subsurface and exosphere) by the combination of an orbiter and a lander. JEM can build on the advanced understanding of this system which the missions preceding JEM will provide: Juno, JUICE and Europa Clipper, and on the Europa lander concept currently designed by NASA (Maize, report to OPAG, 2019).

We propose the following overarching goals for our Joint Europa Mission (JEM): Understand Europa as a complex system responding to Jupiter system forcing, characterize the habitability of its potential biosphere, and search for life at its surface and in its sub-surface and exosphere. We address these goals by a combination of five Priority Scientific Objectives, each with focused measurement objectives providing detailed constraints on the science payloads and on the platforms used by the mission. The JEM observation strategy will combine three types of scientific measurement sequences: measurements on a high-latitude, low-altitude Europan orbit; in-situ measurements to be performed at the surface, using a soft lander; and measurements during the final descent to Europa's surface.

The implementation of these three observation sequences will rest on the combination of two science platforms: a soft lander to perform all scientific measurements at the surface and sub-surface at a selected landing site, and an orbiter to perform the orbital survey and descent sequences. We describe a science payload for the lander and orbiter that will meet our science objectives.

We propose an innovative distribution of roles for NASA and ESA; while NASA would provide an SLS launcher, the lander stack and most of the mission operations, ESA would provide the carrier-orbiter-relay platform and a stand-alone astrobiology module for the characterization of life at Europa's surface: the Astrobiology We Laboratory (AWL). Following this approach, JEM will be a major exciting joint venture to the outer Solar System of NASA and ESA, working together toward one of the most exciting scientific endeavours of the 21st century: to search for life beyond our own planet.

Detalle en proximidad de una de las chimeneas surgidas por precipitación de las sales arrastradas por el agua hirviendo procedente del volcán subterráneo en Dallol.

• Crédito: Felipe Gómez

Image of crater Gale surface from the THEMIS instrument, on board the Mars probe Odyssey. It shows a view to the southwest, towards the central peak of the crater (left).

Crédito: NASA/JPL/Arizona State University, R. Luk.

Advanced Instrumentation department of

Head of Department:

Eduardo Sebastián Martínez

The Advanced Instrumentation Department devotes its research activity to the development of space instrumentation technologies for planetary and astrophysical exploration, as well as to the development of simulation chambers for planetary environments. All technological developments are the result of a multi and transdisciplinary relationship between the members of the Instrumentation Department and the rest of the Center's scientists.

Experimentation and simulation play a fundamental role in the accomplishment of the different research lines at the Center. In many cases they are carried out in the laboratory, in others during field campaigns by studying natural processes, and in other cases in space, either by remote observation or by in situ analysis and measurements on the surface of planetary bodies. The technological aspects of this development range from the conception of prototypes and new concepts of instrumentation, the design and supervision of the industry specialized in the manufacture of flight models, to the execution of testing campaigns for the validation and maturation of the instrumentation and developed technologies, either in simulation chambers or in representative environments (the so-called terrestrial analogues). As for the simulation chambers, the Department has different infrastructures for planetary simulation to scientifically and technologically support the researchers of the group.

During 2020 our Department continued with the leadership, development and operation of different flight instruments. The clearest examples are the REMS (Rover Environmental Monitoring Station) aboard the Curiosity rover, the TWINS (Temperature and Wind for InSight) aboard the lander of the InSight mission, and the MEDA (Mars Environmental Dynamics Analyzer) of the Mars2020 mission, all of them from NASA. These instruments and projects have contributed to consolidate Spain as an international reference in the field of the Martian atmospheric characterization. They have combined advances in the frontier of scientific and technological knowledge within our country, uniting and harmonizing a significant part of the scientific and technological community interested in the Martian atmosphere, in a transversal way to different NASA missions. At the same time, the department has also participated in the development of the SAFARI far-infrared spectrometer for the SPICA telescope of the European Space Agency (ESA). In addition to that, in the field of simulation of planetary environments, the department led the experiments of the WLOM project to simulate the poles of the planet Mars.

The Advanced Instrumentation Department is organized in 1 Research Group:

- Space Instrumentation

Space Instrumentation

Coordinator: José Antonio Rodríguez Manfredi

All the technological activities and members of the Advanced Instrumentation Department are included in the Space Instrumentation research and development group.

Group photo. From left to right: O. Prieto, A. Molina (below), F. Jordan (above), E. Sebastian (below), J. Sobrado (above), J. Martin, S. Navarro (below), J. Romeral, S. Zurita, A. de Vicente (behind), S. Gimenez (below), J. Pla, J. Torres (below), J. Saez

Members	Category
Alvaro De Vicente Retortillo Rubalcaba	Titulado Superior ATP (Postdosc)
Ricardo, Ferrandiz Guibelalde	Técnico Superior ATP
Silvia, Gimenez Torregrosa	Titulado Medio ATP (TEac. Apo. MEC)
Francisco Miguel Jorda Del Jesus	Titulado Superior ATP (Garantía Juvenil)
Alain Lepinette Malvitte	Titulado Superior ATP
Maria De Las Mercedes Marin Jimenez	Titulado Superior ATP
Carolina Martin Rubio	Titulado Superior ATP (PFI)
Javier Martin Soler	E. Cient.Sup.Def
Sara Navarro Lopez	Titulado Superior ATP
Veronica Peinado Gonzalez	Titulado Superior ATP
Jorge Pla Garcia	Titulado Superior ATP
Jose Antonio Rodriguez Manfredi	Titulado Superior ATP
Julio José Romeral Planelló	E. Cient.Sup.Def
Catalina Romero Guzman	Titulado Superior ATP (PFI)
Jorge Luis Saez De Teresa	Becario INTA
Eduardo Sebastián Martínez	E. Científico Titular OPI
Jesus Manuel Sobrado Vallecillo	E. Cient.Sup.Def
Josefina Torres Redondo	Titulado Superior ATP
Maria Rosario Urqui O'callaghan	ISDEFE
Daniel Viudez Moreiras	Titulado Superior ATP
Sofia Zurita Zurita	Titulado Superior ATP

The main activities and scientific achievements during the year 2020 were:

Instrumentation for space missions: MEDA

The Center for Astrobiology leads the development of the MEDA space instrument (Mars Environmental Dynamics Analyzer) for NASA's Perseverance rover of the Mars 2020 mission. Together with CAB, the Departamento de Cargas Útiles at the Instituto Nacional de Técnica Aeroespacial, CRISA Airbus Defense and Space, AVS Added Value Solutions, ALTER Technology, the University of the Basque Country, the Rocasolano Physics-Chemistry Institute (CSIC) and the University of Alcalá participate in this development as Spanish partners. Additionally, the Finnish Meteorological Institute, the Jet Propulsion Laboratory, the Lunar and Planetary Institute, Aeolis Research, the Space Science Institute, NASA Goddard Space Flight Center, Carnegie Institution, and the John Hopkins APL as international partners.

The scientific objective of the instrument is to characterize the environmental parameters and physical properties of the dust, in the local environment of the new vehicle that NASA sent to Mars at the end of July. For this, the instrument is conceived as a suit of sensors that will record: the relative humidity (Relative Humidity Sensor - HS), the air temperature (Air Temperature Sensor - ATS), the net balance of IR radiation (Thermal IR Sensor - TIRS), the speed and direction of the Martian wind (Wind Sensors - WS), the radiation and the properties of the suspended aerosols (Radiation and Dust Sensor - RDS), and the atmospheric pressure (Pressure Sensor - PS).

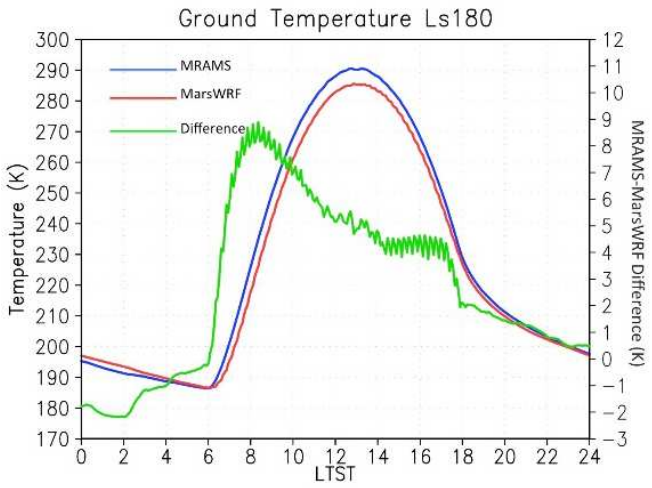
Throughout 2020, as part of the latest phase D activities, the team worked intensively on completing the development and validation of the instrument's flight and ground segment software, and the interface to the rover's on-board computer. In parallel JPL proceeded to conduct global system tests and finish the spacecraft integration. After all those, Perseverance was shipped to Florida for her latest tests and activities before proceeding with the final stacking and launch on July 30, 2020.

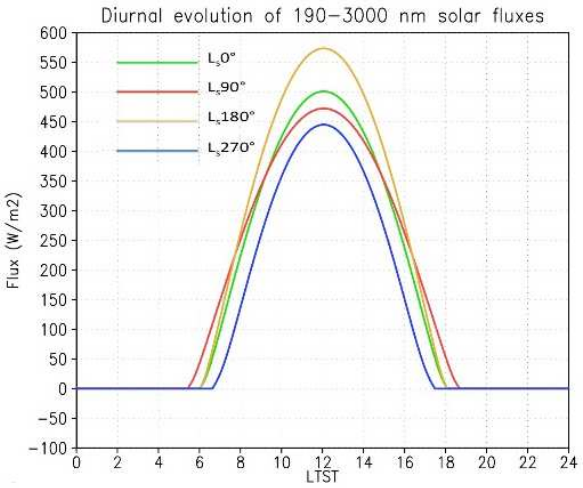
(Left) Perseverance rover, with all MEDA sensors, during heat shield installation, (Right) Mars 2020 mission with the Perseverance rover lifts off, July 30, 2020

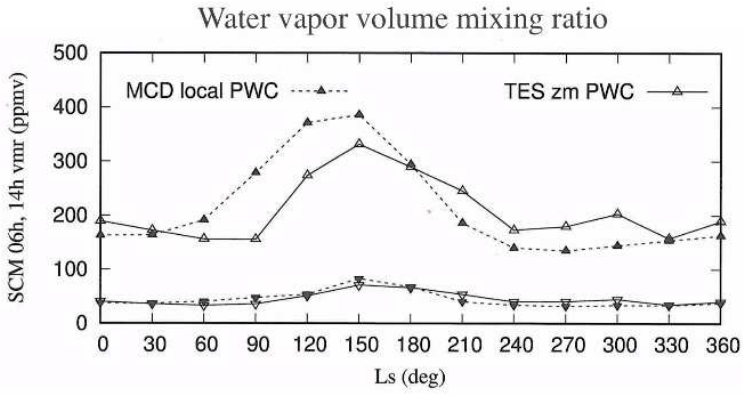
During the cruise to Mars, MEDA was activated several times to assess its correct operation and perform initial calibration in vacuum conditions.

In parallel with all this technological activity, scientific studies have been carried out for the future interpretation of the data from the MEDA station once it is on Mars. It is worth highlighting the use of the MRAMS and MarsWRF weather models to predict the meteorological conditions at the landing site of NASA's Mars 2020 Perseverance rover, inside the Jezero crater (Mars). These results are complemented by predictions of radiative forcing and the water cycle using the COMIMART and the SCM models respectively. The primary objective of this research is to facilitate the interpretation of the meteorological measurements to be obtained by the MEDA instrument aboard the Perseverance rover, but also to provide predictions of the meteorological phenomena and seasonal changes that might impact operations, from both a risk point of view and from the perspective of being better prepared to perform certain measurements.

The total amplitude of pressure at Jezero crater is substantially smaller compared to Gale crater, so the crater circulation at Jezero crater does not appear to significantly amplify the amplitude of the diurnal pressure. In other words, unlike the special Gale crater (where Curiosity rover is located), the local circulation at Jezero crater appears to be suppressed by regional circulation of Isidis Basin in which it is embedded. The strongest modeled winds occur in the mid-afternoon (when upslope winds are strongest) peaking at ~58 km/h (16 m/s) during the evenings of the equinoxes. At all seasons, the modeled winds are from the northwest at night and then transition to a southeast direction during the day, which is consistent with the diurnal slope winds in the Isidis Basin. The highest solar fluxes (570 W/m2) of all our simulations are found at fall equinox, in agreement with the highest air temperatures (-27 °C), found also during that period. The minimum temperatures during most nights of all the periods considered are around -84 °C. The most humid season (water vapor of 371 ppmv) is mid-summer, with implications for atmosphere-regolith interactions and astrobiology. Thin fogs might occasionally appear during early-summer, when the predicted nighttime relative humidity close to the surface exceeds 100%.

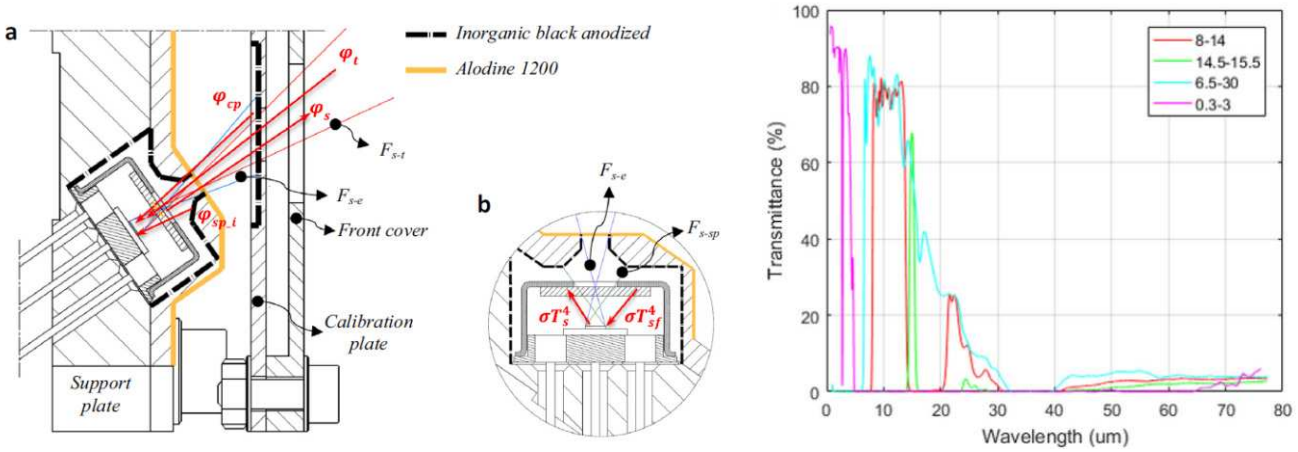






Martian weather models MRAMS and MarsWRF prediction at the NASA's Mars 2020 Perseverance rover landing site inside Jezero crater (Mars)

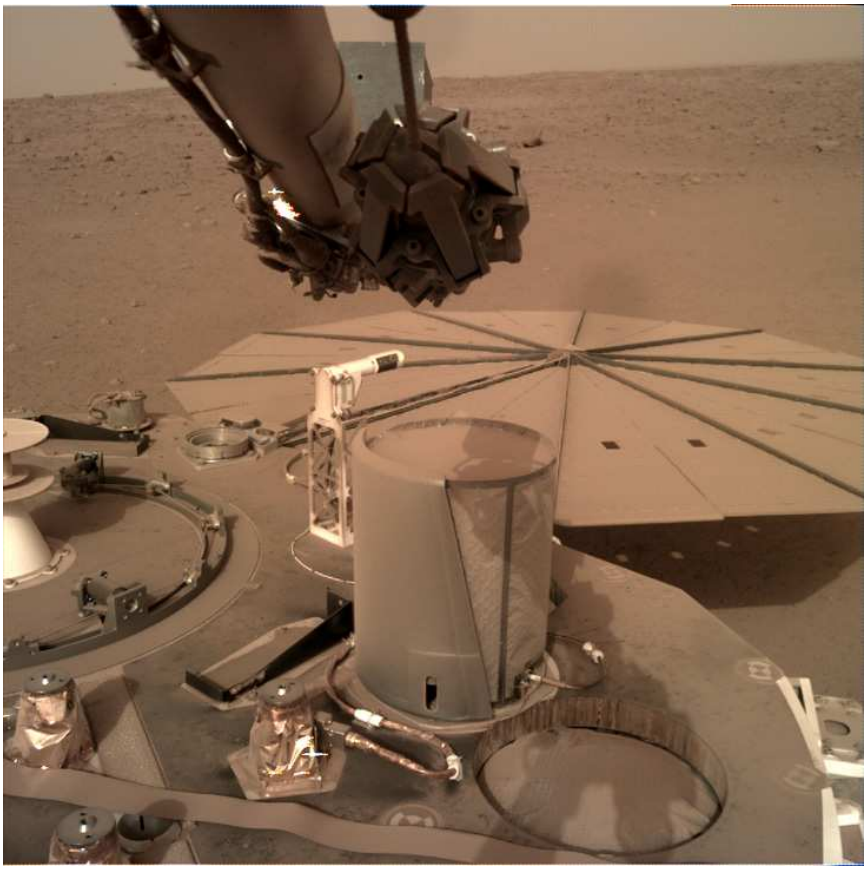
At the same time, the publication of the calibration results of the different sensors that make up MEDA has begun, whose knowledge by the international scientific community is essential for a correct interpretation of the data provided by the environmental station. The first example is the paper dedicated to radiometric and angular calibration of the Thermal InfraRed Sensor (TIRS). The paper provides details of the TIRS optomechanical design, constructional aspects of the IR detectors, and an update of the mathematical model used for the calculation of the internal IR fluxes of the sensor. A set of sequential calibration tests is then defined to identify the radiometer model parameters. The test setups are described, highlighting their limitations and restrictions based on the differences between simulated and actual Martian environmental conditions. Finally, the uncertainty sources and potential systematic errors associated with the calibration tests are quantified and compared to the radiometer scientific requirements established by the instrument science team.



(Left) MEDA-TIRS opto-mechanical model and (Right) calibrated spectral responsivity of IR detectors

Instrumentation for space missions: TWINS

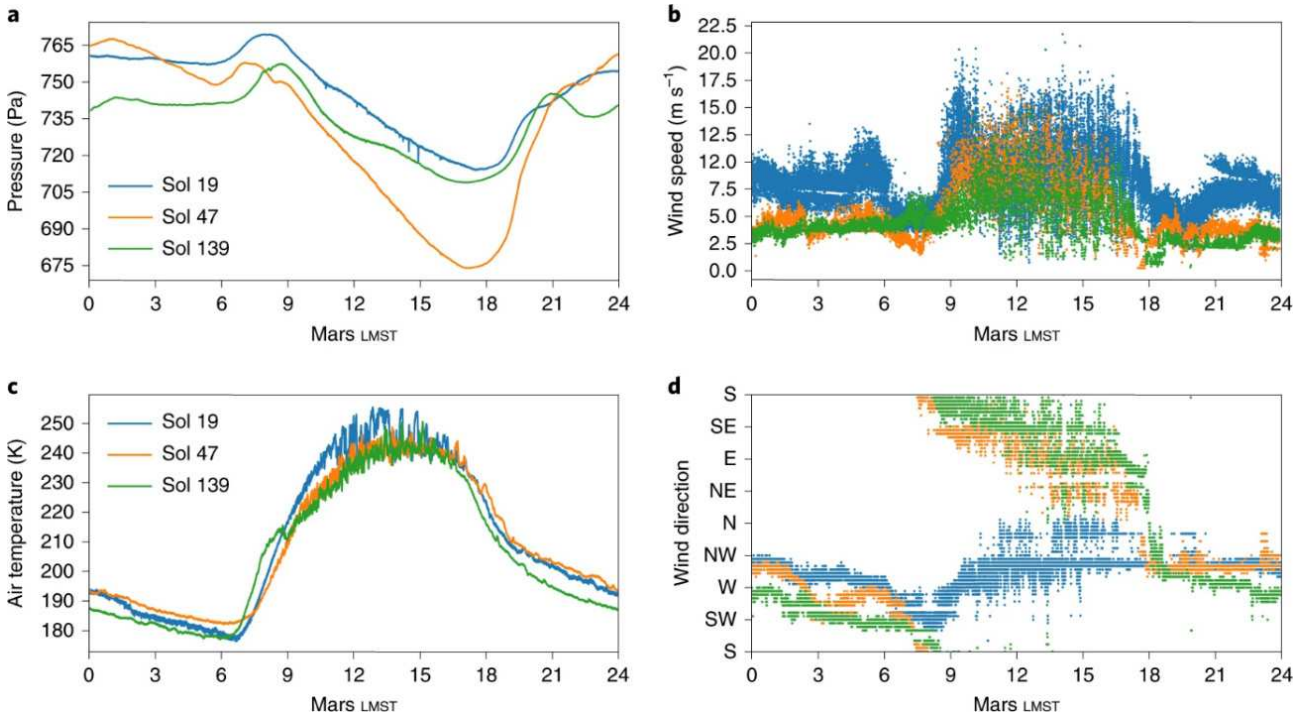
The Advanced Instrumentation Department of the CAB is responsible for the TWINS (Temperatures and Winds for InSight), an instrument dedicated to environmental characterization of the Martian atmosphere. TWINS is part of NASA's InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission, to characterize the interior of the planet Mars through a lander. TWINS is providing a continuous log of the local winds and temperatures at the landing site (Elysium Planitia), being a perfect complement to those other data provided by REMS in the Martian Gale Crater, thus constituting the first mini meteorological-environmental network on the surface of Mars.



TWINS boom and InSight lander cover with dust (July 2020).

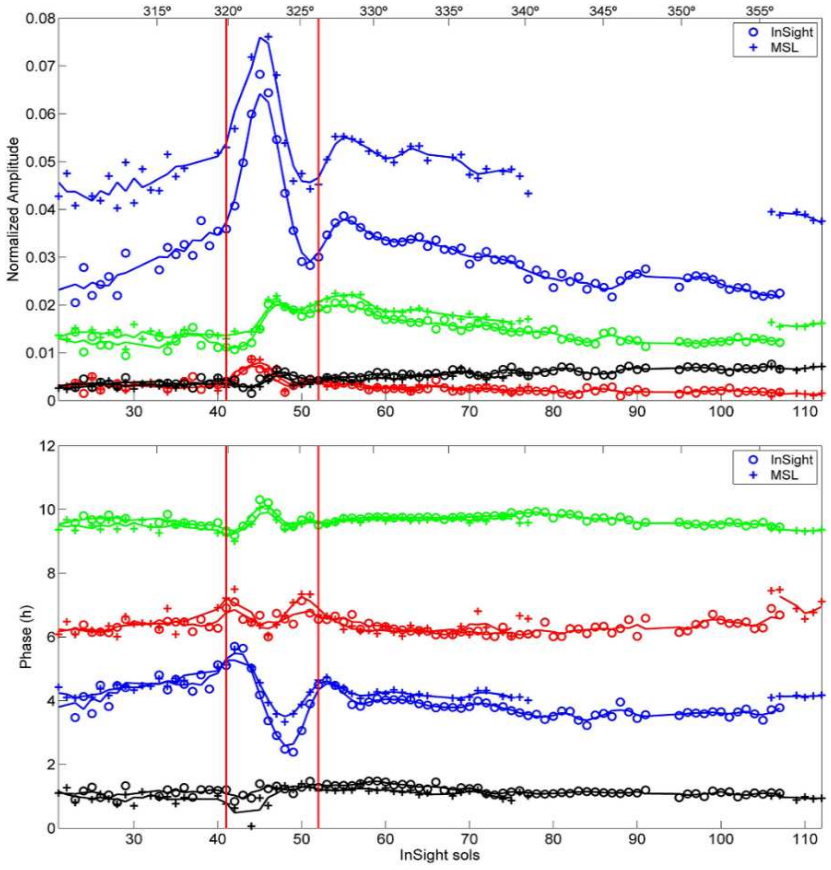
Since its landing on Mars, both InSight and TWINS have been operating with great success. The scientific data provided by TWINS are allowing discarding false seismic readings caused by the strong winds of the environment, and being of a great scientific value given the detailed record that it is carrying out. In addition to the daily operation of the instrument, the group actively participate in the scientific exploitation of the data and its publication during the year 2020.

Using data from TWINS and the APSS (the InSight's pressure sensor) new atmospheric phenomena at Mars have been measured and described, especially in the higher-frequency range, extending our understanding of Mars's meteorology at all scales. InSight is uniquely sensitive to large-scale and regional weather and obtained detailed in situ coverage of a regional dust storm on Mars. InSight observations show a paradox of aeolian science on Mars: despite having the largest recorded Martian vortex activity and dust-devil tracks close to the lander, no visible dust devils have been seen. Meteorological measurements have produced a catalogue of atmospheric gravity waves, which included bores (soliton-like waves). From these measurements, we have discovered Martian infrasound and unexpected similarities between atmospheric turbulence on Earth and Mars.



The Martian meteorology of three typical sols experienced by InSight shows a diversity of scales involved from the planetary scale to local turbulent scales.

TWINS wind and atmosphere temperature data and APSS data haven also used to the characterization of the 2019 Martian Local Dust Storm (LDS). InSight's cameras observed a rise in the atmospheric opacities during the storm from ~0.7 to ~1.9, similar to contemporaneous measurements made by Curiosity at Gale crater. Pressure tides were strongly affected. In particular, the amplitude of the pressure harmonics with a period of 1 sol experienced an abrupt increase during the onset of the LDS most likely as a result of different dust loading as a function of location. Subsequently, the dust redistributed around the planet and the semidiurnal pressure mode evolved according to dust opacity in both missions. The onset of the storm modified the wind patterns measured by TWINS, probably due to enhanced tidal flows. The study shows that TWINS measured air temperatures were strongly perturbed by the lander's thermal effects.

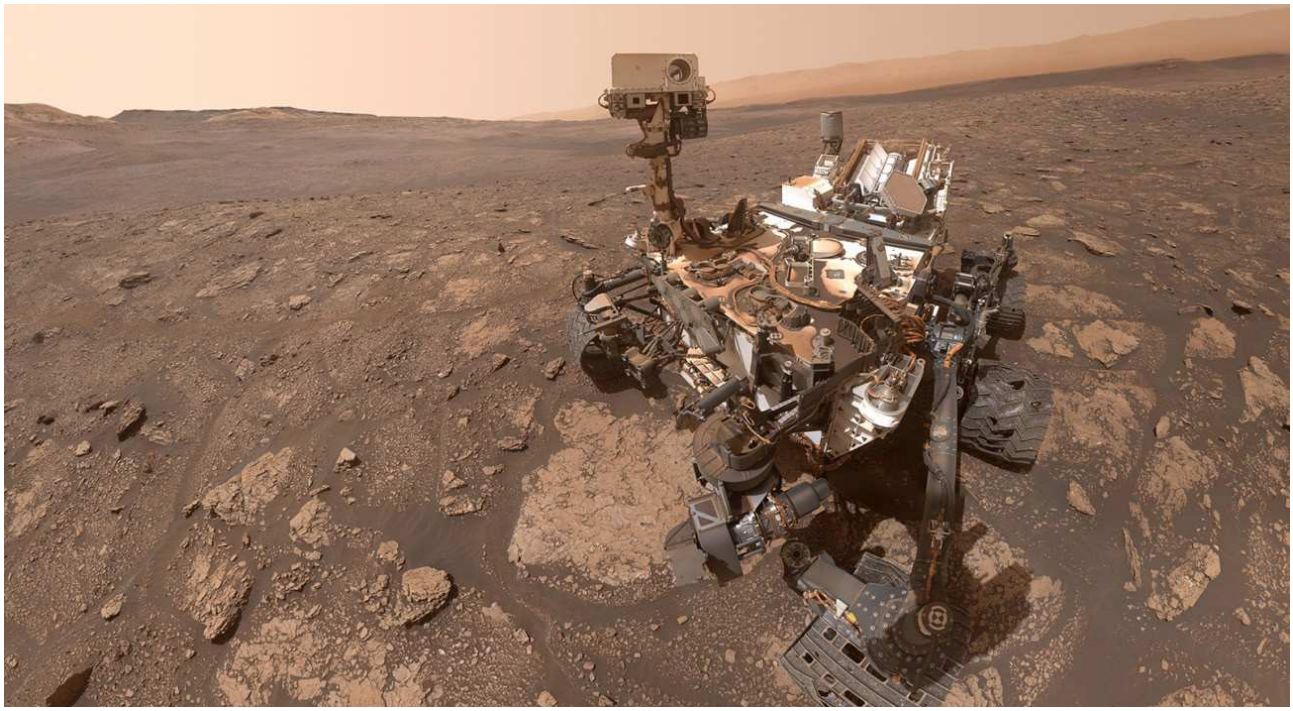


Evolution of the diurnal pressure mode normalized amplitudes (top) and phases (bottom)

Instrumentation for space missions: REMS

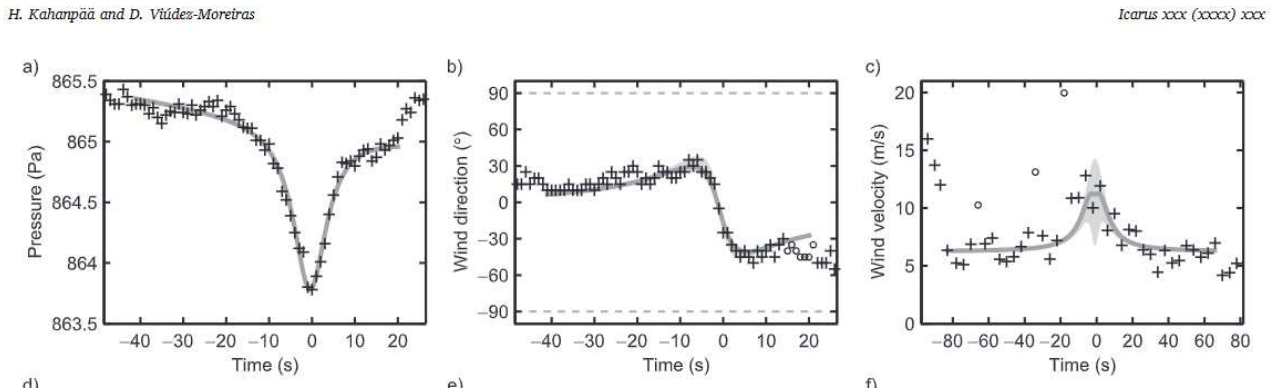
During 2020, the successful operation of the REMS (Rover Environmental Monitoring Station) on Mars, aboard Curiosity, continued. Curiosity, NASA's exploration vehicle, has been recognizing and characterizing the habitation environment of the Martian Gale Crater since August 2012. REMS is the instrument in charge of the characterization of the environment, continuously collecting data on pressure, air and ground temperatures, wind speed and direction, atmospheric relative humidity and incident ultraviolet radiation. During all this time, the instrument has collected more than 80 million readings from each of the sensors.

In addition to the daily operation of REMS, the group participates in the analysis of the scientific data obtained by the instrument, also contributing to the discussions and scientific meetings that periodically and frequently gather all the national and international members of the REMS team.



Curiosity's Selfie at the 'Mary Anning' Location on Mars, November 12, 2020

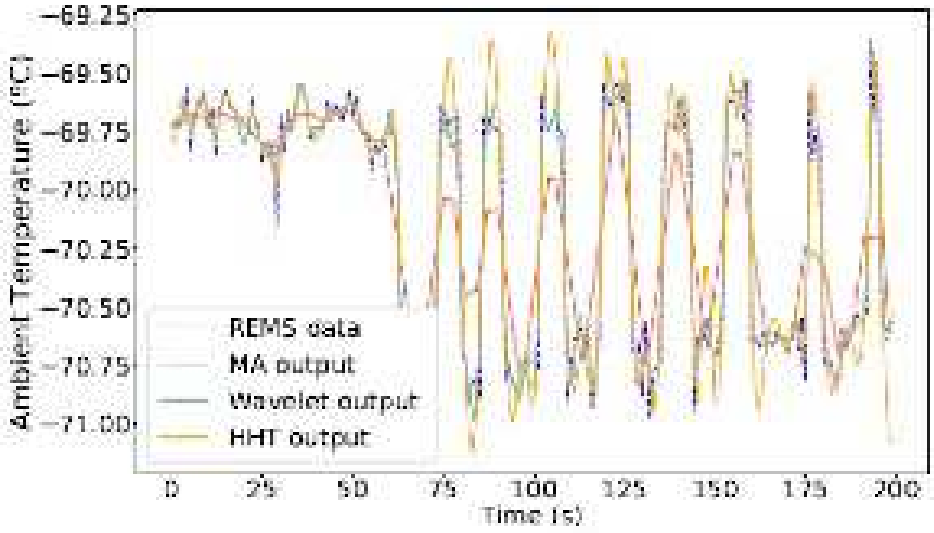
Within the framework of the REMS project, scientific research activities are also carried out. Throughout 2020, one of these contributions is the study of the dynamics of the Martian dust devils by fitting a mathematical model of vortices to the in-situ wind, pressure, and UV radiation readings from REMS. The study shows that clockwise and counterclockwise rotation directions are equally common among the studied convective vortices. The vortices seem to prefer certain trajectories, e.g. avoiding steep slopes. An extension of the methodology is also presented to further constrain the trajectories and the strengths of dust- laden vortices, based on concurrent in situ UV irradiance measurements. This methodology was applied to the only evidently dust-laden vortex in our data set and show that its dust lifting capability is likely based not only on wind stress lifting.



REMS data measured during vortex passes above Curiosity rover

Another example is the study of advective fluxes in the Martian regolith as a mechanism driving methane and other trace gas emissions to the atmosphere. Advective fluxes influence methane and CO_2 emissions from soil to the atmosphere on Earth, and may drive trace gas emissions in the Mars atmosphere. However, their relevance in the Martian regolith has not been assessed to date. Regolith transport simulations show that advective fluxes produced by winds and atmospheric pressure fluctuations can be relevant under Martian conditions and may drive the methane abundance detected by the Mars Science Laboratory. Trace gases such as methane must be emitted or produced from the upper layers of the regolith, or quickly transported to this region from a deeper reservoir through fractured media.

Other research activities carried out within the group is aimed at improving the quality of the REMS data using signal-processing techniques. Thus, a new wavelet algorithm was proposed as an alternative and better option to the current moving average filtering used in the ATS data denoising, due to its computational efficiency, its robustness in the denoising, and the capability of following abrupt signal changes without masking relevant signal features. All this has been verified and corroborated with the ATS calibration data.



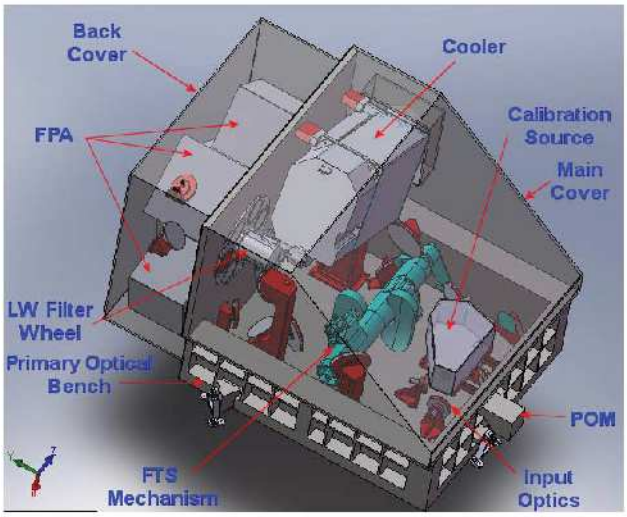
REMS-ATS data processing using different techniques to denoise and retrieve real Martian atmosphere temperature

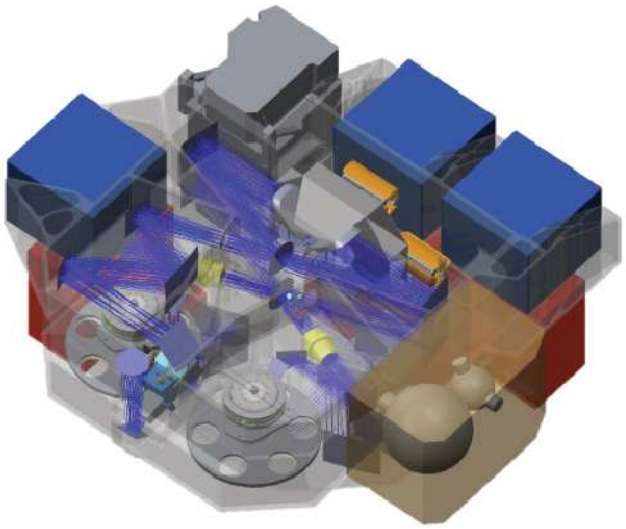
Technological developments of the SAFARI / SPICA project

The Space Instrumentation Group has continued its contribution to the technological development of the SAFARI instrument during the year 2020.

Since the year 2010, CAB and INTA have been the mechanical lead of SAFARI's focal plane unit at 4K. Work at such low temperatures and vacuum conditions has been a great challenge from different points of view: optical, mechanical, and electronic. SAFARI has evolved to adapt to its different payloads during the years, designing the focal plane unit, and accommodating each of the subsystems. In addition, performing mechanical and structural analysis have been performed for each of the different configuration for the project requirements.

As of October 2020, SPICA ceased to be an M5 mission candidate due to a decision by the joint ESA and JAXA project, thus cancelling SAFARI technology developments. The absence of SPICA leaves a gap in the Infra-red scientific and engineering community, which could lead to future mission opportunities in which to continue the work in thermomechanical cryogenic structures.

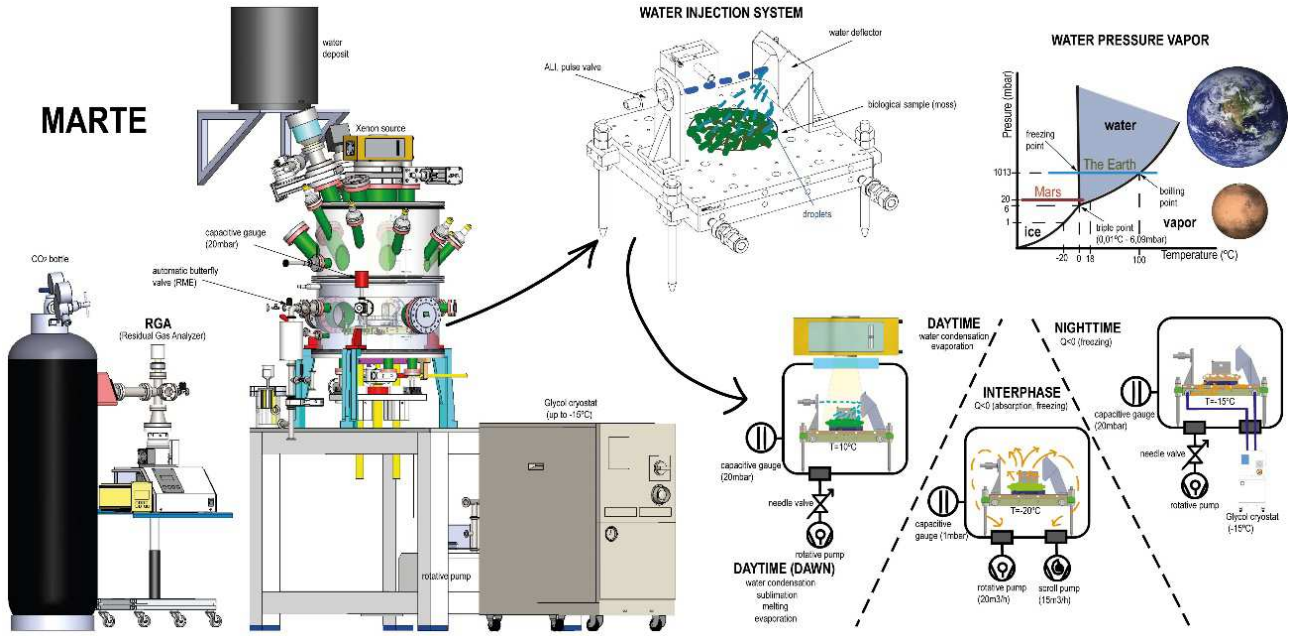


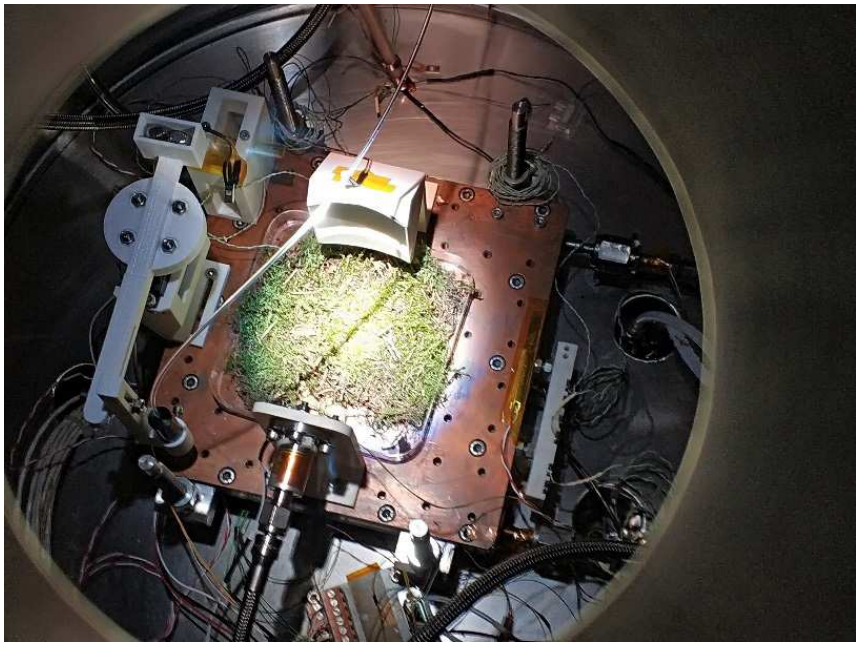


FPU SAFARI. Top Design shown with the four grating modules.

WLOM Project (Water Liquid On Mars).

This is a project led by researchers of the Space Instrumentation Group. Throughout the year 2020, it was concluded the system that simulates the environmental conditions of the red planet including its hydrological cycle. This laboratory facility enables us to control the water cycle in its three phases through temperature, relative humidity, hydration, and pressure with a system that injects water droplets into a vacuum chamber. We successfully simulated the Martian conditions at day and night by recreating water condensation, and created a surface ice layer that protects the sample against external radiation, and minimizes evaporative moisture losses to maintain a moss sample in survival conditions in this extreme environment.





(Top) Graphical abstract of the WLOM project and (bottom) Photo of the set-up inside MARTE chamber. (Cyanobacteria after the cooled water cycle, simulating the Mars poles)

Scientific Culture Unit

The Unit of Scientific Culture (UCC) is responsible for the dissemination of scientific advances in the field of astrobiology. It does so by optimizing the existing internal and external communication channels, as well as enabling an effective interaction between the CAB´s Research Community and the general public. The UCC develops a Communication Plan consisting of the drafting and publication of press releases, the relationship with mass media (press, radio and television), the participation in social networks and collaboration with scientific outreach magazines, such as AstronomiA magazine. Also, the UCC develops an Annual Disclosure Activities Plan. Listed below are the activities carried out during the year 2020.

- Production of press releases and other forms of media related materials. 29 press releases. (+16%)
- Attention to the mass media. 265 media impacts. (+18%)
- Curation of CAB website contents.
- Design and coordination of the new CAB website.
- Social networks maintenance.
  - Twitter: 7438 followers (16/12) (+22%)
  - Facebook: 3488 followers (16/12) (+8%)
  - YouTube channel: 851 subscriptors – 70 videos (16/12) (+75%)
- Attention to the CAB school and public visits. 270 visitors (until 10/03).
- Editorial coordination of Zoé magazine. Issue 5. 20 Years of Astrobiology in Spain.
- Monthly collaboration with AstronomiA magazine
- Planning and conducting outreach activities, talks, courses and workshops. 20 activities, 350 people.

- Participation in education & public outreach events:
  - Madrid Science Week (Semana de la ciencia). 50 people.
  - "Ellas son CAB". International Day of Women and Girls in Science Event at CAB. 40 people
  - "City Science" Project (Ciudad Ciencia). More than 300 students.
  - "Science in the Neighbourhood" Project (Ciencia en el Barrio). 250 students.
- Participation in science education Projects:
  - Planeta STEM. MeteoMarte. Pamplona Planetarium.
- Organization and support for scientific, social or outreach events in the CAB:
  - Mission Mars 2020 Launch Event. 50 attendees.
- Support for public outreach projects:
  - Exposition: "Mars. The Conquest of a Dream". Ciudad de las Artes y las Ciencias (Valencia) y Museo Casa de las Ciencias (Sevilla).
  - Exposition: "Beyond the Moon. Exploring the limits of Space". MUNCYT. Madrid.
  - Exposition: "Madrid Meninas Gallery". The Martian Menina.
- Public support for outreach books:
  - La vida: Un viaje hacia la complejidad en el Universo. Ester Lázaro. Ed. Sicomoro.
  - CIENCIA, y el "Cosmos" del siglo XXI. Quintín Garrido Ed. E. Lázaro, M. Mas, B. Montesinos & J. Pla.
  - ¿Estamos solos? En busca de otras vidas en el Cosmos. Carlos Briones. Ed. Crítica.
  - Marte y el enigma de la vida. J.A. Vaquerizo. Ed. CSIC – Catarata.
- Active participation in the FECYT's Network of Scientific Culture and Innovation Units (FECYT is the Spanish Foundation for Science & Technology).

Scientific Production

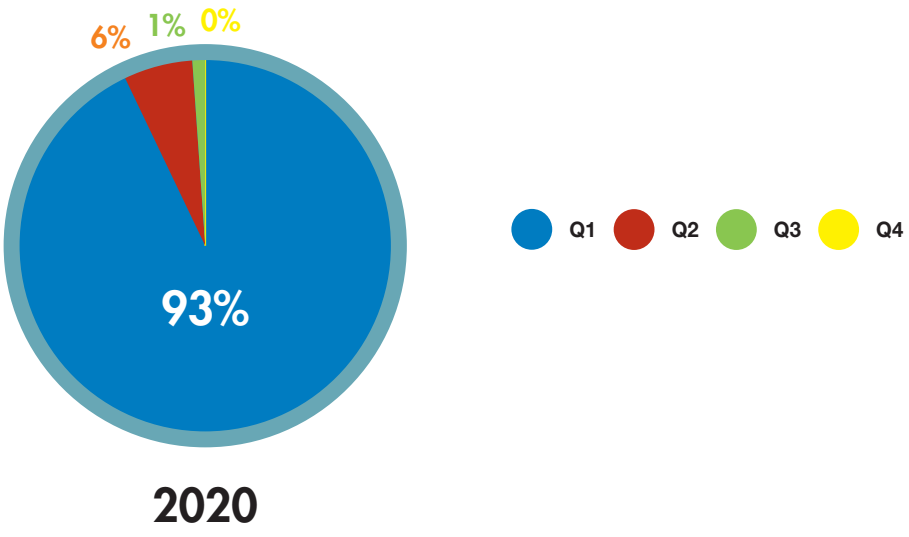
Producción Cientifica	
Artículos Indexados	279
Artículos no Indexados	3
Libros	2
Capítulos de libros	2
Congresos nacionales	
Comunicaciones	24
Congresos Internacionales	
Comunicaciones	30
Formación	
Cursos de postgrado (horas impartidas)	178
Cultura Científica	
Eventos	60
Materiales	34

Scientific Production 2020 (Scopus)

Year	Papers	First Author
2013	200 (Scopus)	76
2014	195 (Scopus)	71
2015	217 (Scopus)	56
2016	204 (Scopus)	48
2017	183 (Scopus)	34
2018	194 (Scopus)	45
2019	256 (WoS)	63
2020	279 (Scopus)	63

CONTRIBUTION	DOCUMENTS
ARTICLE	243
REVIEW	16
ERRATUM	6
EDITORIAL	2
LETTER	2
BOOK CHAPTER	1
CONFERENCE PAPER	7
NOTE	1

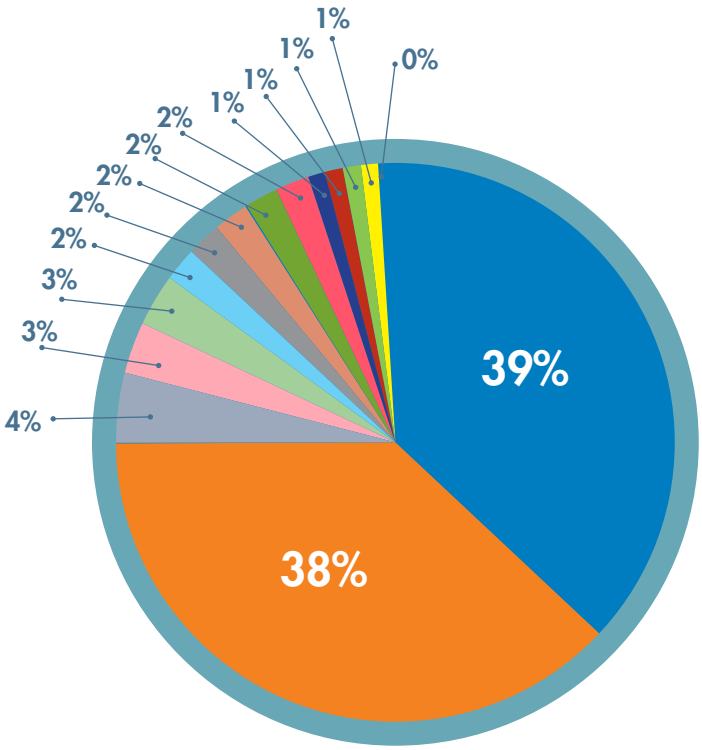
by Quartile 2020



by Subject Area (Scopus)

SUBJECT	PAPERS
Physics and Astronomy	213
Earth and Planetary Sciences	207
Engineering	20
Agricultural and Biological Sciences	15
Chemistry	15
Multidisciplinary	13
Biochemistry, Genetics and Molecular Biology	10
Environmental Science	9
Immunology and Microbiology	9
Materials Science	9
Mathematics	8
Medicine	8
Computer Science	5
Chemical Engineering	4
Energy	2
Social Sciences	2
Veterinary	1

by subject area (chart)



- Physics and Astronomy
- Earth and Planetary Sciencies
- Engineering
- Agricultural and Biological Sciences
- Chemistry
- Multidisciplinary
- Biochemistry, Genetics and Molecular Biology
- Environmental Science
- Immunology and Microbiology
- Materials Science
- Mathematics
- Medicine

by Journal

JOURNAL	PAPERS	Q
Acta Astronautica	1	Q1
Advances In Space Research	1	Q1
Applied Mathematical Modelling	1	Q1
Applied Surface Science	2	Q1
Applied Thermal Engineering	1	Q1
Astrobiology	8	Q1
Astronomical Journal	3	Q1
Astronomy And Astrophysics	101	Q1
Astrophysical Journal	12	Q1
Astrophysical Journal Letters	4	Q1
Atmosphere	1	Q2
Atmospheric Research	1	Q1
Chaos Solitons And Fractals	1	Q1
Chemphyschem	1	Q1
Current Issues In Molecular Biology	1	Q2
Earth And Space Science	1	Q2
Electrochimica Acta	1	Q1
Engineering Geology	1	Q1
Environmental Science And Pollution Research	1	Q1
Environmental Science And Technology Letters	1	Q1
European Journal Of Phycology	1	Q1
European Polymer Journal	1	Q1
Frontiers In Microbiology	3	Q1
Galaxies	2	Q3
Geographical Research Letters	1	Q1
Geophysical Research Letters	2	Q1
Geosphere	1	Q1
Hardwarex	2	Q2
Icarus	3	Q1
IEEE MTT S International Microwave Symposium Digest	1	Q3
Infection Genetics And Evolution	1	Q1
International Journal Of Astrobiology	2	Q2
Journal Of Clinical Microbiology	1	Q1
Journal Of Geophysical Research Planets	3	Q1
Journal Of Low Temperature Physics	1	Q2
Journal Of Raman Spectroscopy	1	Q2

Journal Of Virology	1	Q1
Marine Geology	1	Q1
Measurement Journal Of The International Measurement Confederation	1	Q1
Microbiology Resource Announcements	1	Q3
Microorganisms	1	Q4
Monthly Notices Of The Royal Astronomical Society	38	Q1
Monthly Notices Of The Royal Astronomical Society Letters	4	Q1
Nature	2	Q1
Nature Astronomy	4	Q1
Nature Geoscience	4	Q1
Physical Chemistry Chemical Physics	1	Q1
Physical Review E	1	Q1
Physics Of Fluids	1	Q1
Planetary And Space Science	3	Q2
Proceedings Of SPIE The International Society For Optical Engineering	4	Q3
Proceedings Of The International Astronautical Congress Iac	2	Q4
Proceedings Of The National Academy Of Sciences Of The United States Of America	2	Q1
Proceedings Of The Royal Society A Mathematical Physical And Engineering Sciences	1	Q1
Processes	1	Q3
Protoplasma	1	Q1
Rapid Communications In Mass Spectrometry	1	Q2
Remote Sensing	1	Q1
Review Of Scientific Instruments	1	Q2
Revista De La Sociedad Geologica De Espana	1	Q3
Rsc Advances	1	Q1
Science Of The Total Environment	3	Q1
Scientific Reports	9	Q1
Sensors Basel Switzerland	1	Q1
Sensors Switzerland	4	Q1
Space Science Reviews	9	Q1
Spectrochimica Acta Part B Atomic Spectroscopy	1	Q1
Sustainability Switzerland	1	Q1
Symbiosis	1	Q1

Published Articles in 2020 (Scopus)

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BAE Gabriel de Castilla y Puerto Foster.
Crédito: Comandante Eduardo Insignares Serrano

El futuro Extremely Large Telescope
Crédito: ESO/L. Calçada/ACe Consortium

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