Annual Report 2022

Memoria Anual

CENTRO DE ASTROBIOLOGÍA · CAB

ASOCIADO AL NASA ASTROBIOLOGY PROGRAM

CSIC

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INTA

Centro de Astrobiología (CSIC-INTA)

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Portada: Diversidad de formas de vida microbiana en las profundidades de la Faja Pirítica Ibérica.

A United Launch Alliance (ULA) Atlas V rocket carrying the Mars 2020 mission with the Perseverance rover. Credits: United Launch Alliance

The Milky Way

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Image of the Tinto River. Credits: CAB

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), en el año 2000 el CAB se convirtió en el primer centro no estadounidense asociado al recién creado NASA Astrobiology Institute (NAI), y actualmente es miembro asociado al Programa de Astrobiología de NASA (https://astrobiology.nasa.gov/). Por otro lado, en 2020 el CAB fue uno de los seis socios fundadores principales del recientemente creado Instituto Europeo de Astrobiología (EAI) (https://europeanastrobiology.eu/).

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The Astrobiology Center (CAB) was founded in 1999 as a Joint Center between the Higher Council for Scientific Research (CSIC) and the National Institute of Aerospace Technology (INTA). Located on the INTA campus in Torrejón de Ardoz (Madrid), in 2000 the CAB became the first non-US center associated with the recently created NASA Astrobiology Institute (NAI), and is currently an associate member of the NASA Astrobiology Program (https://astrobiology.nasa.gov/). On the other hand, in 2020 the CAB was one of the six main founding partners of the recently created European Astrobiology Institute (EAI) (https://europeanastrobiology.eu/).

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El objetivo de la Astrobiología es estudiar la vida como una consecuencia natural de la evolución del Universo, y el CAB tiene como objetivo contribuir a llenar los vacíos en la cadena de eventos desde el Big Bang hasta el origen y propagación de la vida, e iluminar a la sociedad sobre cuestiones fundamentales como de dónde venimos y hacia dónde vamos. Muchos procesos aún son desconocidos o poco comprendidos en esa sucesión de eventos y se requiere de un gran esfuerzo interdisciplinar para estudiar el único caso de vida que conocemos. En el CAB nos enfocamos en los que consideramos los procesos más críticos, de manera que nuestros objetivos científicos generales son:

- **Objetivo 1:** Caracterizar los componentes básicos del Universo: Formación y evolución de estrellas y galaxias a través del tiempo cósmico. El objetivo es establecer las condiciones de contorno que llevaron al surgimiento de la vida en el contexto de la formación y evolución de galaxias y estrellas a lo largo del tiempo cósmico.

- **Objetivo 2:** Comprender el ciclo de los elementos químicos: Del medio interestelar a las estrellas y planetas. Con especial interés en la formación y evolución de moléculas complejas y la química prebiótica en el espacio interestelar y discos protoplanetarios.

- **Objetivo 3:** Estudiar entornos planetarios potencialmente habitables. Investigar la formación, evolución y habitabilidad del Sistema Solar y más allá.

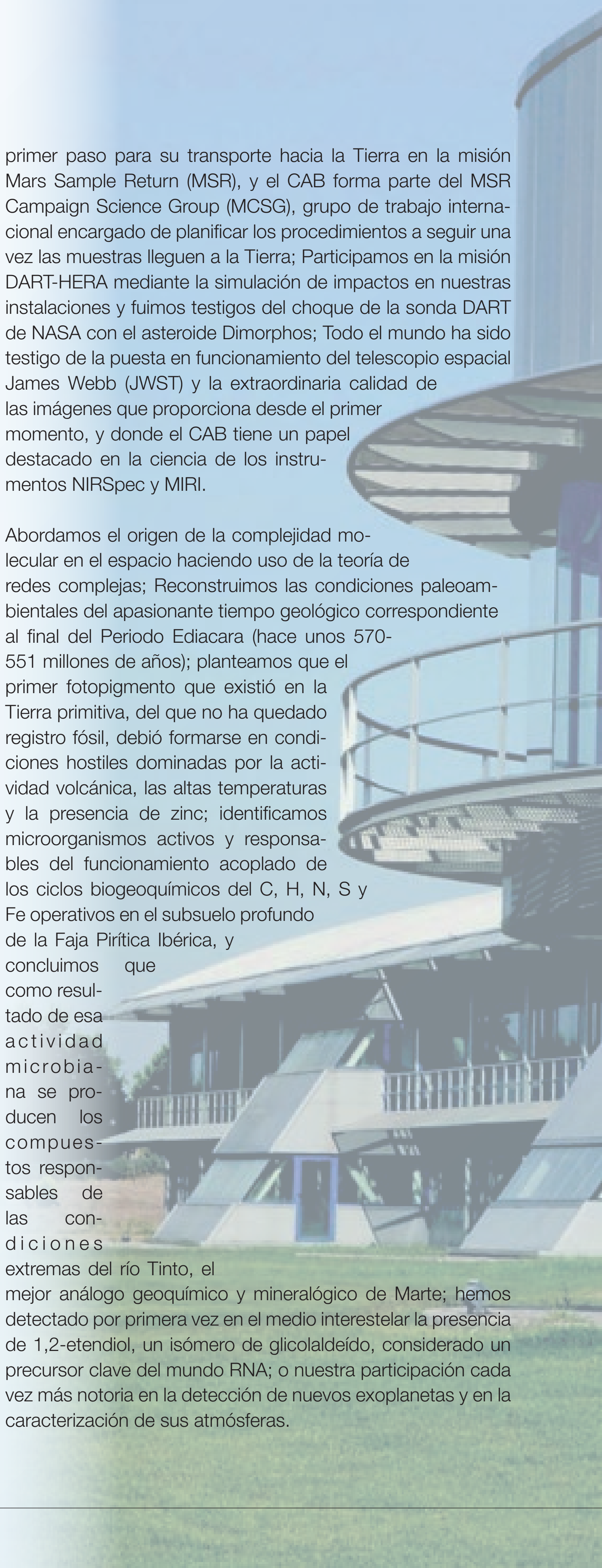
- **Objetivo 4:** Identificar y analizar biomarcadores para la búsqueda de vida en ambientes planetarios. Búsqueda de rastros inequívocos de vida en entornos planetarios.

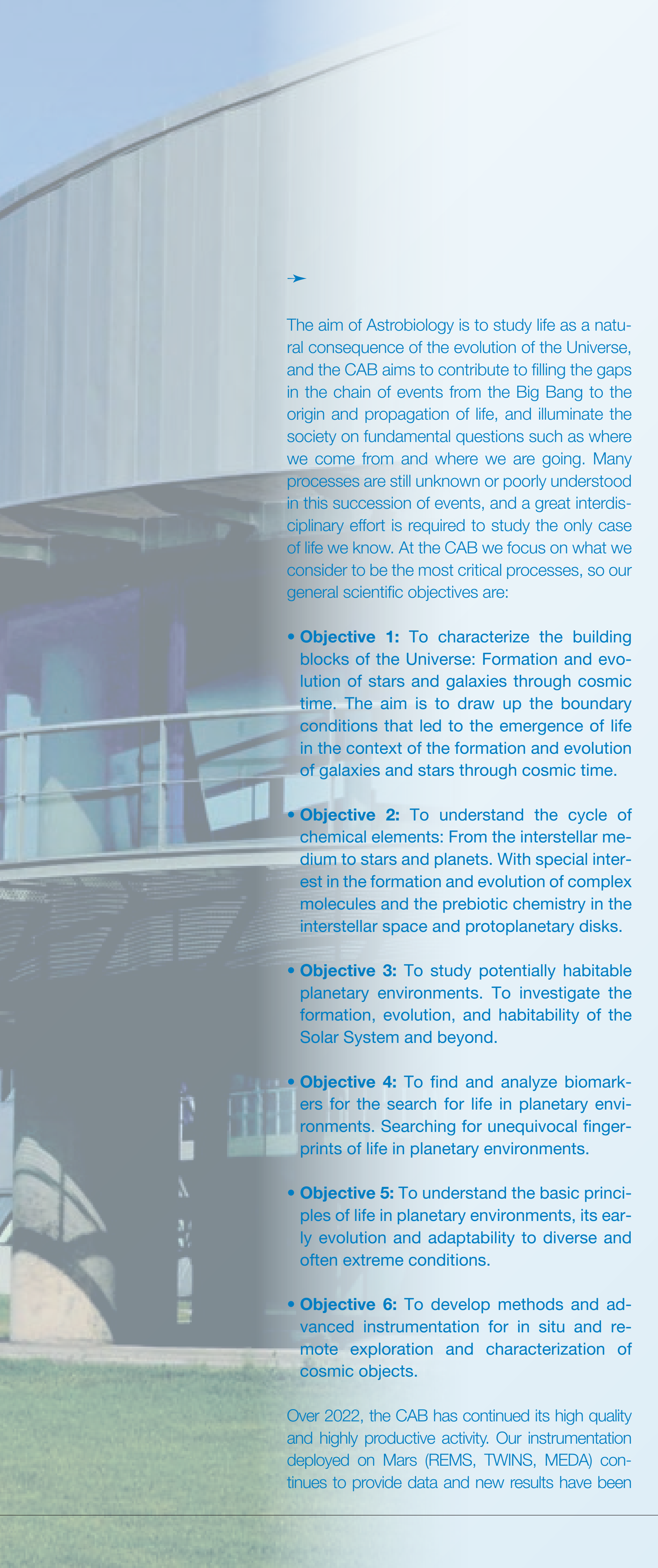
- **Objetivo 5:** Comprender los principios básicos de la vida en ambientes planetarios, su evolución temprana y adaptabilidad a condiciones diversas y a menudo extremas.

- **Objetivo 6:** Desarrollar métodos e instrumentación avanzada para la exploración y caracterización in situ y remota de objetos cósmicos.

Durante 2022, el CAB ha continuado su actividad de gran calidad y altamente productiva. La instrumentación desplegada en Marte (REMS, TWINS, MEDA) sigue proporcionando datos y se han publicado nuevos resultados sobre la caracterización de la atmósfera marciana, entre ellos la localización de la fuente de emisión responsable del metano detectado por Curiosity, o como los sensores de MEDA fueron testigos de torbellinos diarios, entre otros fenómenos atmosféricos; El rover Perseverance ha hecho ya múltiples análisis y ha tomado ya varias muestras de testigos de rocas y sedimentos como primer paso para su transporte hacia la Tierra en la misión Mars Sample Return (MSR), y el CAB forma parte del MSR Campaign Science Group (MCSG), grupo de trabajo internacional encargado de planificar los procedimientos a seguir una vez las muestras lleguen a la Tierra; Participamos en la misión DART-HERA mediante la simulación de impactos en nuestras instalaciones y fuimos testigos del choque de la sonda DART de NASA con el asteroide Dimorphos; Todo el mundo ha sido testigo de la puesta en funcionamiento del telescopio espacial James Webb (JWST) y la extraordinaria calidad de las imágenes que proporciona desde el primer momento, y donde el CAB tiene un papel destacado en la ciencia de los instrumentos NIRSpec y MIRI.

Abordamos el origen de la complejidad molecular en el espacio haciendo uso de la teoría de redes complejas; Reconstruimos las condiciones paleoambientales del apasionante tiempo geológico correspondiente al final del Periodo Ediacara (hace unos 570-551 millones de años); planteamos que el primer fotopigmento que existió en la Tierra primitiva, del que no ha quedado registro fósil, debió formarse en condiciones hostiles dominadas por la actividad volcánica, las altas temperaturas y la presencia de zinc; identificamos microorganismos activos y responsables del funcionamiento acoplado de los ciclos biogeoquímicos del C, H, N, S y Fe operativos en el subsuelo profundo de la Faja Pirítica Ibérica, y concluimos que como resultado de esa actividad microbiana se producen los compuestos responsables de las condiciones extremas del río Tinto, el mejor análogo geoquímico y mineralógico de Marte; hemos detectado por primera vez en el medio interestelar la presencia de 1,2-etendiol, un isómero de glicolaldeído, considerado un precursor clave del mundo RNA; o nuestra participación cada vez más notoria en la detección de nuevos exoplanetas y en la caracterización de sus atmósferas.





The aim of Astrobiology is to study life as a natural consequence of the evolution of the Universe, and the CAB aims to contribute to filling the gaps in the chain of events from the Big Bang to the origin and propagation of life, and illuminate the society on fundamental questions such as where we come from and where we are going. Many processes are still unknown or poorly understood in this succession of events, and a great interdisciplinary effort is required to study the only case of life we know. At the CAB we focus on what we consider to be the most critical processes, so our general scientific objectives are:

- **Objective 1:** To characterize the building blocks of the Universe: Formation and evolution of stars and galaxies through cosmic time. The aim is to draw up the boundary conditions that led to the emergence of life in the context of the formation and evolution of galaxies and stars through cosmic time.

- **Objective 2:** To understand the cycle of chemical elements: From the interstellar medium to stars and planets. With special interest in the formation and evolution of complex molecules and the prebiotic chemistry in the interstellar space and protoplanetary disks.

- **Objective 3:** To study potentially habitable planetary environments. To investigate the formation, evolution, and habitability of the Solar System and beyond.

- **Objective 4:** To find and analyze biomarkers for the search for life in planetary environments. Searching for unequivocal fingerprints of life in planetary environments.

- **Objective 5:** To understand the basic principles of life in planetary environments, its early evolution and adaptability to diverse and often extreme conditions.

- **Objective 6:** To develop methods and advanced instrumentation for in situ and remote exploration and characterization of cosmic objects.

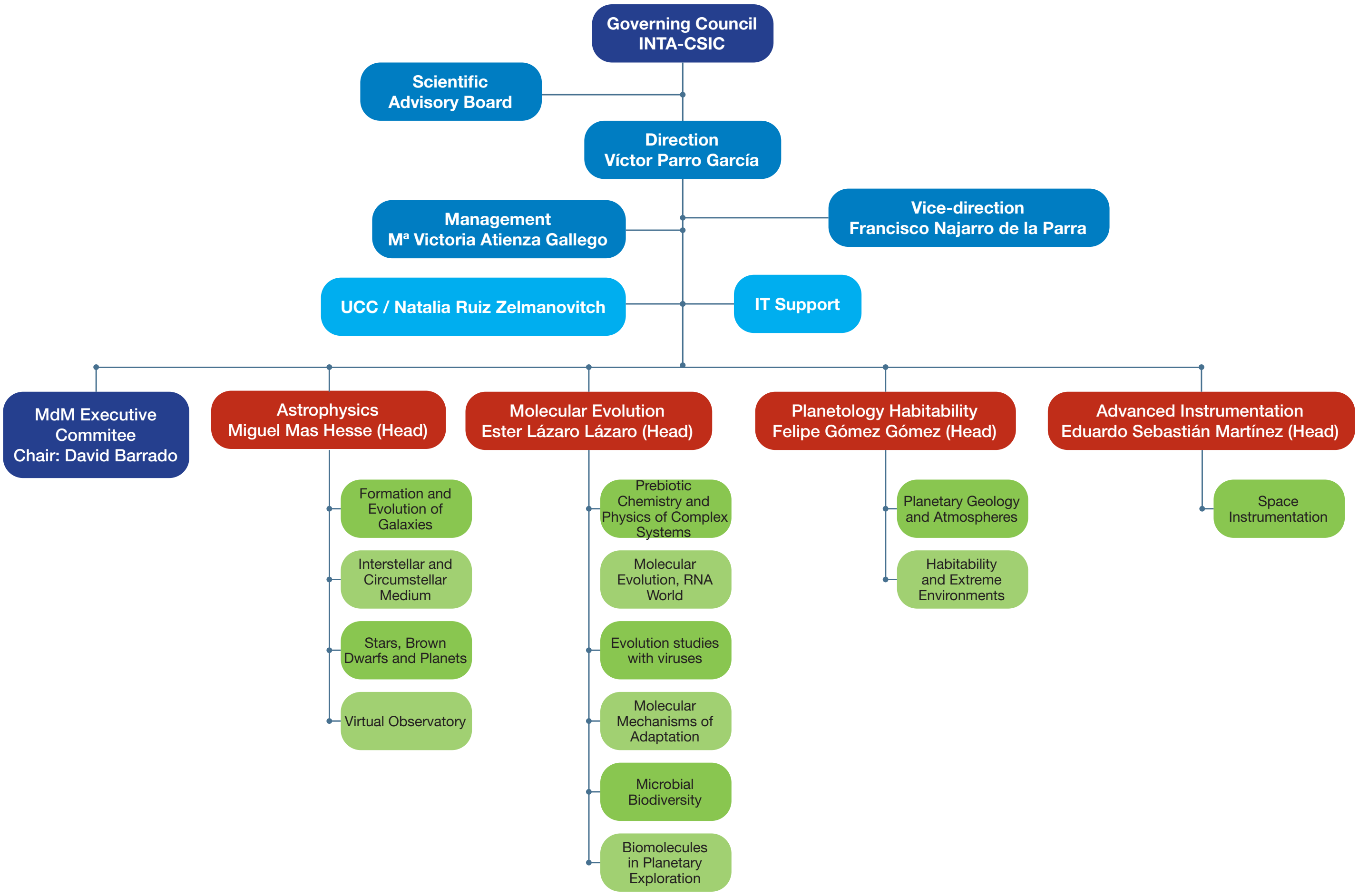
Over 2022, the CAB has continued its high quality and highly productive activity. Our instrumentation deployed on Mars (REMS, TWINS, MEDA) continues to provide data and new results have been published on the characterization of the Martian atmosphere, including the location of the emission source responsible for the methane detected by Curiosity, or how the MEDA sensors witnessed daily whirlwinds, among other atmospheric phenomena; The Perseverance rover has already carried out multiple analyzes and has already taken several core samples of rocks and sediments as a first step for their transport to Earth in the Mars Sample Return (MSR) mission, and the CAB is part of the MSR Campaign Science Group (MCSG), an international working group in charge of planning the procedures to follow once the samples reach Earth; We participated in the DART-HERA mission by simulating impacts at our facilities and followed with expetation the collision of NASA's DART probe with the Dimorphos asteroid; In 2022 the entire world has witnessed the commissioning of the James Webb Space Telescope (JWST) and the extraordinary quality of images it provides right out of the box, with CAB scientists playing a leading role in the science of the NIRSpec and MIRI instruments.

In 2022 we also approached the origin of molecular complexity in space using the theory of complex networks; We reconstructed the paleoenvironmental conditions of the exciting geological time corresponding to the end of the Ediacaran Period (about 570-551 million years ago); We proposed that the first photopigment that existed on the primitive Earth, of which no fossil record remains, must have formed in hostile conditions dominated by volcanic activity, high temperatures and the presence of zinc; We identified active microorganisms responsible for the coupled functioning of the biogeochemical cycles of C, H, N, S and Fe operating in the deep subsoil of the Iberian Pyrite Belt, and we concluded that this microbial activity produces the compounds responsible for the extreme conditions of the Tinto River, the best geochemical and mineralogical analogue of Mars; We have detected for the first time in the interstellar medium the presence of 1,2-ethendiol, a glycolaldehyde isomer, considered a key precursor of the RNA world; Or how CAB is notoriously and increasingly participating in the detection of new exoplanets and in the characterization of their atmospheres.

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).

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).

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 2022. Centro de Astrobiología is 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 2022

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/Dña. Eloisa del Pino

Presidenta Agencia Consejo Superior de Investigaciones Científicas (CSIC)

D. Jesús Marco de Lucas/D. José María Martell

Vicepresidente de Investigación Científica y Técnica (CSIC)

D. José María Salom Piqueres/D. Julio Ayuso Miguel

Director General, Instituto Nacional de Técnica Aeroespacial (INTA)

D. Julio Ayuso Miguel/ D. Antonio Guerrero Mochón

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
Miguel Mas Hesse	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

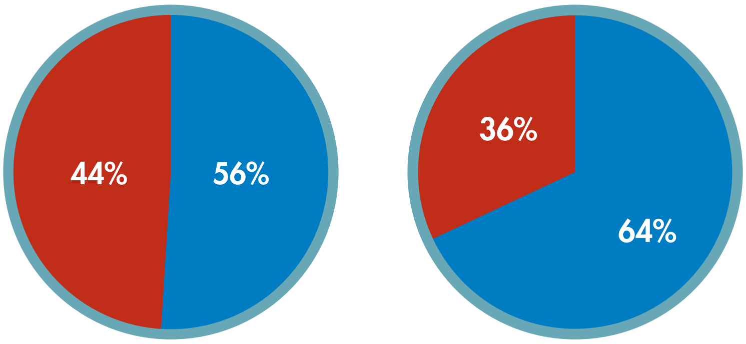
Name	Position
Margie Guitart Martín	Administration
Consuelo Moncayo Ortega	Administration
Virginia Suarez Marsá	Technical management
Susana Cabañero	Support
Jesús Vara Pinedo	UCC and Outreach
Luis Mora Sotomayor	IT support

external support in 2022

María Pilar Alonso del Val	Technical support
Rosa del Olmo	Technical management
Tatiana Fraile Noriega	Technical management
María Teresa García Martín	Technical management
Macarena Gutiérrez Ortega	Technical management
Antonio Parras Rico	Computing support
Sergio Suarez Carrasco	Computing support
Ignacio Barranquero	Scholarship student

Personnel
by gender

December 2022

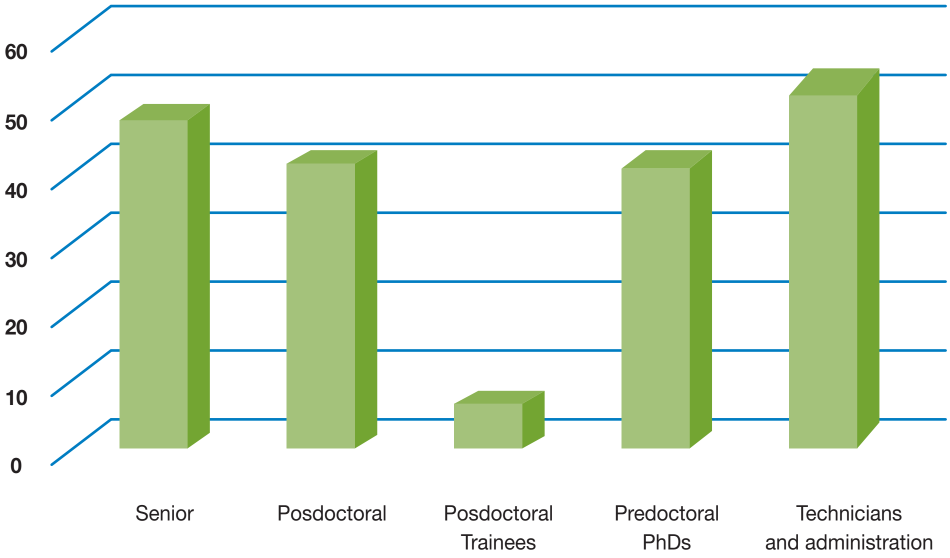


Gender Balance: Total(left); Scientific scales (right).

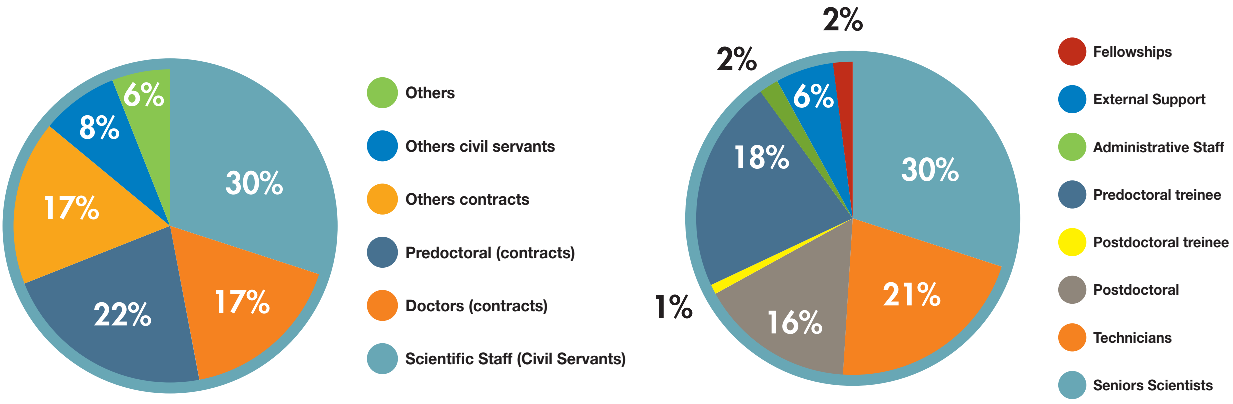
🔴 Women 🔵 Men

Personnel
by category

Personnel by category (including 12 full time equivalents from other entities)



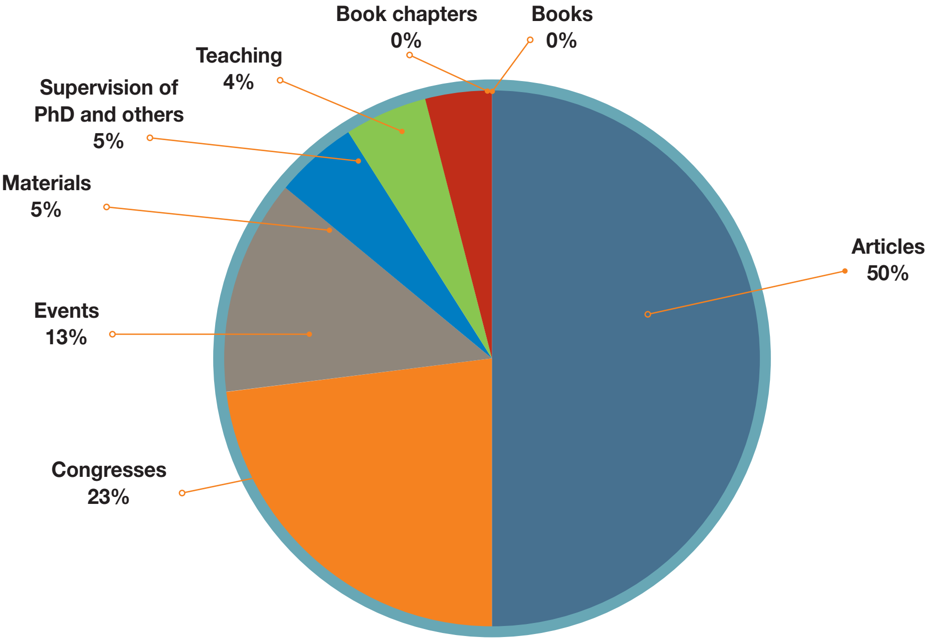
by type of contract



Personnel by type of contract (left) and by professional category (right)

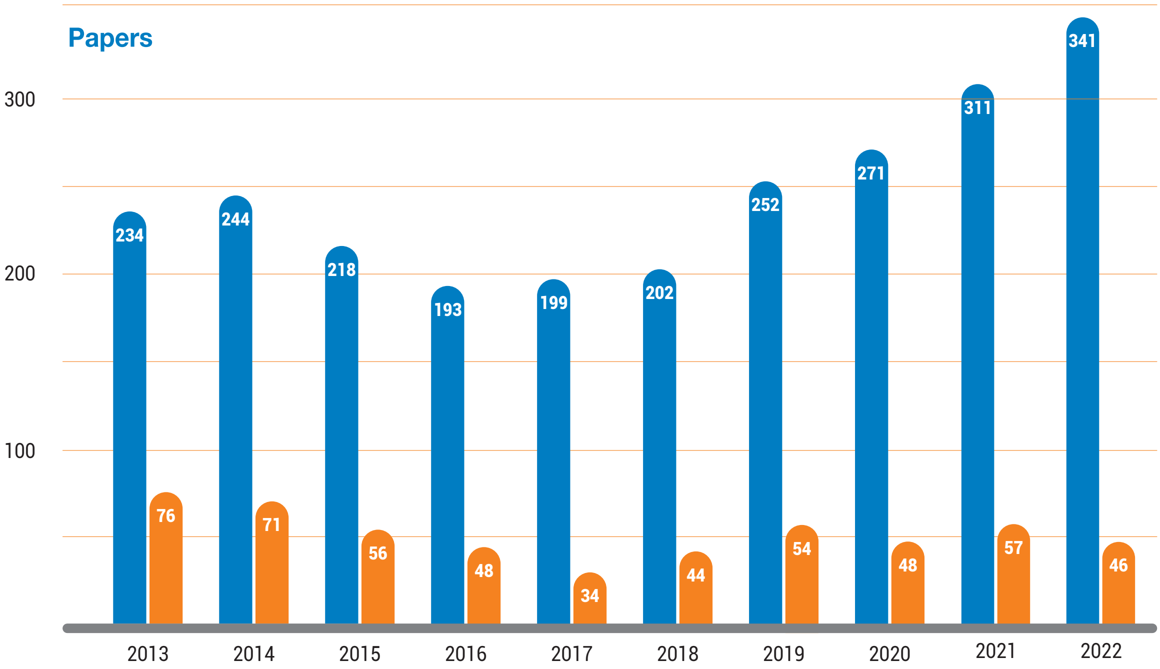
Scientific Production

Different indicators of the scientific production in 2022 (internal sources)

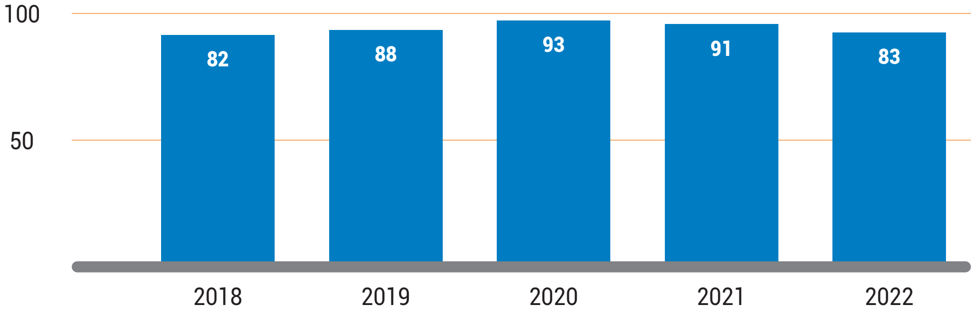


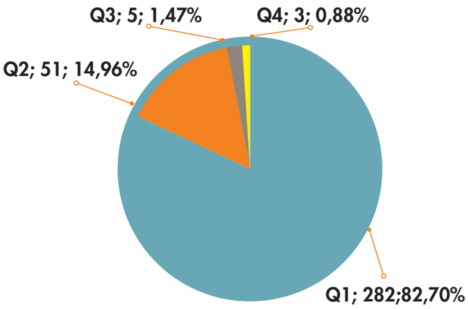
Research Articles

Evolution of the number of articles by year: total (blue) and led by CAB (red)

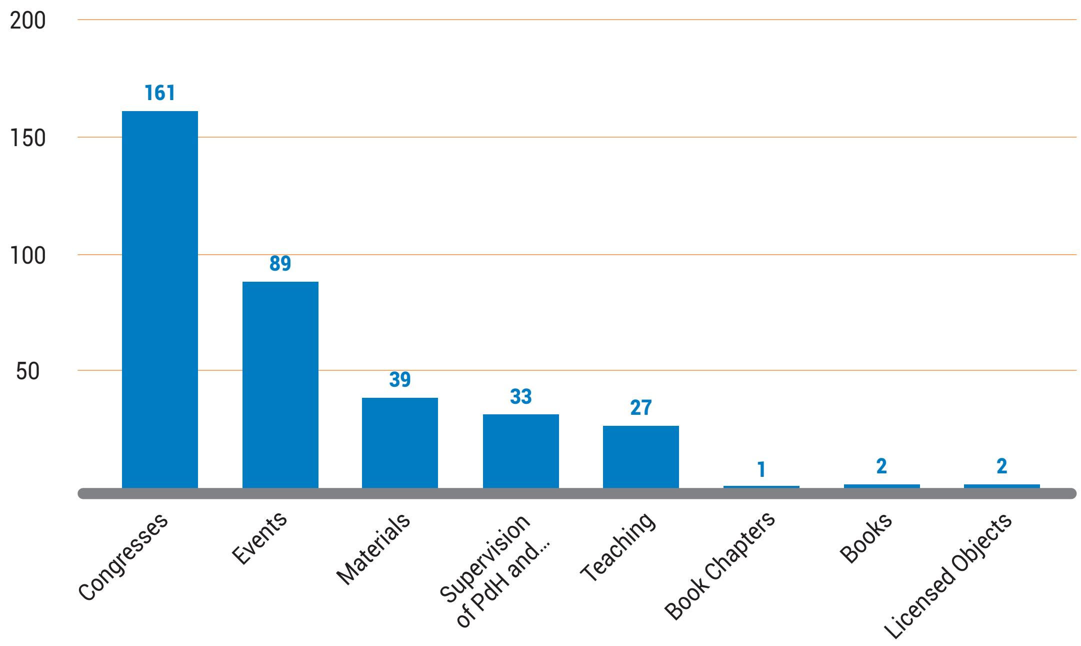


Evolution of the article production in quartile Q1 (%)

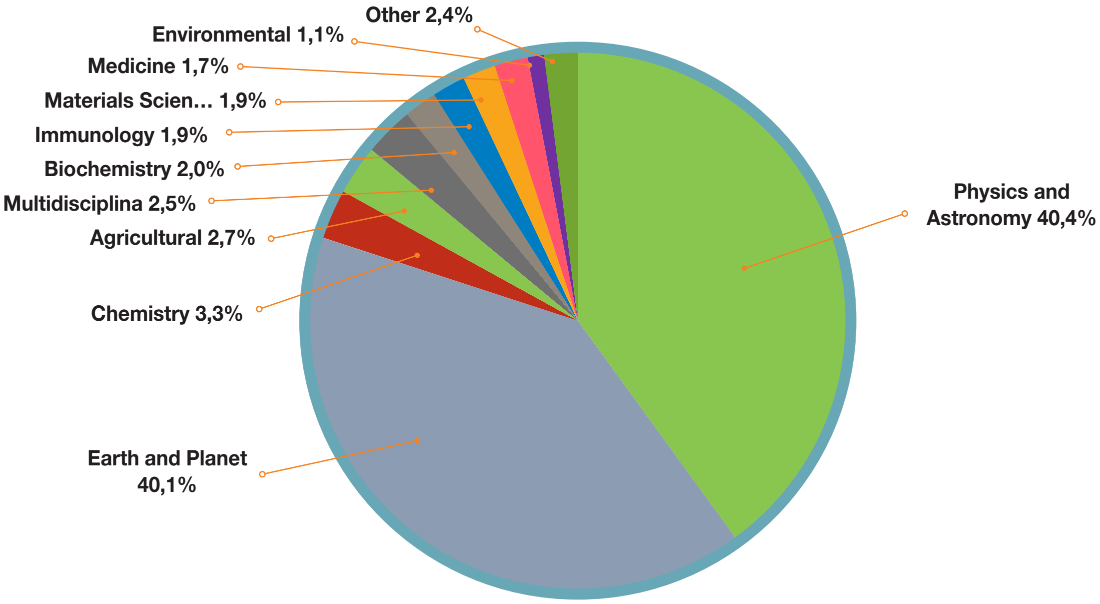




Other scientific production (internal sources)

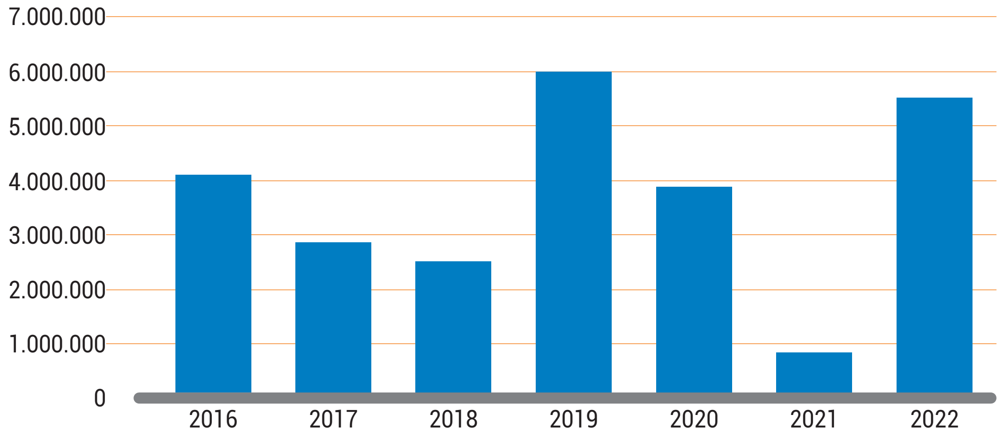


by subject area 2022 (source Scopus)



Documents by subject area

Funds from competitive calls (€ per year)



The Antennae Galaxies (also known as NGC 4038 and 4039)
Credit: ALMA (ESO/NAOJ/NRAO). Visible light image: the NASA/
ESA Hubble Space Telescope

The Eagle nebula observed with JWST/MIRI. Credits: NASA, ESA, CSA, STScI. MIRI was contributed by ESA and NASA, with the instrument designed and built by a consortium of nationally funded European Institutes (the MIRI European Consortium, with an important CAB/INTA participation) in partnership with JPL and the University of Arizona.

Astrophysics
department of

Heads of Department: J. Miguel Mas Hesse

The research at the Department of Astrophysics is focused on the formation and evolution of galaxies, stars and planets and their interplay with the interstellar medium, providing so the large-scale context in which Life emerged and evolved. The objectives are organized around the following questions:

To characterize the building blocks of the Universe: Formation and evolution of galaxies through cosmic time.
Our research is based on the general hypothesis that Life is a consequence of the evolution of matter and energy in the Universe, aiming to link the studies on the origin and evolution of the Universe with the emergence and potential spread of life.

To understand the cycle of chemical elements: From the interstellar medium to stars and planets.
The focus will be on the details of the cycle of chemical elements, from their production by stellar evolution to the formation of complex molecules and dust, the formation of stars, brown dwarfs and planets, and the development of prebiotic chemistry in the interstellar space and protoplanetary disks. All this provides the boundary conditions to study the emergence of life in the solar System (at least) around 4 billion years ago.

To study potentially habitable environments.
We aim to connect the efforts from the point of view of Astronomy to discover (exo)planetary systems, and analyze their components -planets, and minor bodies- architecture and evolution, with those from the side of Biology and Planetary Science to assess their potential habitability.

To develop methods and advanced instrumentation for the characterization of cosmic objects.
Including the development ground- and space-based instrumentation for observing objects within and beyond the Solar System

The Department of Astrophysics is constituted by 4 research groups:

- Formation and Evolution of Galaxies (FEG)
- Formation and Evolution of Stars, Brown Dwarfs and Planets (FESBDP)
- Interstellar and Circumstellar Medium (ICM)
- Virtual Observatory: Scientific exploitation of astronomical archives (VO)

Formation and Evolution of Galaxies

Group coordinator: Giovanni Miniutti

Senior Researchers:

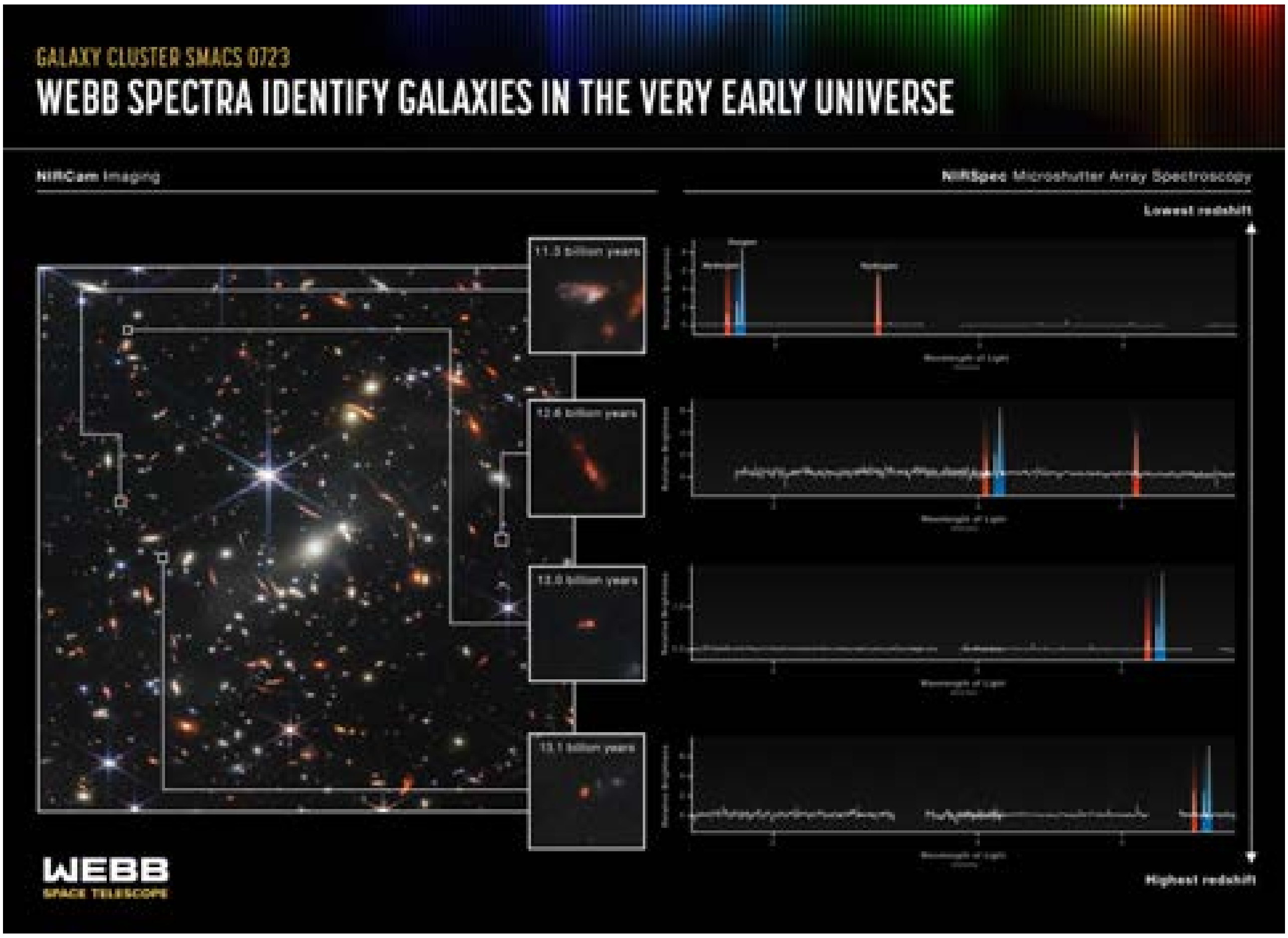
Almudena Alonso Herrero
Santiago Arribas Mocoroa
Miguel Antonio Cerviño Saavedra
Luis Colina Robledo
José Miguel Mas Hesse
Giovanni Miniutti
Pablo Guillermo Pérez González
Montserrat Villar Martín

Postdoctorals

Javier Álvarez Márquez
Marianna Annunziatella
Heribert Argelaguet Vilaseca
Enrica Bellocchi
Luca Costantin
Alejandro Crespo Gómez
Alberto Estrada Piqueras
Margherita Giustini
Isabella Lamperti
Luis Peralta de Arriba
Miguel Pereira Santaella
Ana María Pérez García
Michele Perna
Javier Piqueras Lopez
Bruno Rodriguez Del Pino
Héctor Vives Arias

Summary

The Galaxies Formation and Evolution group (FEG) contributes to objectives O1, O2 and O6 of the Center Strategic Plan. The group aims at providing a global view of the processes of galaxy formation and evolution across cosmic time. The group routinely collects, analyzes, and publishes astronomical data from radio and millimetric to infrared, optical and X-rays, making use of state of the art ground and space-based facilities. The FEG group's scientific expertise and research interests cover a very broad range of physical phenomena from interacting/merging galaxies, winds and gas outflows at large scales from millimetric and infrared to optical and X-rays, to the detailed study of nuclear activity and of its relation with the overall host galaxies properties. The group is heavily involved in technological projects for astronomical instrumentation both in space and on the ground in the framework of the ESA and ESO programs. Group members participate in the instrument teams of the MIRI and NIRSpec instruments for the recently launched James Webb Space Telescope (JWST), they take part in the team responsible for the development of HARMONI, a first light instrument for the European Extremely Large Telescope (EELT), and they participate to the definition of the next ESA large X-ray observatory Athena, among other international projects. The following research highlights exemplify some of the most relevant recent investigations and results led by the group during the course of 2022.



Of the thousands of distant galaxies behind galaxy cluster SMACS 0723, the Near-Infrared Spectrograph (NIRSpec) on board the James Webb Space Telescope (JWST) observed 48 individually, all at the same time. Here, four galaxies are highlighted, and their NIRSpec spectra are shown on the right panels. Light from the most distant galaxy shown here has traveled about 13.1 billion years before reaching JWST detectors. The FEG group is deeply involved in the Webb, and group's member participate in the instrument teams of both the NIRSpec and MIRI instruments.

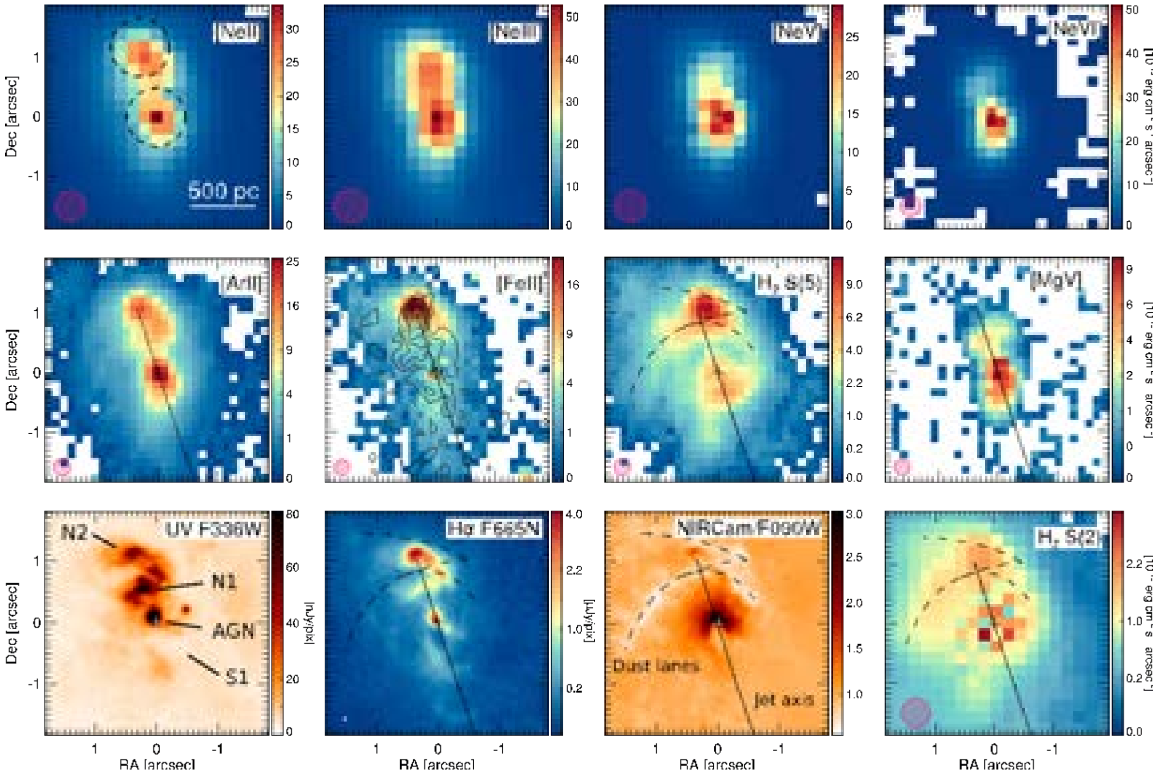
Research Highlights 2022

RH1: Discovery of a jet–interstellar medium interaction in NGC 7319 revealed by JWST/MIRI Spectroscopy

JWST/MIRI MRS spectroscopy of NGC 7319, the largest galaxy in the Stephan’s Quintet was observed as part of the Early Release Observations (ERO). NGC 7319 hosts a type 2 active galactic nucleus (AGN) and a low-power radio jet ($L_{1.4GHz} = 3.3 \times 10^{22}$ W Hz^{-1}) with two asymmetric radio hotspots at 430 pc (N2) and 1.5 kpc (S2) projected distances from the unresolved radio core.

The MRS data suggest that the molecular material in the disk of the galaxy decelerates the jet and causes this length asymmetry. We find enhanced emission from warm and hot H2 and ionized gas at the intersection between the jet axis and dust lanes in the disk. This emission is coincident with the radio hotspot N2, the hotspot closer to the core, suggesting that the jet–interstellar medium (ISM) interaction decelerates the jet. We find that only <1% of the jet energy remains as mechanical energy in these two ISM phases at N2.

We also find extended high-ionization emission ([Mg v], [Ne vi], and [Ne v]) close to the radio hotspots. This initial analysis of NGC 7319 shows the potential of MIRI/MRS to investigate the AGN feedback mechanisms due to radio jets and their radiation field in the, often heavily dust-enshrouded, central regions of galaxies. Understanding these mechanisms is an essential ingredient in the development of cosmological simulations of galaxy evolution.



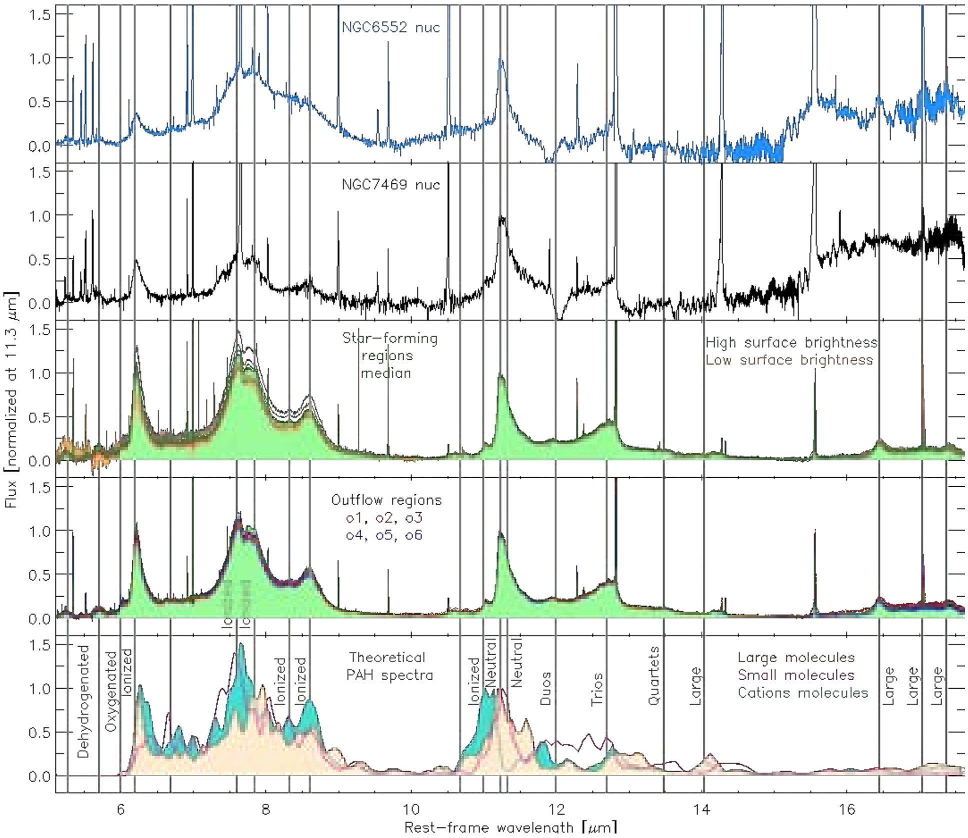
The figure presents the central 3.6×3.6 arcsec^2 region of NGC 7319, which includes the AGN and the northern radio lobe and hotspot N2. *First row (left to right)*: [Ne II]12.81 μm, [Ne III]15.56 μm, [Ne V]14.32 μm, and [Ne VI]7.65 μm MIRI MRS line maps. *Second row (left to right):* [Ar II]6.99 μm, [Fe II]5.34 μm, H_2 S(5) 6.91 μm, and [Mg V]5.61 μm MIRI MRS line maps. The contours on the second panel represent the 1.4 GHz emission. *Third row: first two panels* are HST images presenting the ultraviolet and ionized gas distribution. The third panel is the JWST/NIRCam *F090W* (λ_p=0.90 μm) image while the fourth panel is the H_2 S(2) 12.28 μm emission line. The dotted and dashed black lines trace the jet axis (N2 hotspot–AGN axis) and disk dust lanes, respectively. The red hatched circles represent the PSF FWHM, ~0.26–0.60 arcsec depending on the wavelength, estimated from the unresolved AGN continuum.

RH2: A high angular resolution view of the PAH emission in Seyfert galaxies using JWST/MRS data

Polycyclic aromatic hydrocarbons (PAHs) are carbon-based molecules that are ubiquitous in a variety of astrophysical objects and environments. In this work we use JWST/MIRI MRS spectroscopy of three Seyferts to compare their nuclear PAH emission with that of star-forming (SF) regions. This study represents the first of its kind to use sub-arcsecond angular resolution data of local luminous Seyferts ($L_{bol} > 10^{44.46}$ erg s^{-1}) with a wide wavelength coverage (4.9-28.1 μm).

We present an analysis of their nuclear PAH properties by comparing the observed ratios with PAH diagnostic model grids derived from theoretical spectra. Our results show that a suite of PAH features is present in the innermost parts of luminous Seyfert galaxies (~0.45″ at 12 μm; in the inner ~142-245 pc).

We find that the nuclear regions of active galactic nuclei (AGN) lie at different positions of the PAH diagnostic diagrams, whereas the SF regions are concentrated around the average values of SF galaxies. In particular, we find that the nuclear PAH emission mainly originates in neutral PAHs. In contrast, PAH emission originating in the SF regions favours ionised PAH grains. The observed PAH ratios in the nuclear region of the AGN-dominated galaxy NGC 6552 indicate the presence of larger PAH molecules compared with those of the SF regions. Therefore, our results provide evidence that the AGN have a significant impact on the ionisation state (and probably the size) of the PAH grains on scales of ~142-245 pc.

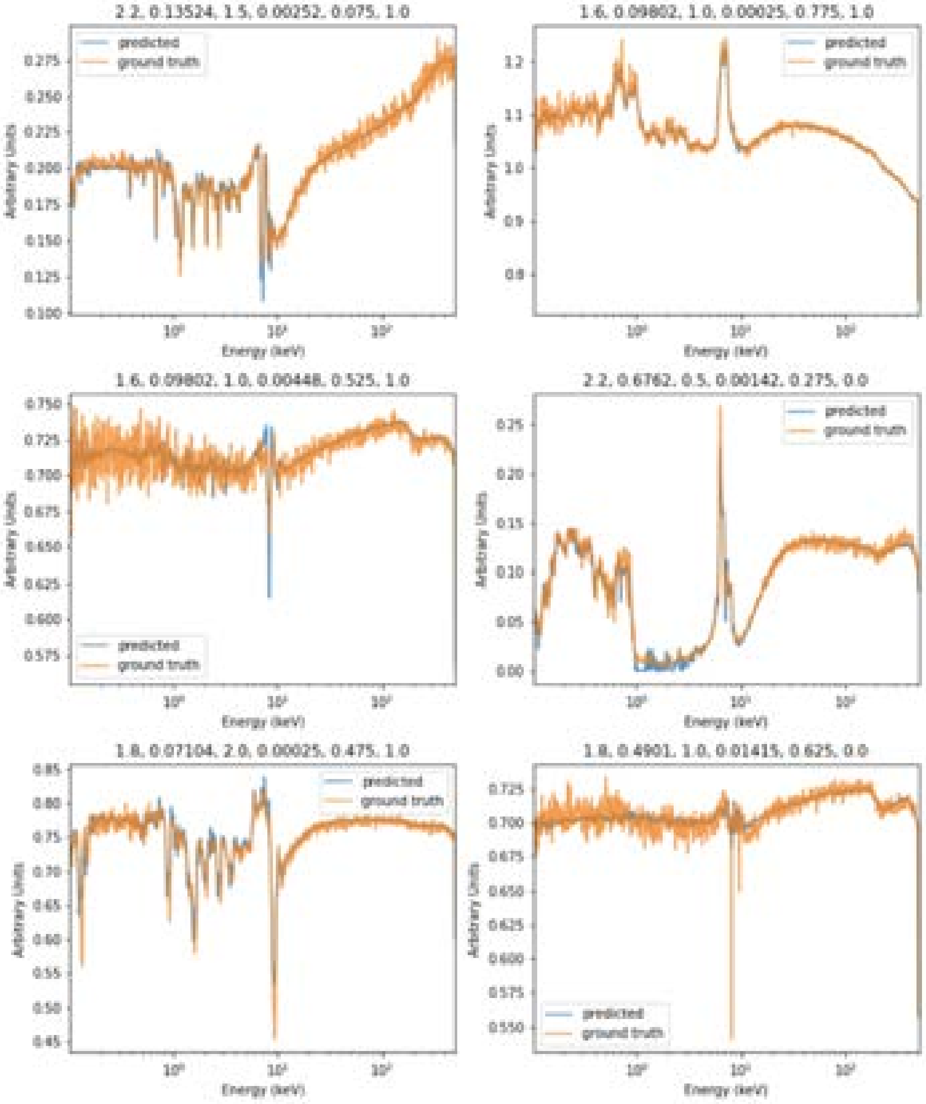


The top four panels show JWST/MIRI continuum-subtracted spectra where the most prominent PAH features are marked. The first top panels correspond to the nuclear regions of NGC 6552 and NGC 7469, respectively. The central panel are spectra from circumnuclear regions of NGC 7469 (solid grey lines) and the median circumnuclear spectra of high and low surface brightness regions (solid green and brown lines, respectively). The fourth panel is a comparison between the median NGC 7469 circumnuclear spectrum and the regions located in the potential outflow zones (blue and red lines). The bottom panel presents synthetic PAH spectral templates of large ($100 < N_c < 400$), small ($20 < N_c < 100$), and ionised PAH molecules. All the spectra are normalised at 11.3 μm.

RH3: XRADE: a new emulated Monte Carlo radiative transfer disc-wind model

Accretion disk winds are one of the possible feedback mechanisms between galaxies and their central supermassive black holes. They are observable in the X-ray spectra of actively accreting supermassive black holes as blue-shifted absorption lines and scattered emission. However, specific theoretical predictions are sparse, as the theoretical computation of accretion disk wind models is computationally very expensive.

In this work we develop a novel emulation method consisting in training, validating, and testing simulated accretion disk wind X-ray spectra into a purposely built artificial neural network. The trained emulator can generate a single synthetic X-ray spectrum for a particular parameter set in a fraction of a second, in contrast to the few hours required by a standard Monte Carlo radiative transfer pipeline. XRADE will be an indispensable tool for the development of high-resolution theoretical models for the next generation micro-calorimeters on board future missions, like XRISM/Resolve and Athena/XIFU.



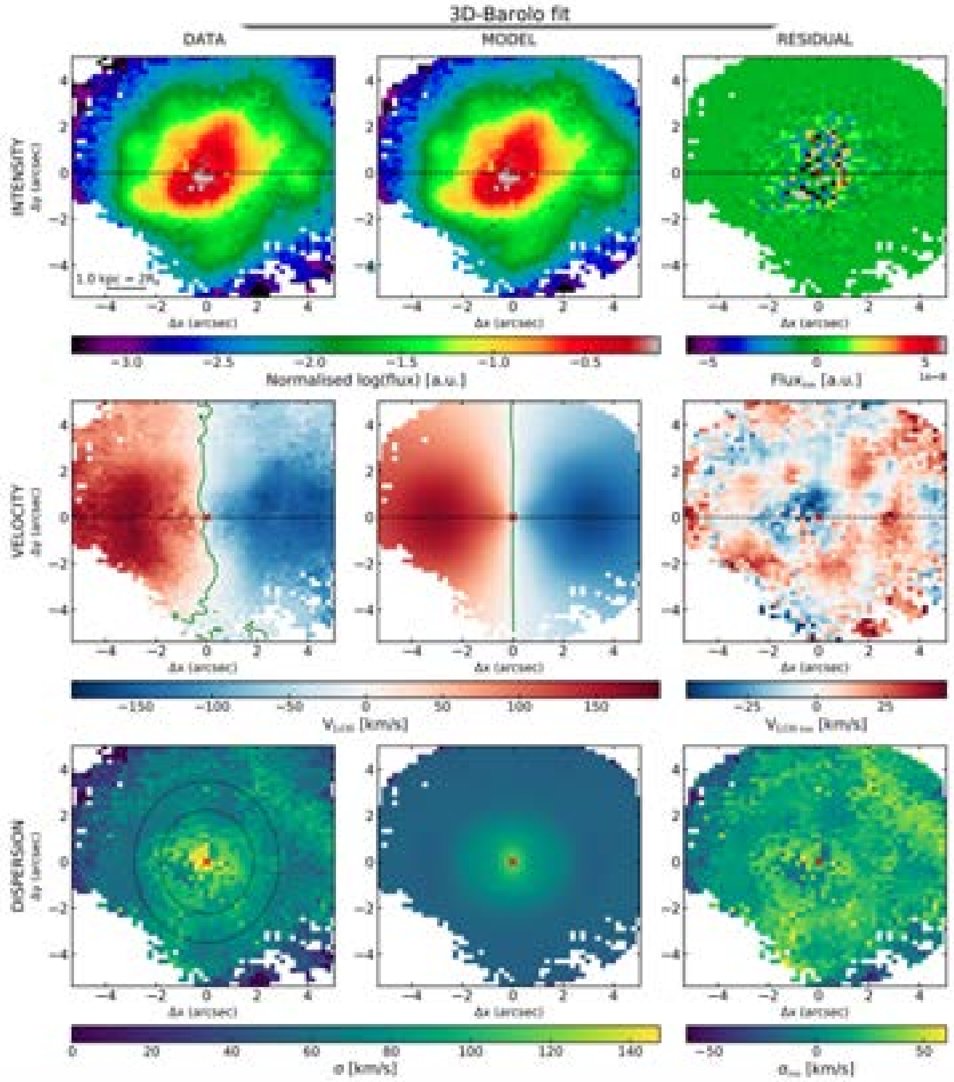
Four randomly chosen randomly chosen examples of “ground truth spectra” (orange) with the corresponding “predicted spectra” emulated by XRADE (blue).

RH4: Physics of ULIRGs with MUSE and ALMA: The PUMA project. III. Incidence and properties of ionised gas disks in ULIRGs, associated velocity dispersion, and its dependence on starburstiness

A classical scenario suggests that ULIRGs transform colliding spiral galaxies into a spheroid dominated early-type galaxy. Recent high-resolution simulations have instead shown that, under some circumstances, rotation disks can be preserved during the merging process or rapidly regrown after coalescence. We analysed MUSE data of a sample of 20 nearby ($z<0.165$) ULIRGs, as part of the "Physics of ULIRGs with MUSE and ALMA" (PUMA) project, to infer the incidence of gas rotational dynamics in late-stage interacting galaxies and merger remnants.

We found that 27% individual nuclei are associated with kpc-scale disk-like gas motions. The rest of the sample displays a plethora of gas kinematics, dominated by winds and merger-induced flows. On the other hand, the incidence of stellar disk-like motions is ~2 times larger than gaseous disks, as the former are probably less affected by winds and streams. By combining our results with those of local and high-z disk galaxies from the literature, we found a significant correlation between σ and the offset from the main sequence (MS), after correcting for their evolutionary trends.

Our results confirm the presence of kpc-scale rotating disks in interacting galaxies and merger remnants, with an incidence of ~27-50%. The ULIRGs gas velocity dispersion is up to a factor of ~4 higher than in local normal MS galaxies, similar to high-z starbursts.



Kinematic modelling of the gaseous rotating disk of the Ultra-Luminous InfraRed Galaxy I13120-5453, with the 3D-Barolo routines. The first to third rows show the moment 0, 1 and 2, inferred rom the data (left), the 3D-Barolo best-fit model (centre), and the residuals (data – model, on the right).

RH5: From Naked Spheroids to Disky Galaxies: How Do Massive Disk Galaxies Shape Their Morphology?

In this work, we studied the mass assembly history of about 100 massive disk galaxies in GOODS-N at redshift 0.1 < z < 1. In particular, we have applied a novel technique of spectrophotometric decomposition to separate the light of the central bulge from that of its disk and study their intrinsic stellar population properties. This was achieved by analyzing a dataset from the Survey for High-z Absorption Red and Dead Sources (SHARDS; PI: P. Pérez-González), a state-of-the-art imaging survey that provides multifilter photometry in 25 bands with spectral resolution R=50. This analysis reveals that bulges form in two waves and two modes (see also Costantin et al. 2021). On the other hand, the disk component forms at z ~ 1 for both first and second-wave bulges.

The cartoon summarizes the morphological evolution of our galaxies. First-wave bulges (upper panel) formed at redshift z>3 and assembled their mass fast (timescales around 200 Myr) in an extreme event of gas compaction. After that, they stopped forming stars and evolved unperturbed for as long as 5 Gyr. For the second wave of bulges (lower panel), assembling at redshift z<3, a slower mode of formation started to become relevant. At redshift z ~ 1, both first and second-wave bulges acquire an extended stellar component, marking the beginning of the disk epoch.

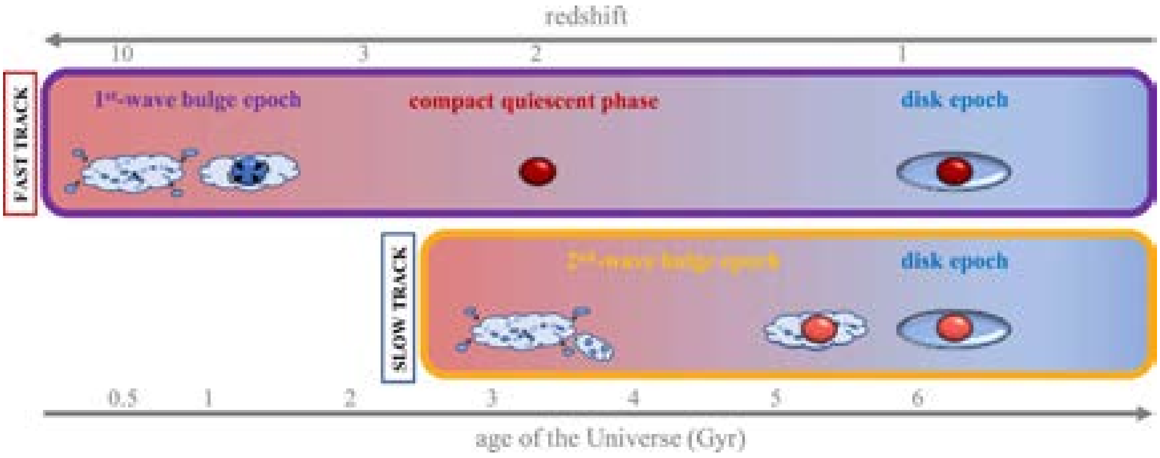


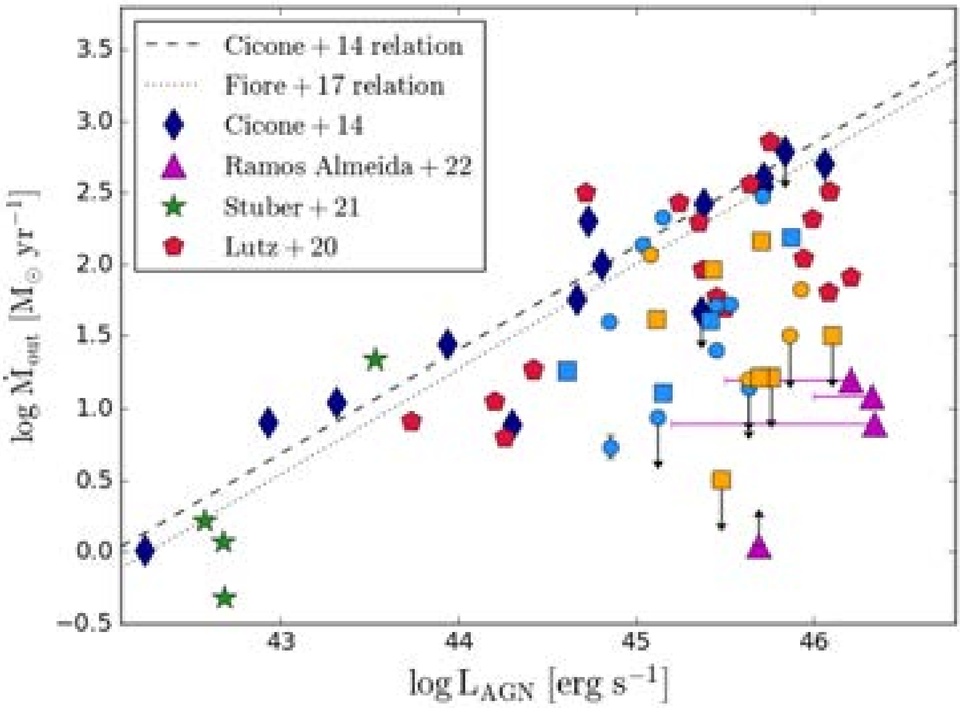
Illustration of the proposed scenario for the formation and morphological evolution of massive disk galaxies at redshift 0.14 < z ≤ 1. Extracted from Costantin et al. (2022).

RH6: Physics of ULIRGs with MUSE and ALMA: The PUMA project. IV. No tight relation between cold molecular outflow rates and AGN luminosities

Local ultra-luminous infrared galaxies (ULIRGs) host the most intense starbursts in the local Universe and many of them host bright active galactic nuclei (AGN) as well. For this reason, they are the ideal places to study AGN and starburst driven outflows, and their feedback effects.

In this work, we study molecular outflows in a sample of 25 nearby (z < 0.17)ULIRG systems as part of the "Physics of ULIRGs with MUSE and ALMA" (PUMA) survey, using 400 pc resolution ALMA CO(2–1) observations. In 77% of the 26 nuclei with infrared luminosity LIR > 1011.8 Lsun, we identified molecular outflows with an average vout = 490 km/s, outflow masses 1-35 x 107 Msun, mass outflow rates 6-300 Msun/yr, and mass-loading factors σ = Mout/SFR = 0.1-1. The outflow detection rate is higher in nuclei dominated by starbursts (SBs, 93%) than in active galactic nuclei (AGN, 55%). Outflows perpendicular to the kinematic major axis are mainly found in interacting star-bursts.

We find a correlation between the outflow velocity and the star-formation rate (SFR), as traced by the infrared luminosity, which is consistent with what was found for the atomic ionised and neutral phases. Using this correlation and the relation between Mout/Rout and vout, we conclude that these outflows are more consistent with the momentum-driven than the energy-driven scenario. We also find that our sample does not follow the relation between mass-outflow rate and AGN luminosity reported in previous works, which means that the AGN luminosity is not the only factor influencing the power of the outflows.



Molecular mass outflow rate versus AGN luminosity for our sample of ULIRGs (orange (AGN) and lightblue (SB) symbols), and other samples from the literature. The dashed and dotted lines show the relations presented by Cicone et al. (2014) and by Fiore et al. (2017), respectively.

Formation and evolution of stars, brown dwarfs and planets

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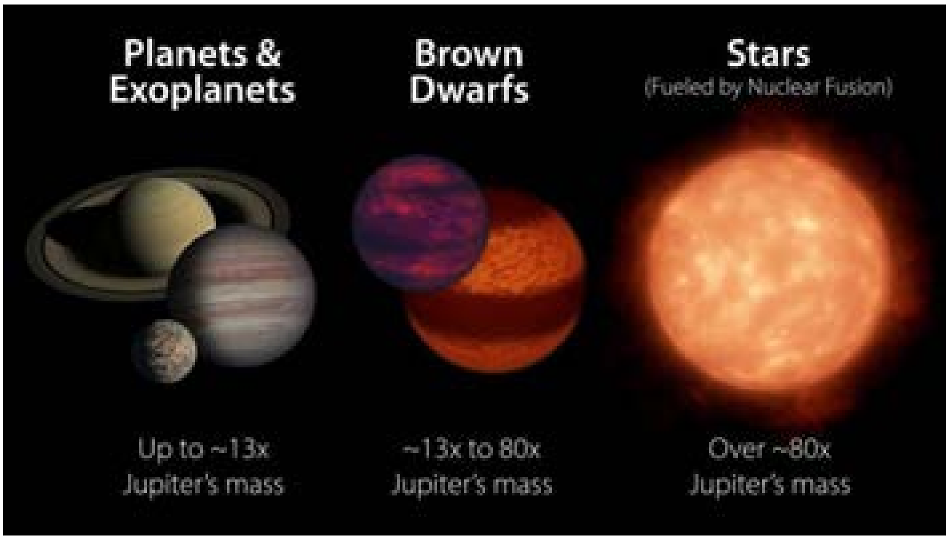
Summary

This group contributes to objectives O2, O3 and O4 of the Centre Strategic Plan by addressing the general questions of how stars, brown dwarfs and exoplanets form and evolve, from the first stages -molecular clouds in the case of stars and brown dwarfs, protoplanetary disks, in the case of planets- to more evolved ones; minor bodies around stars other than the Sun -trojans, and comets- are also among the interests of the group. Observations in all ranges of the electromagnetic spectrum, both from ground-based and space-borne facilities are used, and strong efforts of modelling are also carried out.

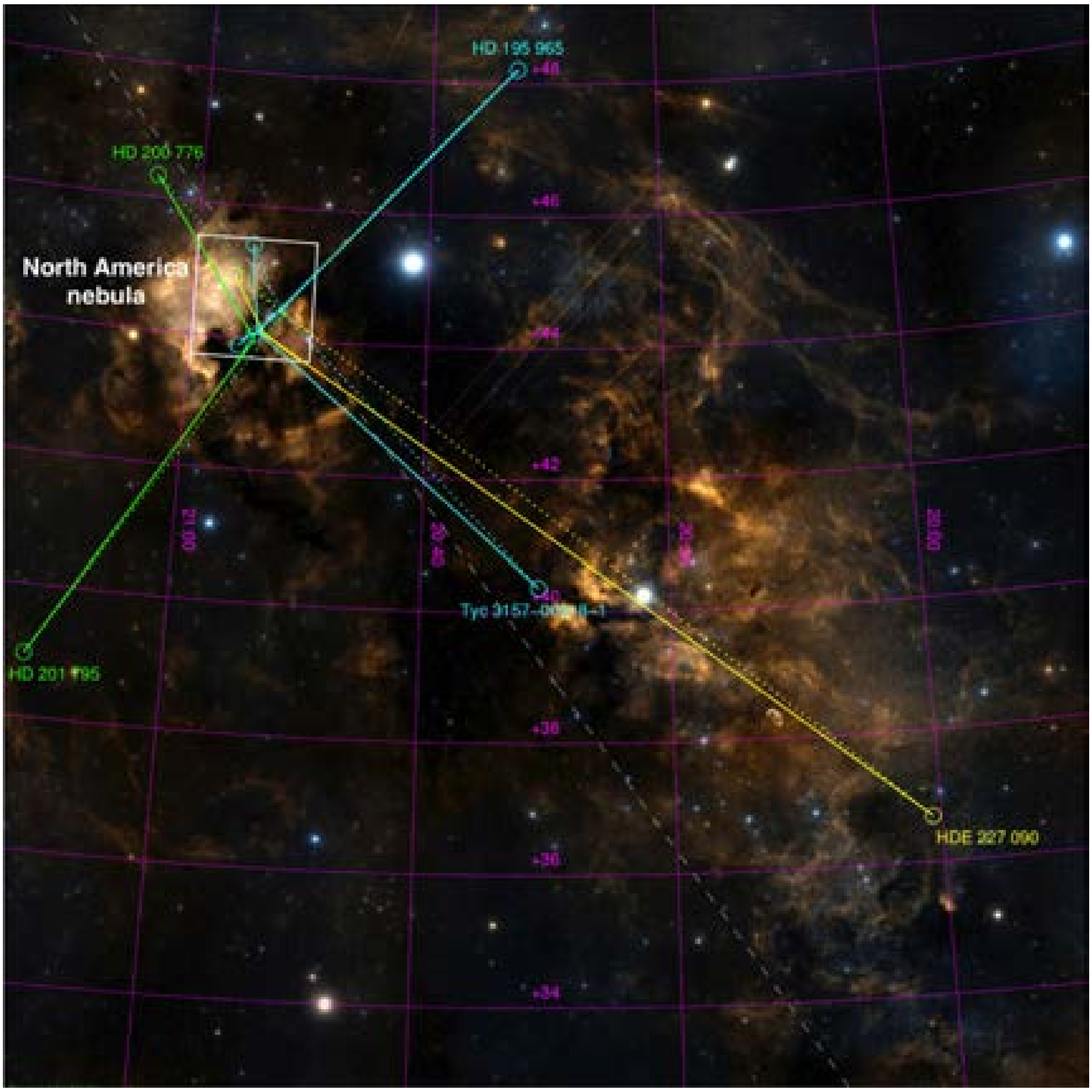


Planets and exoplanets, brown dwarfs and stars in term of mass (Credits: NASA/JPL-Caltech)

Research Highlights 2022

RH1: The discovery of an orphan stellar cluster

We have discovered three stellar ejection events in the Bermuda cluster in the North America nebula that took place 1.9, 1.6, and 1.5 Ma ago. As a result, a large fraction of the mass and most of the massive stars of the cluster has been lost and the system has become unbound. This is the first time the creation of such an orphan cluster has been observed. If this type of event is common, the number of runaway black holes and neutron stars in the Milky Way could be significantly higher than previously thought.

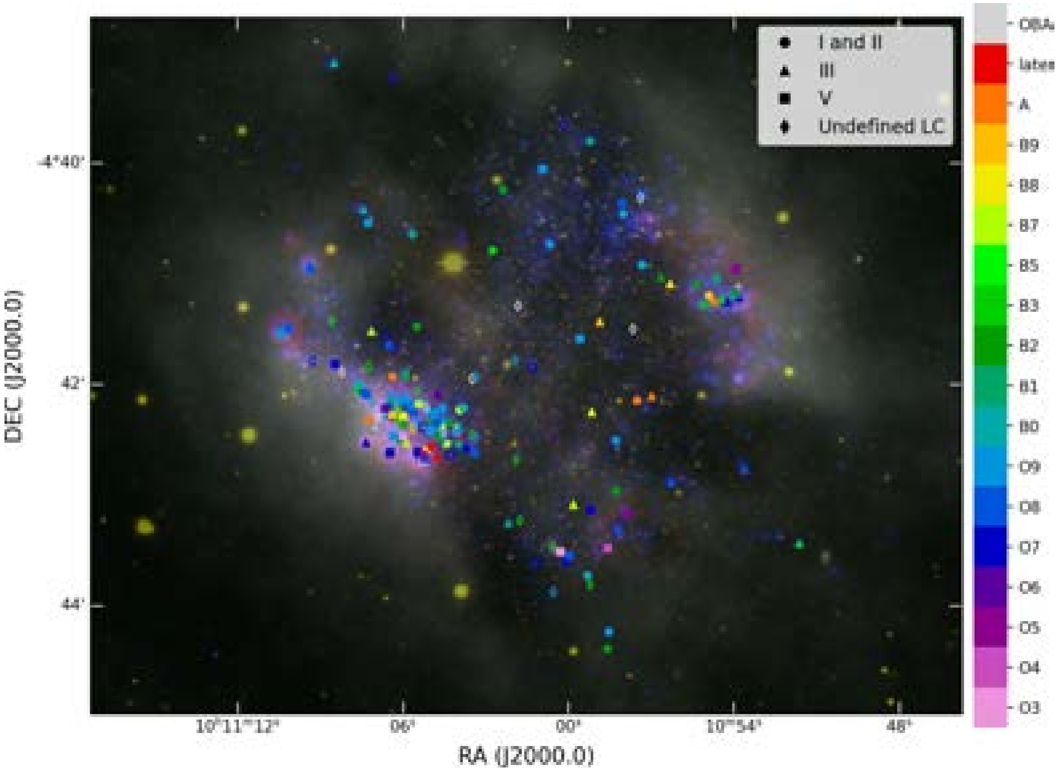


DSS2 image with the three ejection events, colour-coded in cyan (Bajamar), yellow (Toronto), and green (HD 201 795). Colored solid lines show a representative trajectory for each system in the Sun's LSR and colored short-dashed lines the equivalent after subtracting the motion of the Bermuda cluster.

RH2: The first catalog of very metal-poor massive stars, made in CAB

Local Group (LG) very metal-poor massive stars are so far the best proxy for the First Stars of the Universe and are fundamental to modelling the evolution of early galaxies. These stars may be following new evolutionary pathways restricted to very low metallicities. However, given the relatively great distance to the nearest very metal-poor galaxies, no comprehensive spectroscopic studies have been carried out at metallicities lower than the Small Magellanic Cloud (SMC, $Z = 1/5\ Z_\odot$) until now.

CAB researchers have published the first, comprehensive spectroscopic collection of $1/10\ Z_\odot$ massive stars, with more than 150 OB stars in the galaxy Sextans A. Assembled after five observing campaigns at the 10.4-m Gran Telescopio Canarias, this is the largest catalogue ever produced at sub-SMC metallicities. This sample constitutes a fundamental first step to unveiling the evolutionary pathways and fates of very metal-poor massive stars, analyzing the dependence of radiation-driven winds with metallicity, and studying binary systems in an environment analogue to the early Universe.



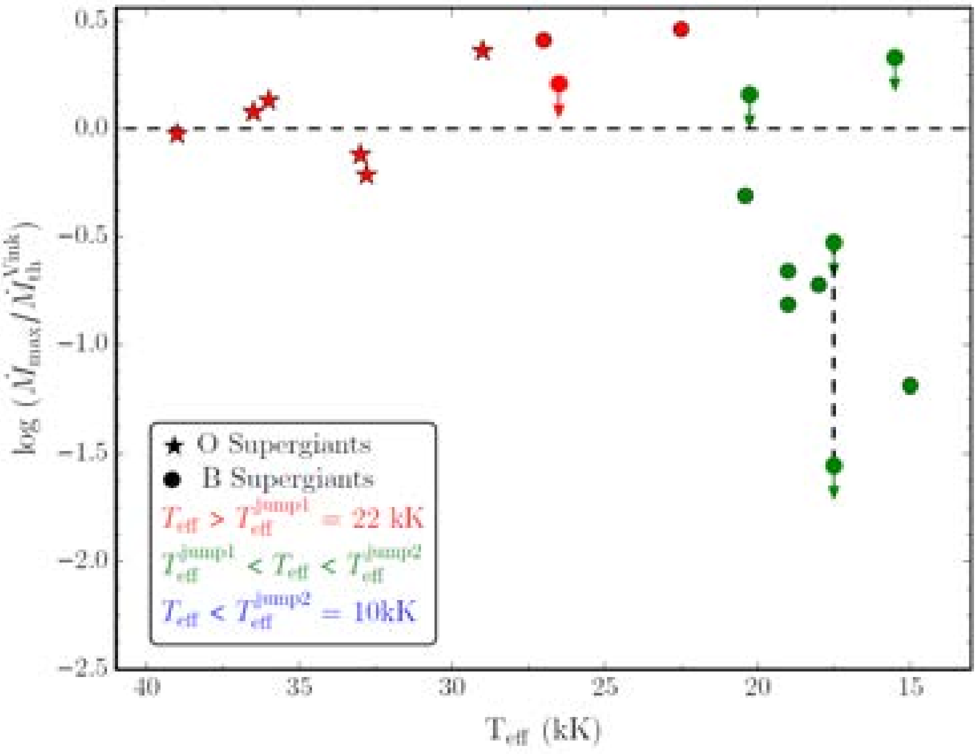
Sextans A RGB composite image made with Hα– (red) and V–bands (green) from Massey et al. (2007), and GALEX FUV (blue). The LITTLE THINGS neutral hydrogen map (Hunter et al. 2012) is overlaid in white. We show the catalogue stars of Lorenzo et al. 2022 colour-coded according to their spectral type and with different symbols based on their luminosity class.

RH3: Clumping in the intermediate and outer wind regions of OB stars

CAB researchers have led the first multi-wavelength study of the stratification of the density-inhomogeneities (clumping) in the intermediate regions of the wind of OB-stars.

The presence of clumping in the winds of OB stars is widely established since the last decade. Studies with the most modern codes indicate that the mass loss rates of hot massive stars need to be revised downwards when this parameter is taken into account. If confirmed, this would imply a severe revision of the models of evolution of massive stars, and how these stars end their life as supernova explosions.

Our team secured far-infrared observations by ESA's Herschel observatory for a sample of 25 OB stars in the Milky Way. The panchromatic analysis, that also included archival observations from optical to radio regime, enabled the first robust study of clumping and its stratification in the wind. We set reliable upper limits for the mass-loss rate of OB stars that confirm that this parameter is overestimated by the analyses that do not consider clumping. Our work provides the first clumping study for the largest sample of B-supergiants ever. For these objects, mass loss rates need a major downward revision of up to two orders of magnitude.

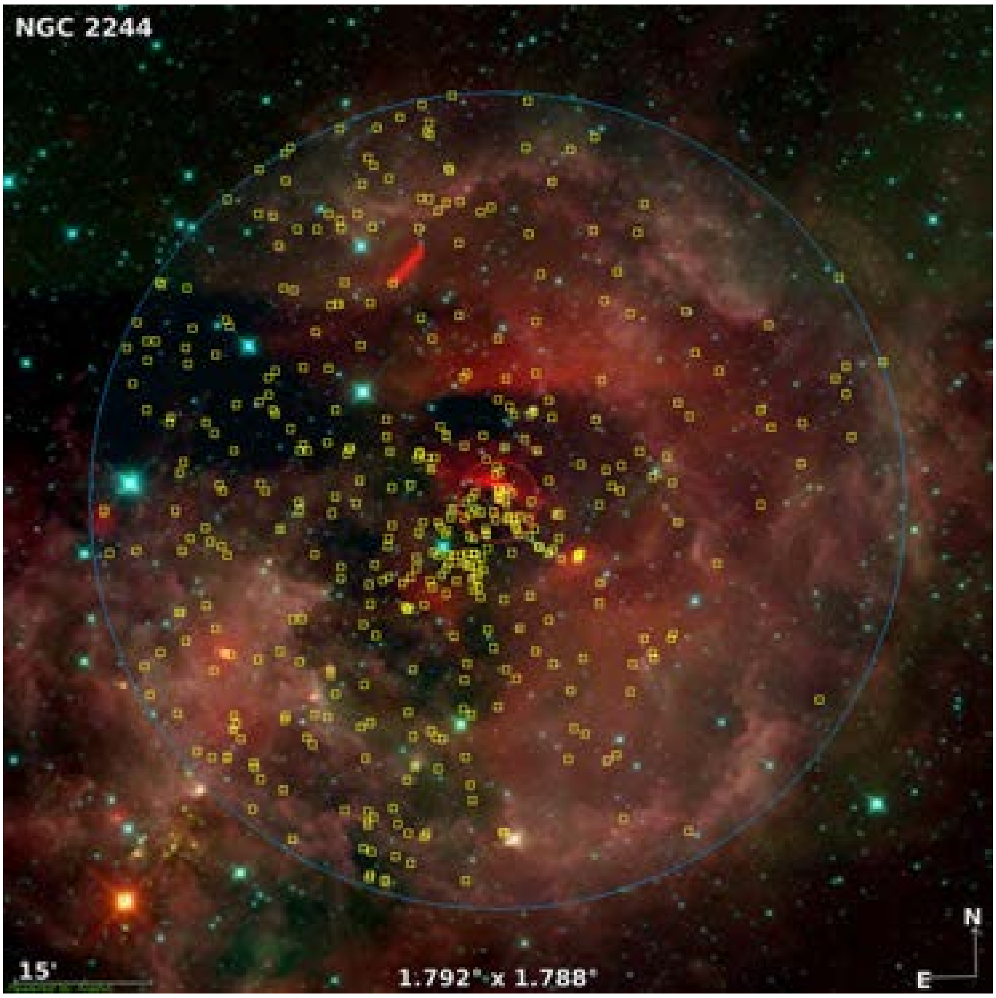


Comparison of the mass-loss rates expected from theoretical prescriptions (Mth, from Vink et al. 2000, 2001) and the mass loss rates derived in Rubio-Díez et al. 2022 (Mmax), as a function of effective temperature. Different colours mark different temperature regimes according to the ionization equilibrium of Iron, which is the element that mainly drives radiation driven winds at this metallicity. Arrows represent upper limits.

RH4: Characterizing the huge “*nurseries*” where stars and planets form

Stars at birth are found grouped together in clusters, which are authentic stellar “nurseries”. In turn, young stars are initially surrounded by gas and dust “protoplanetary” disks , the “cradles” of the forming planets. Previous analyses of stellar clusters were limited to the study of stars located in the central zones, at distances of less than about 10 light-years from the center of each cluster. Such a limitation was largely due to the relatively small field of view of the available telescopes.

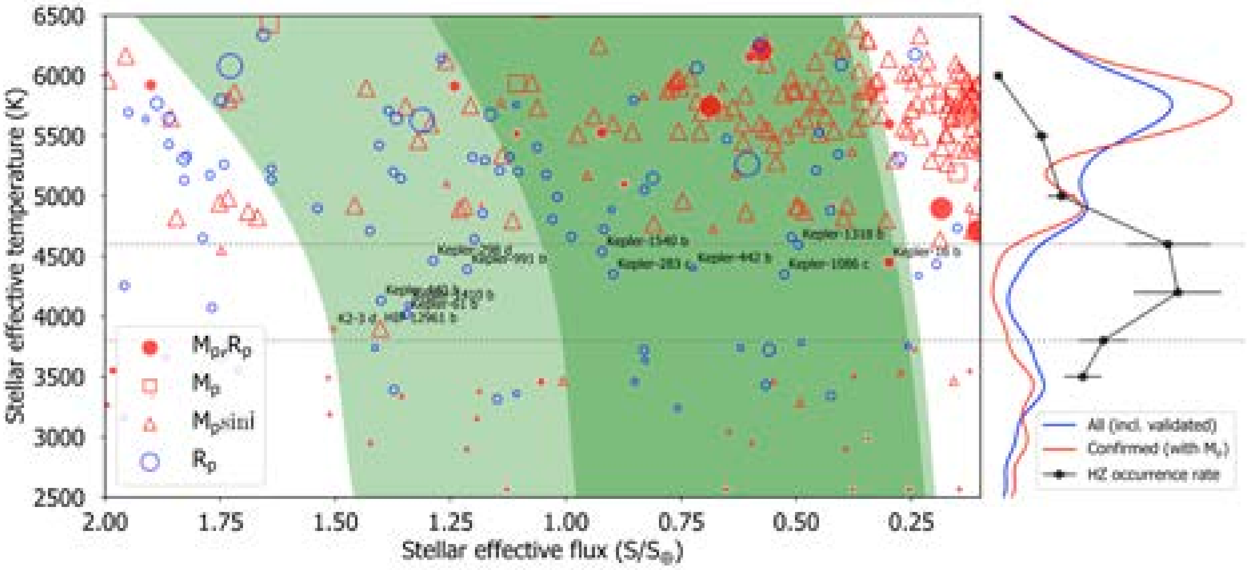
Led by I. Mendigutía and E. Solano, a team including two CAB departments, national and international researchers, has studied several young stellar clusters covering regions with sizes an order of magnitude larger than those previously considered. This has been possible thanks to new data from the Gaia space telescope and the use of Clusterix, an analysis tool developed by the Spanish Virtual Observatory (VO). Mendigutíaet al. (2022) show that young stars and their protoplanetary disks are also found in the outer zones, revealing that the true size of the clusters where stars and planets form is much larger than expected. The huge amount of new data is stored in a VO-based archive, available for future studies.



Example of a young stellar cluster (NGC 2244). The red circle in the center shows the rough region covered by previous studies, and the blue circle the new region surveyed in this work. Stars belonging to the cluster are indicated in yellow.

RH5: Triggering the search for habitable worlds around late K-type stars (KOBE)

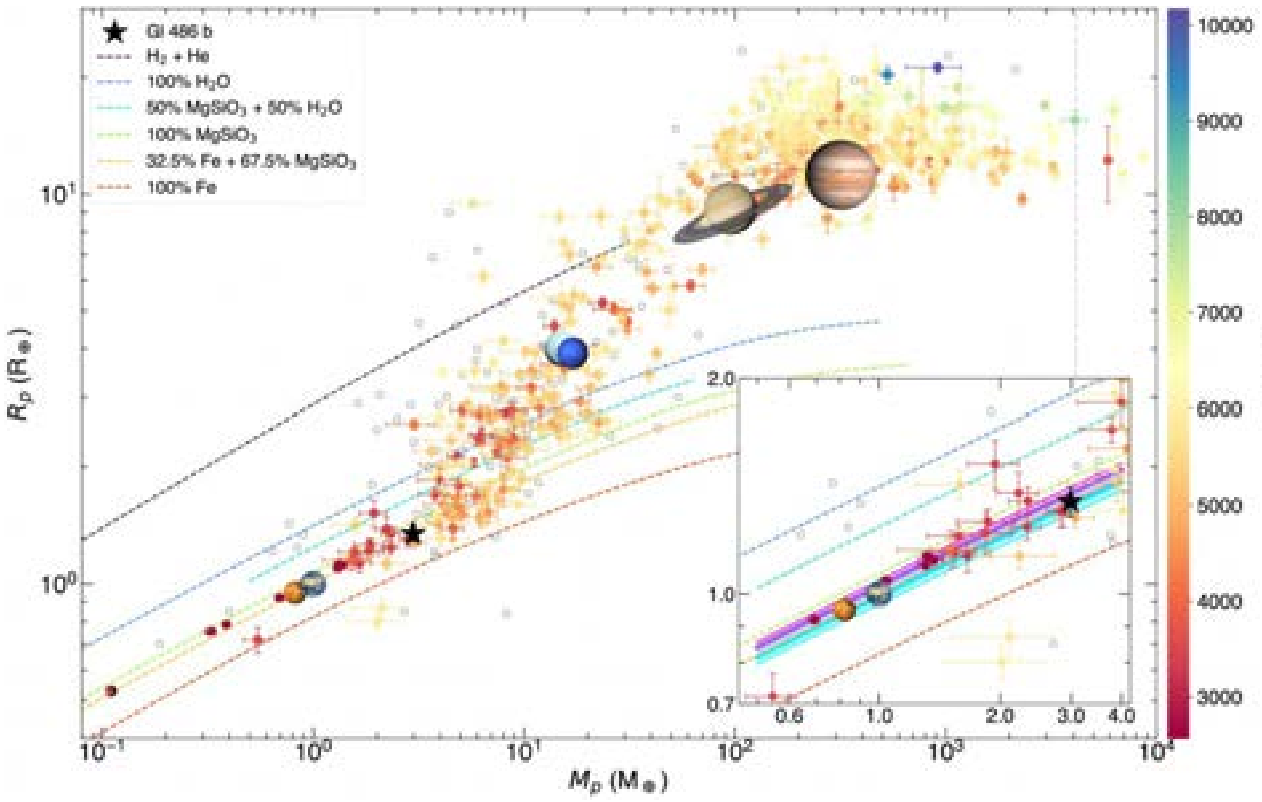
In Lillo-Box et al. (2022) we presented the motivation, goals and target selection of the KOBE experiment, a legacy survey running at Calar Alto Observatory with the CARMENES instrument to fill the gap of habitable-zone planets in late K-type stars, the sweet spot for planet detectability and habitability. Despite the detectability advantages against hotter stars (with the habitable zone being further away for G-type) and the astrobiological benefits against cooler stars (with the M-dwarfs being more active and their habitable-zone planets orbiting too close around them), the K-dwarf domain has remained unchartered so far. KOBE is tackling this historical void through a radial velocity monitoring of 50 late-type K-dwarfs that will last at least four years. This experiment is lead by CAB and has strong participation from PhD students Olga Balsalobre-Ruza and Amadeo Castro-González. Indeed, one of the first products of the survey is the release of the KOBEsim algorithm (Balsalobre-Ruza et al. 2023), a semi-automated strategy design for radial velocity exoplanet searches.



Detected extrasolar planets within the habitable zone for different stellar types. The symbol code is shown in the legend and their size scales with planet radius for circle symbols and planet mass for squares and triangle symbols. Green regions show the optimistic and conservative habitable zones from the Kopparapu et al. (2013) climate models.

RH6: The best known terrestrial planet outside the Solar System

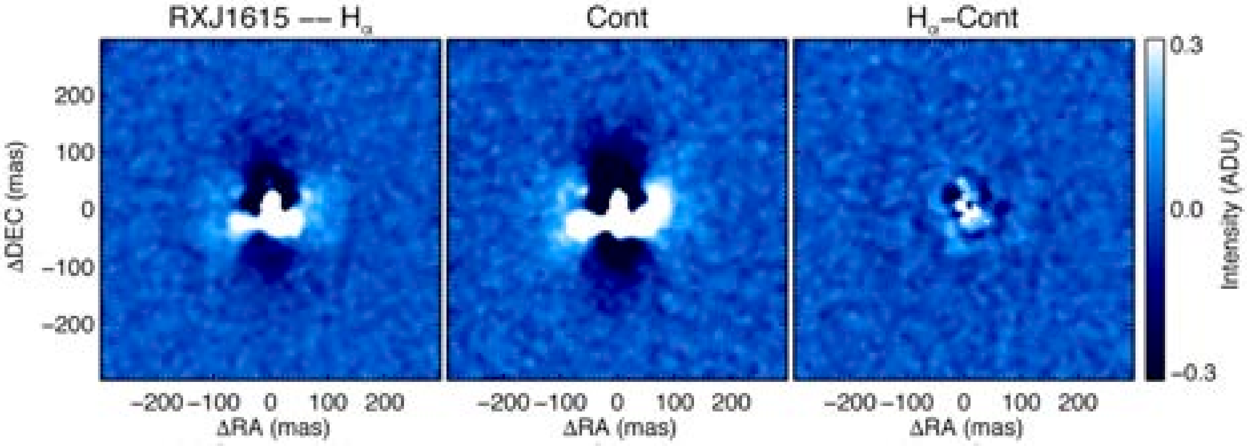
Discovered with CARMENES and the TESS satellite a year earlier by a Spanish-German team with US collaborators, GJ 486 b is, with a radius only 30% larger than that of the Earth, the best-characterised telluric planet outside the Solar System. In this new paper, led by CAB researchers, a very varied plethora of data from the planetary system was presented: from new transits with the CHEOPS satellite to an interferometric measurement of the star's radius with CHARA, from ultraviolet emission with Hubble to the determination of the star's elemental abundances with CARMENES. This allowed modelling meshes of both the internal structure of the planet (size and composition of the mantle and core) and its hypothetical atmosphere (which seems to have been detected recently with the James Webb Space Telescope). At the time of writing, the International Astronomical Union has just announced that, because of their scientific importance, the star system GJ 486 and its planet GJ 486 b have been given the proper names Gar and Su, respectively



Mass-radius diagram of all known transiting exoplanets in 2022 with mass determination (from radial velocity or transit time variations) compared to planets in the Solar System. The planet GJ 486 b is marked with a black star.

RH7: Searching for accreting protoplanets through high contrast imaging observations

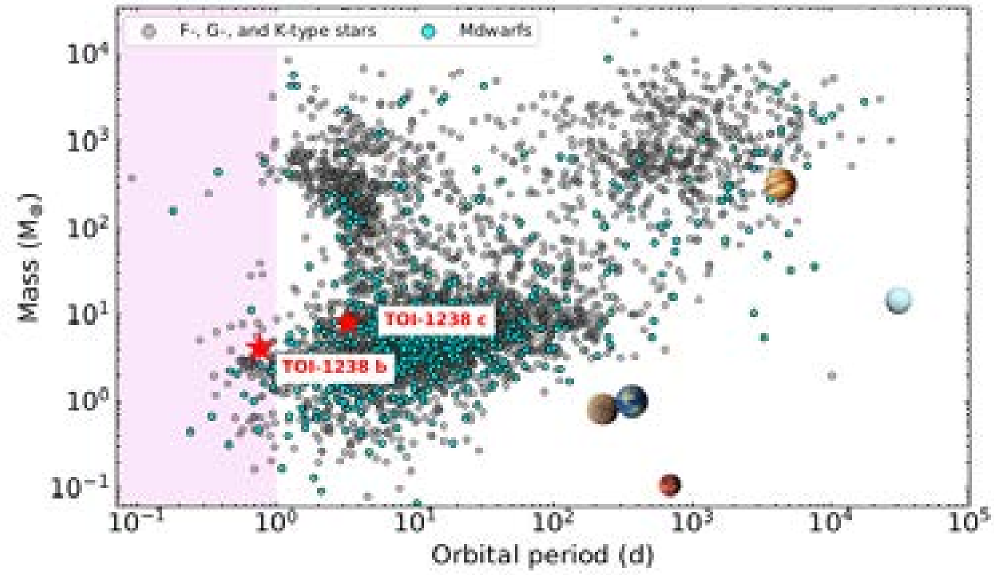
Planet formation theories predict that young planets accrete material from their surroundings, so that they are expected to be strong emitters in accretion tracers like e.g., the Hα emission line. We have looked for accreting protoplanets inside the disks of five young stars through high contrast imaging observations in the Hα and the adjacent continuum filters (see the figure for one example). As in other Hα surveys of young stars, we have not reported any protoplanet detection. We have explained the lack of accreting protoplanets invoking three different scenarios: either protoplanets show episodic accretion and we have observed them in a quiescent phase, or protoplanets do not accrete as strongly as predicted by models. Finally, it is also possible that the extinction from the circumstellar and circumplanetary disks is too high to detect protoplanets at optical wavelengths. Future observations will help us to distinguish between these different scenarios.



High contrast imaging observations of the young star RXJ1615 (from Huélamo et al. 2022). The left and middle panels show the Angular Differential Imaging (ADI) reduced images in the Ha and continuum filters, respectively. The right panel shows the difference of the two filters (Angular Spectral Differential Imaging, ASDI).

RH8: A multiplanetary system orbiting the early M-dwarf TOI-1238

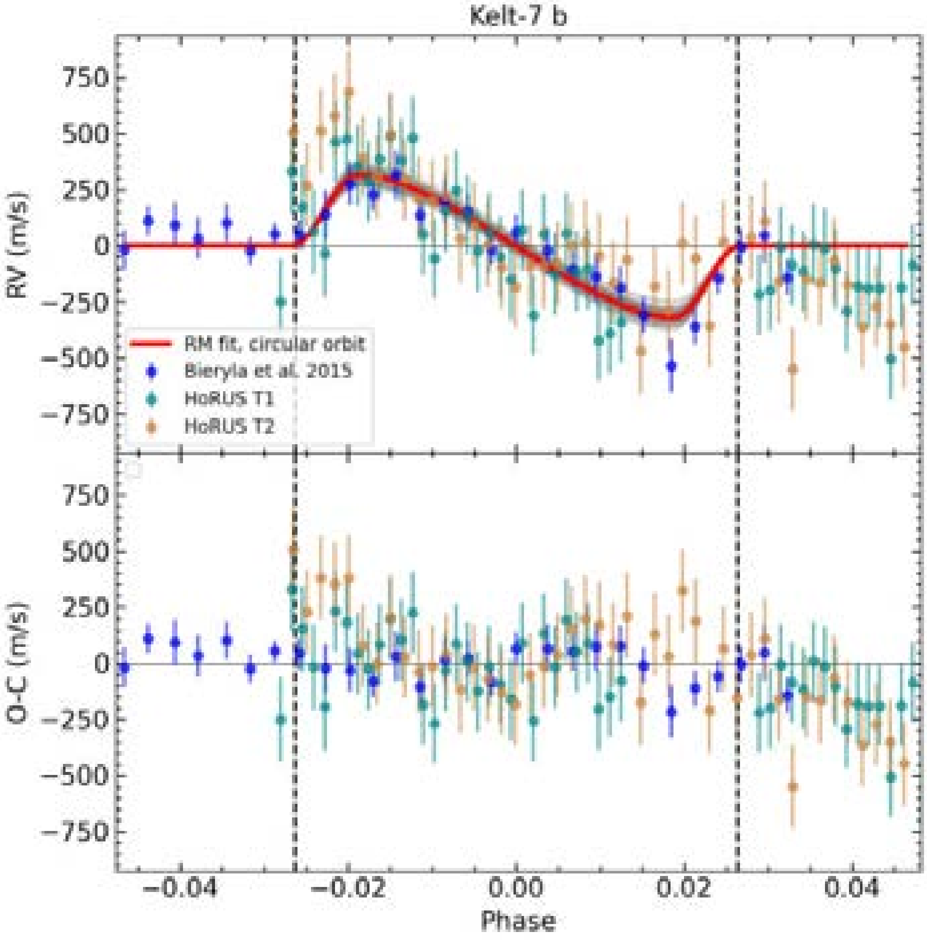
We reported in this work the discovery of two new exoplanets orbiting an M0 dwarf, using data from CARMENES (radial velocity) and TESS (photometry). The planets are super-Earths (1.2 and 2.1 Earth radii, 3.8 and 8.3 Earth masses, respectively). Planet b is one of the densest planets ever discovered, likely due to strong erosion by irradiation in the past. There is a likely outer third planet in the system. The two inner planets are placed next to the radius valley, a gap in the mass-period diagram (see Figure) not yet satisfactory explained.



Mass versus orbital period diagram for all discovered planets around late type stars from the NASA Exoplanet Archive. The red symbols represent the two planets discovered by us. The shaded area on the left corresponds to the location of ultra-short-period planets (USPs).

RH9: HORuS transmission spectroscopy and revised planetary parameters of KELT-7 b

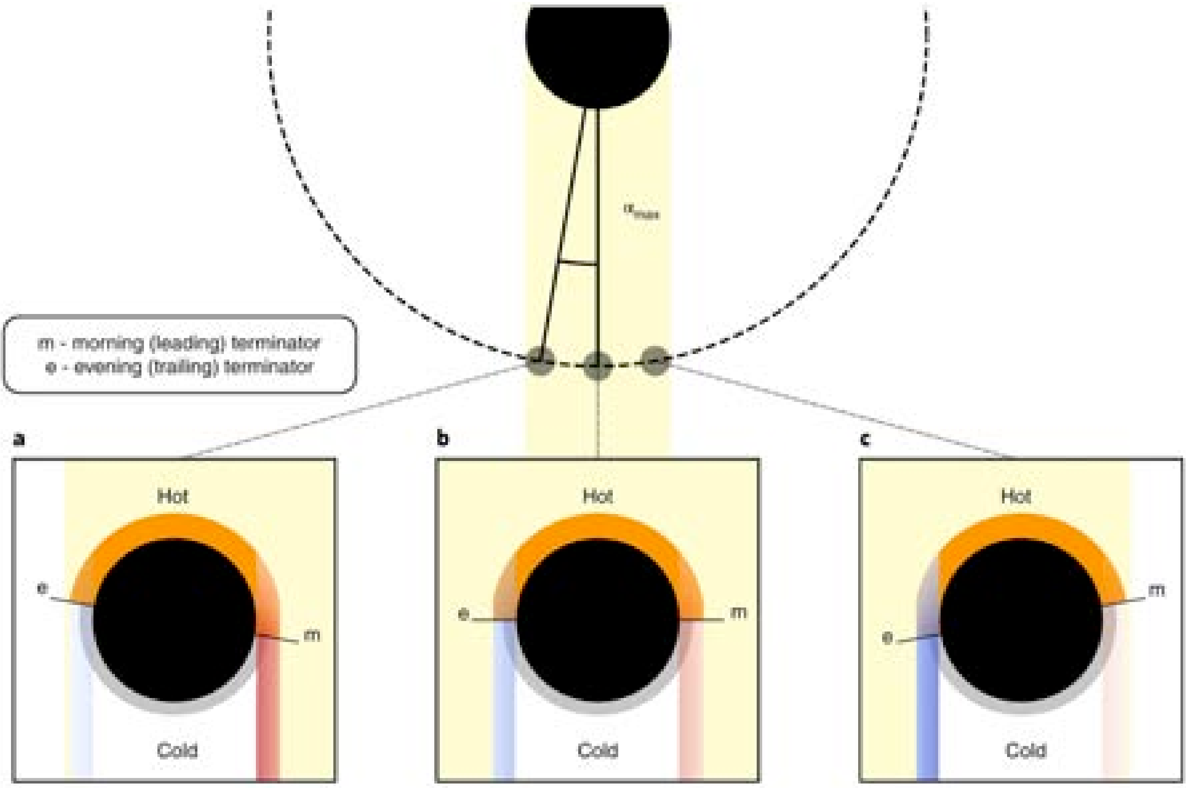
We report in this paper the results from the analysis of high-resolution spectroscopy of two planetary transits of KELT-7 b, a hot Jupiter (M=1.2 MJ, Teq=2028 K) using the ground-based HORuS spectrograph (GTC). We refine the orbital parameters formerly published, and we research for the presence of several atmospheric features, setting upper limits to them due to the stellar activity of the parent star.



Rossiter-MacLaughlin effect of KELT-7 b as a function of the planetary orbital phase (top panel). The best fit and its associated uncertainty are shown with a red line and a greyish area, respectively. The bottom panel shows the RV residuals with an rms of the same size as the individual error bars.

RH10: Titanium oxide and chemical inhomogeneity in the atmosphere of the exoplanet WASP-189 b

The temperature of an atmosphere decreases with increasing altitude, unless a shortwave absorber that causes a temperature inversion exists[1]. Ozone plays this role in the Earth's atmosphere. In the atmospheres of highly irradiated exoplanets, the shortwave absorbers are predicted to be titanium oxide (TiO) and vanadium oxide (VO)[2]. Detections of TiO and VO have been claimed using both low-[3-6] and high-[7] spectral-resolution observations, but subsequent observations have failed to confirm these claims[8-10] or overturned them[11-13]. Here we report the unambiguous detection of TiO in the ultra-hot Jupiter WASP-189 b[14] using high-resolution transmission spectroscopy. This detection is based on applying the cross-correlation technique[15] to many spectral lines of TiO from 460 to 690 nm. Moreover, we report detections of metals, including neutral and singly ionized iron and titanium, as well as chromium, magnesium, vanadium and manganese (Fe, Fe^+, Ti, Ti^+, Cr, Mg, V, Mn). The line positions of the detected species differ, which we interpret as a consequence of spatial gradients in their chemical abundances, such that they exist in different regions or dynamical regimes. This is direct observational evidence for the three-dimensional thermochemical stratification of an exoplanet atmosphere derived from high-resolution ground-based spectroscopy.



Due to the tidal locking of the planet, the atmosphere is subject to a temperature gradient that alters the atmospheric chemistry as a function of longitude. The schematic shows the contributions to the observed absorption signal originating from the two terminators in the absence of dynamical effects other than planetary rotation (no diurnal or nocturnal winds or superrotational flows).

Interstellar and Circumstellar Medium

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Summary

The chemistry in our Galaxy is often determined by UV fields from nearby stars, cosmic rays, shocks, turbulence, and other phenomena. This group aims to obtain a detailed description of the physical and chemical properties of interstellar clouds, circumstellar environments around evolved stars, and protoplanetary disks, to understand the interplay between gas and dust, and to determine the limits of chemical complexity before life emerged on Earth. In particular, reactions leading to complex organic molecules (COMs) are of interest for Astrobiology (O1 and O2). This work is complemented by the development of instrumentation for airborne telescopes (O6).

Astrochemistry is studied following a four-fold approach: i) Observational (detection/mapping of simple molecules and COMs using single-dish telescopes, e.g. IRAM-30m, Yebes, APEX and Robledo de Chavela, and interferometers, e.g. ALMA, ii) Theoretical (development of molecular excitation, radiative transfer, chemical models, and MADCUBA code for data analysis), iii) Instrumentation (contribution to instrumentation on board future missions, development of KID detectors that operate in mm to far-infrared, and iv) Experimental (laboratory simulations of ice-covered dust processes leading to COMs in cold interstellar/circumstellar regions using the Interstellar Astrochemistry Chamber (ISAC) and radiation facilities, e.g. NSRRC synchrotron in Taiwan).

COMs were incorporated into comets and other minor bodies of the solar system. Impact of these objects on Earth delivered water and molecules of high astrobiological significance.

Research Highlights 2022

RH1: Interstellar ice physics and chemistry highlights: Density and infrared band strength of interstellar carbon monoxide (CO) ice analogues.

The motivation to study experimentally CO ice under mimicked interstellar conditions is supported by the large CO gas abundances and ubiquitous presence of CO in icy grain mantles. Upon irradiation in its pure ice form, this highly stable species presents a limited ion and photon-induced chemistry, and an efficient non-thermal desorption. Using infrared spectroscopy, single laser interference (implemented in our system for the first time), and quadrupole mass spectrometry during CO ice deposition, the CO ice density was estimated as a function of deposition temperature. The proposed new methodology serves to obtain the density of other ice components at various deposition temperatures. The apparent tendency of the CO ice density to decrease at deposition temperatures below 14 K is in line with our recently published colorimetric measurements. We provide the revisited value of the infrared band strength needed for calculation of the CO ice column density in infrared observations, 8.7 × 10^{-18} cm molecule^{-1} at 20 K deposition temperature. This value is lower than the previous estimate of 1.1 × 10^{-18} cm molecule^{-1} and therefore leads to higher values of the CO ice column density in interstellar/circumstellar ice mantles.

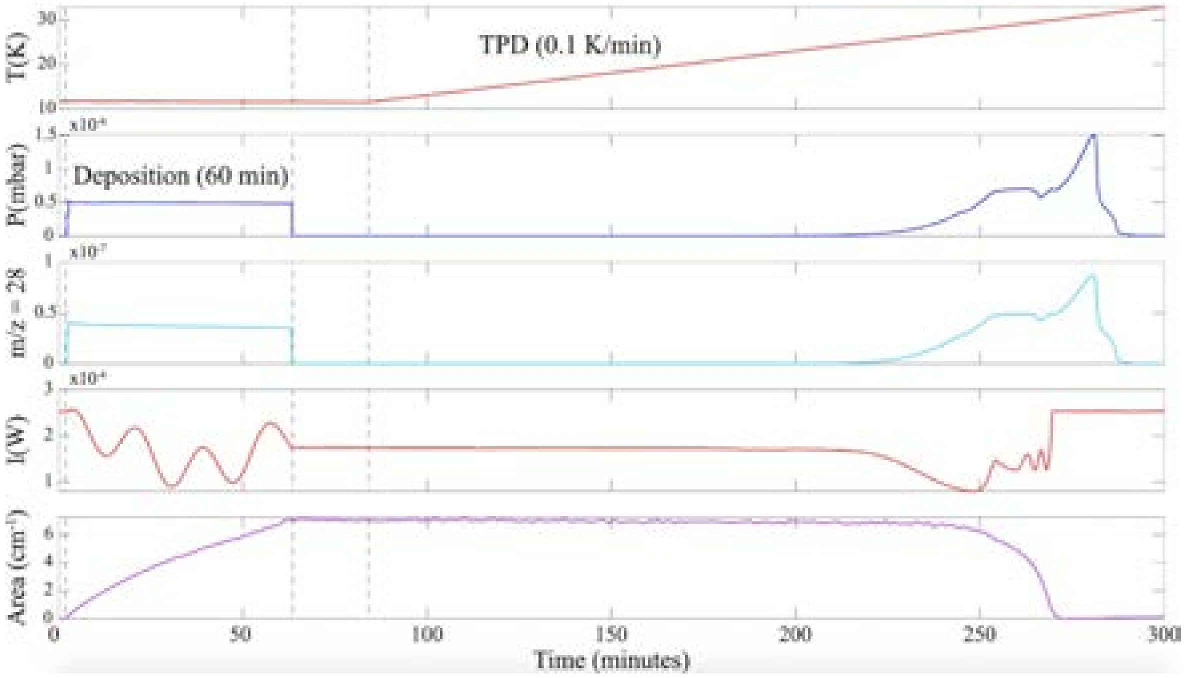
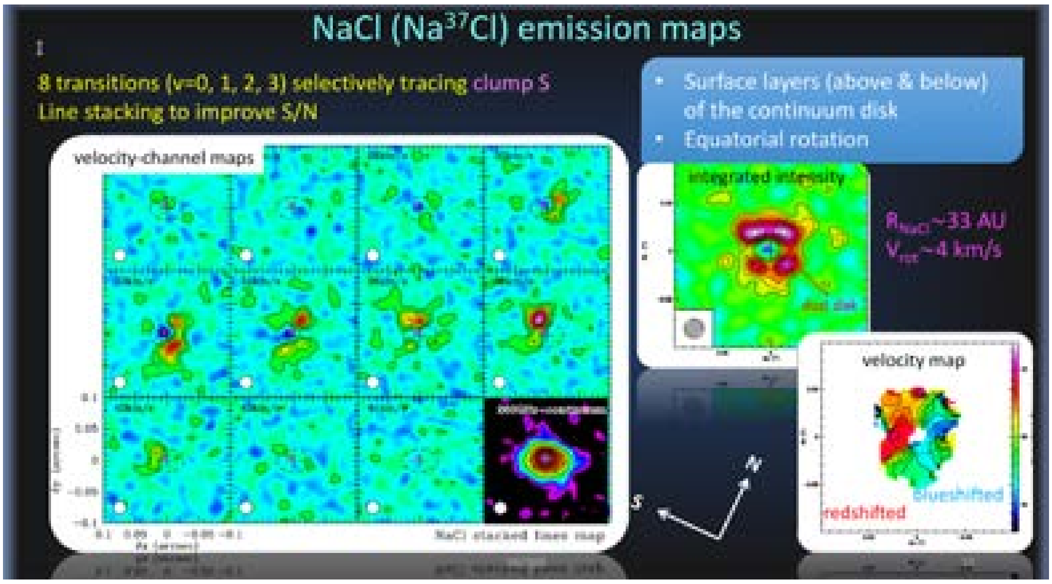


Fig.: Main parameters controlled during experiments as a function of time. From top to bottom: temperature, pressure in the main chamber, mass spectrometer data, laser intensity, integrated infrared absorbance from the CO ice band centred at 2138 cm–1 that is proportional to its column density (from González-Díaz et al. 2022).

RH2: Dissecting the central regions of OH231.8+4.2 with ALMA: A Salty rotating disk at the base of a young bipolar outflow

We present groundbreaking observations of the remarkable bipolar nebula OH231.8+4.2 using the ALMA telescope. This object is of great significance in understanding the transition from the asymptotic giant branch (AGB) to the planetary nebula (PN) phase. Our high-resolution maps provide detailed insights into the central regions, unveiling a major discovery: the presence of a rotating circumbinary disk. This disk, exclusively detected through NaCl, KCl, and H_2O emission lines, has a radius of approximately 30 astronomical units (au) and represents the first detection of KCl in an oxygen-rich circumstellar envelope. The disk is located at the bottom of a young bipolar wind, which displays rotational motion features near its base while predominantly exhibiting expansive motion with a consistent radial velocity gradient. Beyond a radius of 350 au, the wind maintains a constant terminal speed. Our continuum maps reveal a dusty disk-like structure perpendicular to the outflow, with NaCl, KCl, and H2O emissions originating from its surface layers. Within the disk, we identify an unresolved point source, likely representing the central Mira-type star QX Pup. The slight offset of the point source from the disk centroid provides valuable information about the orbital separation (~20 au) and period (~55 years) of the central binary system. These findings shed light on the formation and evolution of OH 231.8+4.2, suggesting that the dense rotating equatorial structure arises from wind Roche lobe overflow mass transfer from QX Pup to its main-sequence companion. The low velocity of the AGB wind, the companion's relatively high mass, and the comparable sizes of the dust condensation radius and the Roche lobe radius support this intriguing scenario. Furthermore, the observed kinematic pattern indicates an active acceleration of the companion-perturbed wind from QX Pup as it interacts with low-density polar regions. These discoveries pave the way for a deeper understanding of the AGB to PN transition and of the complex dynamics and structures of bipolar nebulae.



NaCl ($Na^{37}Cl$) emission maps

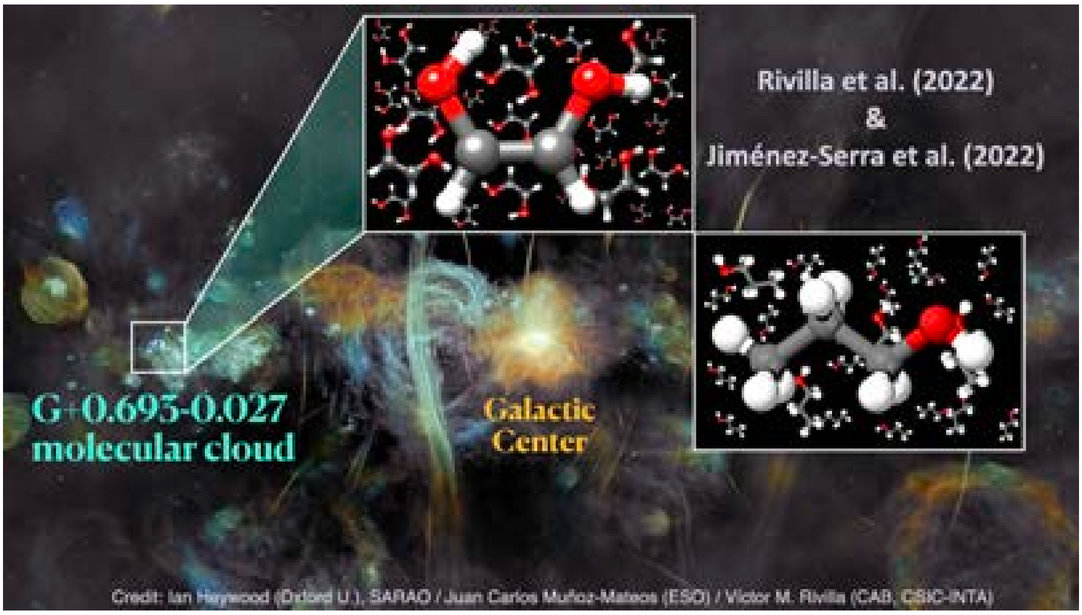
8 transitions (v=0, 1, 2, 3) selectively tracing clump S
Line stacking to improve S/N

- Surface layers (above & below) of the continuum disk
- Equatorial rotation

Fig.: Summary of our NaCl emission ALMA maps unveiling the presence of a rotating disk at the core of OH231.8+4.2. The left panel displays velocity-channel maps and continuum emission, while the right panels exhibit the NaCl integrated intensity map and the velocity map (from Sánchez Contreras et al. 2022).

RH3: Discovery of Z-1,2-ethenediol and n-propanol in the interstellar medium.

In two recent papers, we have reported the detection of two new molecules of prebiotic interest, n-propanol and Z-1,2-ethenediol, in the interstellar medium. While n-propanol represents a precursor of prebiotic lipids, Z-1,2-ethenediol is a key intermediate species in the formation of sugars. These detections have been achieved toward the Giant Molecular Cloud G+0.693-0.027 located in the Galactic Center thanks to a broadband spectroscopic survey carried out with the IRAM 30m and Yebes 40m telescopes. The derived abundances are of a few 10^{-10} with respect to molecular H_2. The relatively high abundances of these prebiotic species indicate that they are likely formed on the surface of dust grains and are released into the gas phase by low-velocity shocks. The detection of these prebiotic molecules, together with many other reported toward the same source by our group, suggests that the precursors of building blocks of life could form in space.



Credit: Ian Heywood (Oxford U.), SARAO / Juan Carlos Muñoz-Mateos (ESO) / Víctor M. Rivilla (CAB, CSIC-INTA)

Fig.: Image of the central region of the Milky Way obtained at 1.28 GHz with the radiointerferometer MeerKAT, adapted from Heywood et al. (2022). The molecules Z-1,2-ethendiol, $(CH_2OH)_2$, and n-propanol, n-$CH_3CH_2CH_2OH$, have been detected for the first time in the interstellar medium towards the molecular cloud G+0.693-0.027, using a deep spectral survey carried out with the Yebes 40m and IRAM 30m telescopes (Rivilla et al. 2022 and Jiménez-Serra et al. 2022, respectively).

RH4: First detection of silicon-bearing molecules in an evolved and highly massive star

η Carina, perhaps the evolved massive star best studied in our Galaxy, is a binary formed by a very massive luminous blue variable (LBV) and another O-type star, in a very eccentric orbit. Its evolution is heavily driven by great eruptions (like those reported in the 19th century), and also by periodic interaction of the two winds during the periastron, every 5.5 years.

We made a spectroscopic survey at an exquisite high angular resolution (33 milli-arcsec) using the ALMA interferometer. The most important finding was the discovery of the silicon-bearing molecules SiO, SiS, and SiN, in the inner wall of the equatorial ring which surrounds the hot stars.

The three molecules are particularly abundant, which seems related to a set of chemical formation and destruction processes linked to the periodic interaction of the two stellar winds. These molecules seem to be formed after shocking the surrounding dust, and soon destroyed by the harsh ultraviolet field from the stars.

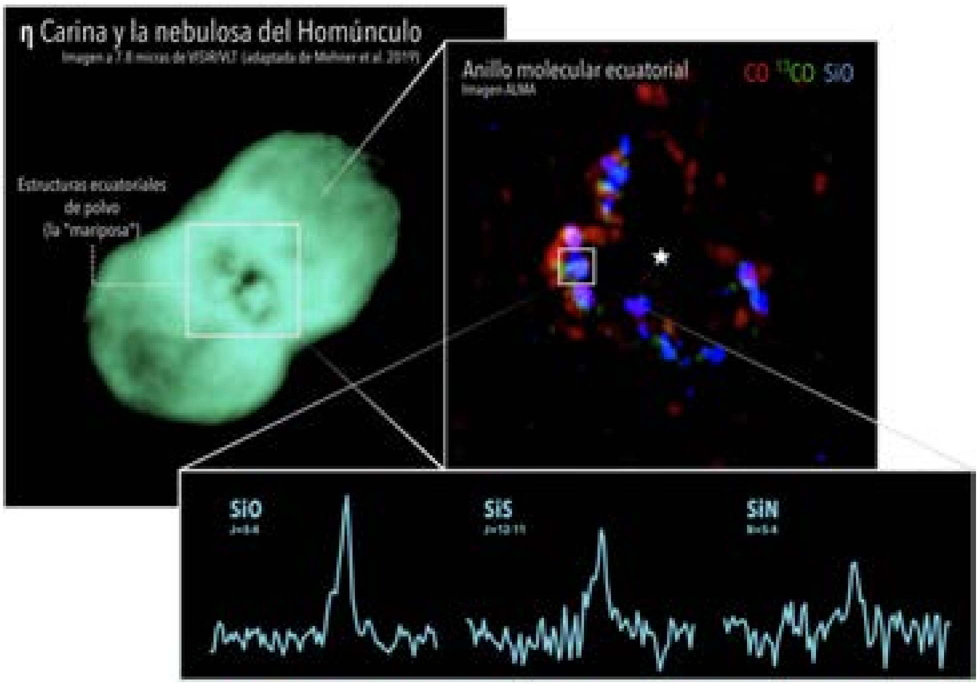


Fig.: Image on top left shows the massive LBV η Carina surrounded by the dusty Homunculus nebula in infrared light at 7.8 microns (source: Mehner et al. 2019, A&A 630, L6). A zoom in the circumstellar "donut", well traced by CO, is depicted as knots in the top right image. SiO clumps, in blue, are located closer to the star when compared to CO. The three molecules detected by us, SiO, SiS and SiN, are displayed in the bottom image.

Virtual Observatory: Scientific exploitation of astronomical archives

Group coordinator: Enrique Solano Márquez

Senior Researcher

Ricardo Rizzo (colaborador externo ISDEFE)

Posdoctorals:

Alba Aller Egea

Miriam Cortés Contreras (left June 30th)

Patricia Cruz Gamba

Francisco Jiménez Esteban

Belén López Martí (left Feb 28th)

M. Cruz Gálvez Ortiz

Technicians:

Almudena García López (Colaborador externo ISDEFE)

Carlos Rodrigo Blanco

Almudena Velasco Trasmonte (Colaborador externo ISDEFE)

Summary

This group contributes to objective O6 of Center Strategic Plan by addressing the question of the development of transdisciplinar mechanisms for data discovery and analysis (including Artificial Intelligence) in the framework of the Virtual Observatory, Big Data and the European Open Science Cloud. The group also plays an important role to fulfill the objectives O1 and O2.

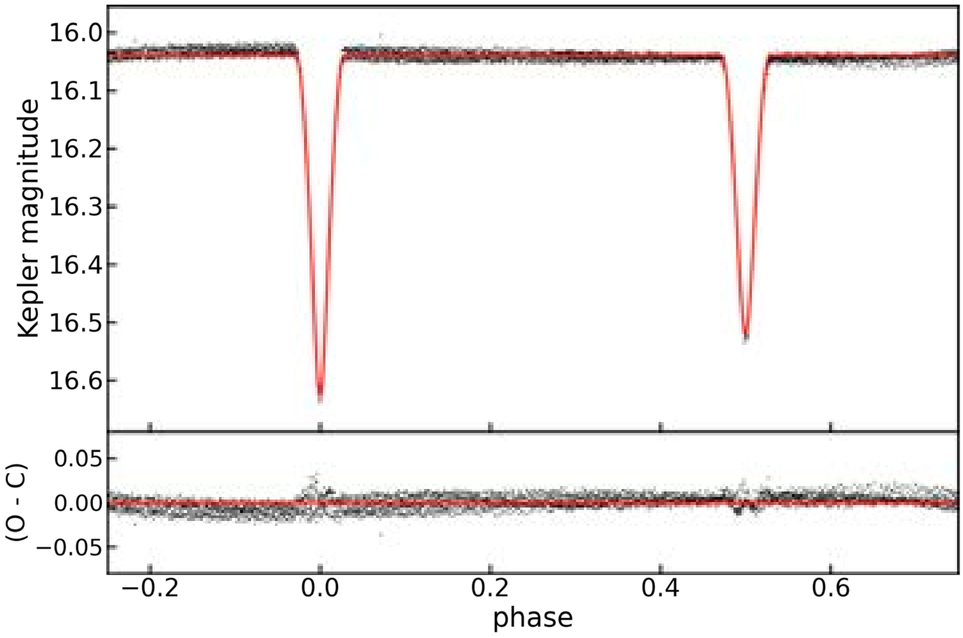
The following research highlights exemplify the most relevant investigations and results in the group.

Research Highlights 2022

RH1: Title: Detached eclipsing binaries from the Kepler field: radii and photometric masses of components in short-period systems

The characterisation of detached eclipsing binary systems with low mass components (where each component of the system is a main-sequence K,M-type star) has become important to verify the role of convection in stellar evolutionary models, which requires model-independent measurements of stellar parameters with great precision. However, spectroscopic characterisation depends on single-target radial velocity observations and only a few tens of well-studied low-mass system have been diagnosed in this way.

In this paper, we characterise eclipsing detached systems with low-mass components observed during the Kepler mission by adopting a purely-photometric method. Based on an extensive multi-colour dataset, we derive effective temperatures and photometric masses of individual components using machine learning (clustering) techniques. We also estimate the stellar radii from additional modelling of the available Kepler light curves. Our measurements confirm the presence of an inflation trend in the mass-radius diagram against theoretical stellar models in the low-mass regime.



Legend: Phase-folded light curve of the eclipsing binary KIC09656543 observed by the Kepler telescope. Black dots are the observed data, in magnitudes. The red solid line shows the best-fitting model.

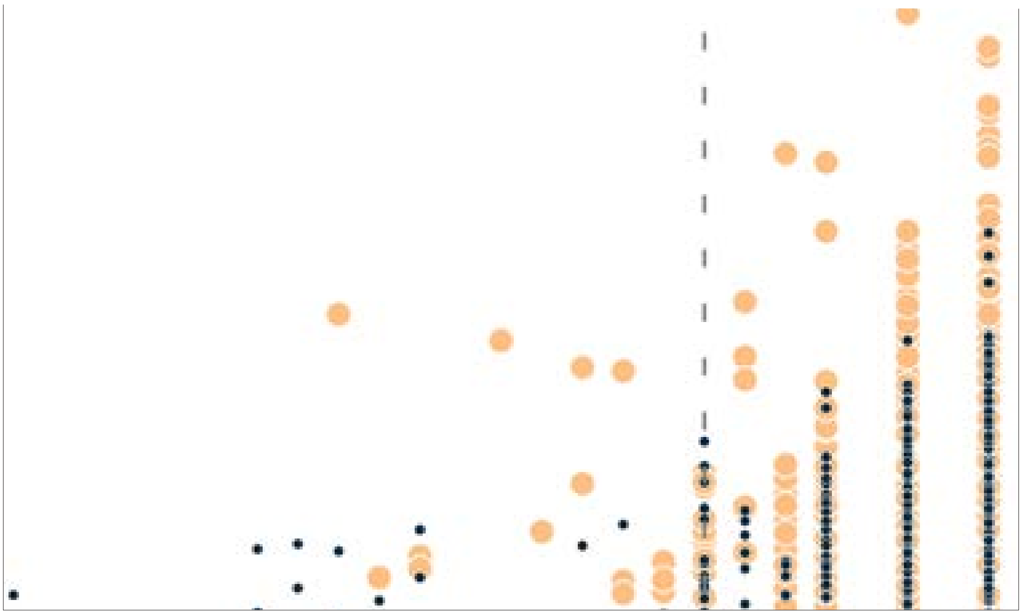
Research Highlights 2022

RH2: Title: Discovery and characterisation of ultracool dwarfs using Virtual Observatory tools II. Second data release and machine learning methodology

Current surveys like J-PLUS, and others to come in the near future, are causing a data avalanche in Astronomy. In this scenario, the Virtual Observatory (VO) makes the difference in what refers to the discovery, access and analysis of scientific data. Moreover, the huge volume of information generated by these surveys goes beyond what traditional processing and analysis methods can offer. To face this situation, machine learning (ML) approaches have gained momentum over the last few years.

We present the search for ultracool dwarfs (UCDs, spectral types later than M7) performed across the entire J-PLUS DR2 (2 176 deg2) data set. For this purpose, we developed a methodology driven by the use of multiple VO tools and services that combines J-PLUS data with astrometric information from Gaia EDR3. Furthermore, we explored the ability to reproduce this search with a purely ML-based methodology that relies solely on J-PLUS optical photometry, with a two-step ML method based on Principal Component Analysis and Support Vector Machine algorithms.

We consolidated the proposed search methodology, which will be used in deeper and larger upcoming surveys like J-PAS and Euclid, and identified a total of 7 827 new candidate UCDs. The online catalogue is available here.

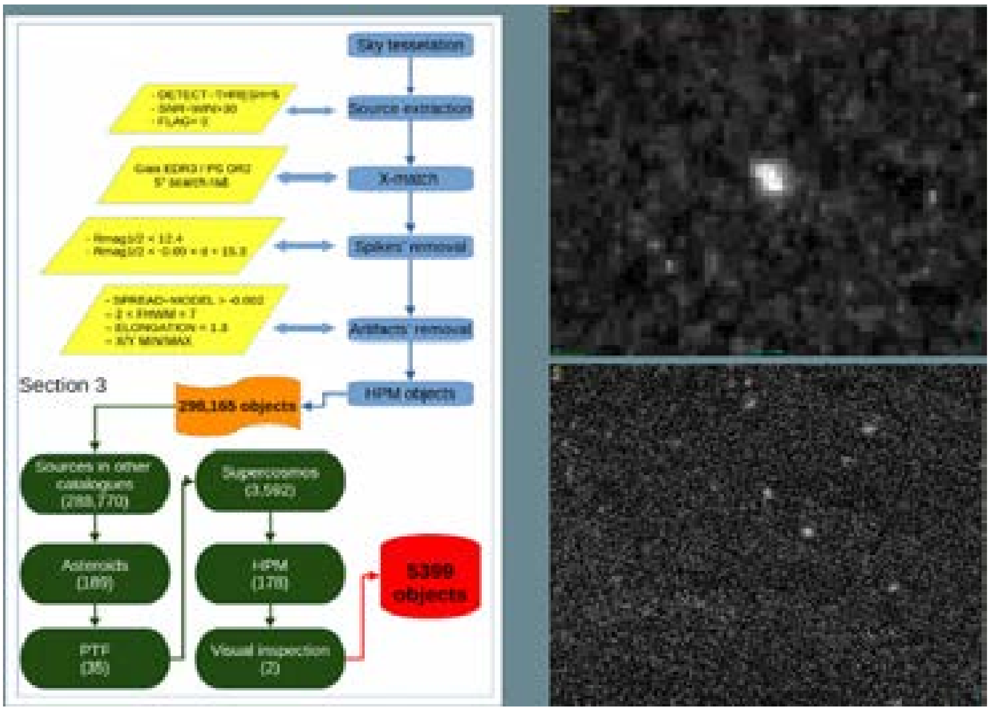


Distance vs effective temperature diagram for previously reported (blue) and new (yellow) candidate UCDs with good parallax conditions. Previously reported candidate UCDs tend to be at shorter distances for any value of the effective temperature.

RH3: Discovering vanishing objects in POSS I red images using the Virtual Observatory

We report a search for vanishing sources in POSS I (Palomar Observatory Sky Survey) red images using virtual observatory archives, tools and services. The search aims at finding POSS I sources not present in recent catalogues like PAN-STARRS DR2 (limiting magnitude r=21.4) or Gaia EDR3 (limiting magnitude G=21).

We found 298 165 sources visible only in POSS I plates, out of which 288 770 had a crossmatch within 5 arcsec in other archives (mainly in the infrared), 189 were classified as asteroids, 35 as variable objects, 3592 as artefacts from the comparison to a second digitization (Supercosmos) and 180 as high proper motion objects without information on proper motion in Gaia EDR3. The remaining unidentified transients (5399 sources) as well as the 172 163 sources not detected in the optical but identified in the infrared regime are available from a virtual observatory compliant archive and can be of interest in searches for strong M-dwarf flares, high-redshift supernovae, asteroids, or other categories of unidentified red transients. The results of this paper are publicly available through a VO-compliant archive.



Flowchart of the candidate selection (left) and example of a source clearly visible in POSS-I (top right) but not detectable in more modern surveys (e.g Pan-STARRS) (bottom right).

Other activities 2022:

Meeting organization

Our group is chairing the organization of the Special Session entitled Science with the Virtual Observatory: status, success cases, the future, in the framework of the European Astronomical Society Anual Meeting (EAS 2023).

The CAB Astronomical Data Centre

The CAB Data Centre is the reference centre at national level for astronomical archives. A complete list of the archives managed by CAB Data Centre can be found here. All these archives are fully VO-compliant.

Among the activities carried out in 2022 we highlight the following ones:

- Gran Telescopio Canarias and Calar Alto archives
- Improvement in the management of OSIRIS data.
- Modification of the ingestion procedure for MEGARA data.
- Database improvement. Error code management.
- Development of Technical Notes.
- CARMENES GTO Archive
- Development of a repository and a web page for the Data Release 1
- Development of a system to manage off-line ingestion of data (templates and re-reduced data).
- Improvement of error handling procedures.
- Remedial actions for the log4j vulnerability.
- Development of Technical Notes.
- New archives:
- SVO Calar Alto CAFOS Direct Imaging First Data Release archive: Detection catalogue.
- The SVO archive of vanishing objects in POSS I red images
- The SVO archive of white dwarfs from Gaia
- The SVO archive of hot subdwarfs
- The SVO archive of ultracool dwarfs in J-PLUS
- First detection of silicon-bearing molecules in σ Car
- The Garraf Wide Pairs (GWP) catalogue
- Gaia EDR3 comparative study of protoplanetary disk fractions in young stellar clusters.
- JWST/MIRI GTO Disks database
- JWST/MIRI GTO Planets database
- Migration of the SVOCat catalogues.
- Modification of the SVO theoretical spectral data collections to make them compliant with the SSA data model.
- Collaboration with other Spanish astronomical data centres:
- Meeting with CEFCA to identity lines of work of common interest (Feb 2022).
- Exchange of technical information for the development of the VO-compliant archive of the Yebes 40m radiotelescope.

VO-tools and services

In 2022 our group has continued working on the field of VO tools and services.

  - VOPubs
- Improvement of the web application and the associated database.
  - Gaia alerts
- Critical redesign of contents and functionalities to broad its scientific usage.
  - Clusterix
- Upgrade and maintenance. Bug fixing.
- Remedial actions for the log4j vulnerability.
- Control version.
  - VOSA
- User support.
- New release (VOSA 7.5).
- Gaia DR3 information has been included to estimate distances and extinction.
- New photometric catalogues: ZTF DR12, NeoWISE, J-PLUS DR2, Gaia DR3, Gaia DR3 SyntPhot, Gaia DR3 Synt J-PAS phot. Synthetic photometry in the J-PAS bands was obtained from the Gaia DR3 BP/RP spectra using the GaiaXPy tool.
- Collaboration with Gaia DPAC to provide photometric information using the GaiaXPY tool. The information can be extracted from Gaia DR3 BP/RP spectra in any of the photometric filters available from the Filter Profile Service.
- VOSA usage statistics:

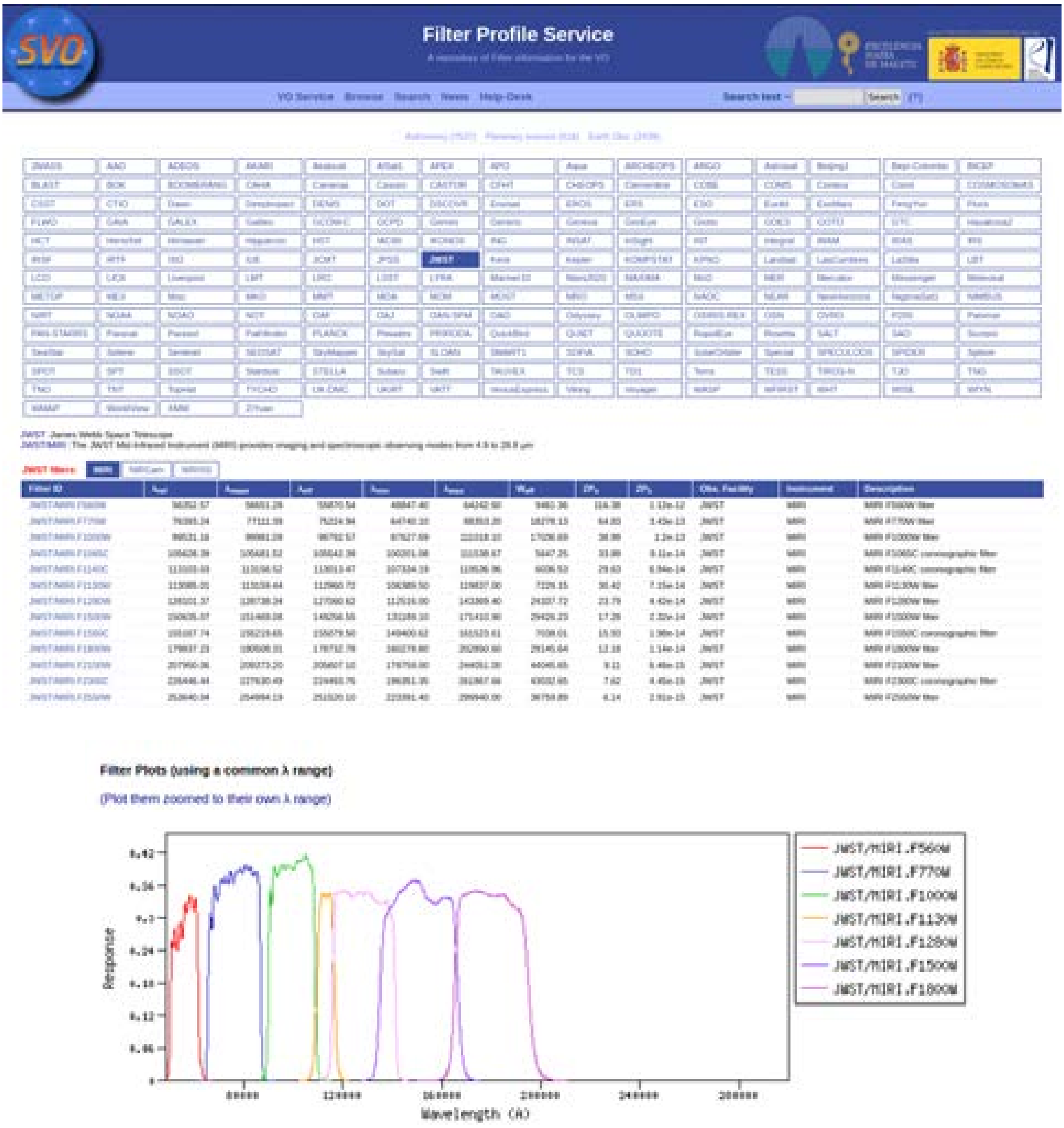
	Users	**Objects analyzed**
2022	**999**	**1 266 900**
Total	**3873**	**13 733 550**

  - FPS (Filter Profile service)
- User support.
- Update of HST/WFC3 filter curves.
- Bug fixing in Subaru/HSC filter curves.
- Ingestion of the VLT/ERIS, SUBARU/VAMPIRES and Swift/UVOT filter curves.
- Ingestion of 147 new filters in 2022.
- Implementation of the MIVOT standard.
- Implementation of the GaiaXPy base XML files to be used for the GaiaXPy tool.
- At present, the Filter Profile Service provides access to 10739 filters (7684 for astronomy, 616 for solar system and 2439 for Earth observation).

Others

- Technical assessment of the VO-compliance of MADCUBA

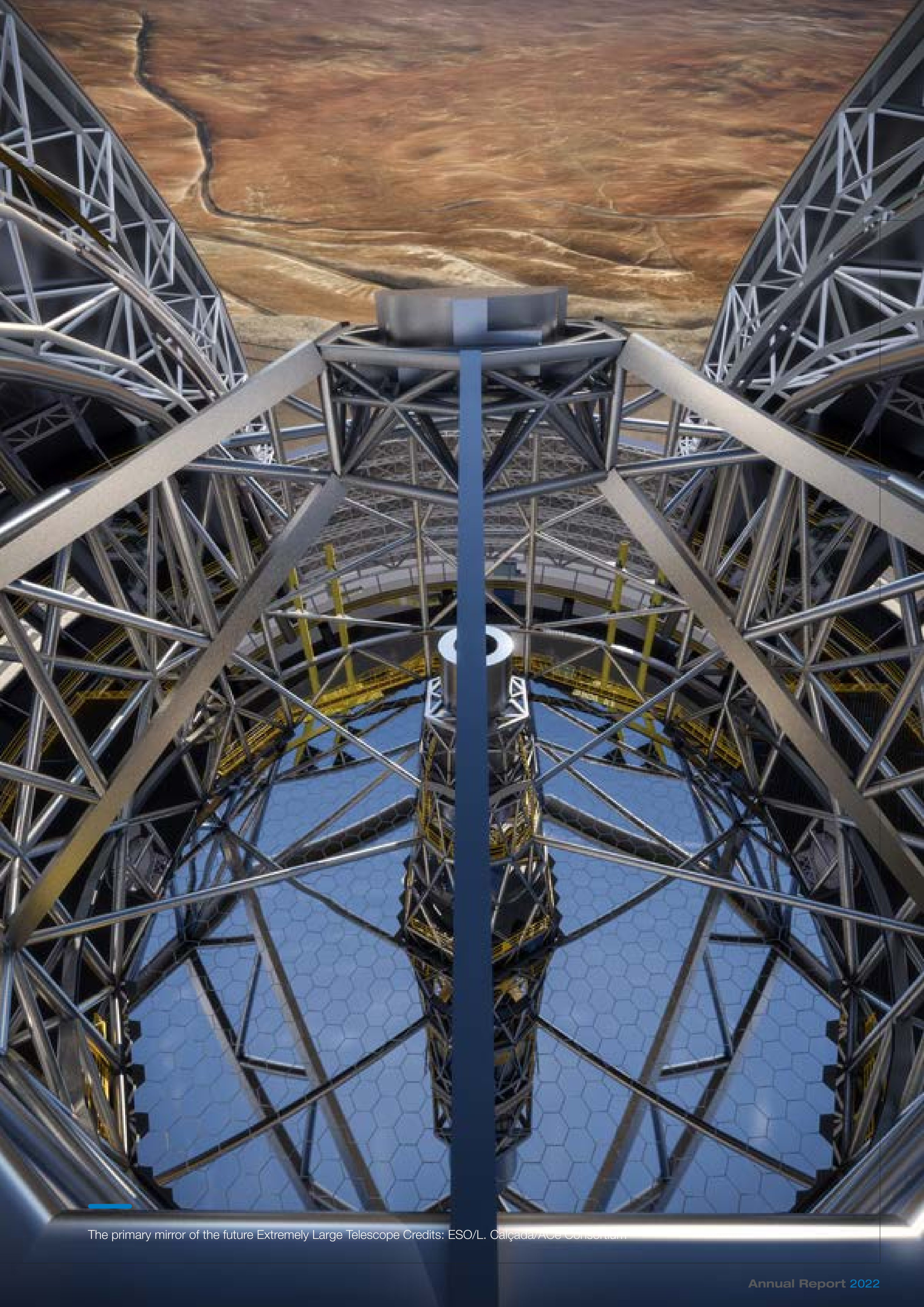
➛



Filter Plots (using a common λ range)

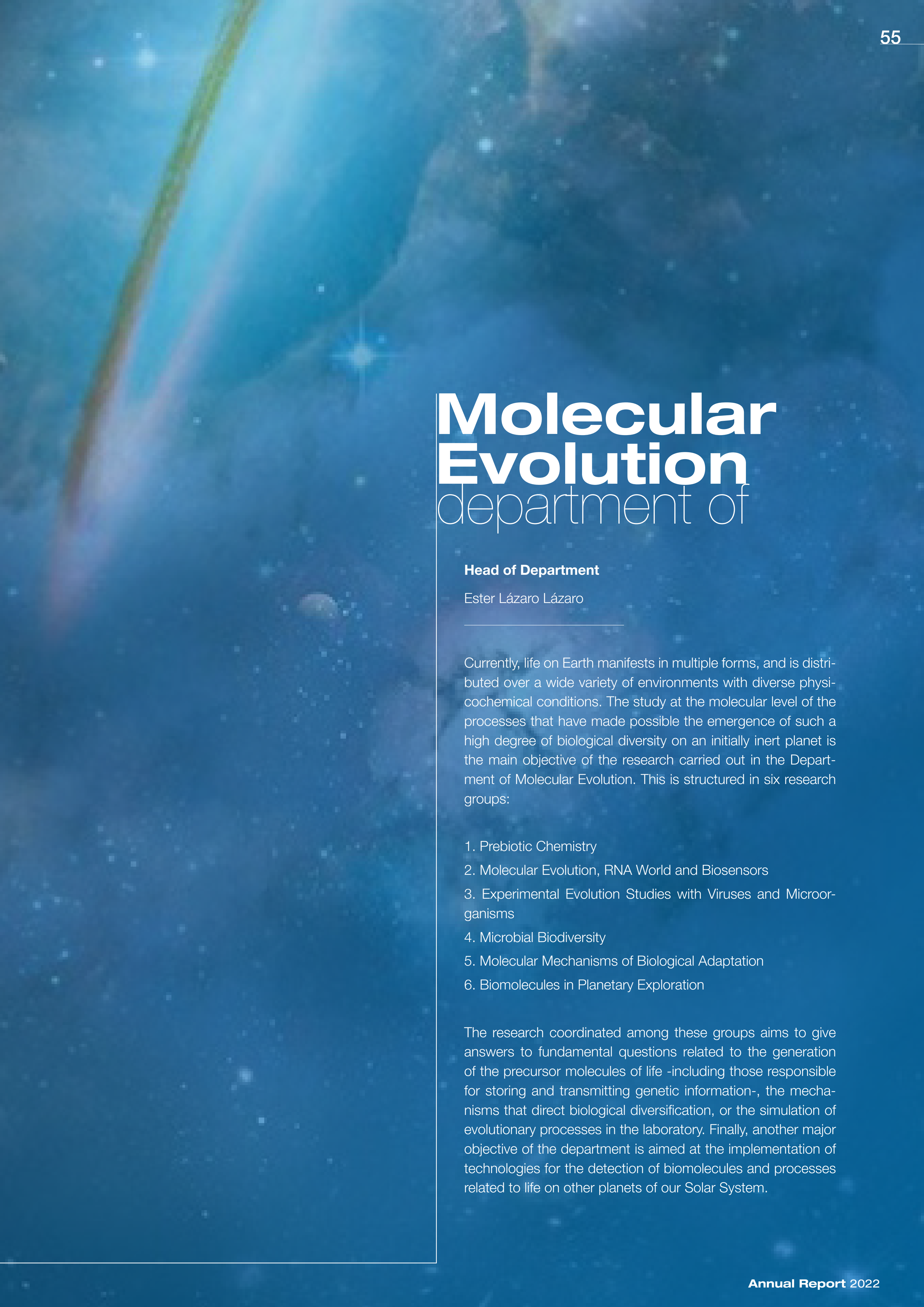
(Plot them zoomed to their own λ range)

Screenshot of the information available at the Filter Profile Service on the JWST/MIRI filters.



The primary mirror of the future Extremely Large Telescope Credits: ESO/L. Calçada/ACe Consortium

Credits: NASA / Jenny Mottar



Molecular Evolution department of

Head of Department

Ester Lázaro Lázaro

Currently, life on Earth manifests in multiple forms, and is distributed over a wide variety of environments with diverse physicochemical conditions. 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 in 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 and Physics of Complex Systems

Group coordinator: David Hochberg

Senior Researchers

Marta Ruiz-Bermejo
Eva Mateo-Martí
Jacobo Aguirre

Postdoctorals

Eduardo Cueto Díaz
Laura Jiménez Bonales.

Postdoctoral trainees

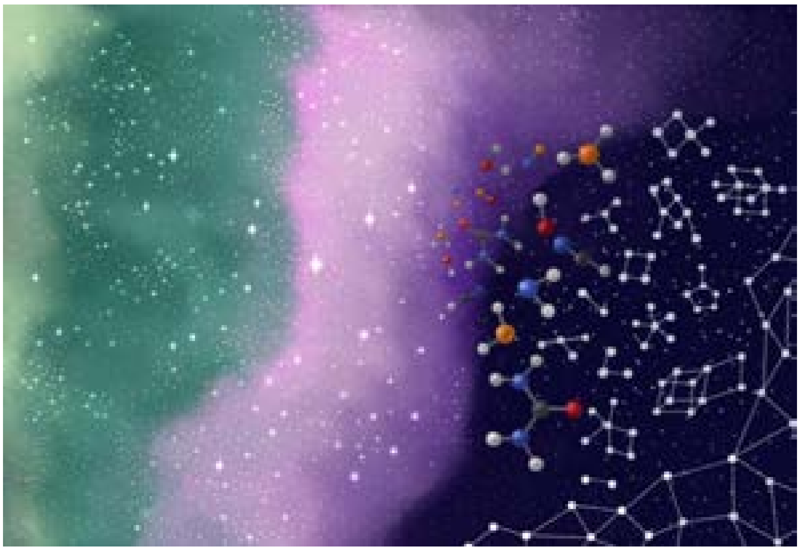
(1-3 years since PhD thesis): Adrián Aguirre Tamaral.

Technicians: Pedro Rayo Pizarroso

Summary

The Prebiotic Chemistry and Physics of Complex Systems group is concerned with the study of the chemical and physical aspects regarding the possible origins of life and its evolution on Earth, as well as with aspects related with the increase of molecular complexity and habitability on other planetary environments in the Solar System. These objectives are pursued from a completely transdisciplinary perspective exploiting the connection between areas of expertise such as prebiotic chemistry, the physics and chemistry of surface science, the use of non-equilibrium and stochastic thermodynamics in symmetry breaking phenomena in chemistry and physics, and the modelling of reaction-diffusion-advection processes and fluid mechanics. We also pursue complexity theory, whose complementarity in the context of Astrobiology has not been sufficiently developed until only recently. Our methods range from experimental work simulating conditions on the primitive Earth to planetary environments in the Solar System, with an emphasis on liquid water interfaces, interaction of biomolecules on mineral surfaces and chemical reactivity, to the mathematical modeling of complex processes, supported by computation based on the use of experimental and observational data.

The research carried out by our group contributes to objectives O1.4, O2, O2.1, O3.2, O5, O5.2, O5.3, O5.5 and O5.6 of the strategic plan.



Research Highlights (RH) 2022

RH1: Resilience of parity-violation-induced chiral selectivity to non-equilibrium temperature fluctuations in open systems

Chiral molecules cannot be superposed on their mirror images by any combination of rotations or translations. In living organisms, all sugars are right-handed and all amino acids left-handed. On the contrary, in the chemistry laboratory, in the absence of any chiral auxiliary, a racemic mixture is always obtained (50/50 of right- and left-handed enantiomers). Since almost all chiral auxiliaries come from biological molecules, we face the question of the origin of this biological homochirality. One appealing suggestion, based on fundamental physics, invokes the role of the nuclear weak interaction: right- and left enantiomers differ by an extremely tiny amount of energy. Here, we propose a calculation showing that this very tiny, but permanent parity violating energy difference (PVED) parametrized by g, can be sufficient to deracemize a macroscopic system, even in the presence of unavoidable thermal fluctuations represented by ξ.

Our calculations are based on nonlinear stochastic differential equations. The reaction rate constants of the enantiomers are sensitive to the thermal fluctuations, and also to the PVED. When the thermal fluctuations $\xi > g$ are larger than the PVED bias, both enantiomers D and L are likely, see histogram (d). However, lowering the amplitude of the thermal fluctuations makes the output statistically shifted toward the enantiomer favored by the PVED, see (c). Reducing again the thermal fluctuations leads to the preferred enantiomer D with total certainty, see (b) and (a) in the above figure. See more details, see Hochberg, D; Buhse, T; Micheau, J-C and Ribó, JM, PHYSICAL REVIEW RESEARCH 4, 033183 (2022).

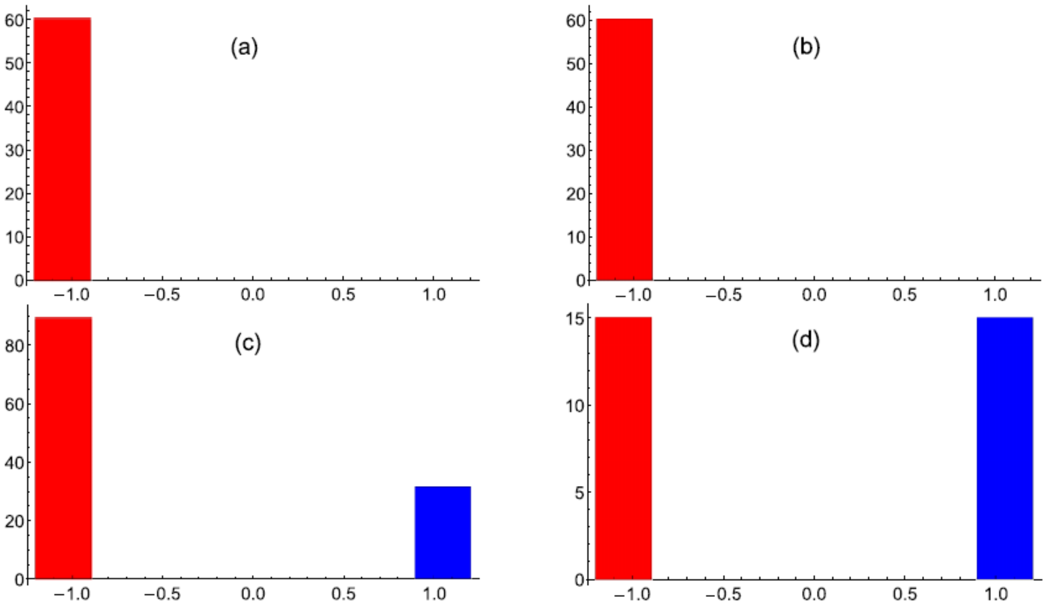


Figure 1 Histograms of outcomes showing competition between fixed chiral bias due to the parity violating weak interaction and internal temperature fluctuations in an open-flow and stochastic model of chiral symmetry breaking. Red (blue) bar: total number of D (L)-handed outcomes.

Research Highlights 2022

RH2: Stoichiometric network analysis in reaction networks yielding spontaneous mirror symmetry breaking in a prebiotic atmosphere

The generation of amino acid homochirality under prebiotic atmosphere conditions is a relevant issue in the study of the origin of life. This research is based on the production of amino acids via Strecker synthesis and how it is adjusted to the Kondepudi–Nelson autocatalytic model.

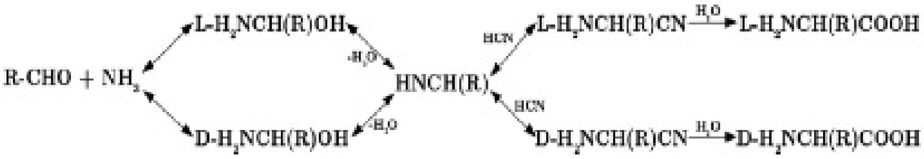


Figure 2 Amino acid production by the Strecker reaction (the imine pathway).

The spontaneous mirror symmetry breaking (SMSB) of the new Kondepudi–Nelson–Strecker model, subject to two modifications (with Limited Enantioselective and Cross Inhibition), and also their combinations were studied using the stoichiometric network analysis (SNA). In the calculations, the values obtained from the literature for alanine were considered. A total production of alanine of 7.56 x 10^9 mol/year was determined under prebiotic atmosphere conditions and starting from that value, the reaction rates for the models studied were estimated. Only the model with cross inhibition or achiral dimer formation is driven by stochastic fluctuations during SMSB. The stochastic fluctuation was estimated for a value of 2.619 x 10^{-15} mol/ L. This perturbation was sufficient to trigger SMSB (see Figure 3). For more details see, Bourdon-García, RD; Ágreda, J; Burgos-Salcedo, J; Hochberg, D; Ribó, JM; Bargueño, P; and Salamanca, AE, PHYSICAL CHEMISTRY CHEMICAL PHYSICS 24 (35) 2022, pp.20788-20802

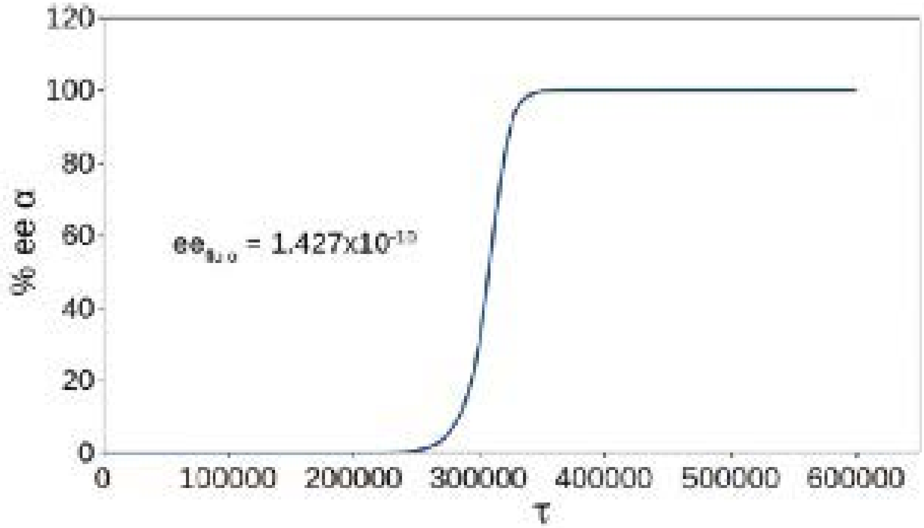


Figure 3. Dynamic behavior of the Kondepudi-Nelson-Strecker model under an initial tiny enantiomeric excess. The stochastic fluctuations in ee_{flu} are 1.427 x 10^{-10}. System reaches 100% homochirality after approximately 320,000 dimensionless time steps.

RH3: The emergence of interstellar molecular complexity explained by interacting networks.

This work introduces the computational framework NetWorld to address how fruitful can complexity theory and network science be to disentangle the origin of the building blocks of life and their role in the long way from astrochemistry to biology. In our model, complex networks simulate interacting chemical compounds, and we describe the emergence of a transition from simple networks that mimic the most basic initial molecular ensembles towards chemical complexity when the parameter representing the environment reaches a critical value. Our results, while obtained in an abstract context that is totally different to that of real chemistry, predict the evolution of chemical complexity in the interstellar medium, proving the applicability of the conceptual scenario here presented and suggesting that the rules leading to the emergence of complexity may be universal. For more details, see M García-Sánchez (Univ. Comillas), I Jiménez-Serra (CAB), F Puente-Sánchez (Univ. Uppsala) and J Aguirre, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 119 (30) e2119734119 (2022). Objectives O2.1, O5.6.

Figure 3 Dynamic behavior of the Kondepudi-Nelson-Strecker model under an initial tiny enantiomeric excess. The stochastic fluctuations in ee_{flu} are 1.427×10^{-10}. System reaches 100% homochirality after approximately 320,000 dimensionless time steps.

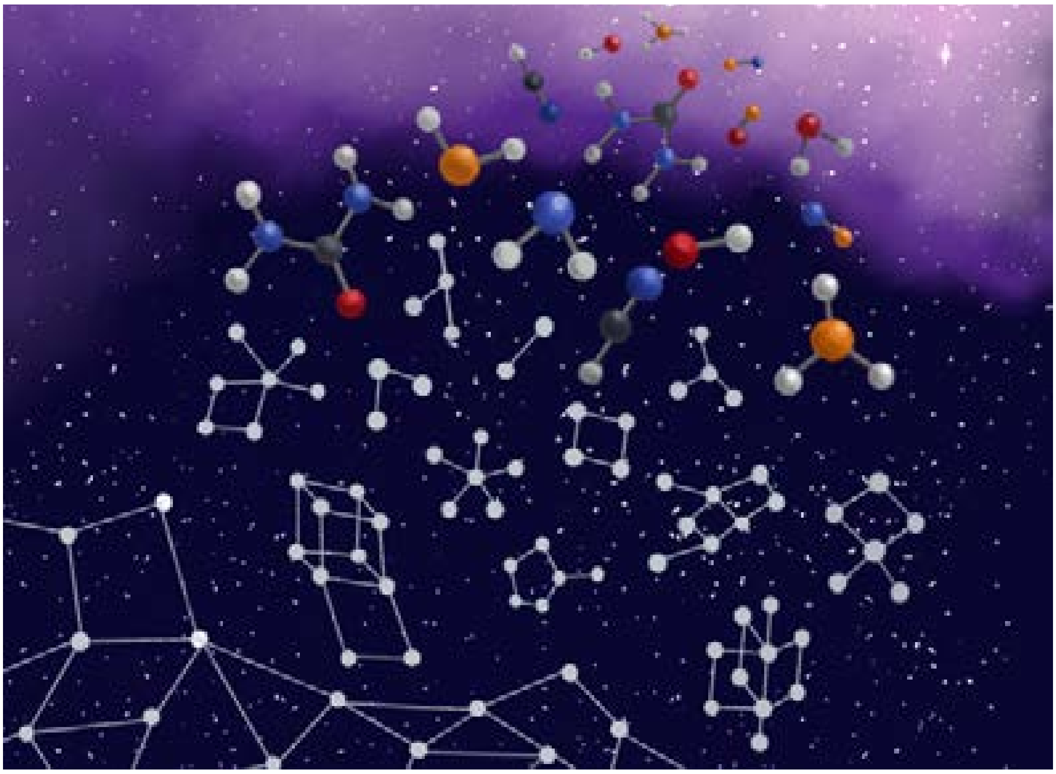


Figure 4. The figure sketches the connection between network science and astrochemistry that we introduced to explain the emergence of chemical complexity in the interstellar medium. With this work, we argue that the properties that condition the extremely complex journey from the chemistry in space to prebiotic chemistry and finally to life could show simple and universal patterns.

Research Highlights 2022

RH4: Journeying through our understanding of evolutionary fitness landscapes

In the field of evolutionary biology, fitness landscapes serve as essential tools for visualizing the relationship between genotypes and reproductive success, or fitness. Fitness landscapes were described almost a century ago as smooth surfaces with peaks and valleys that are difficult to navigate. Now, more realistic high-dimensional genotype-phenotype maps show that fitness maxima can be reached from almost any other phenotype while avoiding fitness valleys, which are very rare. This means that life can find a way to survive even in the face of drastic changes to the environment.

In this work, we review the extensive literature that has focused on understanding genotype-phenotype maps, resulting in a constant updating of the seminal interpretation of fitness landscapes. Specifically, we aim to convey to the next generation of scientists that they will need to work with fitness landscapes that are far more complex than they were taught. For more information, see J Aguirre, NATURE ECOLOGY & EVOLUTION 6, 1599 (2022). Objective O5.6.

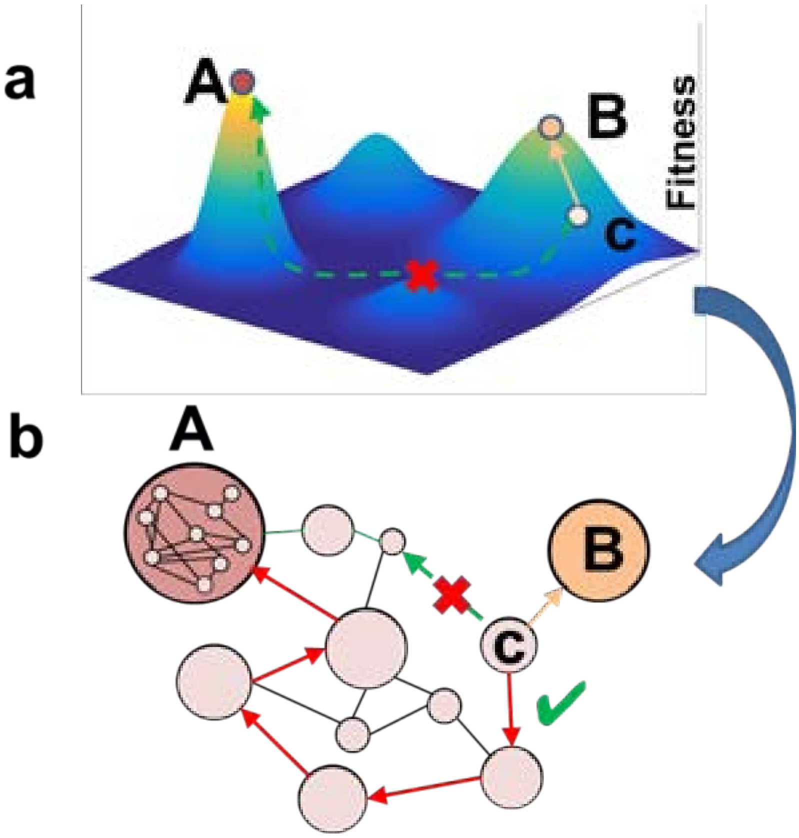


Figure 5. This figure illustrates the evolution of fitness landscapes from Wright's era to the present day. In traditional low-dimensional fitness landscapes, genotypes are required to cross deep valleys to reach the global maxima of fitness, and there is a significant risk of extinction. However, in the multidimensional, networked, and extremely complex realistic fitness landscapes, navigation for evolution is much easier, allowing life to find a way.

RH5: Study of the increase of complexity from the origin of life to the present biosphere.

In this ongoing line of research we are focusing on three systems of different nature and scale:

1. The complex chemical evolution of phosphorus in the interstellar medium. We introduce and analyze a model of the P-chemical network in an interstellar diffuse cloud. We employ a novel and productive association between complex network theory, Bayesian statistics and astrochemistry to improve existing astrochemical models by significantly decreasing their level of parameter uncertainty. Through this approach, we attain a deeper understanding of the formation of chemical precursors for organic macromolecules in space. In collaboration with Izaskun Jiménez-Serra (CAB). Objectives O2.1, O5.6.

2. A complexity theory approach to prebiotic chemistry in the early Earth: towards the first RNA replication. We combine the mathematical modeling of complex systems with the RNA biochemistry to develop a computational model to study the possible first replication of RNA molecules located in an appropriate environment of the early Earth, and how it could depend on the parameters of the system (RNA length, size of genetic alphabet, strength of chemical bonds and probability of rupture, environmental conditions, etc.) In collaboration with Carlos Briones (CAB). Objectives O5.5, O5.6.

3. Complexity in the present biosphere: Study of the interaction between the protein co-expression networks of four large DNA viruses and human cells during a viral infection. In this work, our aim is to bridge the gap between the system-level perspective of viral infection processes and their dynamics, by reconstructing and investigating the topological and dynamical features of virus-host protein co-expression networks. We believe that this approach can complement more standard analytical approaches for quantitative temporal viromics, and provide useful insights. In collaboration with Raúl Guantes (UAM). Objectives O5.5 and O5.6.

RH6: Exploring functional silica nanoparticles as suitable for CO2 detection and storage, under well controlled experimental Martian conditions.

It is crucial to develop different methods for CO_2 sequestration or detection to improve solid sorbent capabilities (NPs). To this end, the surface of 200-nm silica nanoparticles (SiO_2NPs) was covalently anchored with aminated ligands, 3-aminopropyltriethoxysilane (APTES), poly(amidoamine) dendrimers (PAMAM) and a short peptide comprising two lysine units, aiming for CO_2 adsorption over a wide range of pressures. Our goal was to explore the influence of functional chemical groups (attached to the SiO2NPs) on CO_2 sequestration under planetary simulation conditions. The observed results showed that at low and high CO_2 gas pressure conditions, typical APTES functionalized SiO2Np surpassed the CO_2 adsorption capacities of dendritic and peptide-based nanoparticles bearing amine-polymer functionalities, a remarkable effect that was investigated in this work. For further information see E. J. Cueto Díaz, F. Suárez García, S. Galvez Martinez, M. P. Valles and E. Mateo-Martí. Reactive and Functional Polymers, 170 (2022) 105100 (DOI: 10.1016/j.reactfunctpolym.2021.105100)

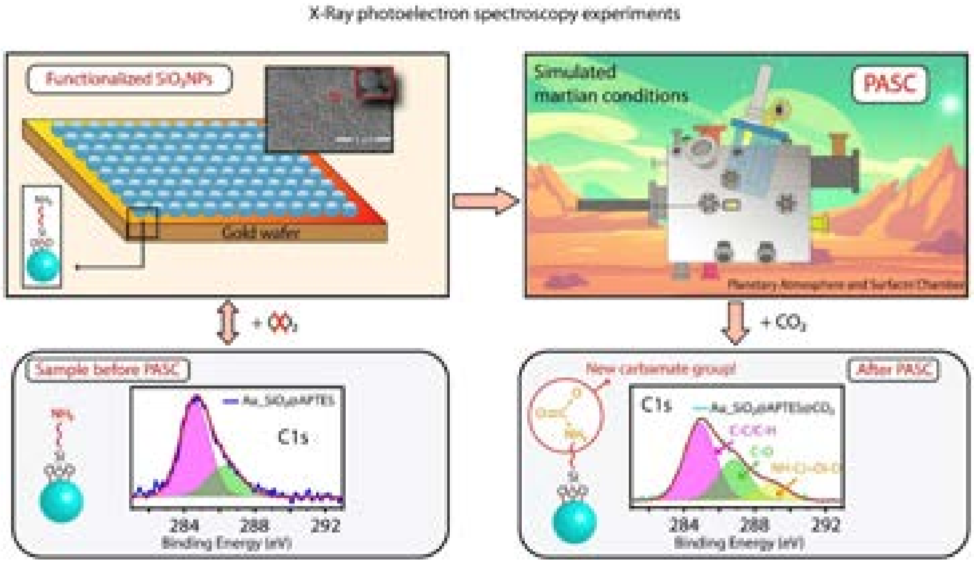


Figure 6. Functional silica nanoparticles for CO_2 adsorption inside PASC and their characterization by surface science techniques.

RH7: Exploring Raman molecular/mineral spectroscopic fingerprints under Mars conditions.

In this work, we studied the dehydration process of the glycine-MgSO4.5H2O complex under Mars-relevant conditions (99% CO2 and 0.6% H2O under UV irradiation exposure at 7 mbar pressure and high vacuum conditions: 8×10-5 mbar and 5×10-5 mbar) by in situ Raman spectroscopy inside a planetary atmosphere and surface chamber (PASC). This work provides quality Raman spectra taken under simulated planetary conditions (to be integrated in a database), as Raman spectroscopy forms part of the current and upcoming NASA and ESA Mars planetary missions. The results demonstrate that Raman spectroscopy can be used to calculate rates of dehydration of the glycine-MgSO4 5H2O compound to study the chemical stability with respect to photodecomposition 1) of metal-bound glycine molecules forming the complex and 2) glycine expelled from the complex, both under Mars-simulated conditions; finally, Raman spectroscopy can also be used to quantify intermolecular interactions in terms of local pressures. Importantly, advanced detection of water molecules as part of a complex with astrobiological interest under planetary conditions plays a crucial role in planetary missions. For more information see (1) L.J. Bonales, N. Rodriguez, M. Fernandez-Sampedro and E. Mateo-Martí. Journal of Raman Spectroscopy, 53, 724-734 (2022)(DOI: 10.1002/jrs.6301) and (2) L. J. Bonales and E. Mateo-Martí. Astrobiology, 22,1, 75-86 (2022) (https://doi.org/ 10.1089/ast.2021.0048)).

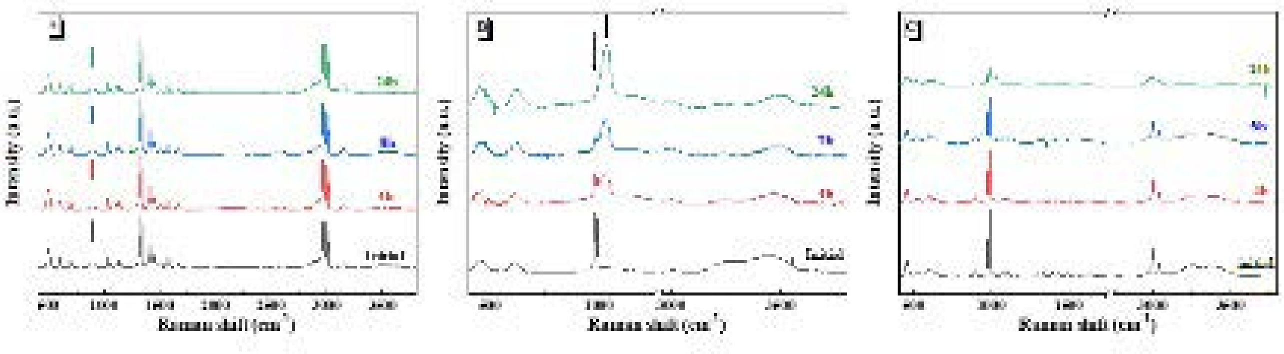
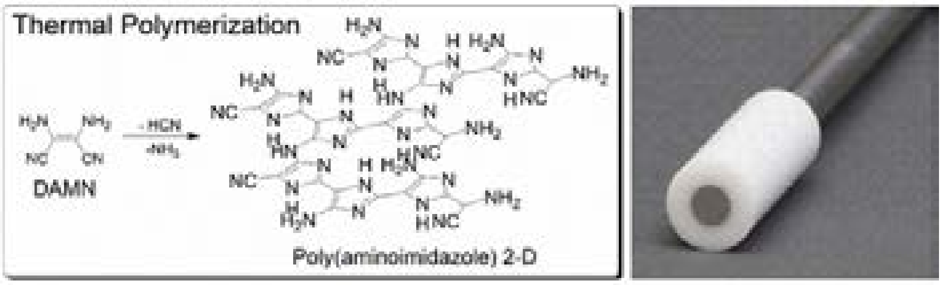


Figure 7. Time evolution of in situ Raman spectra of A: glycine, B: MgSO4·7H2O and C: Gly.MgSO4·5H2O at 7 mbar pressure of 99 % CO2 and 0.6% H2O and room temperature along 0-24 hours, Mars-relevant simulated conditions inside PASC.

RH8: Developing biosensors inspired by prebiotic chemistry

HCN-derived polymers have recently attracted considerable attention due to their promising applications as multifunctional materials. This study, inspired by plausible early Earth geochemical conditions, describes a strategy to synthesize them from the self-initiated thermal bulk polymerization of the HCN tetramer, diaminomaleonitrile (DAMN), with outstanding sensing properties. These conjugated polymers were obtained through noncatalysed and simple isothermal reactions at 170º C in the solid-state, and experiments at 190º C permitted polymerization in the melt. Both processes are highly efficient, allowing quantitative yields of the end products. The conductivity properties of both polymers were explored to show their high potential, especially DAMN polymers synthesized in melt, as nonenzymatic peroxide sensors. This novel application for this new HCN-derived polymeric film shows the huge unexplored potential of these complex bidimensional conjugated C-N networks, whose properties are directly and markedly dependent on the reaction conditions used for their production. We selected hydrogen peroxide because of its importance in the development of electrochemical biosensors that include oxidase enzymes. Hydrogen peroxide is produced in the biochemical reactions catalysed by these enzymes during the oxidation of the corresponding substrates, and their determination is a way of indirect determination of substrates such as glucose or xanthine. In addition, hydrogen peroxide degradation can be considered a potential method for the identification of bioorganics in extraterrestrial bodies, and from a prebiotic chemistry point of view H_2O_2 decomposition can be a significant biological redox reaction useful for studying the possible catalytic activity of protoenzymes. This study demonstrates the robust and straightforward character of the DAMN thermally activated polymerizations, which are of interest to chemical evolution research and to current materials and surface science. For more information see: Ruiz-Bermejo, M.; García-Armada, P.; Mateo-Martí, E.; de la Fuente, J. L. HCN-derived polymers from thermally induced polymerization of diaminomaleonitrile: A non-enzymatic peroxide sensor based on prebiotic chemistry. *Eur. Polym. J. 2022,* 162, 110897. https://doi.org/10.1016/j.eurpolymj.2021.11089 ➛



Modified electrodes by DAMN polymers are highly competitive as it showed in the figure. Cathodic hydrogen peroxide calibration plot obtained at Pt electrodes modified with a DAMN polymer at -0.3 V vs. SCERH9: Prebiotic semiconducting particles

Research Highlights 2022

➛ The polymers based on diaminomaleonitrile (DAMN polymers) are a special group within an extensive set of complex substances, namely HCN polymers (DAMN is the formal tetramer of the HCN), which currently present a growing interest in materials science. Recently, the thermal polymerizability of DAMN has been reported, both in an aqueous medium and in bulk, offering the potential for the development of capacitors and biosensors (RH1), respectively. In the present work, the polymerization of this plausible prebiotic molecule was hydrothermally explored using microwave radiation (MWR) via the heating of aqueous DAMN suspensions at 170–190°C. In this way, polymeric nanoparticles derived from DAMN were obtained for the first time. The structural, thermal decomposition, and electrochemical properties were also deeply evaluated. The redox behavior was characterized from DMSO solutions of these highly conjugated macromolecular systems and their potential as semiconductors was described. As a result, new semiconducting polymeric nanoparticles were synthetized using a very fast, easy, highly robust, and green solvent process. These results show a new example of the great potential of the polymerization assisted by MWR associated with the HCN-derived polymers, which has a dual interest both in chemical evolution and as functional materials.

Classically, HCN polymers have been considered preferential prebiotic precursors of biomonomers (RH3) and theDAMN as a key intermediate in the oligomerization/polymerization of HCN. Beyond the interest in the generation of organics with biological applications, it was shown in this work that DAMN under the simulated conditions of plausible prebiotic-subaerial-hydrothermal environments (high temperatures, relatively high pressure, and a lack of oxygen) lead to the generation of semiconducting nanoparticles, which could notably enrich the chemical space and enable the discovery of new protobiological reaction networks due to their potential as catalyzers and photocatalyzers. These results are especially interesting when considering the hypothesis about the role of hydrothermal scenarios as good niches for the origins of life or at least for the advancement of molecular complexity. For more information: Ruiz-Bermejo, M.; García-Armada, P.; Valles, P.; de la Fuente, J. L. Semiconducting soft submicron particles from the microwave-driven polymerization of diaminomaleonitrile. *Polymers* 2022, 14, 3460.

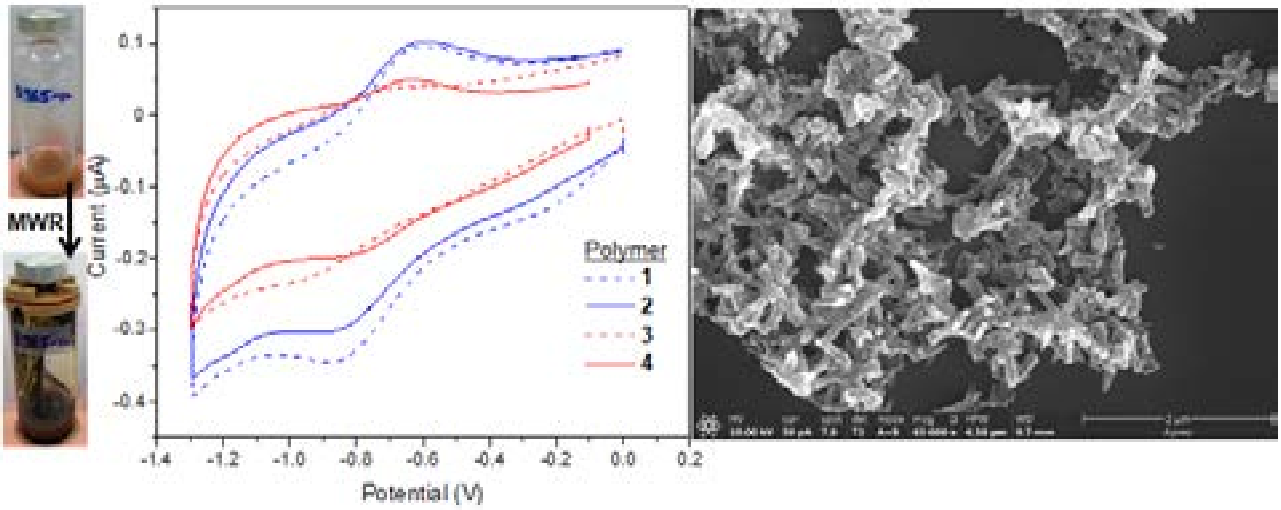


Figure 9. Nanoparticles from the hydrothermal polymerization of DAMN presenting redox activity and semiconductive properties.

RH10: The potential role of the alkaline hydrothermal systems in the arose of a plausible pre-RNA world

In this work, the potential of alkaline hydrothermal environments for the synthesis of possible ancestral pre-RNA nucleobases using cyanide as a primary source of carbon and nitrogen was described. Water cyanide polymerizations were assisted by microwave radiation to obtain high temperature and a relatively high pressure (MWR, 180 °C, 15 bar) and were also carried out using a conventional thermal system (CTS, 80 °C, 1 bar) to simulate subaerial and aerial hydrothermal conditions, respectively, on the early Earth. For these syntheses, the initial concentration of cyanide and the diffusion effects were studied. In addition, it is well known that hydrolysis conditions are directly related to the amount and diversity of organic molecules released from cyanide polymers. Thus, as a first step, we studied the effect of several hydrolysis procedures, generally used in prebiotic chemistry, on some of the potential pre-RNA nucleobases of interest, together with some of their isomers and/or deamination products, also presumably formed in these complex reactions. The results show that the alkaline hydrothermal scenarios with a relatively constant pH are good geological scenarios for the generation of noncanonical nucleobases using cyanide as a prebiotic precursor. For more information see: Pérez-Fernández, C.; Vega, J.; Rayo-Pizarroso, P.; Mateo-Martí, E.; Ruiz-Bermejo, M. Prebiotic synthesis of noncanonical nucleobases under plausible alkaline hydrothermal conditions. *Sci. Reports* 2022, 12, 15140. https://doi.org/10.1038/s41598-022-19474-0;

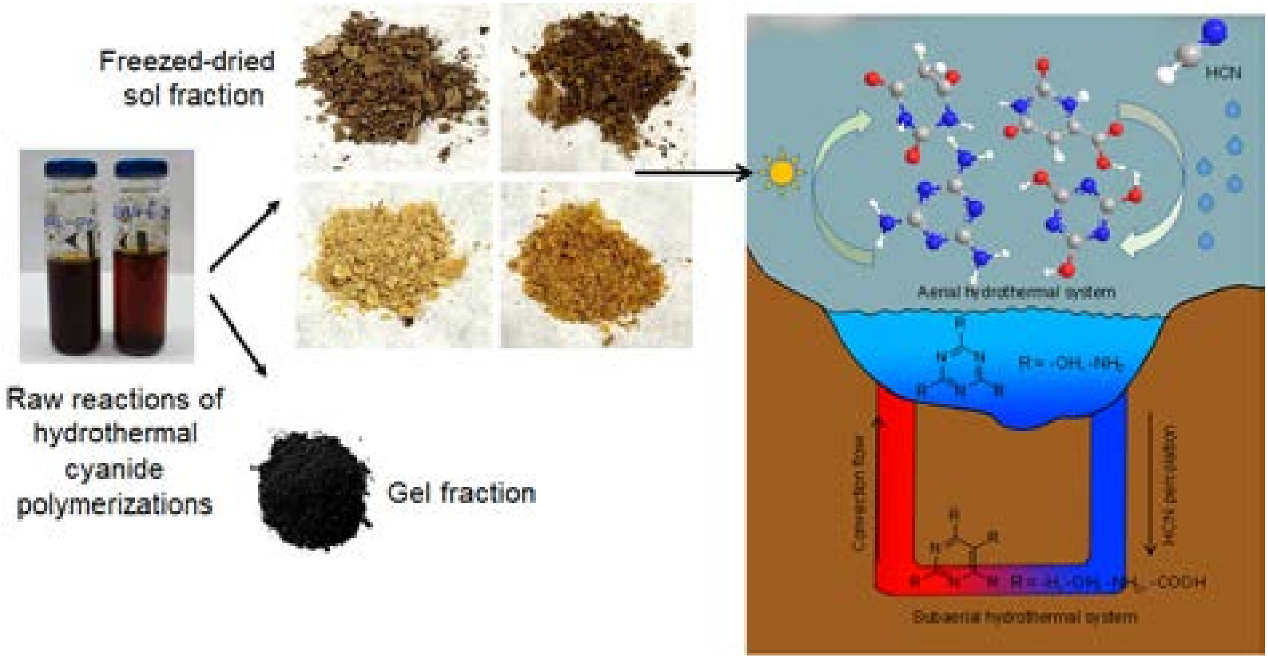
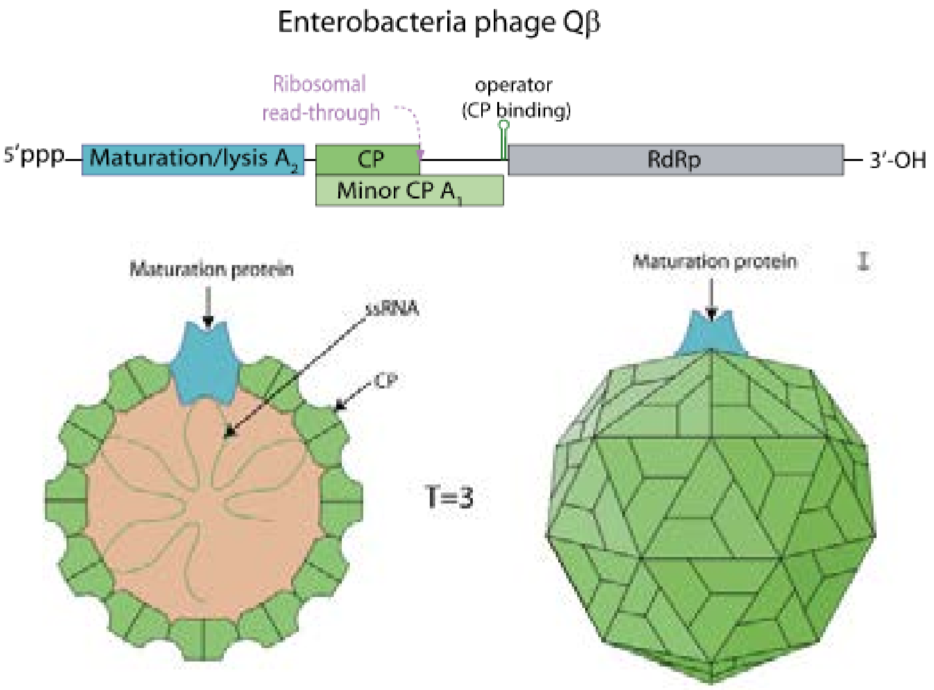


Figure 10. Main products obtained by cyanide polymerizations under simulated hydrothermal conditions.

Experimental evolution studies with viruses and microorganisms

Group coordinator: Ester Lázaro

Technician: María Arribas



Summary

This group contributes to objective 5 (O5) of Center Strategic Plan. In order 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.

Our experimental system is bacteriophage Qσ, a lytic virus that infects the bacterium *Escherichia coli* using as receptor the conjugative F pilus. It has a single-stranded, positive-sense RNA genome of 4217 nucleotides that encodes four proteins: A2 or maturation protein, which is present in a single copy and mediates phage binding to the bacterial pili, penetration of the viral genome and cell lysis; coat protein, which is the major capsid protein; A1 or the minor capsid protein, which is produced occasionally when the stop codon of the capsid protein is read as tryptophan; and the replicase that copies the RNA genome. Evolutionary experiments carried out in our group are usually focused on analyzing the genotypic and phenotypic changes experienced by Qσ when it is propagated under the particular conditions whose influence on evolution we want to analyze. The following research highlights exemplify the most relevant investigations and results in the group.

Research Highlights (RH) 2022

RH1: Adaptation of viruses to low host density at optimal and suboptimal temperatures

Host density is one of the main factors affecting the infective capacity of viruses. When host density is low, it is more difficult for the virus to find a susceptible cell, which increases its probability of being damaged by the physicochemical agents of the environment. Nevertheless, viruses can adapt to variations in host density through different strategies that depend on the particular characteristics of the life cycle of each virus. We found that, at optimal temperature (37 °C) and lower-than-optimal bacterial density, bacteriophage Qβ increased its capacity to penetrate into the bacteria through a mutation in the minority capsid protein (A1) that is not described to interact with the cell receptor (Laguna-Castro and Lázaro 2022). The same mutation was selected when temperature was decreased to 30 °C. However, when temperature increased to 43 °C, the mutation selected was located in a different protein (A2), which is involved both in the interaction with the cell receptor and in the process of viral progeny release. The new mutation also increased phage entry into bacteria at the three temperatures assayed. However, it also considerably increased the latent period at 30 °C and 37 °C. The conclusion is that the adaptive strategies followed by bacteriophage Qβ, and probably other viruses, in the face of variations in host density depend on the balance between advantages and fitness costs, which can change as a function of other environmental parameters.

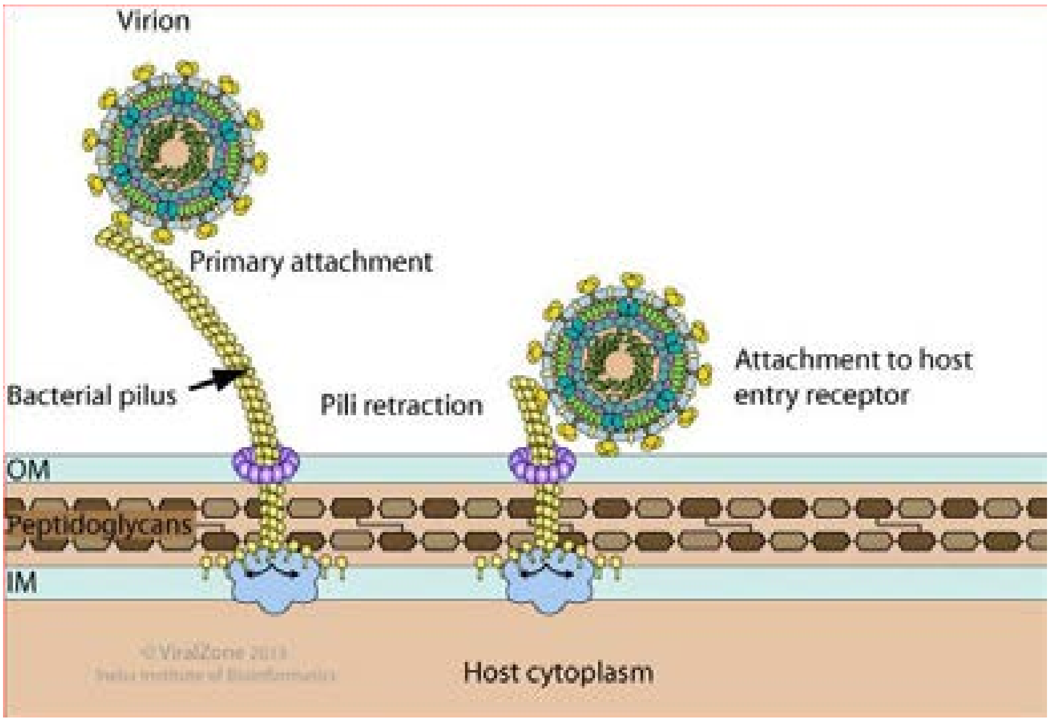


Figure. Illustration showing the attachment of bacteriophage Qβ to the host receptor. Our proposal is that protein A1 provides primary binding sites to the pilus. Then, the pilus retracts, allowing interaction of A2 protein with the channel that traverses the membrane at the basis of the pilus. Only the complex formed by A2 and viral genomic RNA penetrates into the cytoplasm. Figure taken from ViralZone (Swiss Institute of Bioinformatics).

Research Highlights 2022

RH2: Genotype-to-Protein Map and Collective Adaptation in a Viral Population

Despite the evolutionary relevance of the heterogeneity of RNA virus populations, statistical approaches to quantifying the extent to which viruses maintain a high genotypic and/or phenotypic diversity have been rarely pursued. We have addressed this issue by analyzing a nucleotide-to-protein sequence map through deep sequencing of populations of the bacteriophage Qσ adapted to high temperatures. Tens of thousands of different sequences corresponding to two fragments of the gene coding for the viral replicase were recovered. A diversity analysis of two independent populations consistently revealed that about 40 % of the mutations identified caused changes in protein amino acids, leading to an almost complete exploration of the protein neighborhood of (non-silent) mutants at a distance of one (Villanueva et al., 2022). The functional form of the empirical distribution of phenotype abundance agreed with analytical calculations that assumed random mutations in the nucleotide sequence. Our results concur with the idea that viral populations maintain a high diversity as an efficient adaptive mechanism and support the hypothesis of universality for a lognormal distribution of phenotype abundances in biologically meaningful genotype–phenotype maps, highlighting the relevance of entropic effects in molecular evolution.

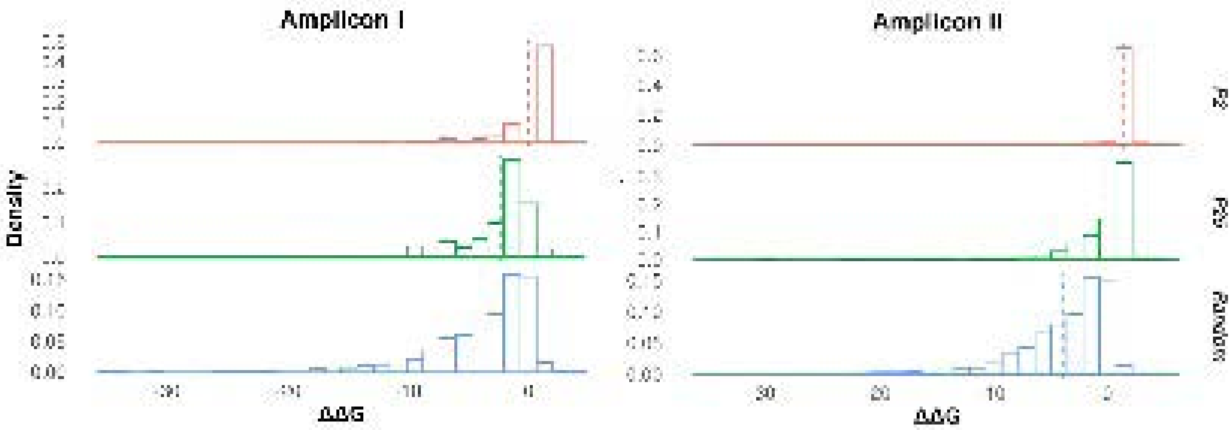


Figure. Changes in protein stability for evolved and randomly mutated sequences. The panels show a histogram of changes in folding energy for the two amplicons studied and three different sets of sequences, as indicated. From top to bottom, the distributions correspond to populations evolved from two different ancestors differing in their diversity (P2 or P25), and 1000 sequences with two (on average) amino acid substitutions at random positions. Mean values are indicated with a dashed line.

RH3: Review on the relevance of viruses in astrobiology

Despite that viruses are the most abundant biological entities on Earth, they have not received enough consideration in astrobiology. Viruses are also extraordinarily diverse, which is evident in the types of relationships they establish with their host, their strategies to store and replicate their genetic information and the enormous diversity of genes they contain. The fact that viruses always need cellular resources to multiply means that they establish very close interactions with cells. Although in the short term these relationships may appear to be negative for life, it is evident that they can be beneficial in the long term. Viruses are one of the most powerful selective pressures that exist, accelerating the evolution of defense mechanisms in the cellular world. They can also exchange genetic material with the host during the infection process, providing organisms with capacities that favor the colonization of new ecological niches or confer an advantage over competitors, just to cite a few examples. In addition, viruses have a relevant participation in the biogeochemical cycles of our planet, contributing to the recycling of the matter necessary for the maintenance of life. Therefore, although viruses have traditionally been excluded from the tree of life, the structure of this tree is largely the result of the interactions that have been established throughout the intertwined history of the cellular and the viral worlds.

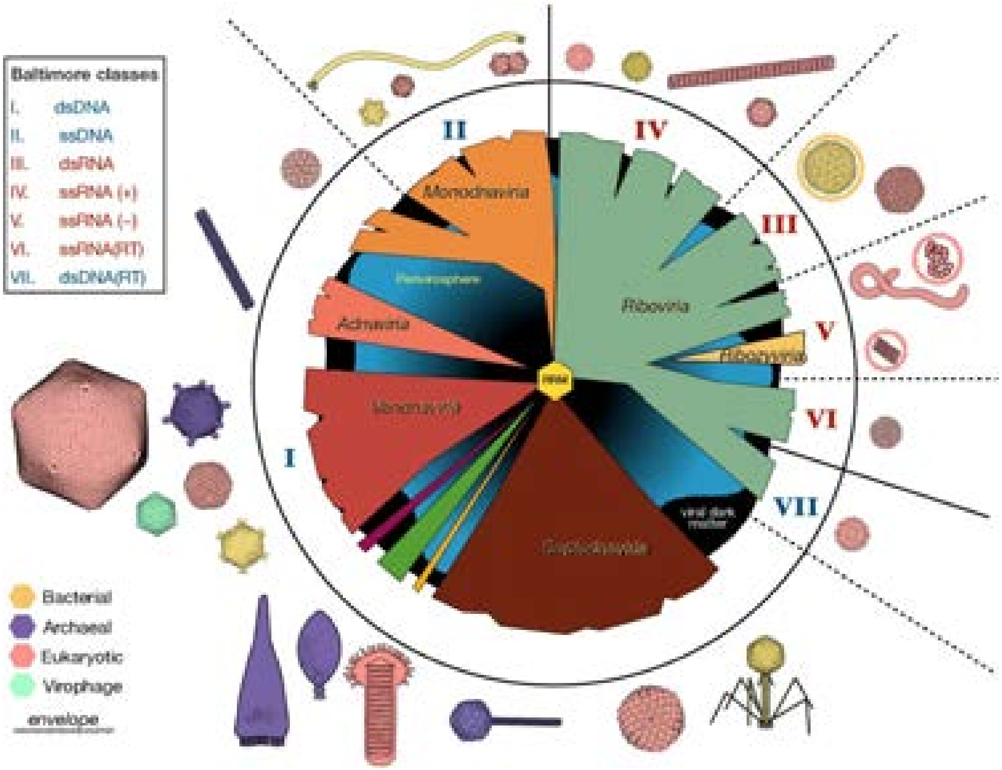


Figure. Organization and Diversity of the Virosphere. Here, we represent the six virus realms in the middle circle, as they emerge from an ancestral RNA-recognition motif (RRM) in the center. The roman numbers indicate the nature of the packaged nucleic acid according to the Baltimore classification scheme, where blue numbers represent DNA and red numbers RNA.

Molecular Evolution, RNA World and Biosensors

Group coordinator: Carlos Briones Llorente

Senior Researchers

Yolanda Blanco López

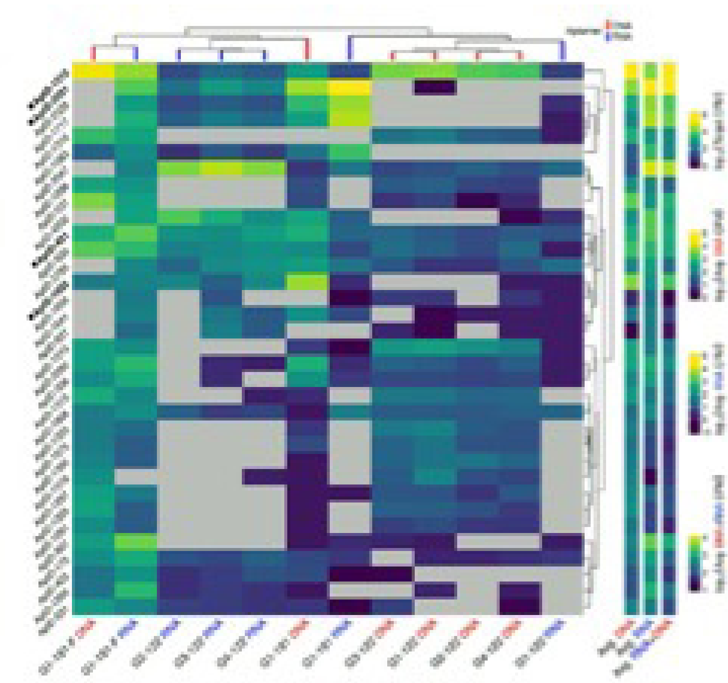
Technicians

María Fernández Algar

Summary

This research group contributes to objectives O2, O4, O5 and O6 of CAB's Strategic Plan by addressing the following questions: i) Collaboration with the Astrochemistry group in the search for and characterization of molecular precursors of the RNA world in the interstellar medium; ii) Development of experimental approaches to abiotically polymerize ribonucleotides in mineral-water interfaces (including clay minerals) and other complex media, in the framework of our research in prebiotic systems chemistry; iii) Characterization of the dynamics and evolution of RNA virus quasispecies under different selective pressures; iv) *In vitro* selection of RNA and DNA aptamers against different molecular targets, including low molecular weight biomolecules, astrobiologically-relevant peptides and proteins, and viral proteins; v) Development of ultrasensitive, aptamer-based biosensors with applications in biotechnology and astrobiology; vi) Collaboration with other CAB groups for the characterization of biodiversity in the Río Tinto subsurface.

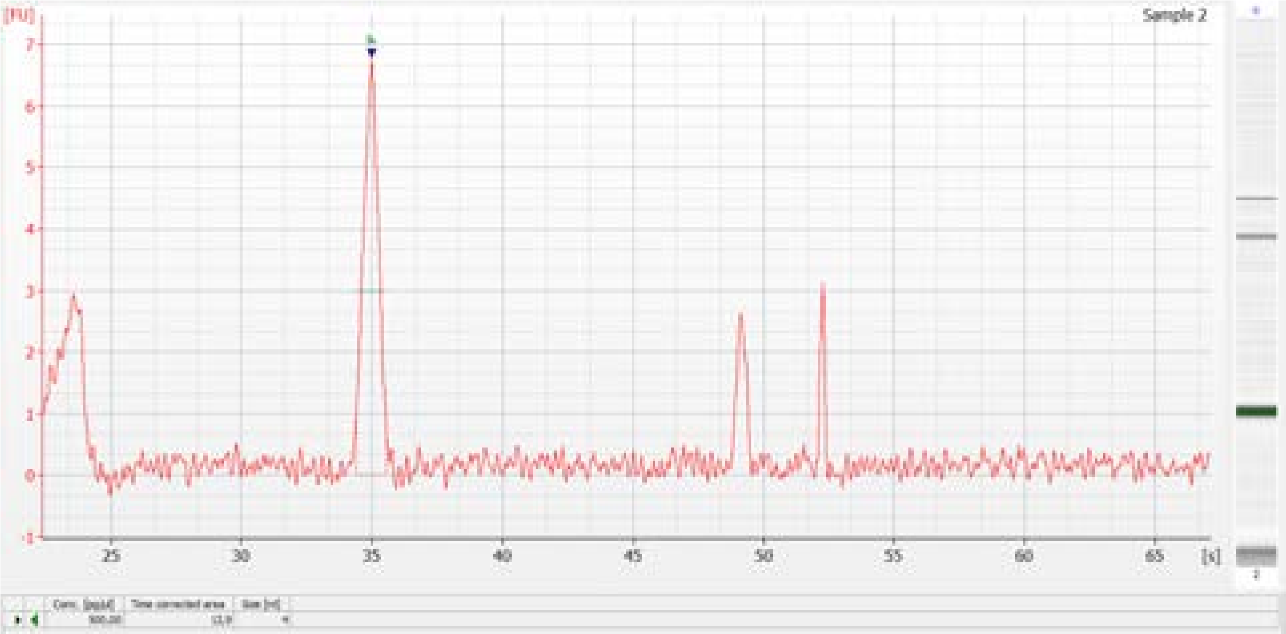
The following research highlights exemplify the most relevant investigations and results of the group during 2022.



Research Highlights (RH) 2022

RH1: Development of experimental systems for abiotic polymerization of ribonucleotides on clays

One of the research lines of this group focuses on investigating the chemical processes that could lead to the establishment of the RNA World, following a prebiotic systems chemistry perspective. In 2022, in collaboration with the group of Andrés de la Escosura (UAM), we have optimized and tested experimental systems for the abiotic polymerization of RNA oligonucleotides. This was achieved by using cyclic phosphate-containing monomers (and their mixtures) and various clay minerals as catalytic substrates. We conducted these experiments at different pH levels and ionic strengths in order to investigate their influence on the polymerization process. To analyze the results of the polymerizations we set up the Agilent Bioanalyzer 2100 with the Small RNA Chips, as a screening system prior to the use of HPLC and mass spectrometry. The results of this work will be published in the coming months.

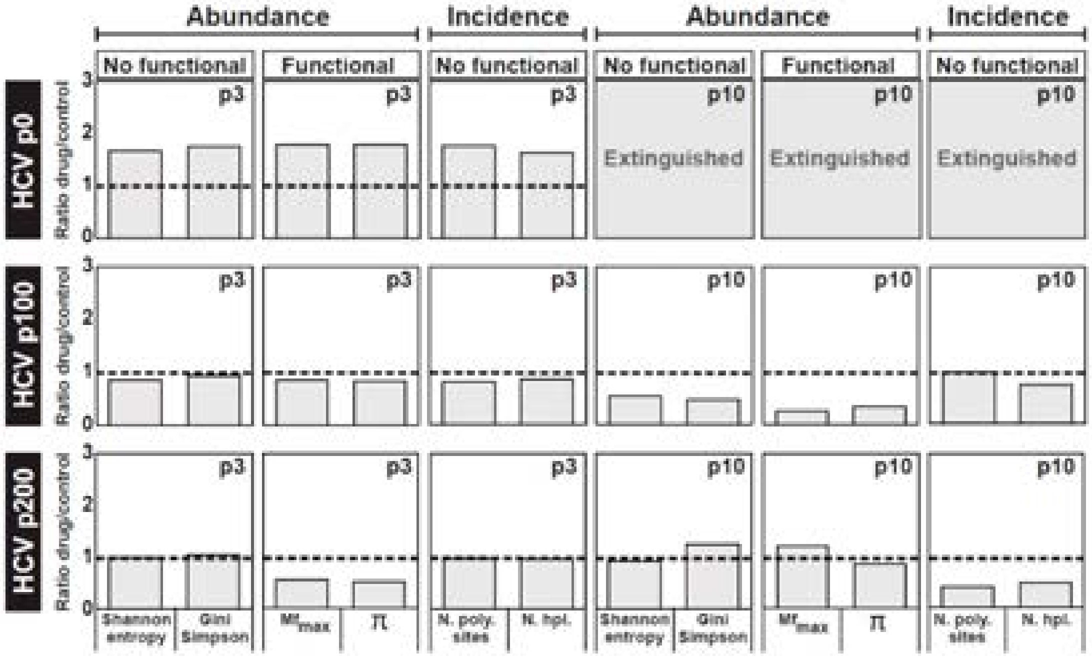


Result of one of the ribonucleotide polymerization experiments on clays, visualized on the Agilent Bioanalyzer 2100.

RH2: Evolution of virus RNA quasispecies under different selective pressures

RNA virus quasispecies serve as suitable models for studying the population dynamics during the RNA World. The replication of RNA viruses is characterized by exploring a broad sequence space, enabling their adaptation to changing environments. Additionally, modifications in population size can further enhance diversification. Over the past years, we have collaborated with the research groups led by Esteban Domingo (CBMSO, CSIC-UAM, Madrid) and Jordi Gómez (IPBLN, CSIC, Granada) to investigate quasispecies dynamics using various RNA viruses as model systems.

In 2022, our research work using hepatitis C virus (HCV) as a model system has been focused on the concept of 'mild mutagens', which was coined to describe a minor mutagenic activity exhibited by some nucleoside analogues that potentiate the efficacy of antiretroviral agents (Martínez-González et al., in press). In parallel, we have delved deeper into the use of certain RNA virus sequences and activities as 'archaeological tools' to unveil ancient molecular relationships that may have existed in the RNA world. Such identified RNA elements could have evolved as biological signals with significant structural and functional relevance, though they had to coexist with the standard coding information of nucleic acid molecules that were established during the RNA/protein world (Ariza-Mateos et al., in press).



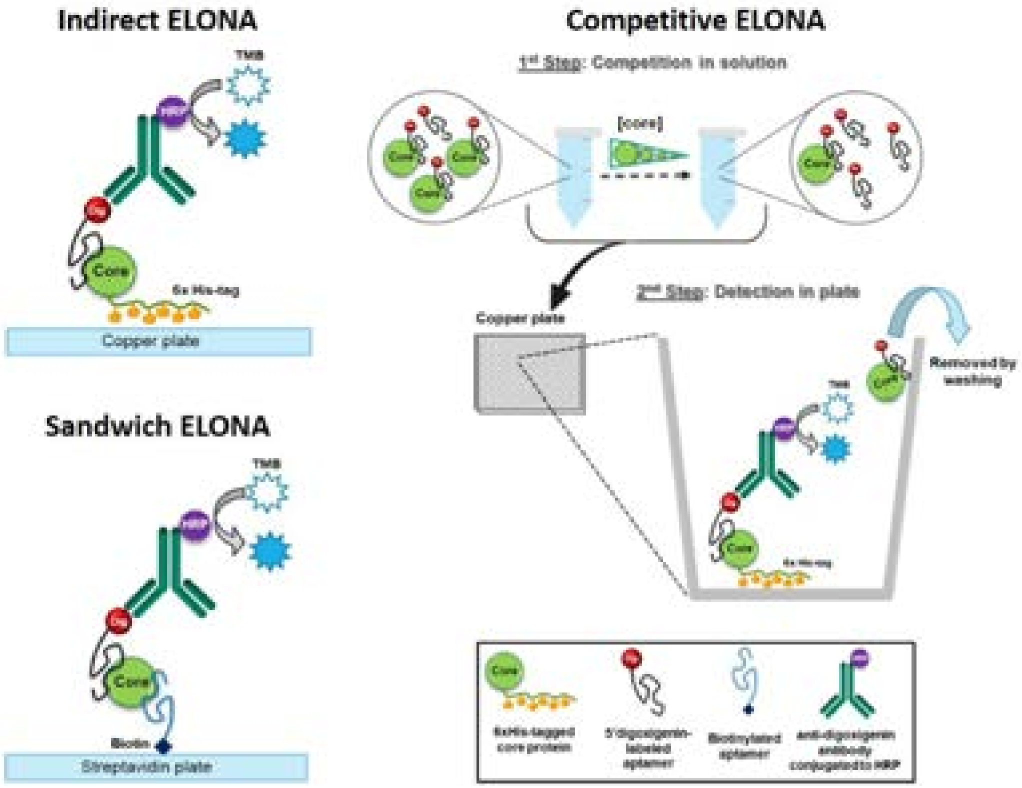
Diversity indices of mutant spectra of HCV populations in absence or presence of a mild mutagen (Martínez-González et al., in press).

Research Highlights 2022

RH3: In vitro selection of RNA and DNA aptamers against molecular targets relevant in biotechnology and astrobiology. Application to the development of aptamer-based biosensors

We have previously established and refined various systems for the *in vitro* selection and evolution of RNA and DNA molecules, with a specific focus on generating aptamers against diverse targets of interest in the fields of biotechnology and astrobiology. During 2022, our efforts were dedicated to characterizing DNA aptamers targeting conserved peptides found in metal-binding proteins. These aptamers hold significant potential for the development of biosensors capable of detecting biomarkers in extreme environments, useful in planetary exploration (Blanco et al., in preparation).

Also, we have completed the functional characterization of high affinity RNA and DNA aptamers against six different variants of HCV core protein: two versions of the full-length protein of genotype 1, and the hydrophilic domain of genotypes 1 to 4. A group of aptamers with nanomolar or subnanomolar Kd values were the common outcome of DNA and RNA selections against different HCV core variants. They were tested in sandwich and competitive, ELONA-based biosensor assays, reaching a limit of detection for HCV core of 2 pM. Additionally, the two most prevalent and high affinity aptamers decreased the viral progeny titer and the extracellular viral RNA level, while increasing the amount of intracellular viral RNA in HCV cell culture (Torres-Vázquez et al., 2022). In collaboration with research groups from the International Iberian Nanotechnology Laboratory (INL, Braga, Portugal), Institute of Physics (Czech Academy of Sciences, Prague, Czech Republic) and Institute of Materials Science of Madrid (ICMM, CSIC), the anti-HCVcore aptamer which exhibits the highest affinity and specificity for its target has been used as a molecular probe in the development of graphene-based aptasensors. These aptasensors demonstrate remarkable attomolar (10^{-18} M) sensitivity for detecting the viral protein (Palacio et al., 2023).



Colorimetric, ELONA-based biosensing formats used to functionally characterize anti-HCVcore aptamers, with applicability to other molecular targets relevant in biotechnology and astrobiology: indirect, sandwich and competitive (Torres-Vázquez et al., 2022).

Microbial Diversity

Group coordinator: Ángeles Aguilera Bazán

Senior Researchers	Technicians
Cristina Cid Sánchez	Graciela de Diego
Elena González-Toril	Eva García López
	Thalia Parro Dávila

Summary

This group contributes to objective “O5. To understand the basic principles of life in planetary environments, its early evolution and adaptability to diverse and often extreme conditions”, of Center Strategic Plan by addressing the question of how metabolic diversity has occurred as well as its molecular adaptations to the extreme environmental physicochemical parameters. The following research highlights exemplify the most relevant investigations and results in the group.

Research Highlights (RH) 2022

RH1: 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.

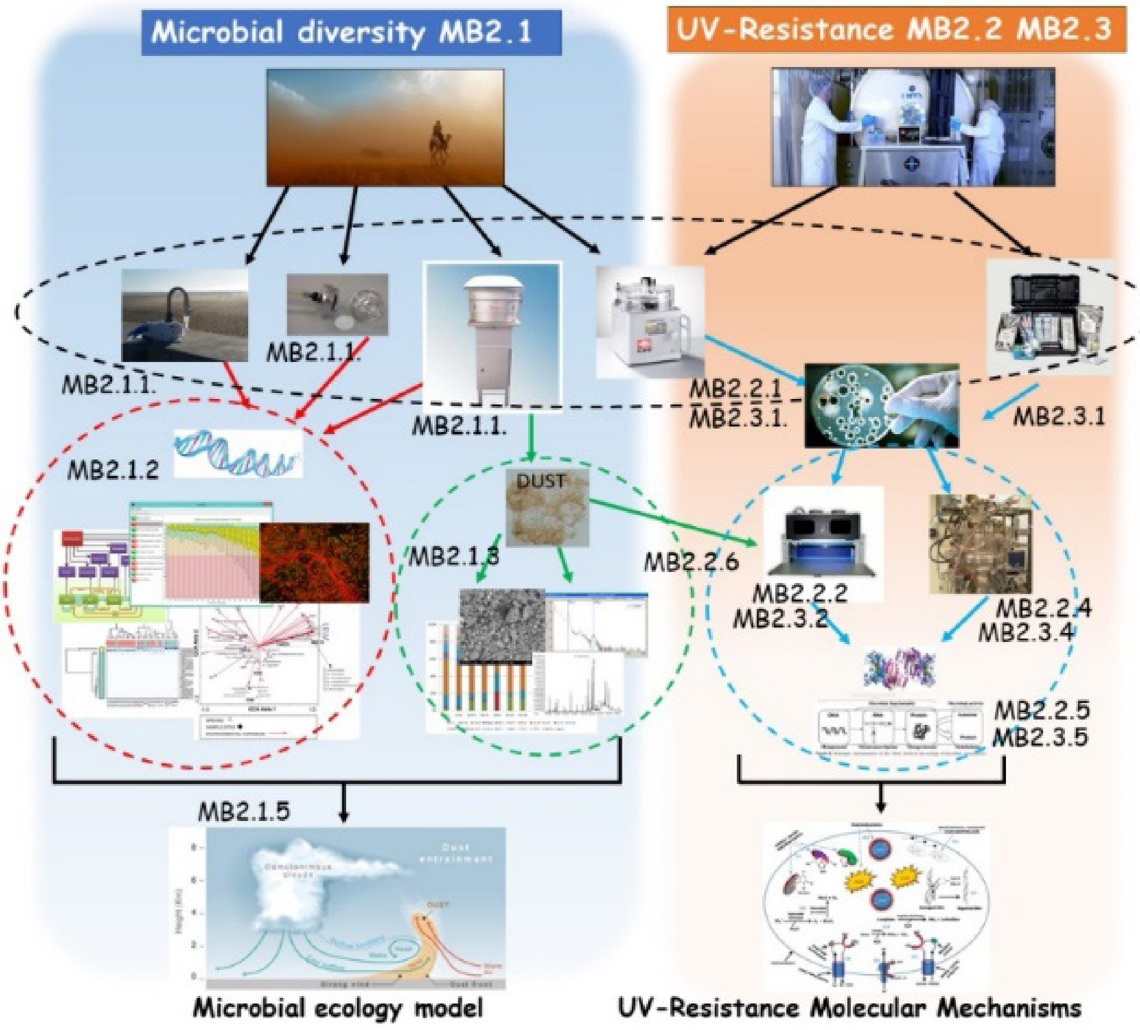


Fig. 1. Workflow in the analysis of atmospheric ecology.

RH2 Bacterial molecular machinery in Martian conditions (CAMELIA-MICRO)

The exploration of Mars is one of the main objectives of space missions since the red planet is considered to be, or was in the past, potentially habitable. Until now, experiments have been carried out on the survival of microorganisms in Martian conditions, but it remains unknown how their adaptation mechanisms are to these harsh environmental conditions (Garcia-Descalzo et al., 2022). In this work, two bacterial species were subjected to Martian conditions using a planetary simulation chamber. Afterward, the molecular machinery of both species was studied to investigate how they had been modified. These results are especially important due to their implications for planetary protection, missions to Mars and sample return since contamination by microorganisms would invalidate the results of these investigations.

RH3: Microbial ecosystem in the perennial ice from ice caves (ORCHESTRA)

Over the last years, perennial ice deposits located within caves have awakened interest as places to study microbial communities since they represent unique cryospheric archives of climate change. Since the beginning of the twentieth century, the temperature has gradually increased, and it is estimated that by the end of this century the increase in average temperature could be around 4ºC. In this context of global warming the ice deposits of the Pyrenean caves are undergoing a significant regression. These types of caves house microbial communities which have so far been barely explored, and therefore their study is necessary. In this work, the microbial communities of the Pyrenean ice cave A294 were identified using metabarcoding techniques. In addition, research work was carried out to analyze how the age and composition of the ice affect the composition of the bacterial and microeukaryotic populations. Finally, the ***in vivo*** effect of climate change on the cellular machinery that allow microorganisms to live with increasing temperatures has been studied using proteomic techniques (Ruiz-Blas et al., 2023)

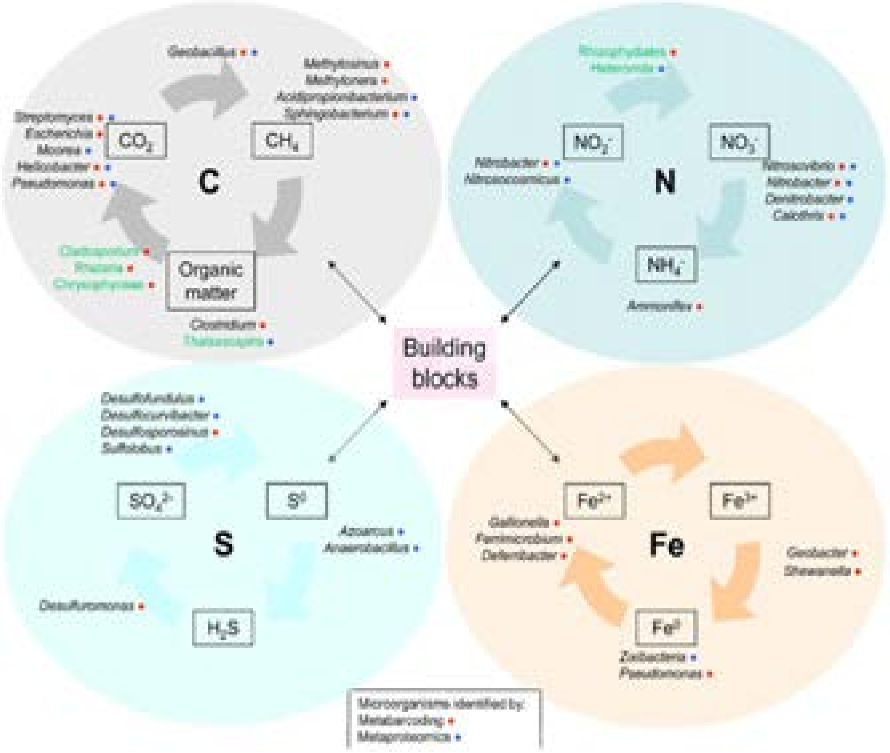


Fig. 2. Model of the metabolic potentials between dominant microorganisms in the ice cave.

RH4: Endolithic microorganisms in Antarctic volcanic rocks

The volcanic Antarctic environment is an excellent analogue of the icy worlds of the solar system.

The most active volcanic islands in Antarctica, constitute a wasteland of ice and rock formed by pyroclasts, such as ash, lapilli and other volcanic debris. The combination of all these factors makes the microbial community that inhabits the area unique and worthy of study. This work studied the composition of the microbial community living on Antarctic volcanic rocks and their survival mechanisms, and analyzed them as a possible model for astrobiological exploration, especially focusing on the bacteria and microeukaryotes that live inside the volcanic rocks.

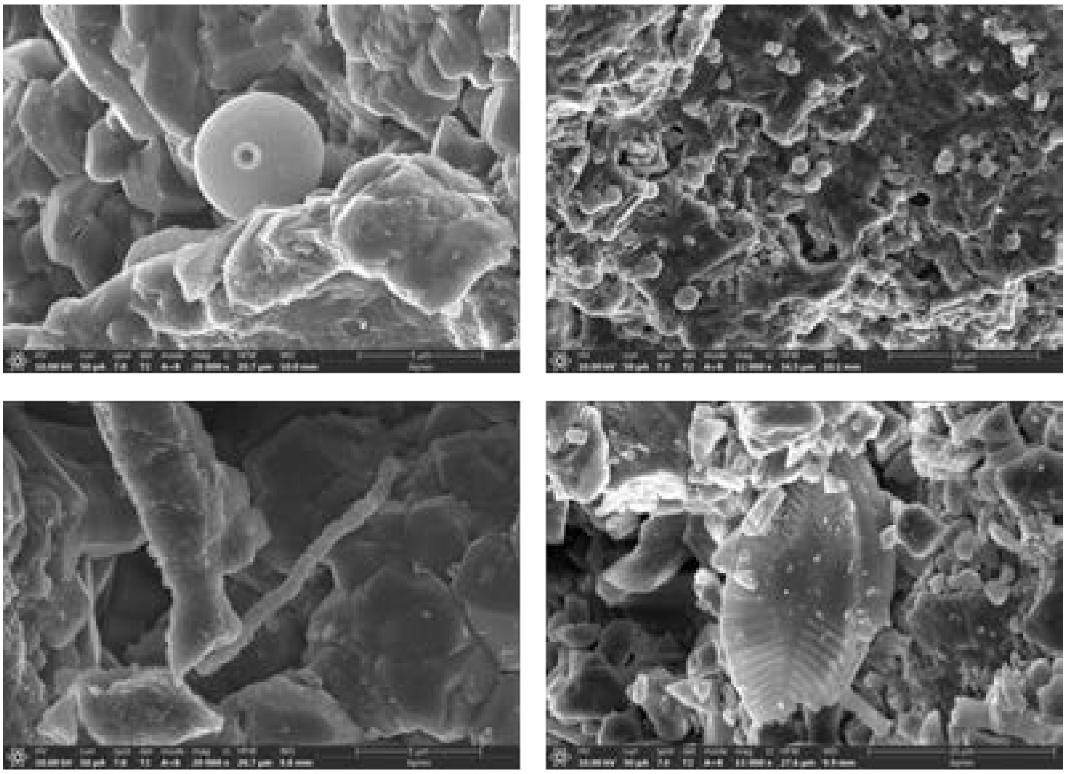


Fig. 3. Scanning electron microscopy images of endolithic microorganisms in Antarctic volcanic rocks.

RH5: Microbiological Control in the Formation of Mineral Deposits (MINLIFE)

MINLIFE seeks to understand the role the role played by subsurface microorganisms in the genesis of secondary mineral deposits, using one of the best secondary mineral deposit examples: the supergene alteration zone of the Las Cruces volcanogenic massive sulphide located at the contact between a Paleozoic basement (Upper Devonian-Lower Carboniferous) and the Miocene sediments of the Cenozoic Miocene sediments of the Guadalquivir Basin, at about 250 m depth. From the microbiological point of view, the ecosystems found in the subsoil are mainly supported by methanogenic archaea and sulfate-reducing bacteria (Sulfate-producing sulfate-reducing bacteria (SRB). This assumes that methane production and sulfur reduction are the most important metabolic pathways in this ecosystem and the main responsible for the precipitation of sulfate complexed heavy metals. While this occurs in the anaerobic zones, in regions where oxygen is filtered, sulfur is oxidized to sulfate by sulfur-oxidizing bacteria (SOB) and methane oxidized by methanotrophic bacteria. Microscopic analysis, Secondary Ion Mass Spectrometry, as well as biomarker analyses has demonstrated the existence of a thriving microbial community, both living and fossilized, associated with the mineralization, providing direct and indirect evidence of the important biological control throughout the secondary mineralization. The fossil prokaryotes encountered were preserved due to a massive precipitation event that was probably promoted and indirectly accelerated by biological activity.

Fig. TEM micrograph of bacilli found in the mineral cementation zone at Las Cruces mine.

Molecular Mechanisms Of Biological Adaptation

Group coordinator: José Eduardo González-Pastor

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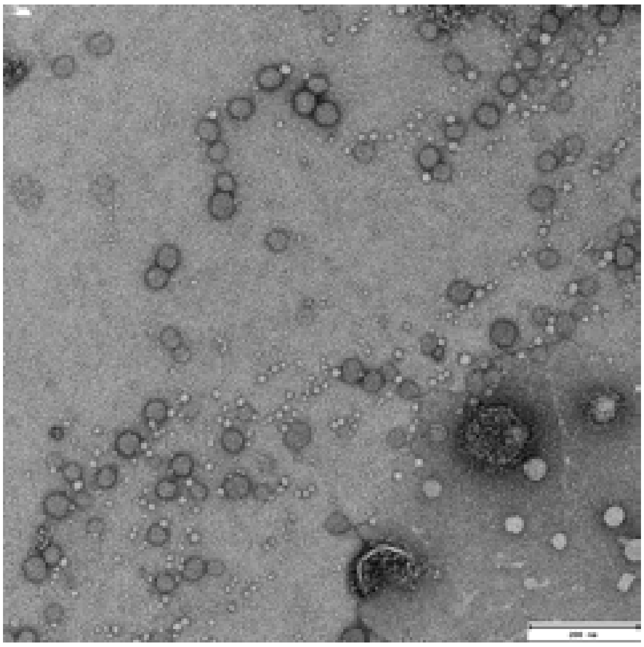
Summary

Microorganisms that inhabit extreme environments (extremophiles), have developed complex molecular mechanisms that allow them to survive in these conditions. The research in this group is focused on the discovery and characterization of new molecular adaptation mechanisms from extremophiles, more specifically those that thrive in hypersaline environments considered analogous to Mars and icy satellites such as Europa (Jupiter) and Enceladus (Saturn) (contribution to objectives O3.2 and O5.6 of CAB Strategic Plan). A major problem is that a high percentage of environmental microorganisms cannot be cultivated or there are no molecular tools for their genetic manipulation, and therefore their study is impossible. Thus, this group is using culture independent techniques, such as metagenomic sequencing, functional metagenomics and metatranscriptomics, which allow access to 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. In addition, they are also exploring the design of microorganisms and plants that are more resistant to the conditions of space or other planetary bodies, by expressing in them resistance genes isolated from extremophiles (contribution to O5.7 of the Strategic Plan).

Currently, this group is researching in: i) molecular mechanisms of adaptation to salt, UV radiation and day/night cycles in microorganisms that inhabit hypersaline environments; ii) gene transfer mechanisms in extreme halophilic microorganisms, such as the square archaea *Haloquadratum walsbyi*; and iii) expression of UV and acid resistance genes in the plant *Arabidopsis thaliana*. The following research highlights exemplify the most relevant investigations and results in the group.



DNA-containing extracellular vesicles produced by the extreme halophilic archaea Haloquadratum walsbyi

Research Highlights 2022

RH1: tRNA modifications regulate salt adaptation in extreme halophilic archaea, and affect the functionality of microbiomes

It is thought that perchlorate may promote the formation of perchlorate-rich salt liquid brines on Mars, which could be niches for extreme halophilic microorganisms. In previous studies, we identified several molecular mechanisms that confer tolerance to perchlorate in extreme halophilic archaea, such as tRNA modifications, and we observed that these mechanisms may also increase the tolerance towards low salinity conditions. We have analyzed the role of the tRNA modification archaeosine, which reduced both perchlorate and low salinity tolerance when its biosynthesis was increased (Figure 1). Therefore, we propose archaeosine modification as a novel mechanism that regulates adaptation to salinity in halophilic archaea.

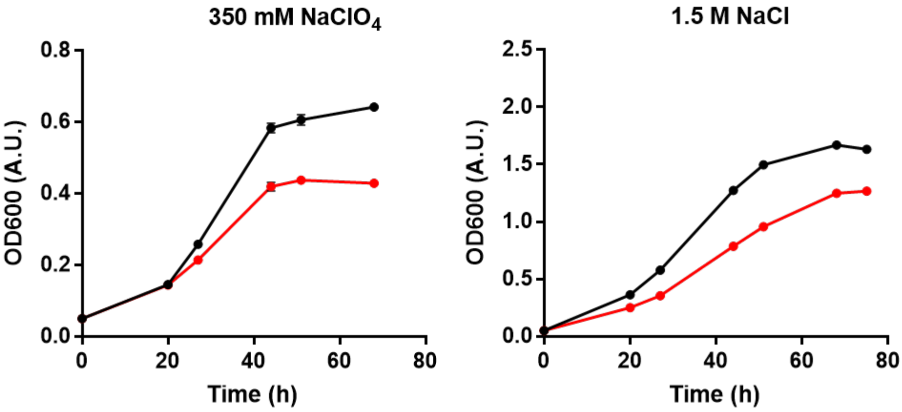


Fig. 1. Growth curve of *Haloferax volcanii* overexpressing archaeosine synthase gene (red) or harboring empty plasmid (black) incubated in YPC medium at 42 °C, at standard salinity (2.4 M NaCl) or in low salinity conditions (1.5 M NaCl).

In a second project, we studied the role of queuosine (Q), another tRNA modification present in bacteria and eukaryotes. We proposed tRNA Q-modification as a new mechanism that regulates adhesion, biofilm formation and virulence in bacteria. Q availability would depend on the bacterial species that form a microbial community. We observed that certain species produce Q (Q-sources) or use the Q produced by other bacteria (Q-sinks). Considering the relevance of Q in adhesion and biofilm formation, the functionality of a microbiome would be conditioned by an adequate balance between Q-source and Q-sink populations. Alterations in this balance would affect the Q availability and thus the dysregulation of Q-related processes in a microbiome.

RH2: Study of the effect of light and dark on gene expression in *Salinibacter ruber*

Previous results of the effect of day and night cycles on gene expression from hyperhalophilic microbial communities revealed an opposite night-day expression gene pattern between *Salinibacter ruber (Sal. ruber)* and *Haloquadratum walsbyi (Hqr. walsbyi),* as well as a decrease on *Sal. ruber* growth under light exposition. According to these results, a new transcriptomic analysis were carried out in order to study light and dark effect on *Sal. ruber* in laboratory conditions, eliminating natural competition. For this purpose, multiple cultures of *Sal. ruber* were grown under constant light and dark conditions, and samples were taken at 8 and 24 hours of growth. RNA was extracted from the samples, converted to cDNA and sequenced (RNA seq). Genes with differential expression were identified and classified in COG Groups (Figure 2). We observed that *Sal. ruber* grows better and faster under constant dark conditions, with a high number of genes induced at 8h of growth, and stabilisation of major functions at 24h. However, an increase in induction could also be observed at 24h after exposure to constant light, suggesting that *Sal. ruber* is able to activate its main metabolic functions in the presence of light. This may be due to decreased competition with other microorganisms such as *Hqr. walsbyi* under adverse conditions, which enables its growth, albeit at a slower rate.

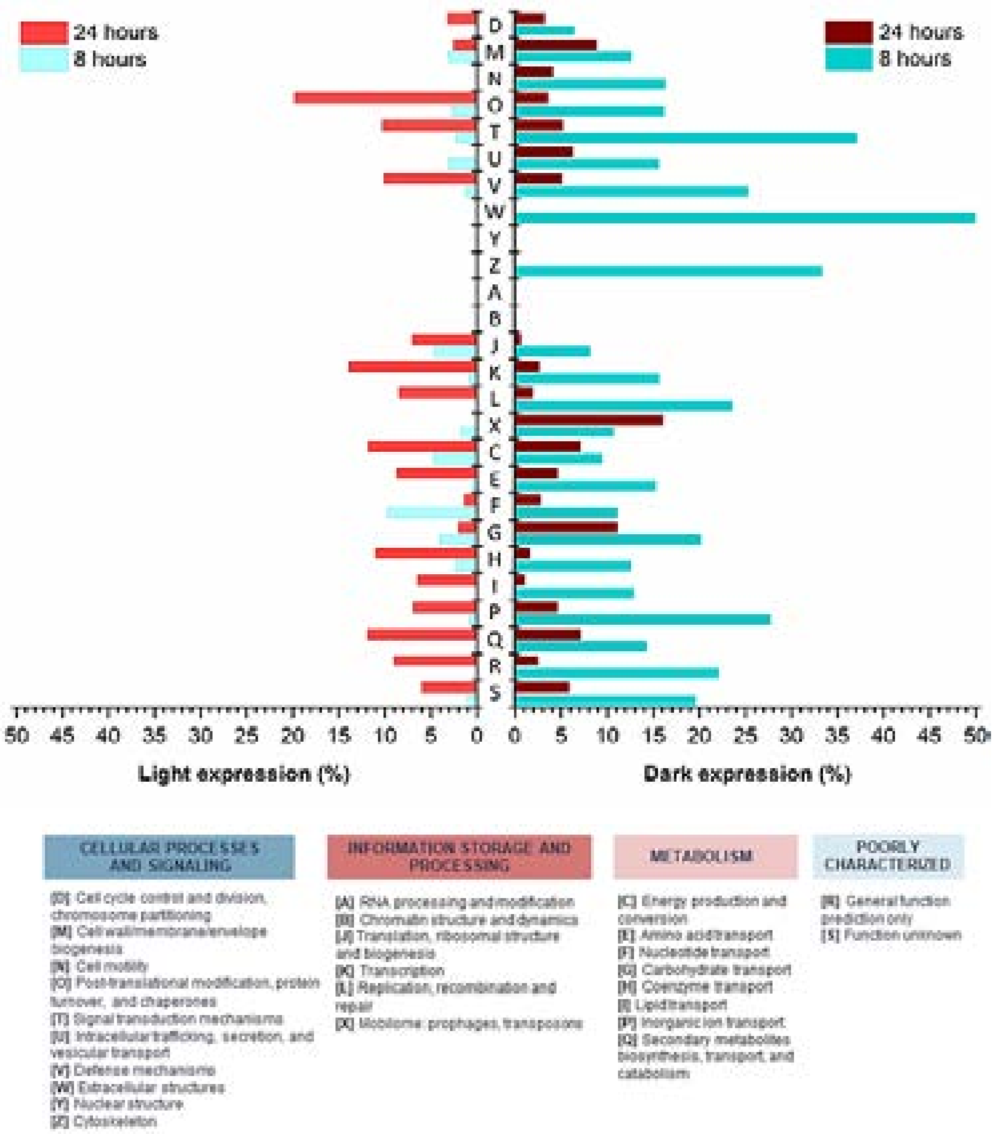


Fig. 2. Functional profile of dark and light induced genes at 8 hours and 24 hours in Salinibacter ruber based on COG categories. Data represented as a percentage of significantly induced genes out of the total genes of each functional category. The standardization was performed as the number of genes differentially expressed assigned to each COG category divided by the total number of genes assigned to each COG.

RH3: 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. Using fluorescence microscopy, we observed that, when cultures of the strain DSM16790 were entering into stationary phase (A600nm= 0.16-0.22), many particles much smaller than cells started to appear, which intensely stained with green fluorescence using the bacterial viability kit LIVE/DEAD™ BacLight™ Invitrogen (Figure 3), suggesting that they contain genetic material protected by a functional membrane. Transmission electron microscope revealed these particles were about 50 nm in diameter and potentially surrounded by membranes (Figure 3). Sequencing of their DNA showed that they contain both genomic and plasmidic DNA from *Hqr. walsbyi.* Proteomic analyses of EVs shows an apparent enrichment (when compared with the global proteome) in proteins implied in functions such as translation, energy production and conversion (including bacteriorhodopsins and electron transport chain proteins) and amino acid transport and metabolism. Also present are photolyases which protect DNA from ultraviolet radiation damage, FtsZ and homologues of Vps4 proteins from *Sulfolobus,* which have been also detected before (and though to be key) in EVs produced by other *Euryarchaeota.* All these proteins could contribute to the maintenance of an active 'metabolism' in the vesicles and protection of their biological cargo. The presence of EVs produced by Hqr. walsbyi has also been detected indirectly in natural samples coming from Santa Pola salterns, in which this archaeon coinhabits with other microbial species. This suggests that their production is not a mere artefact of its growth under laboratory conditions and supports the possible biological relevance of the production of these vesicles. This phenomenon, undescribed until now for *Hqr. walsbyi,* 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). 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.

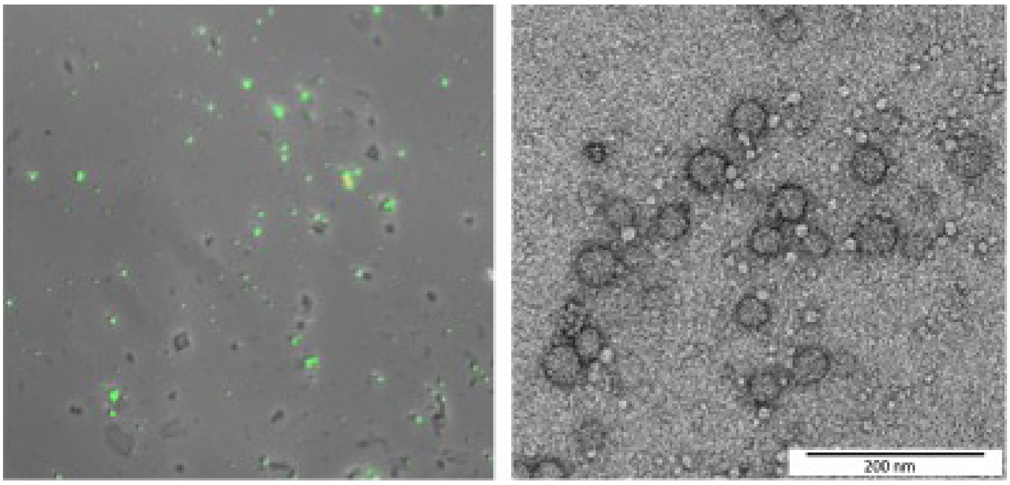


Fig. 3. Left: Fluorescent microscopy image of *Haloquadratum walsbyi* (DSM 16790) cells and vesicles labelled with Life/Dead staining. DNA from live cells and vesicles (small fluorescent dots) were labelled in green. Right: Transmission electron microscopy image of vesicles isolated from the culture.

RH4: Cold plasma for surface sterilization and improvement of plant growth

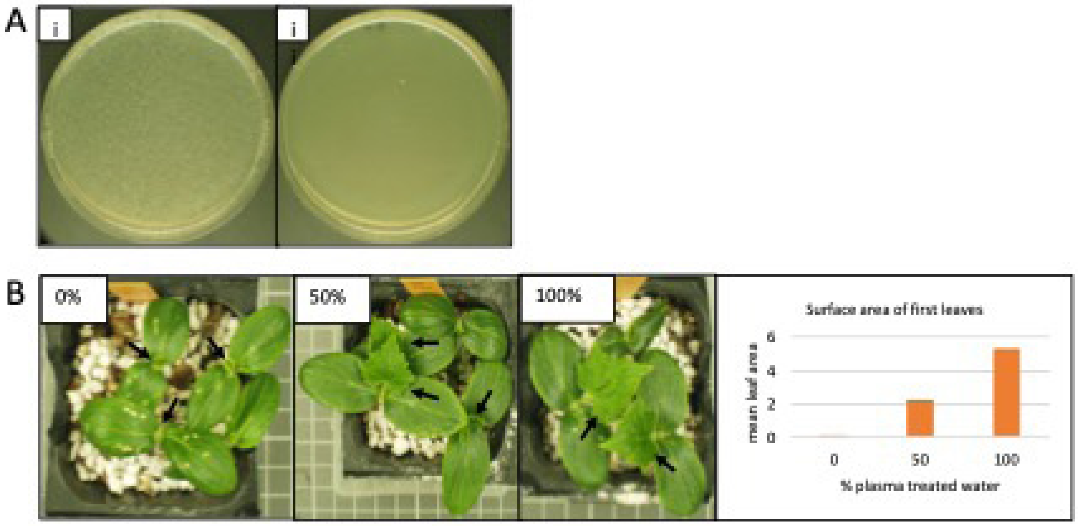
Plasma is the fourth state of matter similar to the gaseous state but where most of the particles are ionized, so they are great electrical conductors, and have their own characteristics. In a joint project with the INTA Plasma laboratory (belonging to the Flight Physics Department) we are studying various uses:

1.- Germicidal action. Use of cleaning white rooms, material that is going to be sent into space or even cleaning the air and surfaces inside spacecraft in manned missions. We are demonstrating and improving the germicidal action of the cold plasma actuator developed at INTA so that it is capable of eliminating bacteria, spores and yeasts in the fastest and most efficient way possible with the least energy waste. (Figure 4A)

2.- Improvement of plant growth.

a) Use of Plasma Activated Water (PAW). When plasma acts on water, like lightning in the sea, it produces nitrates, nitrites and other products that remain dissolved in it and can serve as fertilizer, improving the growth of hydroponic crops in which it is used as irrigation. (Figure 4B)

b) Direct use of plasma in plants. It is known that treatment with the plasma actuators in the early stages of plant development can favor their growth and eliminate fungi and bacteria from the seeds that could later affect them. In our case, we are studying whether this effect can be reproduced by doing the treatment in later stages of development and in a more continuous way (Figure 4C).



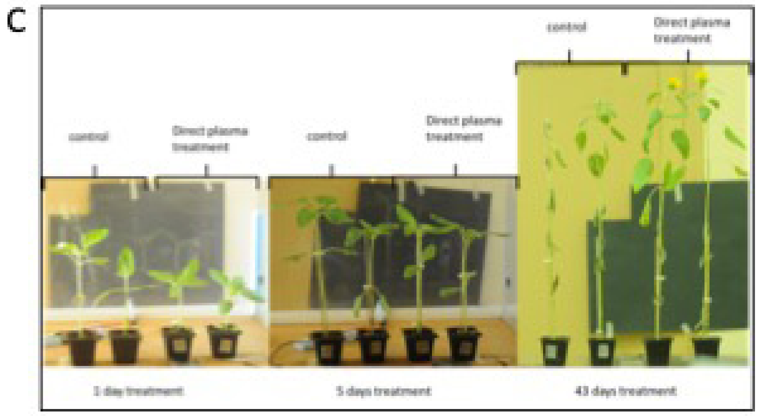


Fig. 4. A. Germicidal effect of cold plasma treatment on E. coli (DH10B). i) control without treatment; ii) irradiated 15 min with plasma. B. Plants grown for 17 days irrigated with tap water with different percentages of water treated with double polarization plasma (0%, 50% and 100%). C. Images at different times (1 day, 5 days and 43 days) of the plants directly treated with plasma compared to the untreated control plants.

RH5: Microbial diversity of a moderate salinity pond through a dilution and a concentration experiments

This ongoing study employs metagenomics and metatranscriptomic sequencing data in order to determine which salt adaptation mechanisms were differentially expressed under two different conditions of salt stress. To this end, the same brine sample was used for two laboratory experiments and subsequent high-throughput RNA sequencing. A dilution experiment was performed (denoted as BRAS2) where the salt sample was diluted from 12.4% to 7% and a concentration experiment (denoted as BRAS3) where the brine sample was concentrated from 12.4% to 17%.

The results obtained so far have revealed that as expected the bacterial fraction, rather than archaeal, accounts for a vast majority of the overall microbial diversity detected. We analyzed the microbial diversity at the phyla, genus and family levels of the genes expressed under both salt stresses. In both experiments, most of the significantly expressed genes (both induced and repressed) were related to the *Rhodobacteraceae,* an ecologically diverse alphaproteobacteria which thrives in marine environments (Figure 5). Further work is in process for deciphering the main functional adaptation mechanisms within the microbial population observed under these two conditions by using the Clusters of Orthologous Groups of proteins (COGs) analysis and comparative KEGG pathways.

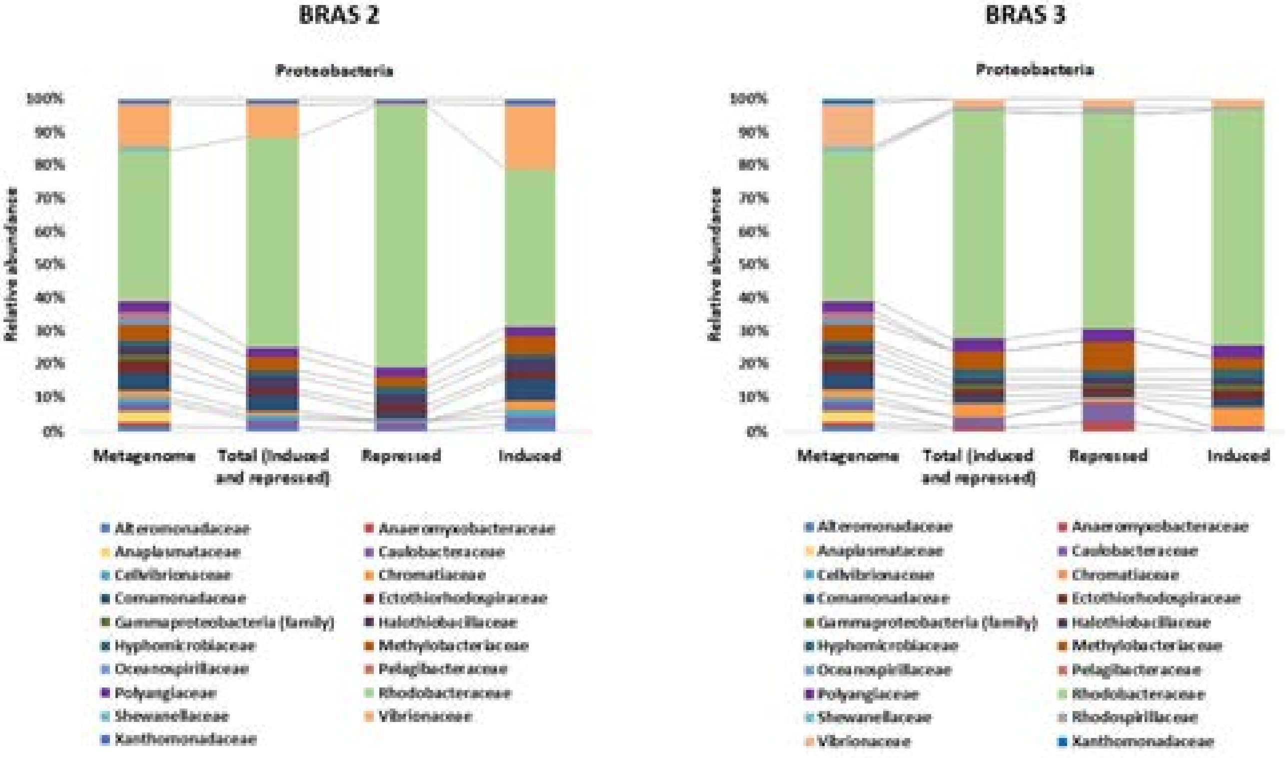


Fig. 5. Microbial diversity of metagenomic and metatranscriptomic sequences at the family level observed within the proteobacteria in both experiments. In pale green is depicted the *Rhodobacteraceae*.

Biomolecules in Planetary Exploration

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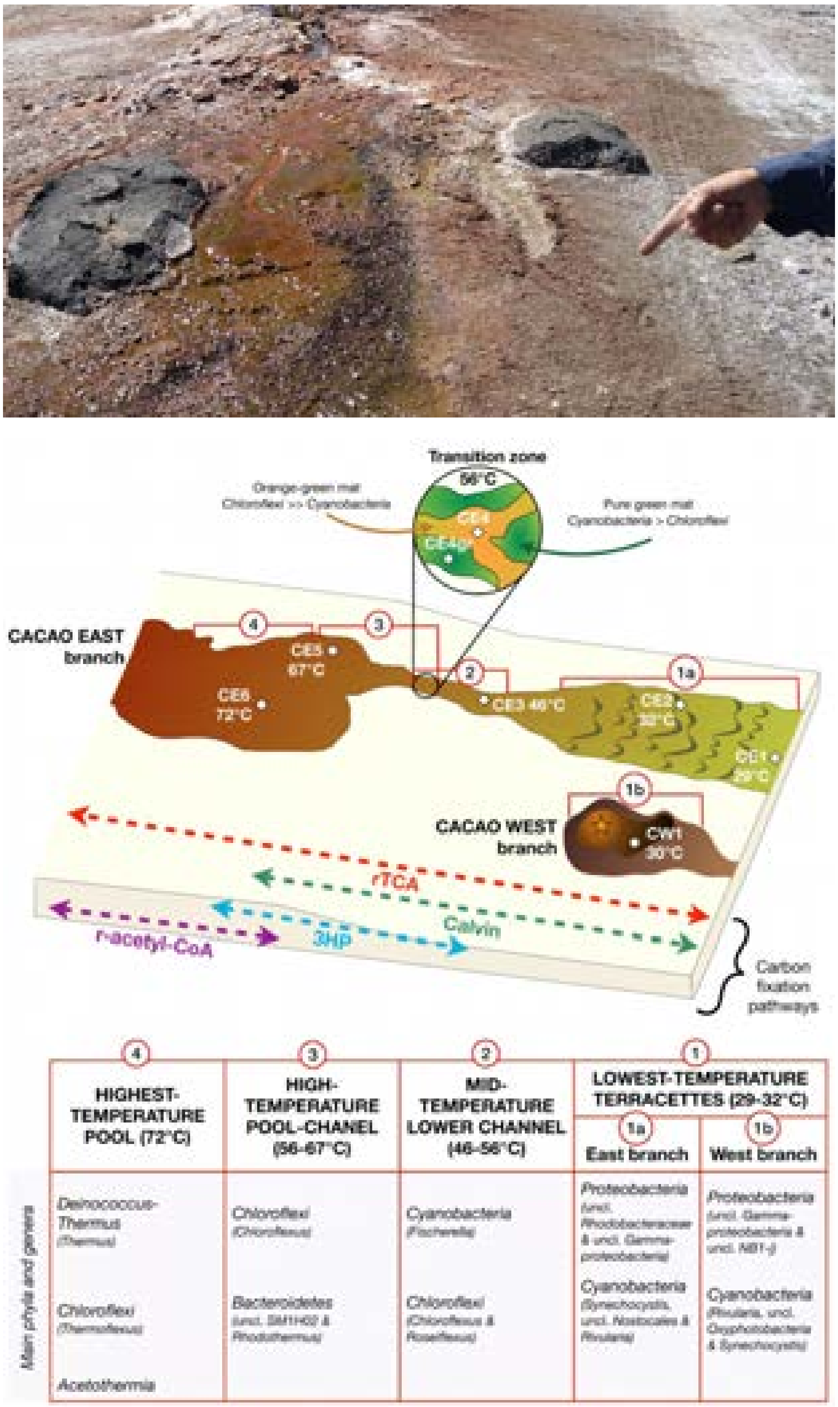
Summary

A multidisciplinary group devoted to investigating the microbial metabolic potential and the preservation of molecular biomarkers (in space and time) in terrestrial analog environments to others found in different planetary bodies. The experimental approach is based on the study of the biological material and the information it provides in situ (field campaigns) and in the laboratory, its preservation and interaction with the physical environment, the identification of molecular biomarkers, and the development of methodologies and instrumentation for in-situ detection. The objective is to infer how life could be in other planets and to design methods and strategies for detecting molecular biomarkers in planetary exploration missions and in samples brought to Earth in the future. Over 2022 the group has contributed to objectives O4, O5, and O6 of CAB's Strategic Plan with investigations such as: Identifying molecular biomarkers (lipids and proteins) associated with ancient and current terrestrial analog environments and their similarities with other worlds (O4.1); deciphering the microbial diversity and adaptation to extreme physicochemical parameters in Antarctic nunataks, as potential analogues of cold and wet early Mars (O5.4), or the implementation of sensors for in situ molecular biomarker detection in planetary exploration and potential terrestrial applications (O6.4).

Research Highlights 2022

RH1: Local calibration of lipid biomarker profiles along a hydrothermal transect to provide the template to interpret fossil records in ancient deposits analogous to Martian opaline silica structures.

Hydrothermal systems and their deposits are primary targets in the search for fossil evidence of life beyond Earth. To learn how to decode fossil biomarker records in ancient hydrothermal deposits, we must first be able to interpret unambiguously modern biosignatures, their distribution patterns, and their association with physicochemical factors. We investigated the molecular and isotopic profile of microbial biomarkers along a thermal gradient (from 29 to 72°C) in a hot spring (Cacao) from El Tatio, a geyser field in the Chilean Andes with abundant opaline silica deposits resembling the nodular and digitate structures discovered on Mars. As a molecular forensic approach, we focused on the analysis of lipid compounds bearing recognized resistance to degradation and the potential to reconstruct the paleobiology of an environment on a broader temporal scale than other, more labile, biomolecules. By exploiting the lipid biomarkers' potential to diagnose biological sources and carbon fixation pathways, we reconstructed the microbial community structure and its ecology along the Cacao hydrothermal transect. The taxonomic adscription of the lipid biomarkers was qualitatively corroborated with DNA sequencing analysis and provided a modern molecular and isotopic endmember to facilitate recognition of past biosources and metabolisms in fossilized counterparts (sinter deposits) (Megevand et al., 2022).

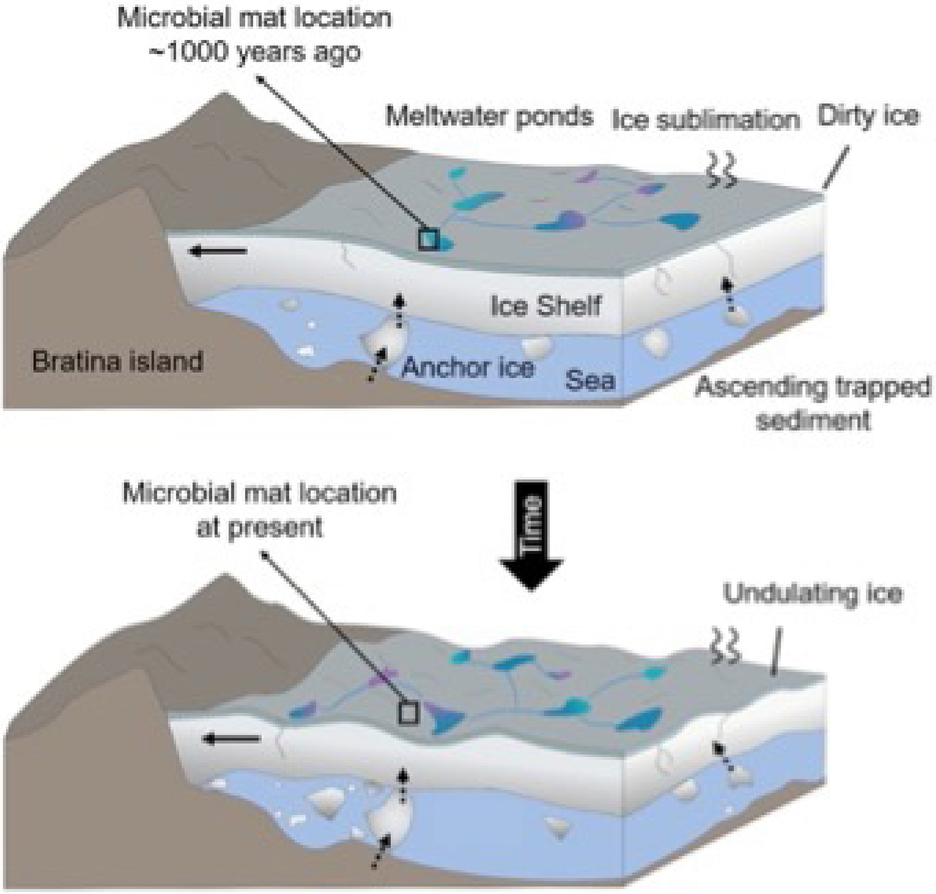


④ HIGHEST-TEMPERATURE POOL (72°C)	③ HIGH-TEMPERATURE POOL-CHANEL (56-67°C)	② MID-TEMPERATURE LOWER CHANNEL (46-56°C)	① LOWEST-TEMPERATURE TERRACETTES (29-32°C)	
			1a East branch	1b West branch
Deinococcus-Thermus (Thermus) *Chloroflexi (Thermoflexus)* *Acetothermia*	*Chloroflexi (Chloroflexus)* *Bacteroidetes (uncl. SM1H02 & Rhodothermus)*	*Cyanobacteria (Fischerella)* *Chloroflexi (Chloroflexus & Roseiflexus)*	*Proteobacteria (uncl. Rhodobacteraceae & uncl. Gamma-proteobacteria)* *Cyanobacteria (Synechocystis, uncl. Nostocales & Rivularia)*	*Proteobacteria (uncl. Gamma-proteobacteria & uncl. NB1-j)* *Cyanobacteria (Rivularia, uncl. Oxyphotobacteria & Synechocystis)*

Ecological reconstruction of the microbial community distribution along a hydrothermal transect based on lipid biomarkers and DNA sequencing.

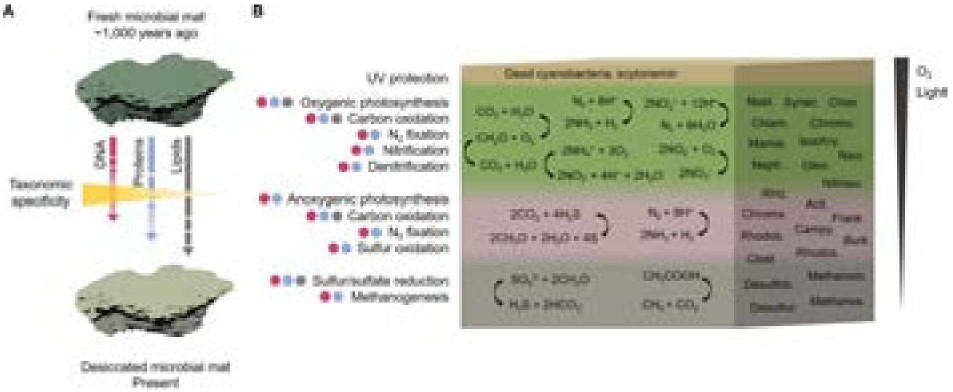
RH2: Integration of genetic, metaproteomic and lipid biomarker analyses to reconstruct taxonomic and metabolic traits of an ancient microbial mat from Antarctica.

Paleobiological reconstructions based on molecular fossils may be limited by degradation processes causing differential preservation of biomolecules, the distinct taxonomic specificity of each biomolecule type, and analytical biases. A combination of analyses of DNA, proteins and lipid biomarkers using 16S and 18S rRNA gene metabarcoding, metaproteomics and lipid extraction was used to reconstruct the taxonomic composition and metabolisms of a ~1,000 years-old desiccated microbial mat from the McMurdo Ice Shelf (MIS; Antarctica). The different lability, taxonomic resolution and analytical bias of each biomolecule type led to a distinct microbial community profile. DNA analysis showed selective preservation of DNA remnants from the most resistant taxa, whereas proteins revealed microorganisms missed by DNA sequencing, and showed a microbial composition similar to fresh microbial mats in the MIS. Lipids confirmed the presence of Cyanobacteria and suggested that of plant remnants from a period in Antarctica when the climate was warmer (Mid-Miocene or Eocene). The combined analysis of the three biomolecule types also revealed diverse metabolisms that operated before the mat desiccation (Fig. XXB). Therefore, the joint analysis of DNA, proteins and lipids resulted in a powerful approach that improved taxonomic and metabolic reconstructions overcoming information gaps derived from using individual biomolecules types (Lezcano et al., 2022). ➛



Sketch of the temporal shifts and physical processes occurring in the MIS close to the coast of Bratina Island. Horizontal black arrows in the ice shelf indicate the sense and direction of the ice compression against the coast of Bratina Island that causes the undulation of the ice.

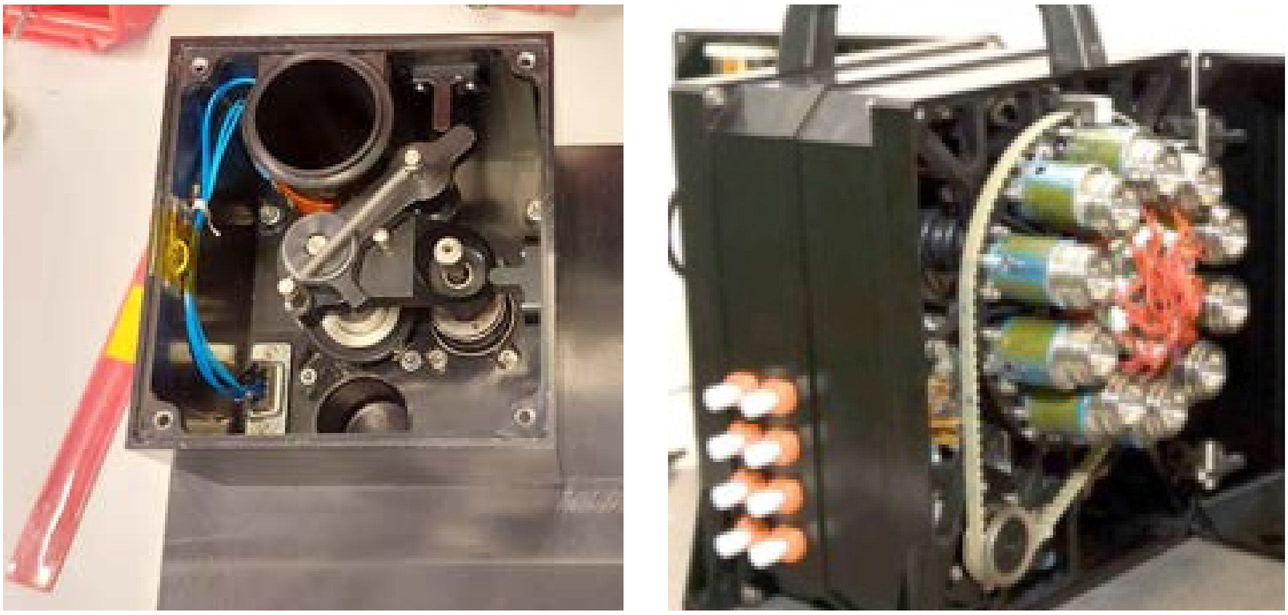
Research Highlights 2022



Reconstructive sketch of the biological composition and metabolisms that operated in the ancient microbial mat on the MIS before desiccation. (A) Temporal shift of the microbial mat from the hypothetical scenario of a fresh and photosynthetically active microbial mat ~1,000 years ago to the present desiccated state. (B) Reconstruction of the biological composition and metabolisms across a representative cross-section of the Bratina microbial mat.

RH3: Assessment of SOLID (Signs Of Life Detector) Sample Preparation Unit instrument as an Automated Nucleic Acid Extraction System for feeding the nanopore-based MinION DNA Sequencing

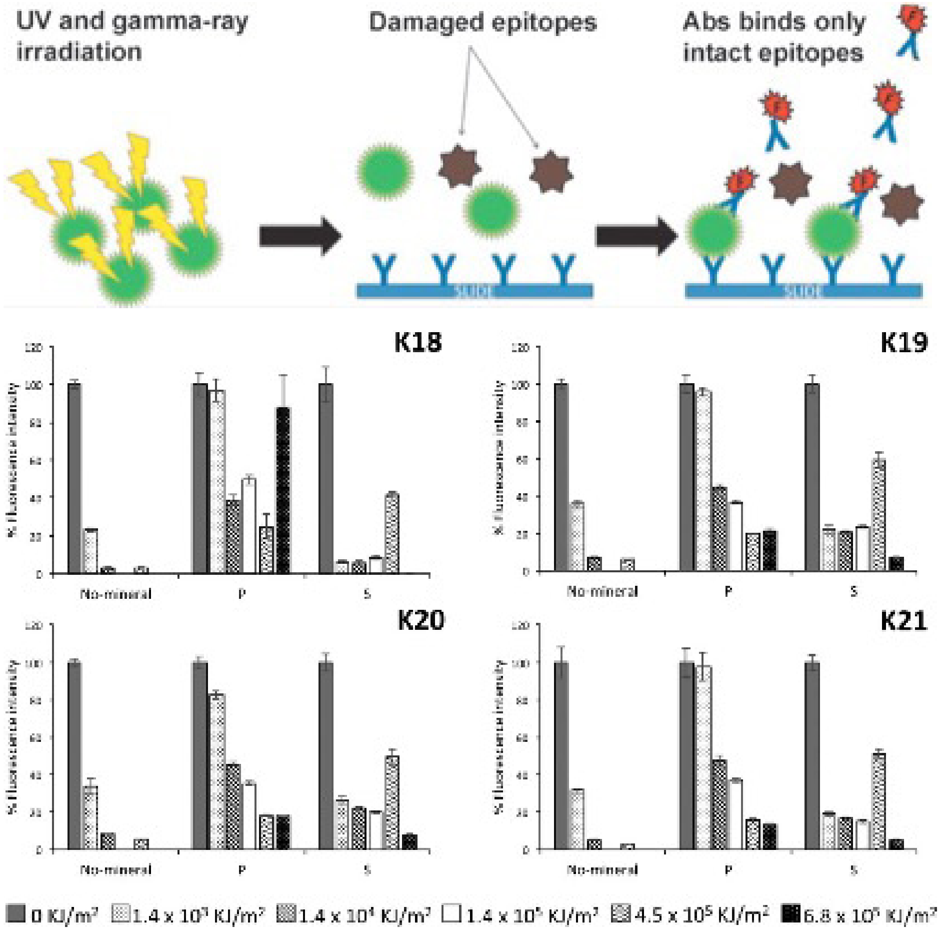
The utilization of nanopore technologies for the detection of organic biogenic compounds has garnered significant focus in recent years. Oxford Nanopore Technologies' (ONT) MinION instrument, which can detect and sequence nucleic acids (NAs), is one such example. These technologies have much promise for unambiguous life detection but require significant development in terms of methods for extraction and preparation of NAs for biosignature detection and their feasibility for use in astrobiology-focused field missions. In this study, we tested pre-existing, automated, or semiautomated NA extraction technologies, coupled with automated ONT VolTRAX NA sample preparation, and verification with Nanopore MinION sequencing. All of the extraction systems tested (SuperFastPrep2, ClaremontX1, and SOLID-Sample Preparation Unit) showed potential for extracting DNA from Canadian High Arctic environments analogous to Mars, Europa, and Enceladus, which could subsequently be detected and sequenced with the MinION. However, they differed with regard to efficacy, yield, purity, and sequencing and annotation quality. We showed that the MinION could sequence unpurified DNA contained in crude cell lysates obtained from SOLID-SPU. This is valuable for planetary exploration because purification steps are time-consuming and complicate the requirements for an automated extraction and life detection payload system. Our results indicated that SOLID-SPU can also be used for NA extraction, and with increased optimization and automation could be coupled to a larger platform incorporating nanopore detection and sequencing of NAs for life detection applications (Maggiori et al., 2022).



SOLID3.0 Sample Preparation Unit (SPU) showing its ten extraction cells (left) used for cell lysis for DNA preparation to feed MinION sequencing system. (right) a new Sample Delivery Module (SDM) prototype have been fabricated for receiving, dosing, and delivery to a single extraction cell.

RH4: Mars-like UV Flux and Ionizing Radiation Differently Affect Biomarker Detectability in the Desert Cyanobacterium Chroococcidiopsis as Revealed by the Life Detector Chip Antibody Microarray. Minerals protect biomarkers.

The effect of a Mars-like UV flux and gamma-radiation on the detectability of biomarkers in dried cells of *Chroococcidiopsis* sp. CCMEE 029 was investigated using the SOLID-LDChip fluorescence sandwich microarray immunoassay. The production of anti-*Chroococcidiopsis* antibodies allowed the immunoidentification of a reduced, though still detectable, signal in dried cells mixed with phyllosilicatic and sulfatic Mars regolith simulants after exposure to 6.8 · 10^5 kJ/m^2 of a Mars like UV flux. No signal was detected in dried cells that were not mixed with minerals after 1.4 · 10^5 kJ/m^2. For gamma radiation (^{60}Co), no detectable variations of the fluorescence signal occurred in dried cells exposed to 113 kGy compared to non-irradiated dried cells. Our results suggest that immunoassay-based techniques could be used to detect life tracers eventually present in the martian subsurface in freshly excavated materials only if shielded from solar UV. The preservation of the structural integrity of antibody target biomarkers irradiated with gamma radiation that mimics a dose accumulated in 13 Myr at 2 m depth from the martian surface, has implications for the potential detectability of similar organic molecules/compounds by future life-detection missions such as the ExoMars Rosalind Franklin rover (Billi et al., 2022).



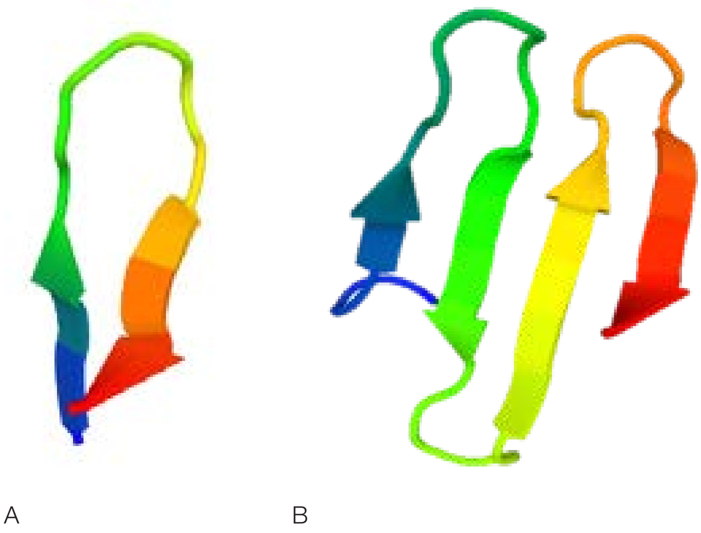
Effect of a Mars-like UV flux on the immunoidentification of target compounds from Chroococcidiopsis sp. CCMEE 029 exposed to up to 6.8 · 105 kJ/m2. The fluorescence intensity of the immunoassays of dried, irradiated cells was quantified and plotted as a function of non-irradiated dried cells, corresponding to 100%. No-mineral: irradiated, dried cells not mixed with minerals (control). S: irradiated, dried cells mixed with S-MRS. P: irradiated, dried cells mixed with P-MRS. The average intensities of six spots corresponding to each printed antibody (K18, K19, K20, and K21) are shown.

RH5: Searching for biomarkers in the early stages of life on earth and in Mars analogs

Peptides and proteins have likely a fundamental role in biology due to they were probably key molecules involved in the origin of life on Earth. To explore the transition from abiotic to biotic chemistry of proteins we are searching for universal target biomolecules as witnesses or remnants of a primitive complex pre-biochemical chemistry, such as i) hypothetical prebiotic primordial peptides; ii) well-conserved peptide sequences reported in secondary structures in proteins with relevant functions, and iii) ancestral proteins and/or peptides. We have produced antibodies and developed fluorescence immunoassays for recognizing peptides reported to be involved in the origin of proteins in the first stages of the origin of life on Earth.

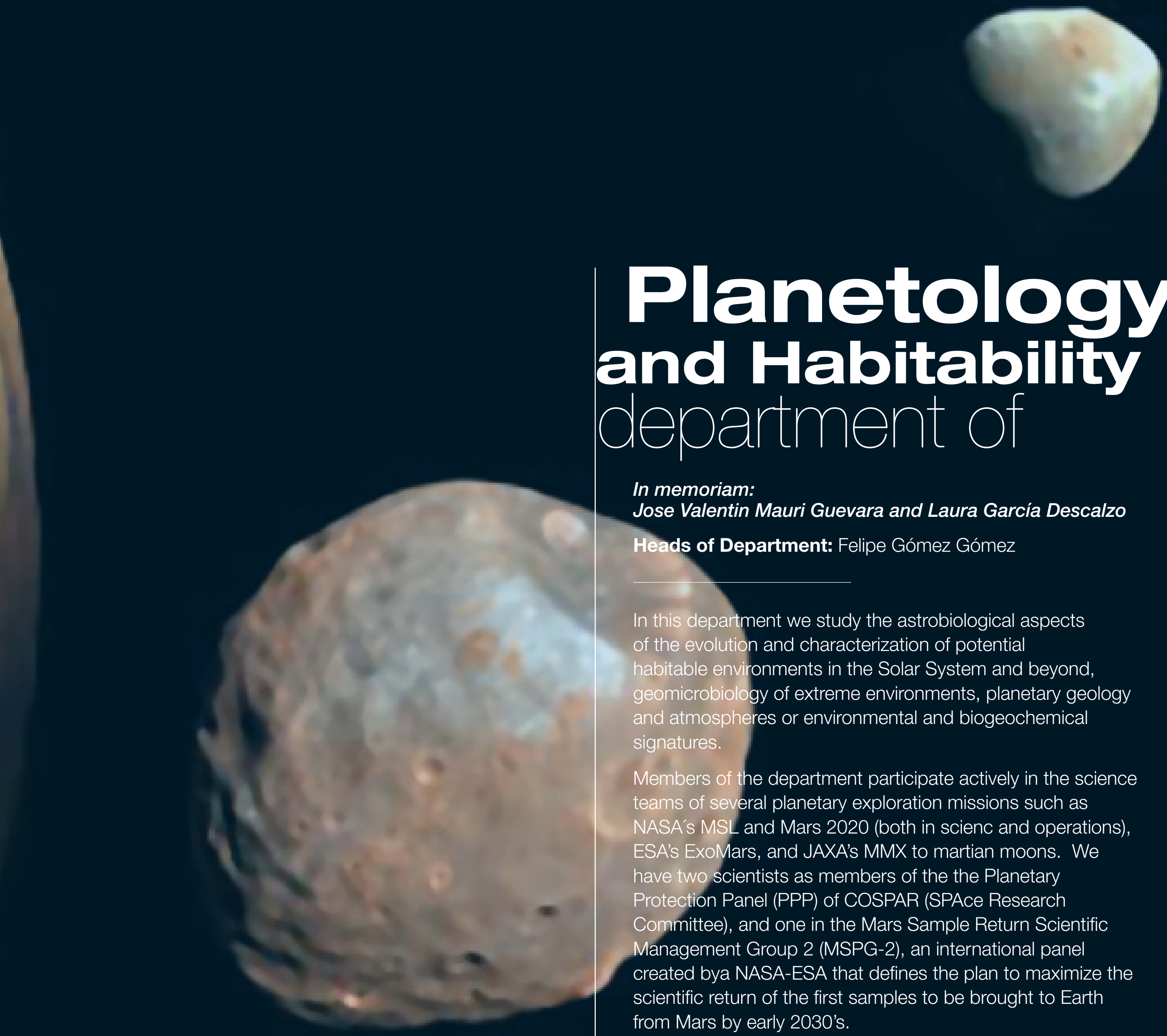
Also, we are developing experiments of prebiotic chemistry with the most abundant amino acids detected in meteorites and comets, and presumably present in the early Earth. Under the prebiotic chemistry conditions hypothetically present in early Earth, these amino acids might have led to the synthesis of small peptides that could have been key in the formation of other relevant functional peptides, and therefore, could have probably contributed to early chemical evolution as well as the formation of the first proteins. Some peptides highly conserved in nature are part of important motifs and domains in proteins, which have a particular function by themselves (ej. zinc finger). We have produced antibodies that recognize different secondary structures in proteins, such as the P-loop or the Beta-propellers that can be considered universal targets.

Finally, we have studied several ancestral proteins as possible targets for detecting and identifying peptide biomarkers in early Earth samples and Mars analog environments. Particularly, Polyclonal antibodies produced against ancestral resurrected thioredoxins and beta-lactamases were used for their detection in samples from El Tatio (Chilean Andes) early Earth hydrothermal environment analogue. These antibodies will finally implement the LDCHip with new probes to identify molecular biomarkers as proof for life in early Earth and Mars analogs as well as for future planetary exploration missions.



Examples of secondary structure of universal peptides highly conserved in nature. A) Peptide GDGDG involved in ATP binding and B) Beta-propeller peptide whose function varies based on the blade number is a universal peptide involved in motifs relevant in proteins.

Didymos and its small moon Dimorphos system Credit NASA, DART mission



Planetology and Habitability department of

In memoriam:
Jose Valentin Mauri Guevara and Laura García Descalzo

Heads of Department: Felipe Gómez Gómez

In this department we study the astrobiological aspects of the evolution and characterization of potential habitable environments in the Solar System and beyond, geomicrobiology of extreme environments, planetary geology and atmospheres or environmental and biogeochemical signatures.

Members of the department participate actively in the science teams of several planetary exploration missions such as NASA´s MSL and Mars 2020 (both in scienc and operations), ESA's ExoMars, and JAXA's MMX to martian moons. We have two scientists as members of the the Planetary Protection Panel (PPP) of COSPAR (SPAce Research Committee), and one in the Mars Sample Return Scientific Management Group 2 (MSPG-2), an international panel created bya NASA-ESA that defines the plan to maximize the scientific return of the first samples to be brought to Earth from Mars by early 2030's.

Two research groups:

- Planetary Geology and Atmospheres (PGA)
- Habitability and Extreme Environments (HEE)

Planetary Geology and Atmospheres

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María Teresa Fernandez Sampedro
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Summary

This group contributes to the objectives O3, O4, O5 and O6 of the Strategic plan by investigating the Solar system bodies: (i) Participating in the science exploitation of space missions to Mars (e.g. ExoMars, Trace Gas Orbiter, Curiosity, and Perseverance, where a researcher acts as Returned Sample Scientists), its moons (MMX, where a group member is PI of RAX instrument), small bodies of the Solar System (DART), and the Ocean Worlds of the Solar System (JUICE). (ii) Performing laboratory experiments and field work that resulted to the characterization of fluid environments of icy worlds, determine the presence of biosignature in extreme environments such as cold seeps or geothermal regions studying how lipids biomarkers and their stable isotopic composition can give us unequivocal information about the presence of life (extinct or extant) in the Solar System and exoplanets. (iii) Modeling geological processes that affect the evolution of planetary environments, such as the formation of deltas by remote sensing data interpretation, or marine impacts by computer modeling. (iv) Advising in international panels such as the COSPAR Planetary Protection Panel and the ESA Expert Group for Ocean Worlds.

The following research highlights exemplify the most relevant investigations and results in the group

Research Highlights 2022

RH1: Integration of the RAman spectrometer for MMX (RAX) instrument.

INTA contributes to the MMX mission led by JAXA with both, the Laser Assembly (RLA), and the Verification Target for the Raman spectrometer (RAX), which will be carried as part of the IDEFIX rover payload (Pertenais et al. 2022). MMX mission is a sample return mission planned to be launched in September 2024, which is going to explore the Martian Moons Phobos and Deimos. The group at CAB took the lead of RAX science in December 2021. RAX will measure signatures of the mineralogical composition of the surface material. RLA and VT were delivered to DLR in May 2022, and the full rover is being integrated at CNES to be delivered to JAXA in mid-2023.

Figure. MMX Raman spectrometer (RAX) configuration

Research Highlights 2022

RH2: Mars sample return (MSR): first in-situ characterization of the samples

The MSR program, a cooperative project between NASA and ESA, aims to collect samples from the planet's surface and send them to Earth within a decade from now. The first collection of samples has already been prepared, documented, and sealed at the base of Jezero's Crater floor. The rover's in-situ analysis at the sample extraction site has shown that the rocks of the Jezero crater are igneous (Liu et al. 2022). The rocks come from two different processes: some were formed in the depths of the subsoil from magma that cooled slowly, and present olivine crystals and the others were formed from volcanic activity that took place on the surface. These rocks, which formed the crater bed, have been exposed to different periods of interaction with the circulating water that ended up filling the lake. Specifically, two regions covered by igneous rocks have been explored in detail: the Máaz zone, where the rocks show patches of concentrated salts produced by evaporation of different brines and the Séítah zone where the samples seem to indicate the interaction with carbonated water. This suggests that water flowed in this water system intermittently (Scheller et al. 2022). These samples will be analysed on Earth to understand the evolution of Mars and its potential to host life.

Figure: View of the abrasion patch, for in-situ analysis, and the two drill holes of the samples acquired at this site. This image was acquired by the Navcam camera (Left Navigation Camera), located on the mast, on August 3, 2022 (Sol 516). Credits: NASA/JPL-Caltech

Research Highlights 2022

RH3: Arrival of DART and Hera Missions

NASA's Double Asteroid Redirection Test (DART) mission is humanity's first attempt to alter the path of a natural celestial body in space (Statler et al. 2022, Stickle et al, 2022)). Members of the group contribute to the mission by analyzing the results of the experiments. Their study show some predictions for momentum transfer based on different levels of reconnaissance. They propose strategic targeting to optimize the deflection and reduce the risk of a counterproductive deflection of asteroids in the wrong direction.

Photo from one of the EPIC (CAB CSIC-INTA) "rubble-pile" impact experiments obtained with a high-velocity video camera. It shows how embedded "boulders" in the target move in relation to the sand matrix. The crater is approximately 20cm wide- Credits: Laboratory for Experimental Impacts (CAB, CSIC-INTA). [Image modified from Ormö et al., 2022]

RH4: Molecular and isotopic lipid fingerprints in extreme environments

The group reported the molecular and isotopic lipid fingerprints in wetlands from the central Andean Puna for the first time. They found the effects of desiccation on Andean lacustrine ecosystems and the potential impact on the microbial community structure. They confirm that the molecular and compound-specific isotopic analysis of highly resistant lipid biomarkers represents a powerful tool to record those changes over time, which has great value for interpreting the paleobiology of ancient sediment deposits on Earth and beyond (Carrrizo et al. 2022b)

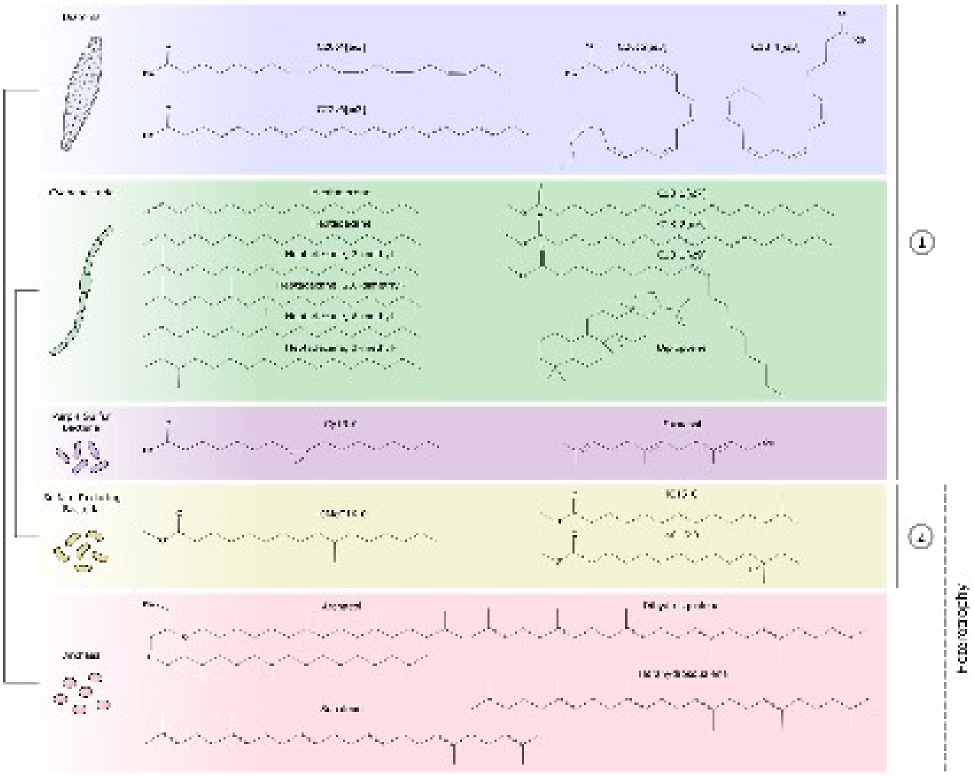

Figure. Ecological and compositional variability of the microbial community in the three saline ponds with increasing salinity, based on lipid biomarkers. The names and chemical structure of lipid compounds characteristic of five dominant microbial groups, whose phylogenetic relationships are shown at left (cladogram), are represented in colored boxes and their associated carbon fixation pathways.

RH5: The discovery of sedimentological fingerprints of magnitude of marine impacts

During the cratering process, fragments from the solid target are mixed with the seawater, and, after an initial turbulent phase, they commonly get deposited inside the seafloor crater when it is filled up by the resurging water. The group conveyed a mathematical model for the aquatic settling process of the resurge material. They assume that the finer particles mixed with water give rise to a fluid mixture in which the density and viscosity will depend on the relative water-to-solid content. This variation of the mixture's properties will cause a different settling velocity of the coarser particles, and thus different settling patterns will be observed for craters with different relative target water depths (Herreros and Ormo, 2022).

RH6: Biomimetic carbonate formation with brines, through CO_2 sequestration, under Martian atmospheric conditions.

Curiosity's Sample Analysis at Mars (SAM) instrument in Gale crater, has identified the presence of carbonates by isotopic analysis of CO_2 and O_2. This analysis determined also that organic salts, like oxalates, may have been formed in situ on Mars and preserved. To investigate possible abiotic paths for carbonate and organic salt mineral precipitation we have investigated experimentally the formation of the precipitates formed in alkaline brines of silica and other salts like $CaCl_2$, Mg and Fe sulphates (all salts which have been found by Perseverance and Curiosity rovers on Mars). We have analysed with ESEM micrographs, micro-Raman and XRD, the products of a set of reaction-precipitation experiments performed under increasing CO_2 concentration, including current Martian atmospheric conditions, with and without Martian soil analogues. The experiments confirm the formation of biomorphs, with calcium carbonates and other organic salts like oxalate, which is usually taken as indicator of biomineralization. The experiments demonstrate that many abiotic chemical processes can lead to morphological structures that may be misinterpreted as biomarkers because of their composition, size and shape (Escamill-Roa et al. 2022).

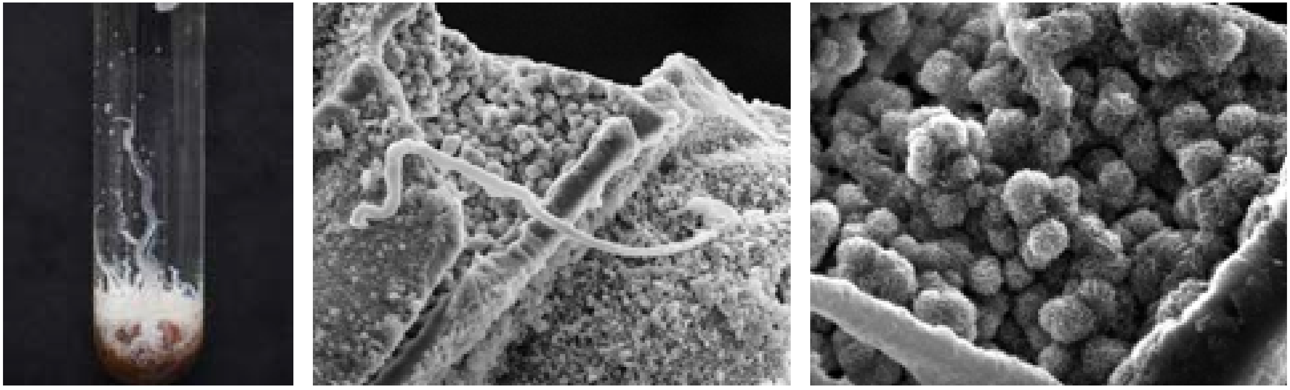

Figure 1: (Left) Growth of biomimetic silica gardens with tubular structures after 24 hours of exposure to CO_2 of a silicate solution brine with $MgSO_4.7H_2O$ and Martian soil simulant. (Centre and Right) ESEM micro-scale view of carbonate precipitates formed from silicate solutions with Martian regolith simulant in an enriched CO_2 atmosphere. Credit: Escamilla-Roa et al. (2022).

RH7: Finding how fluids behaves within icy worlds.

The presence of aqueous layers, partially or totally liquid, highly influences the bulk physical properties of icy bodies, particularly the thermal state, and consequently, the geological activity and the potential habitability over time. The group characterized the thermal budgets of aqueous environments in planetary bodies depending on the main solute composition, and quantified the heat associated with water-rich materials' phase transitions occurring during planetary evolution. The calorimetric properties of the slurries of several salt- and volatile-systems may sustain the potential habitability of icy moons and support the formation of certain surface features, in particular due to the high latent heat density and the promotion of the exothermic local growth of ice blocks that can separate from the remaining liquid (Prieto-Ballesteros et al. 2022).

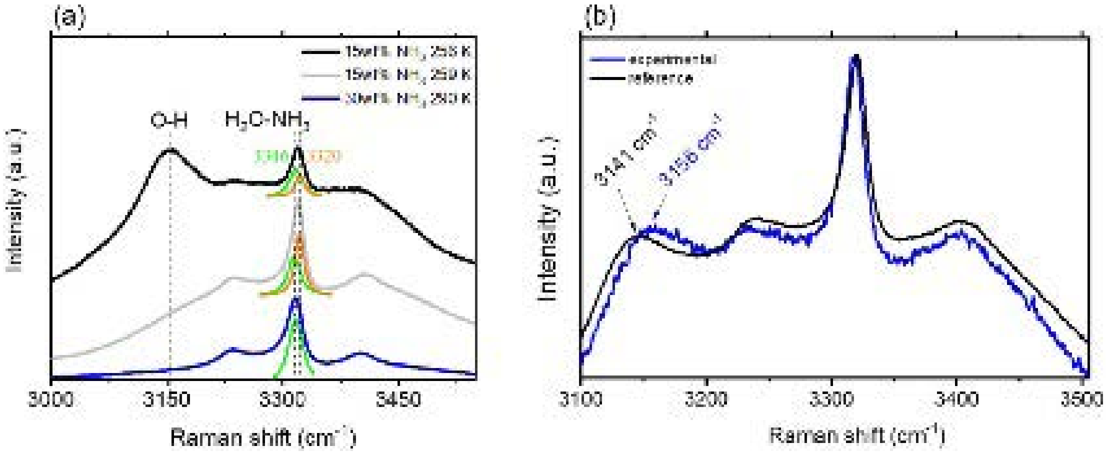

Figure. a): Raman spectra of the 15 wt. per cent NH 3 system at 259 K (completely melted) and 256 K (after the partial crystallization of pure water ice), and of the 28 wt. per cent NH 3 aqueous solution. b) Comparison of the reference spectra (calculated as the sum spectrum of water ice I h and NH 3 aqueous solution) with the experimental spectrum acquired at 256 K. Intensity is in arbitrary units (a.u.).

On the other side, the kinetics and pH evolution of the moderate low-temperature (down to 240 K) and high-pressure (up to 500 bar) chemistry of ammonia–methanol aqueous solutions in the presence of different types of carbon sources were determined. Such cryomagmas may lead to an interesting organic chemistry (Muñoz-Iglesias et al. 2022).

Regarding this topic, the group won the outstanding poster award for the work "Abiotic clathrite synthesis from CO2-clathrate under ocean world conditions" in the Europlanet Science Congress EPSC2022

Extremophiles and Habitabilty Group

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Summary

This group contributes mainly to objective 3, 4, 5 and 6 of our strategic plan, by addressing the questions of understanding the habitability of Mars (and tangentially of other Solar System bodies); to find and analyze biomarkers for the search for life on Mars; to understand the basic principles of the adaptability of life to the Martian extreme conditions; and to develop methods and advanced instrumentation for in situ exploration and characterization of Mars. The study of the habitability of extreme environments on Earth as terrestrial analogues of other planetary settings, as well as to study the adaptability of life to extreme physico-chemical parameters had been crutial issues addressed by the group during 2022, as well as the characterization the early Martian volatile budget by refining the estimated volume of volcanic infill in the northern lowlands; on the understanding of the phosphorus cycle and its and bioavailability in Archean carbonates as analogues for Martian paleoenvironments; on the effects that the presence of perchlorate salts in aqueous solutions have on habitability; on the resources needed for the exploration of planetary caves, particularly on Mars; and we have continued our work on astrobiologically exploring the Atacama Desert, the driest environment on Earth. Additionally, this group explore the fingerprints that life can leave in the medium and its tight contact with mineral world. Members of the group are part of the REMS and MEDA instrument to characterize the martian near ground atmosphere as part of the NASA`s MSL and Mars2020 missions. Over 2022 we have been working on the habitability and microbial metabolic traits of the polyextremophilic environment of severa Earth analogues as Río Tinto and the Dallol area in Ethiopia, as well as daily participation in the REMS and MEDA operations and scientific discussions. The following research highlights exemplify the most relevant investigations and results in the group:

Research Highlights 2022

RH1: Phot0, a plausible primeval pigment on Earth and rocky exoplanets

The possibilities that photosynthesis can take place on a hypothetical extrasolar planet depends on several fundamental factors, among which we can count the type of star and distance to it, that the planet orbits, and the type of atmosphere of the planet. Analysis of these parameters led us to propose a number of known exoplanets that could trigger the process of photosynthesis on their surface. This study made us think about the origin of the photosynthetic process on planet Earth. We wonder about the first photosynthetic pigments and how different they would be from the photopigments we know in today's photosynthetic organisms. We did a theoretical work on a hypothetical first pigment, simpler than those currently existing, which collects energy from solar radiation on surfaces similar to Earth, exoplanets. Our theoretical results show that geochemical conditions could exist that allow the abiotic formation of a primitive pigment that could become sufficiently abundant in the early stages of habitable rocky exoplanets. These conditions would place this pigment before the appearance of life on a very young planet, thanks to chemical routes instead of biochemical transformations. Therefore, our results may refute the currently accepted hypothesis that the complex biomolecules that allowed photosynthesis to take place were synthesized through complex and evolved metabolic pathways. Furthermore, we show that the proposed primitive pigment, which we call Phot0, is also a precursor to the more evolved pigments known on Earth today and demonstrate, for the first time, an abiotic chemical pathway leading to tetrapyrroles that do not involve derivatives of pyrrole. Our proposal places simple and highly abundant raw materials in previously unproposed geochemical conditions that lead to the formation of biomolecules of biological interest.

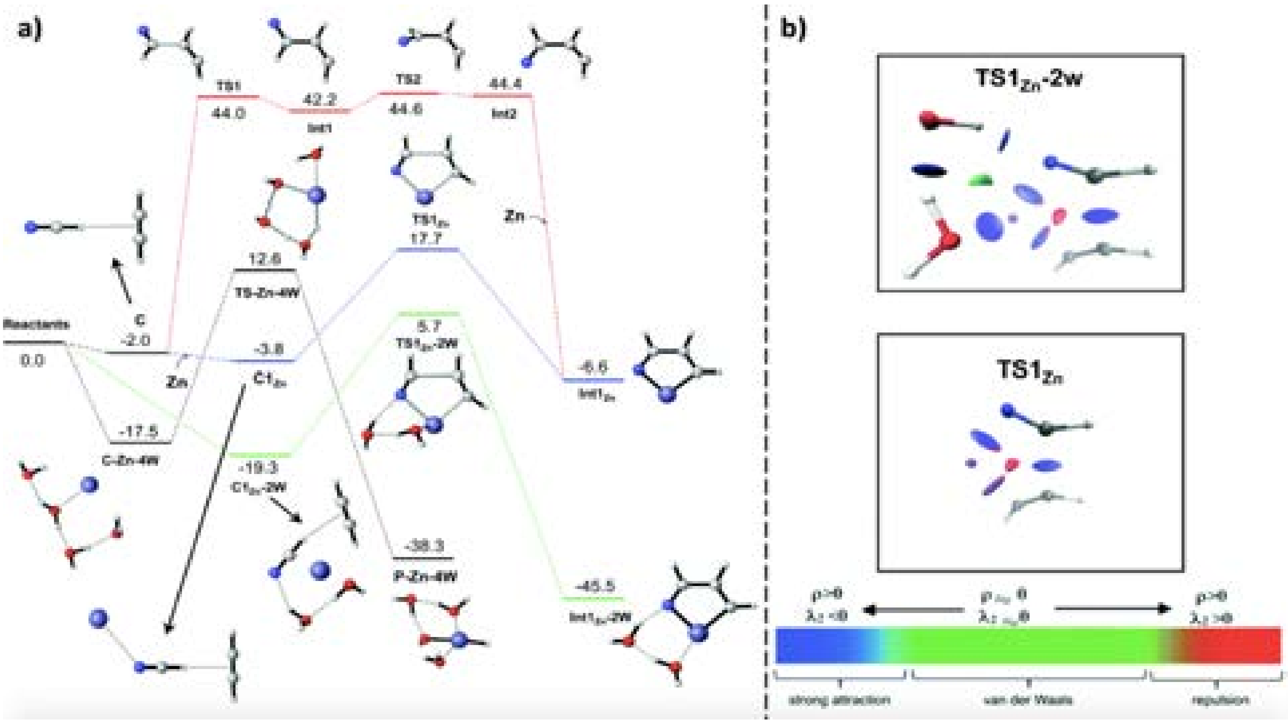


Figure RH2: (a) E + ZPE energy profiles leading to the intermediates Int1Zn, Int1Zn-2W and P-Zn-4W. Energy values are given in kcal mol−1. (b) Non-covalent interactions (NCI) in the transition structures TS1Zn and TS1Zn-2W. From de la Concepción et al., (2022)

RH2: Microbial Metabolism of Amino Acids—Biologically Induced Removal of Glycine and the Resulting Fingerprint as a Potential Biosignature

The identification of reliable biomarkers, such as amino acids, is key for the search of extraterrestrial life. A large number of microorganisms metabolize, synthesize, take up and excrete amino acids as part of the amino acid metabolism during aerobic and/or anaerobic respiration or in fermentation. In this work, we investigated whether the anaerobic microbial metabolism of amino acids could leave a secondary biosignature indicating biological activity in the environment around the cells. The observed fingerprints would reflect the physiological capabilities of the specific microbial community under investigation. The metabolic processing of an amino acid mixture by two distinct anaerobic microbial communities collected from Islinger Mühlbach (ISM) and Sippenauer Moor (SM), Germany was examined. The amino acid mixture contained L-alanine, β-alanine, L-aspartic acid, DL-proline, L-leucine, L-valine, glycine, L-phenylalanine and L-isoleucine. In parallel, an amino acid spiked medium without microorganisms was used as a control to determine abiotic changes over time. Liquid chromatography mass spectrometry (LC-MS) was used to track amino acid changes over time. When comparing to the control samples that did not show significant changes of amino acids concentrations over time, we found that glycine was almost completely depleted from both microbial samples to less than 3% after the first two weeks- This results indicates a preferential use of this simple amino acid by these microbial communities. Although glycine degradation can be caused by abiotic processes, these results show that its preferential depletion in an environment would be consistent with the presence of life. We found changes in most other amino acids that varied between amino acids and communities, suggesting complex dynamics with no clear universal pattern that might be used as a signature of life. However, marked increases in amino acids, caused by cellular synthesis and release into the extracellular environment (e.g., alanine), were observed and could be considered a signature of metabolic activity. We conclude, that substantial anomalous enhancements of some amino acids against the expected abiotic background concentration may be an agnostic signature of the presence of biological processes.

RH3: Oxidized and Reduced Sulfur Observed by the Sample Analysis at Mars (SAM) Instrument Suite on the Curiosity Rover Within the Glen Torridon Region at Gale Crater, Mars

The Mars Science Laboratory (MSL) *Curiosity* rover has been assessing the habitability and geologic history of Gale crater, Mars since landing in 2012. One of the primary objectives of the mission was to investigate a clay-bearing unit identified using orbital spectral data, designated the Glen Torridon (GT) region. This region was of particular interest because of its elevated abundance of clay minerals that may have preserved geochemical evidence of ancient habitable environments. The *Curiosity* rover explored the GT region for σ750 sols and analyzed eight drilled samples with the Sample Analysis at Mars (SAM) instrument suite using evolved gas analysis-mass spectrometry. Evolved sulfur-bearing gases provided insight about the composition of sulfur-containing compounds in Martian samples. Evolved gases were analyzed by three methods to understand the oxidation state of sulfur in the samples: (a) SO_2 evolution temperature, (b) quadratic discriminant analysis comparing SAM data to SAM-like laboratory investigations, and (c) sulfur isotope values from evolved $^{34}SO_2/^{32}SO_2$. The results of these three methods were consistent with the majority of sulfur in the GT region being in an oxidized state, but two of the eight samples analyzed by SAM were consistent with the presence of small amounts of reduced sulfur. The oxidized and reduced sulfur could have a variety of sources and represents a nonequilibrium assemblage that could have supported putative ancient chemolithotrophic metabolisms.

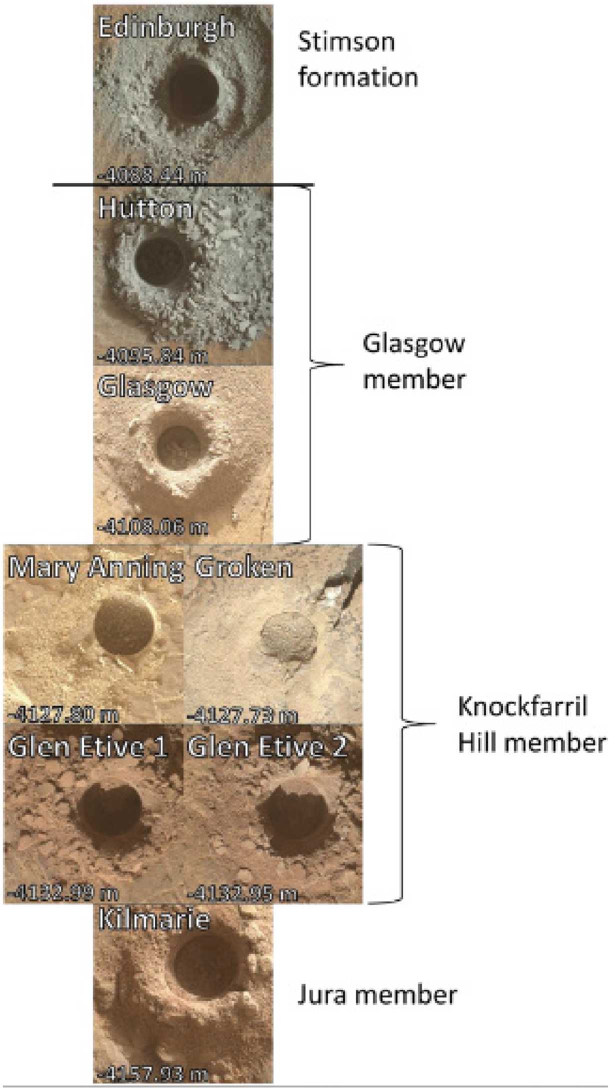
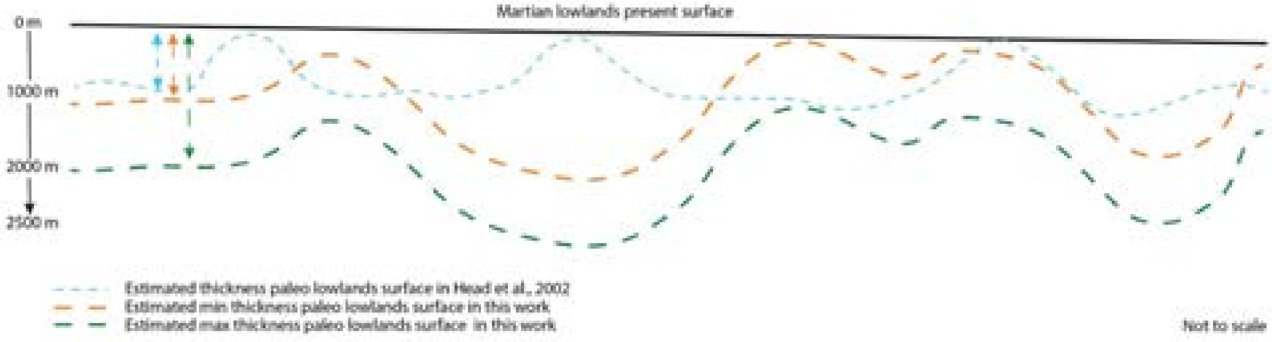


Figure RH3: Mars Hand Lens Imager (MAHLI) images of the drill holes acquired during the Glen Torridon and Greenheugh pediment campaigns. Drill holes are ordered according to stratigraphy but do not reflect true vertical distances between samples. Glen Etive 1 and 2 were drilled from the same rock for two sets of experiments. Each drill hole is ~1.6 cm in diameter. Courtesy of NASA/JPL-Caltech/MSSS. From Wong et al., (2022)

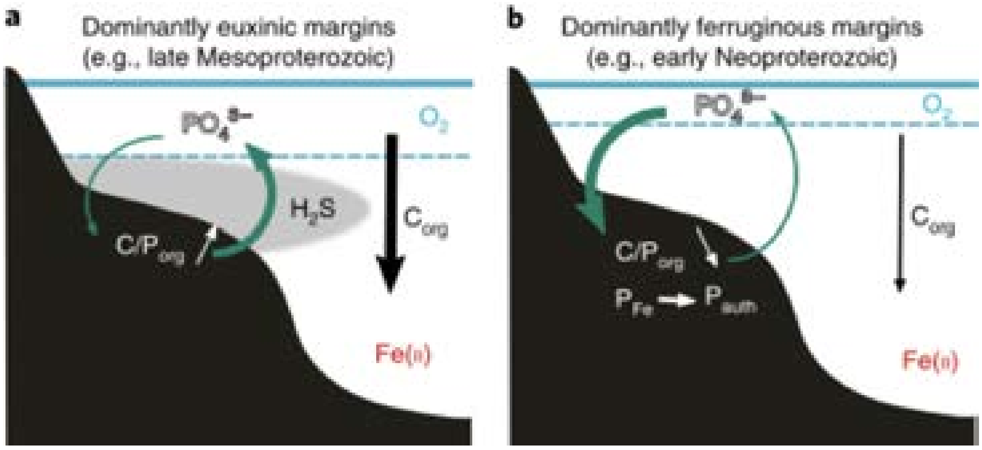
RH4: Constraining the early Martian volatile budget by refining the estimated volume of volcanic infill in the northern lowlands

This effort is of critical importance for understanding early Martian hydrology and the potential for surface and near-surface habitability. To achieve this goal, our analysis was based on the usage of geological and statistical tools that allowed to estimate the distribution of the original abundance of impact craters in the northern lowlands before they were filled and covered by younger material. Our analysis concluded that the volume of volcanic materials in the northern lowlands is at least a factor of three larger than previous estimates, which significantly increases the volume of volcanic volatiles that would have been expelled into the early Martian atmosphere as well. Our quantitative constraint allows to refine paleoclimate models of Mars, offering a first order estimate of the time-integrated volatile budget available for thickening the mid- to late Martian atmosphere and flooding the lowlands.

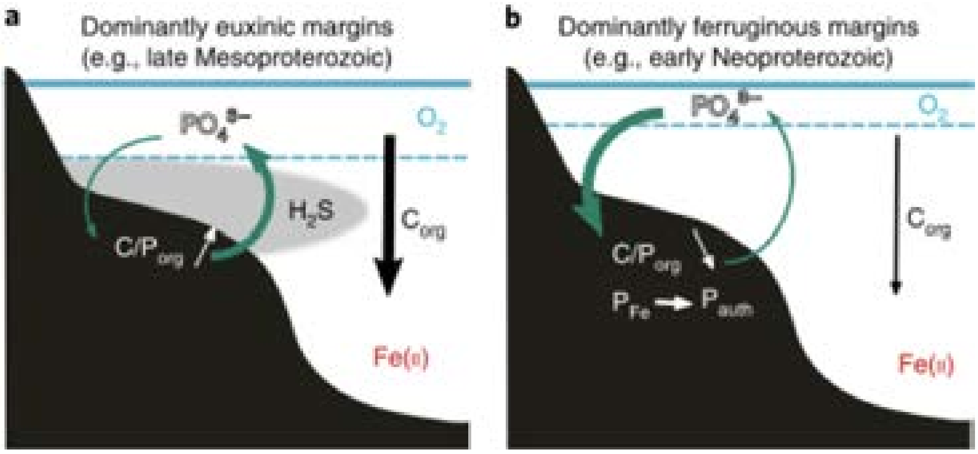


Three hypothetical Mars lowlands surface paleoprofiles. The profile dashed in blue is according with Head et al., (2002), in which the convex parts coincide with Hesperian wrinkle ridges considering an average thickness of the lowlands of about one kilometer, while the other two profiles dashed in orange and green indicate those assumed by this work, one considering a lowlands thickness of about 1 kilometer and the other considering an average lowlands thickness of up to 2 kilometers.

RH5: Understanding the phosphorus cycling and its bioavailability in Archean carbonates, as analogues for Martian paleoenvironments



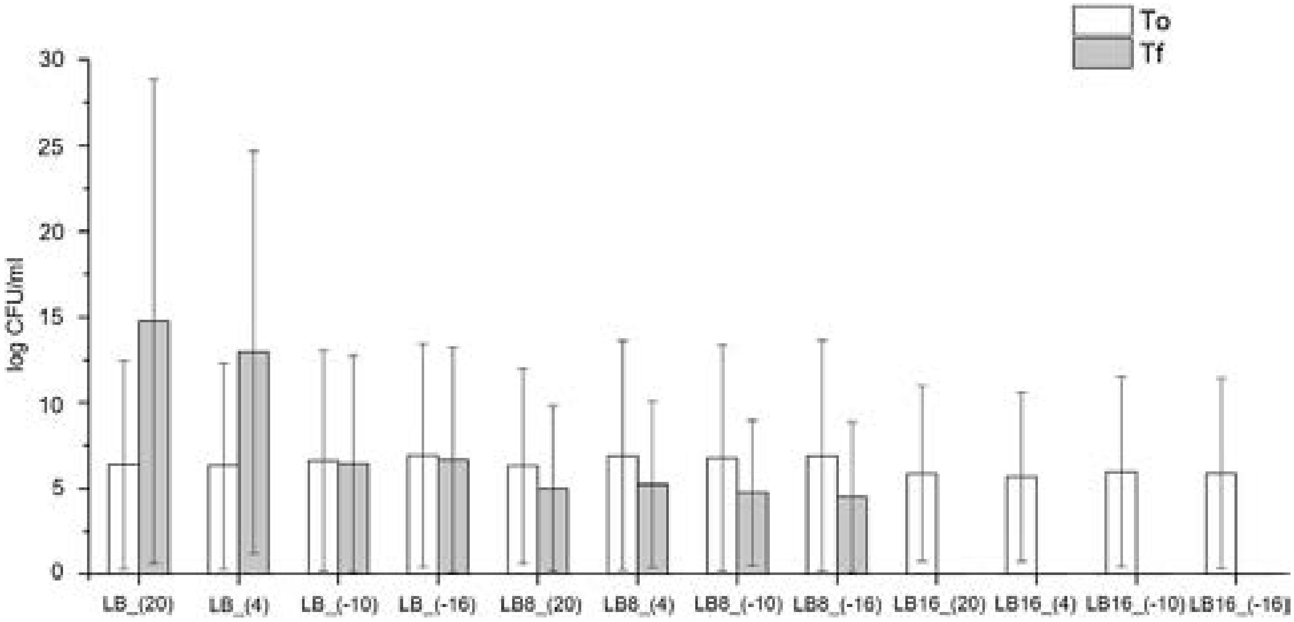
Investigation on P recycling and bioavailability in carbonate and iron-rich Archaean deposits (~3 Ga) helps expanding our understanding of the possible origin of life on Earth, and to test the astrobiological implications on other terrestrial planets, like Mars. Iron speciation results will determine whether the studied carbonates were deposited under euxinic or ferruginous conditions, relative to total iron, and will track the redox evolution upward stratigraphy. Phosphorus speciation results will quantify different operationally defined P sedimentary pools, including iron associated, authigenic, detrital, organic and total. Subsequently, Fe and P results were modeled to address two fundamental research questions: a) shifts from ferruginous to euxinic conditions promoted the accumulation of dissolved phosphate, and b) iron reduction (microbial or abiotic) favored the increase of alkalinity, contributing to carbonate precipitation.



Pregeneration under euxinic (a) and ferruginous water conditions (b) during the Mesoproterozoic/Neoproterozoic boundary (ca. 1 Ga).

RH6: Quantifying the effects that the presence of perchlorate salts in aqueous solutions have on habitability

The adaptation of microbes to low temperatures allows them to succeed in diverse cold environments owing to molecular strategies. Many of these natural cold environments also include additional stressing conditions, like high concentrations of salts, which force cells to develop strategies to cope with both cold and salinity at the same time. This makes polyextremophiles prime candidates to study the limits of microbial life when they respond simultaneously to cold and salinity, conditions that are of high astrobiological interest, particularly for early Mars and icy moons. Our analyses contributed to understand the strategies for survivability and adaptation of extremophilic microorganisms under polyextreme conditions, such as those existing in the Martian subsurface today and/or in the past, which include the documented presence of magnesium perchlorate salts in ancient sediments and global cold temperatures.



Viable Rhodococcus sp. JG-3 cells expressed as colony forming units (CFU)/mL that grew on LB medium plates at the beginning (day 0) and at the end (day 10) of the treatments: 0.5x LB (sample labels preceded by LB), 0.5x LB + 8% Mg(ClO4)2 (sample labels preceded by LB8), and 0.5x LB + 16% Mg(ClO4)2 (sample labels preceded by LB16), incubated at 20°C, 4°C, –10°C and –16°C. Bars indicate means and error bars indicate standard errors of triplicates.

Research Highlights 2022

RH7: What we will need to explore Planetary caves

The continuing discovery of caves in other bodies of the Solar System gave rise to the new field of Planetary Caves. We contributed to an interdisciplinary team of researchers in the proposal of a detailed strategy to explore caves beyond Earth. Focusing primarily on astrobiology, the cave environment, geology, robotics, instrumentation, and human exploration we produced a framework to guide this subdiscipline for the next decade.

Figure. Sampling a cave in the Coastal Range of the Atacama Desert.

RH8: Updating what is known on the Atacama Desert, the driest environment on Earth

The Atacama Desert is by far the driest and oldest desert on Earth, showing a unique combination of environmental extremes (extreme dryness, the highest UV radiation levels on Earth, and highly saline and oxidizing soils), explaining why the Atacama has been largely investigated as a Mars analog model for almost 20 years. On 2022 we continued exploring the characteristics of this fascinating environment, actively used as the testing ground of the technologies (detection instruments, rovers, etc.) that were sent and will be sent to Mars.

Exploring one of the driest sites of the Atacama Desert.

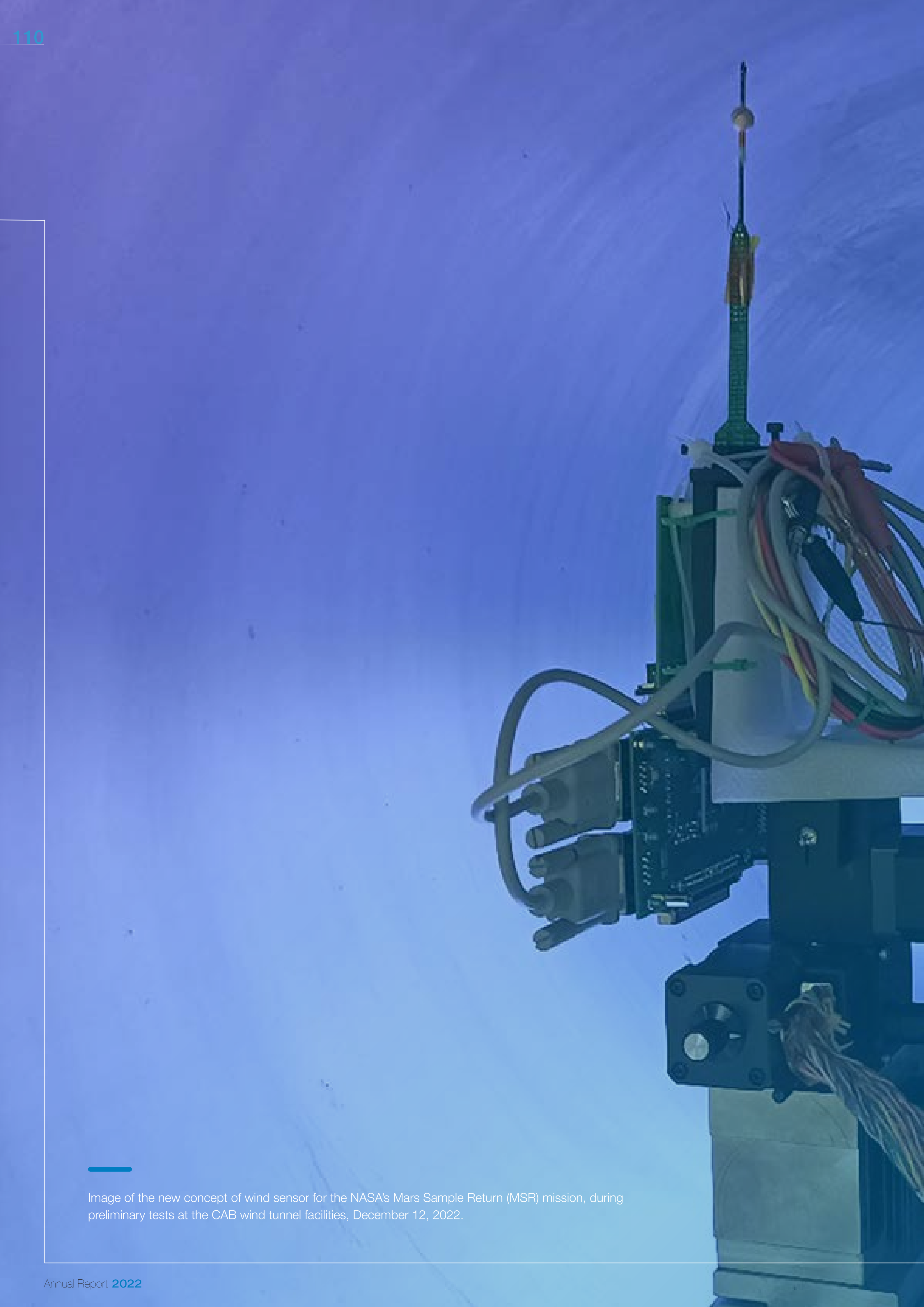


Image of the new concept of wind sensor for the NASA's Mars Sample Return (MSR) mission, during preliminary tests at the CAB wind tunnel facilities, December 12, 2022.

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. The Department has different infrastructures for planetary simulation, and to scientifically and technologically support the researchers of the group.

During 2022 our Department continued with the leadership in the development, operation and scientific data exploitation of different flight instruments for the characterization of the Martian atmosphere: REMS (Rover Environmental Monitoring Station) aboard the Curiosity rover, TWINS (Temperature and Wind for InSight) aboard the InSight lander, and MEDA (Mars Environmental Dynamics Analyzer) onboard *Perseverance* Mars2020 rover. All of them belonging to missions of the National Astronautic Space Agency (NASA). In addition, throughout the year new contacts have been established for future participation in the exploration of the planet Mars within the framework of NASA's Mars Sample Return (MSR) mission.

The Advanced Instrumentation Department is organized in 1 Research Group:

- Space Instrumentation

Space Instrumentation (SI)

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María Teresa Magaz Pérez

Lab. Technicians:

Ricardo Ferrandiz Guibelalde

Summary

Experimentation and simulation play a fundamental role in the accomplishment of objectives the Centro de Astrobiología. In many cases, experiments 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. This group covers the all the technological aspects of these developments, from the conception of prototypes and instruments, 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 technologies, either in simulation chambers or in representative environments (the so-called terrestrial analogues). Also, in the scientific field, it carries out the exploitation of the data, through analysis, hypothetization, modeling and validation of results, as far as the study of the environment of other planets is concerned.

The group thus contributes to objectives Ob3.2, Ob3.5, Ob4.2, Ob6.3, Ob6.5 and Ob6.6 of the Center Strategic Plan by studying the habitability of subsurface of other planetary environments and the effect of extreme physicochemical parameters in the laboratory. It also addresses the understanding of past and present Martian habitability through the dynamics of the Martian atmosphere. The group is also leading the development of environmental sensors for in-situ planetary atmospheric characterization and habitability assessment, and is contributing to the definition of the future ESA and NASA missions with Astrobiological objectives and including environmental sensors. Finally, the group is working on the development of state-of-the-art superconducting detectors for astronomical and quantum applications.

Research Highlights (RH) 2022

RH1: Operation of REMS, TWINS and MEDA instruments and development of new instrumentation and sensors for the study of planetary atmospheres.

The Space Instrumentation group is leading the development and operation of three space instruments dedicated to environmental characterization of the Martian atmosphere and the study of the physical properties of its dust. MEDA (Mars Environmental Dynamics Analyzer) for NASA's Perseverance rover, TWINS (Temperatures and Winds for InSight) of NASA's InSight mission and REMS (Rover Environmental Monitoring Station) for the NASA's Curiosity rover. All three have been in operation along the year 2022.

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. For these projects, the CAB has collaborated with national and international partners as 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 Polytechnic University of Catalonia, the Rocasolano Physics-Chemistry Institute (CSIC) and the University of Alcalá, 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.

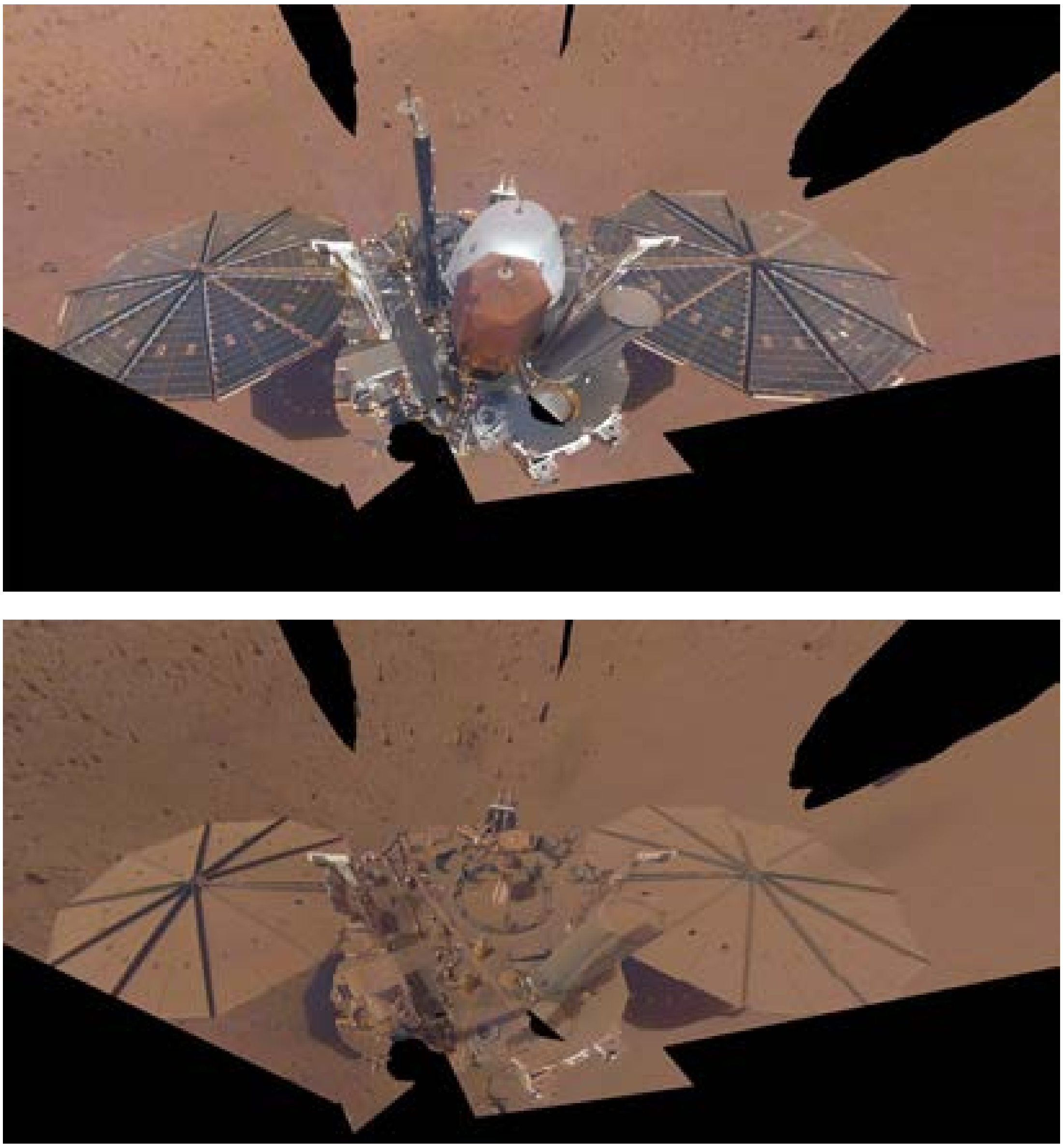
NASA's Mars 2020 *Perseverance* rover landed at Jezero crater on 18 February 2021. The rover include the MEDA environmental station, conceived as a suit of sensors that record: relative humidity (Relative Humidity Sensor - HS), air temperature (Air Temperature Sensor - ATS), net balance of IR radiation (Thermal IR Sensor - TIRS), speed and direction of the Martian wind (Wind Sensors - WS), radiation and properties of the suspended aerosols (Radiation and Dust Sensor - RDS), and atmospheric pressure (Pressure Sensor - PS).

Throughout 2022, as part of the phase E activities, both the engineering and the scientific teams of the project have led the instrument operation tasks, in close collaboration with NASA personnel and the rest of the mission. This activity enables the retrieval of the scientific data from the surface of Mars. MEDA has been running every day of the year except for 19 days. This implies that more than 15.5 million measurements were made, equivalent to 12 Martian hours of measurement per sun, and 973 images have been taken with SkyCam. Throughout the year, scientific data have been delivered to the PDS (Planetary Data System) on three occasions, making them available to the international scientific community.

In addition to the specific activities of operation and scientific exploitation of the data, a set of tasks of a more technological nature have been carried out. Some examples are: The new ground calibration campaigns for the WS, with the aim of adapting to new operational circumstances. The analysis and interpretation of in-flight calibration sequences of the TIRS sensor to obtain a measurement of the degradation associated with deposition of dust on the detectors. Maintenance and improvements in the ground segment software to increase the quality of the data provided to the PDS and in the flight software of the Instrument Control Unit (ICU) itself to introduce new performances in the instrument operation strategies, saving tactical resources. ➛

MEDA WS detail photograph during Martian operations, image taken on Feb. 2, 2022 the 339th Martian day of the mission.

➛ Throughout 2022, TWINS provided a continuous log of the local winds and temperatures at the landing site (Elysium Planitia). Both InSight and TWINS have performed with great success. However, the accumulation of dust on the surface of the solar panels has reduced the energy available to the spacecraft. The last time InSight communicated with Earth was Dec. 15, 2022, leading mission controllers to conclude the spacecraft's solar-powered batteries have run out of energy. Thus, NASA had declare the mission over, in spite they will continue to listen for a signal from the lander, just in case, but hearing from it at this point is considered unlikely. The scientific data provided by TWINS allowed to rule out false seismic readings caused by the strong winds in the environment, and is of great scientific value given the detailed record that it is carrying out. ➛



InSight Mars lander final selfies with TWINS booms on top. (Top) on Dicember 2018 not long after landing and (bottom) on April 24, 2022, the 1211th Martian day, or sol, of the mission. The lander is covered with far more dust than it was in its first selfie.

➛ REMS is operating on the surface of Mars, in Gale Crater, since August 2012, collecting data on pressure, air and ground temperatures, wind speed and direction, atmospheric relative humidity and incident ultraviolet radiation. Throughout the year 2022, the instrument has been running every day of the year except for 12 days, collecting more than 10.6 million readings from each of the sensors, which is equivalent to 8 Martian hours of measurement per sol.

Scientific data have been delivered to the PDS (Planetary Data System) on three occasions, making them available to the international scientific community

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

In parallel with all the activities associated with the operation of the instruments on the surface of Mars, the group also works on the design of new instruments and sensors in preparation for new space missions. A clear example of these activities are the tasks carried out with the aim of increasing the Technology Readiness Level (TRL) with a view to a future spatialization of a new miniatured 3D wind sensor for Mars. Another would be the design of a multidetector infrared sensor, aimed at minimizing measurement errors when working in a hostile thermal environment, and whose development has been the subject of the application, at the end of 2022, for an international patent entitled “Infrared Sensor”.

RH2: Study and modeling of Martian atmospheric dynamics and its main constituents.

In addition to the previously described technological activities, the group was actively involved in the scientific exploitation of the data. REMS and MEDA instruments were collecting data at Gail and Jezero craters respectively, characterizing the physical processes in the lowest layer of the Martian atmosphere. The observations unveil the diversity of processes driving change on today's Martian surface. Many of the measurements made by MEDA so far are the first time they have been obtained on Mars, revealing interesting surprises in Jezero's atmosphere. Overall, MEDA observations show a dynamic environment rich in atmospheric phenomena that is different from other locations on Mars like Gail crater. The characterization of Jezero's atmosphere plays an important role in the development of the Mars Sample Return mission and in the exposure of the samples being collected by Perseverance.

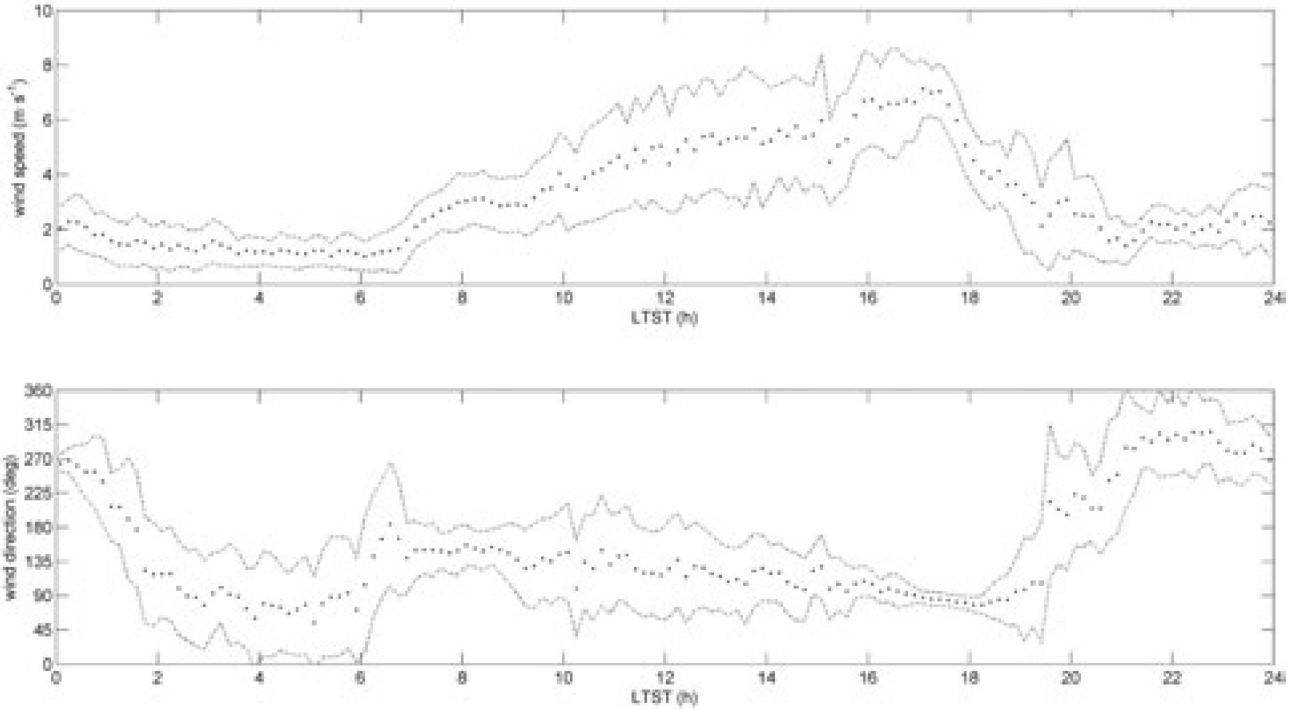
These are some of the most relevant results published during the year 2022:

Winds at the Mars 2020 Landing Site: Wind Patterns variability and turbulence at Jezero Crater

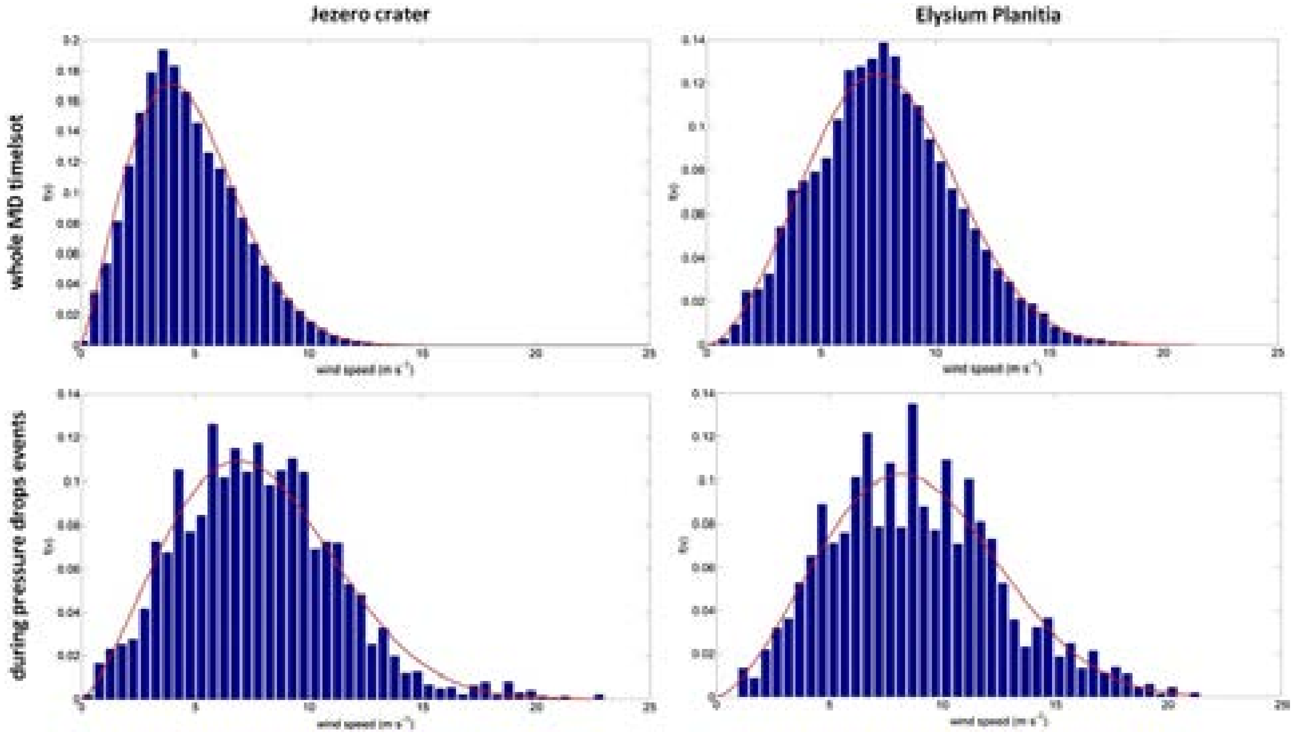
Winds at the Mars 2020 landing site were presented in a two part paper in the Special Issue "The Mars Perseverance Rover Jezero Crater Floor Campaign" of the journal JGR Planets. The wind data acquired by the rover measured a mostly repeatable diurnal cycle with two regimes: (a) a convective period, from dawn to sunset with average easterly to southeasterly winds, in which maximum wind speeds were measured, and (b) a nighttime regime with westerly-northwesterly winds followed by a relatively calm period with highly variable wind directions as a function of sol and time of night. The timing and magnitude of the observed regimes are consistent with primary control by regional and local slope flows, as have been observed to varying degrees at other landing sites on Mars. Data suggest that the surface circulation at Jezero is highly unaffected by large-scale circulation, except during particular periods. An early regional dust storm prior to fall equinox also disturbed wind patterns with changes suggesting the strengthening of flows linked to large-scale atmospheric oscillations called tides. The latter are primarily driven by the daily pattern of solar heating around Mars and its interaction with topography.

Also, Jezero winds as measured in the crater floor by Perseverance were found to be much calmer on average than in previous landing sites. Turbulence and wave activity provoked rapid fluctuations that changed wind speed from calm conditions to more than 10–15 ms–1 in the timescale of seconds to minutes. Daytime wave activity is related to convection cells and smaller eddies in the boundary layer, advected over the crater. These convection cells are produced under strong thermal gradients typically present during daytime. Pressure drops, associated with convective vortices, were usually involved in rapid wind fluctuations and, in some cases, in extreme winds as measured by Perseverance. An intense aeolian activity was observed at Jezero crater produced by transient high wind events. This aeolian activity had major implications for instrumentation, with the Perseverance wind sensor suffering damage probably due to flying debris advected by winds. Also, the detection of a strong dust cloud of 0.75–1.5 km passing over the rover was reported.

The wind speeds were characterized by fitting the wind data as a Weibull distribution. InSight wind data acquired in Elysium Planitia were also used to contextualize the observations. The Weibull distribution fits the wind speed data at Jezero using a scale parameter c = 3.60 ms–1 and a shape parameter k = 1.49, and the wind data at Elysium Planitia using a scale parameter c = 6.20 ms–1 and a shape parameter k = 1.91. Elysium Planitia values align with those previously found for Gale crater, but Jezero winds strongly diverge and are much quieter than those found in previous missions. Among the three landing sites on Mars in which high-frequency measurements are available, Jezero crater shows the lowest wind speeds in the total winds. The probability of wind speeds greater than 12 ms–1 was 0.2% during the mission, and it was only close to 10% around the summer solstice afternoon. Wind speeds at Elysium Planitia were 68% greater, on average, than at Jezero. ➛



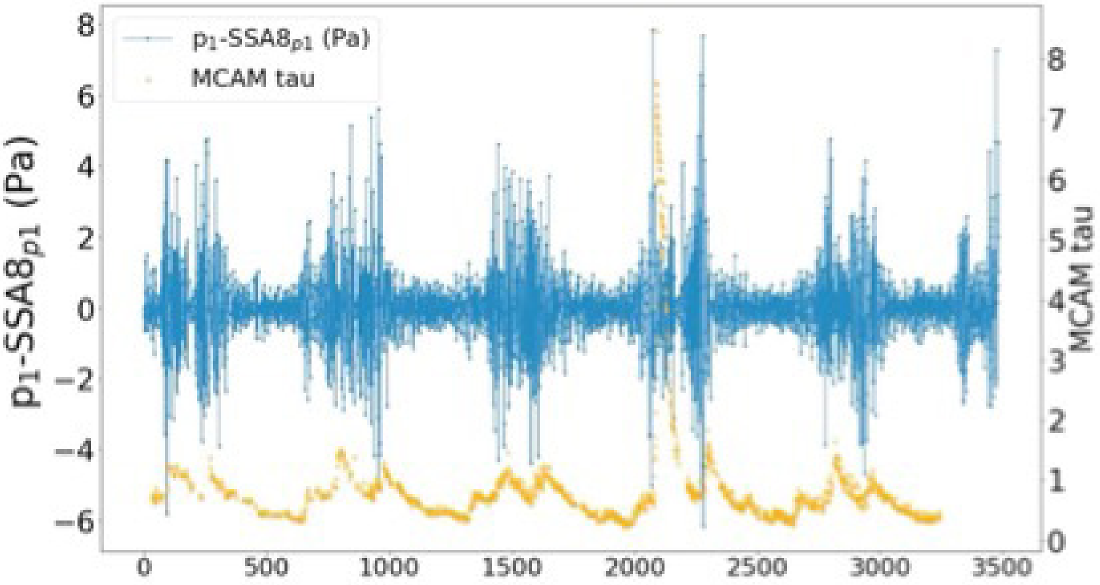
Diurnal variation in wind speed and direction as a function of local true solar time (LTST) over a period of 40 sols close to the northern summer solstice (L_s ~ 90°–120°).



Weibull probability density functions (PDFs) (red line) and comparison with empirical data (blue histogram) for the midday (MD timeslot), both for Jezero (left column) and Elysium Planitia (right column). (top) PDF for the whole MD timeslot period, (bottom) PDF of wind speeds in the MD timeslot but during pressure drop events.

➛ Mars Surface Pressure Oscillations as Precursors of Large Dust Storms Reaching Gale

There have been many efforts to characterize the impact of large-scale dust storms on Mars's atmospheric circulation and wave activity. Modeling and observations have long demonstrated that Martian dust storms strongly interfere with global circulation patterns and change the diurnal and semidiurnal pressure variability as well as oscillations with periods greater than one sol associated with planetary waves. As of early 2022, five Mars years of pressure data have been collected by the Curiosity Rover in Gale crater with the Rover Environmental Monitoring Station (REMS). This surface pressure measurements enable the study of some of these changes in global circulation patterns. Relatedly, numerical modeling and imaging by orbital spacecraft indicate that particular atmospheric circulation patterns, including particular combinations of waves, favor the growth and propagation of dust storms. Such patterns may be identified via their signature in surface pressure prior to the growth of the storm. This work was presented in the paper "Mars Surface Pressure Oscillations as Precursors of Large Dust Storms Reaching Gale" of the journal JGR Planets. Several analyses were used to find equatorial waves preceding the growth of local dust opacity in Gale crater during the storm periods. In order to do that, a combination of signal filtering techniques, such as harmonic series, Singular Spectrum Analysis or Empirical Mode Decomposition were studied. Opacity data from MCAM camera, from the Jet Propulsion Laboratory, have been used to assess the precursors obtained.

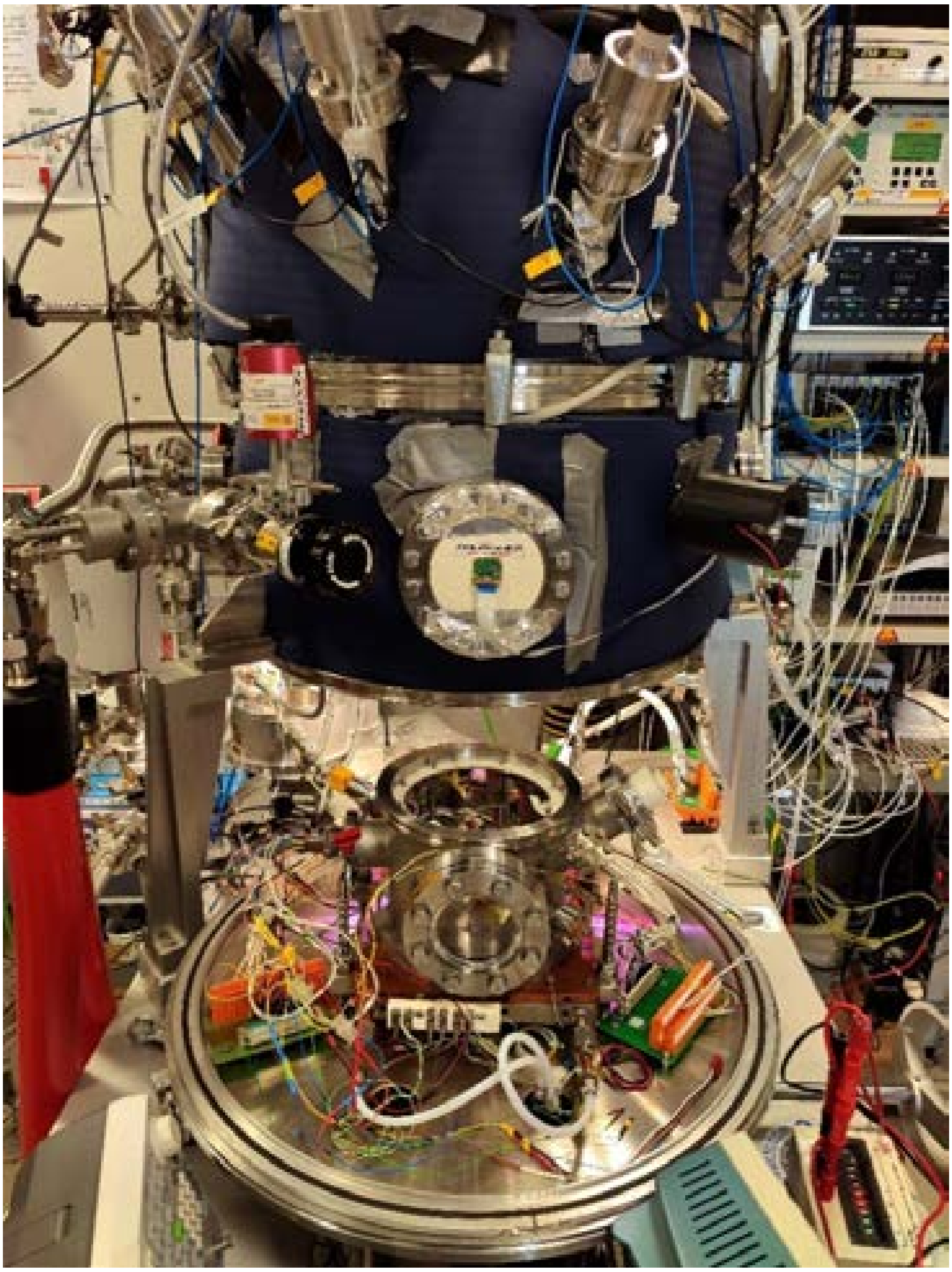


In blue, diurnal pressure minus reconstruction from Singular Spectrum Analysis. Jumps in these values predict the arrival of a storm period; in orange, opacity from MCAM camera. Jumps in opacity marks a storm period.

RH3: Mimicking planetary subsoil under the ice film in the laboratory

Getting to simulate an atmosphere and an ice sheet. This is the main aims in the MPSL project (Mimicking Planetary Simulation in the Laboratory). The ice makes it possible to control the relative humidity inside the BGR (Biological Geological Reactor), filter or reducing the external radiation and maintain a thermostatic balance between the exterior and the interior.

From this experimental development we will study the influence of the different gases with biological samples and biosensors that help us to know the evolution of this extreme environment in the subsoil of telluric planets in the solar system.



Biological Geological Reactor inside the MARTE vacuum chamber is the device that simulate the subsoil under ice film.

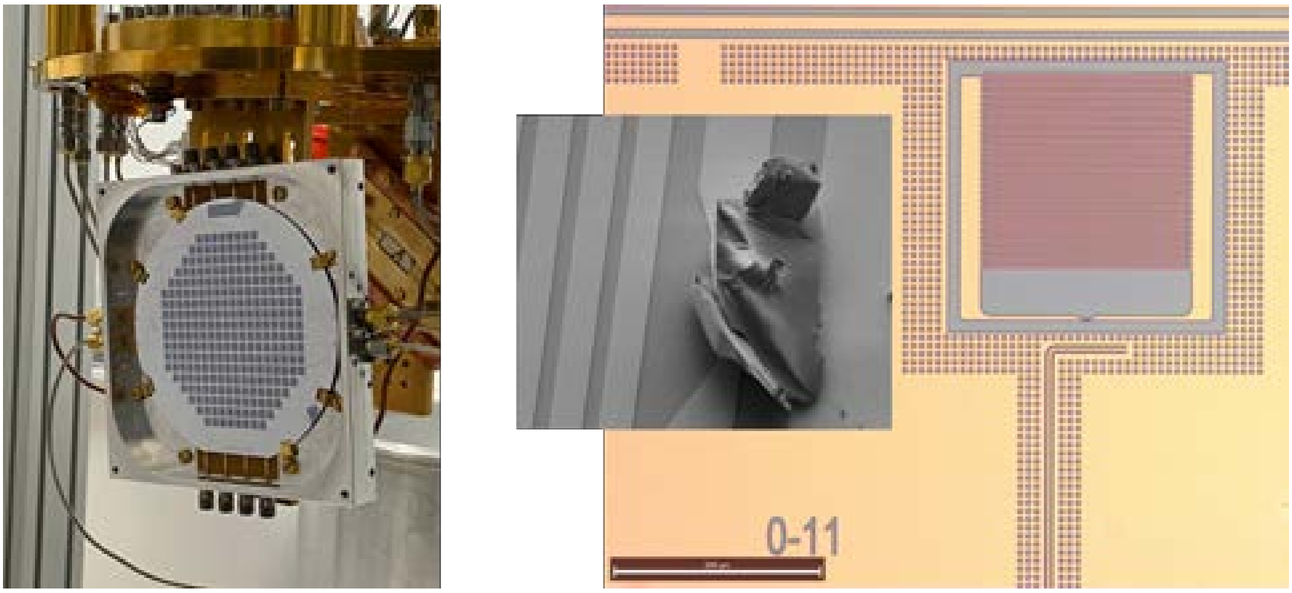
Research Highlights 2022

RH4: Developing superconducting resonators for space and quantum applications

The Space Instrumentation group is also focused on developing superconducting circuits, a state-of-the-art enabling technology with applications that expands from the astronomical field towards its use for quantum processing and sensing, biology or security applications. Specifically, our research relays on two pillars: i) the design and fabrication of cutting-edge superconducting detectors for astronomical instrumentation, and ii) the development of superconducting circuits for quantum applications.

Regarding the first, we coordinate the Spanish developments of Kinetic Inductance Detectors (KIDs) for the development of a mature large-format camera with polarization sensitivity in the W-band suitable for future space missions. We also, have participated in European Consortiums such as the NIKA2 and CONCERTO instruments, led by I. Néel in France and in the Spanish group CADEx for the development of a KID-based instrument for dark matter exploration.

Additionally, high-quality superconducting circuits are the ideal on-chip platform to operate, sense and characterize different quantum systems. Particularly, we are focused on the development of on-chip innovative superconducting circuits capable of coupling to small spin ensembles, aiming for the development of a functional molecular spin quantum processor unit. For this purpose, we are part of the Spanish CSIC Quatum Platform and the European FATMOLs FET-OPEN project.



Left: Large format KIDs array detector for W-band astronomical experiment.
Right: Low impedance LER for the development of spin quantum processor.

NASA Curiosity Rover in the place called “Big Sky”in Gale Crater. Credits: NASA/JPL-Caltech/MSSS.

Artist's reproduction (not to scale) of the trajectory of the fast radio burst FRB 20220610A, from the distant galaxy where it originated and traveled to Earth. Credits: ESO/M. Kornmesser

PhD and Master theses, funded projects, outreach and other indicators

PhD Theses

Name	Title	Director	University	Date	Department
Alberto Álvarez Saavedra	Explotación científica de TESS, K2 y Kepler: Determinación de la edad mediante rotación	David Barrado Navascués and María Morales Calderón	Universidad Complutense	Ongoing	Astrofísica
Alicia Rodríguez-Moreno	Adaptación de bacteriófagos a condiciones extremas de interés astrobiológico	Ester Lázaro	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
Alina Ikhsanova	*When galaxies die: tracing galaxy evolution in last 7 Gyrs through stellar populations*	Luca Costantin and Alessandro Pizzella	Universidad de Padua	Ongoing	Astrofísica
Álvaro López-Gallifa	Estudio comparativo de la complejidad química en regiones de formación estelar y objetos del sistema solar.	Víctor Manuel Rivilla Rodríguez	Universidad Complutense	Ongoing	Astrofísica
Amadeo Castro González	Exoplanet exploration in the PLATO era: planetary systems and their habitability	Jorge Lillo-Box and david Barrado Navascués	Universidad Complutense	Ongoing	Astrofísica
Ana de Dios Cubillas	Estudio de la mineralogía y estructuras de cold seeps. Sus implicaciones astrobiológicas en el satélite Europa	Olga Prieto-Ballesteros and Daniel Carrizo	Universidad Rey juan Carlos	Ongoing	Planetología y Habitabilidad
Andrés Megías Toledano	El origen del material molecular orgánico complejo en sistemas planetarios	Izaskun Jiménez Serra	Universidad Complutense	Ongoing	Astrofísica
Antonio López García	Prebiotic chemistry: Increasing molecular complexity in aqueous media	Marta Ruiz-Bermejo	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
Antonio Martínez Henares	The impact of ionized winds, UV photoevaporation and stellar multiplicity on planet formation in disks around massive stars	Izaskun Jiménez-Serra y Nuria Huélamo	Universidad Autónoma de Madrid	Ongoing	Astrofísica
Beatriz Torres Vázquez	*In vitro* selection of DNA and RNA aptamers specific to hepatitis C virus core protein: applications to viral diagnosis and therapy	Carlos Briones and Miguel Moreno	Universidad de Alcalá de Henares	Read	Evolución Molecular
Carlos Cifuentes San Román	Astrophysical parameters of M dwarfs with exoplanets	José Antonio Caballero Hernández and Jorge Sanz Forcada	Universidad Complutense	Ongoing	Astrofísica
Carlos del Burgo	Formation of COMs in interstellar ice analogs	G. M. Muñoz Caro	Universidad Autónoma de Madrid	Ongoing	Astrofísica
Carolina Martín Rubio	Caracterización de la atmósfera de Marte a partir de datos satelitales y en superficie	José Antonio Rodríguez Manfredi and Felipe Gómez Gómez and Álvaro de Vicente Retortillo	Universidad Complutense	Ongoing	Instrumentación Avanzada
Catalina Romero Guzmán	Thermal analysis of space systems in Martian conditions	José Antonio Rodríguez Manfredi and Isabel Pérez Grande	Universidad Politécnica de Madrid	Ongoing	Instrumentación Avanzada

Cristina Perez Fernandez	Reactividad de polímeros de HCN en superficies: Química prebiótica	Eva Mateo-Marti and Marta Ruiz-Bermejo	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
Cristina Robas	Evidencias regionales del Ciclo Hidrológico en Marte: Arabia Terra	Alberto Fairén, Olga Prieto and Iván López	Universidad Rey Juan Carlos	Ongoing	Planetología y Habitabilidad
Cristina Robas	Evidencias regionales del Ciclo Hidrológico en Marte: Arabia Terra	Alberto Fairén, Olga Prieto, Iván López	Universidad Rey juan Carlos	Ongoing	Planetología y Habitabilidad
David Rodríguez Rodríguez	Integration of superconducting circuits and magnetic molecules for quantum technologies	Alicia Gómez and Fernando Luis	Universidad Autónoma de Madrid	Ongoing	Instrumentación Avanzada
Diego Cuenda Muñoz	Análisis estadísticos de datos astronómicos ligados a la determinación de edades estelares a partir de los datos proporcionados por el satélite PLATO y otros instrumentos	David Barrado Navascués	Universidad Complutense	Ongoing	Astrofísica
Eduardo Alonso Pintado	Pre-biotic peptides as targets for a complex prebiotic biochemistry	Victor Parro and Mercedes Moreo-Paz	Universidad de Alcalá de Henares	Ongoing	Evolución Molecular
Eva Herrero Cisneros	Atmospheres of ultra-hot and hot massive planets	María Rosa Zapatero Osorio and Jorge Sanz Forcada	Universidad Complutense	Ongoing	Astrofísica
Federico Mansilla	Cartografía de la habitabilidad actual de la superficie de Marte. Implicaciones en protección planetaria y la dispersión de aerosoles	María Paz Zorzano Mier and Javier Ruíz Pérez	Universidad Complutense	Ongoing	Planetología y Habitabilidad
Felipe Ruymán Alonso Ravelo	Production of extracellular vesicles containing DNA by the hyperhalophilic archaeon Haloquadratum walsbyi and study of their role in horizontal gene transfer	José Eduardo González Pastor		Ongoing	Evolución Molecular
Gonzalo José Carracedo Carballale	Desarrollo e implementación del modelo de apuntado de ELT-HARMONI y estudios científicos asociados.	Javier Piqueras López	Universidad Complutense		Astrofísica
Héctor Carrascosa de Lucas	Interstellar ice analogs: energy transfer, photodesorption and photochemistry	G. M. Muñoz Caro	Universidad Autónoma de Madrid	Read	Astrofísica
I Abhilash Vakkada-Ramachandran	A planetary chamber to investigate the thermal and water cycle on Mars	M.-P. Zorzano	Luleå University of Technology of Sweden	Read	Planetología y Habitabilidad
I Samuel Konatham	Atmospheric Species and Spectral Radiation in Terrestrial Exoplanets: Implications for Astrobiology	M.-P. Zorzano	Luleå University of Technology of Sweden	Read	Planetología y Habitabilidad
Jaime Alonso Hernández.	Binariedad en estrellas AGB: impacto en la física y química nebular	Carmen Sánchez Contreras y Jorge Sanz Forcada	Universidad Autónoma de Madrid	Ongoing	Astrofísica

PhD Theses

Javier González Payo	Multiplicity of stars, ultracool dwarfs and planetary systems	José Antonio Caballero Hernández and Miriam Cortés Contreras	Universidad Complutense	Ongoing	Astrofísica
John Fabio Aguilar Sánchez	Caracterización fotométrica de estrellas de tipo F a M para la obtención de parámetros físicos mediante machine learning	Patricia Cruz and Enrique Solano	Universidad Autónoma de Madrid	Ongoing	Astrofísica
Jorge Díaz-Rullo Aroco	Búsqueda de nuevos mecanismos de Resistencia a perclorato en microorganismos de ambientes extremos	José Eduardo González Pastor		Ongoing	Evolución Molecular
Jorge Guzmán Díaz	Herbig Ae/Be systems: stars, disks, and star-disk interactions	Ignacio Mendigutía Gómez and Benjamín Montesinos Comino	Universidad Autónoma de Madrid	Ongoing	Astrofísica
Macarena Benguigui de la Camara	Exploración de los mecanismos de adaptación y resistencia a radiación UV en microorganismos halófilos extremos	José Eduardo González Pastor	Universidad de Alcalá de Henares	Read	Evolución Molecular
Mara Arribas Hernán	Adaptación del bacteriófago Qσ a temperatura elevada	Ester Lázaro	Universidad de Alcalá de Henares	Ongoing	Evolución Molecular
Mara Laguna-Castro	Efecto de la densidad de hospedadores en las estrategias adaptativas de bacteriófagos	Ester Lázaro	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
María Sánchez García	Las relaciones de la formación estelar en galaxias luminosas en el infrarrojo	Miguel Pereira Santaella, Santiago García Burillo	Universidad Complutense	2022	Astrofísica
Marina Calero de Ory	Superconducting Resonators for Space and Quantum Applications	Alicia Gómez and Daniel Granados	Universidad Complutense	Ongoing	Instrumentación Avanzada
Marina Fernández-Ruz	Modeling of the origin of life as a complex and emergent process	Jacobo Aguirre and Marta Ruiz-Bermejo	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
Marta Lorenzo González	Sextans A, a Rosetta stone for massive star formation and evolution at low metallicity	Miriam García García and Francisco Najarro de la Parra	Universidad Autónoma de Madrid	Ongoing	Astrofísica
Miguel Arribas Tiemblo	Organic preservation in Mars Surface	Dr. Felipe Gómez Gómez	Universidad Autónoma de Madrid	Ongoing	Planetología y Habitabilidad
Miguel Arribas Tiemblo	Organic preservation in Mars Surface	Felipe Gómez Gómez	Universidad Autonoma de Madrid	Ongoing	Planetología y Habitabilidad
Nerea Maestu Fonseca	*Observación y representación del Cosmos: los cometas en la tradición medieval hispana*	Montserrat Villar y Laura Fernández	Universidad Complutense	Ongoing	Astrofísica
Nuria Fonseca Bonilla	Estudios de estrellas con discos circunestelares a través de observaciones ópticas e infrarrojas	Benjamín Montesinos Comino and Amaya Moro Martín	Universidad Complutense	Ongoing	Astrofísica
Olga Balsalobre Ruza	Coorbital planets and Lagrangian points: could they be the Rossetta stone of planet formation?	Jorge Lillo-Box and Nuria Huélamo Bautista	Universidad Complutense	Ongoing	Astrofísica
Oscar Ercilla Herrero	Caracterización de los sistema salinos de Ceres, Europa, Encelado a partir de análogos terrestres	Olga Prieto-Ballesteros and Victoria Muñoz-Iglesias	Universidad Complutense	Ongoing	Planetología y Habitabilidad

Pablo de Lucía Finkel	Lipid biomarkers and patterns for life detection and paleoenvironmental recontruction	Laura Sánchez García and Victor Parro	Universidad de Alcalá de Henares	Ongoing	Evolución Molecular
Pablo Rodriguez Beltrán	*Surface Brightness Fluctuations to constrain galaxy stellar populations*	Alexander Vazdekis, Miguel Cerviño, Mike Beasley		Ongoing	Astrofísica
Pedro Mas Buitrago	Aplicación de técnicas de Machine Learning a cartografiados espectroscópicos y fotométricos	Enrique Solano Márquez, Ana González Marcos	Universidad Complutense	Ongoing	Astrofísica
Pedro Mustieles del Ser	Well conserved protein-peptide structures as target for Early Earth and Mars life detection	David Ruano Gallego and Victor Parro	Universidad de Alcalá de Henares	Ongoing	Evolución Molecular
Raquel Murillo Ojeda	Enanas blancas con compañeras subestelares: Gaia y observatorio virtual	Francisco Jiménez Esteban, Alberto Rebassa Mansergas, Enrique Solano Márquez	Universidad Complutense	Ongoing	Astrofísica
Raúl Castellanos Sánchez	Estrellas masivas como motores del universo: Estudios en el IR-cercano	Francisco Najarro de la Parra and Miriam García García	Universidad Autónoma de Madrid	Ongoing	Astrofísica
Rita sofía dos Santo Severino	Ancestral proteins and peptides as targets for life detection	Victor Parro and Mercedes Moreo-Paz	Universidad de Alcalá de Henares	Ongoing	Evolución Molecular
Rosa María Mérida González	Extending star formation scaling relations down to 10^8-9 Msun at 1 < z < 3 with HST, ALMA and GTC.	Pablo Pérez González	Universidad Autónoma de Madrid		Astrofísica
Sandy Morais	*Integral field observations and modeling of extended emission line halos in high redshift active galaxies*	Andrew Humphrey and Montserrat Villar	Universidad de Oporto	Ongoing	Astrofísica
Santos Galvez-Martinez	Interacción y reactividad de péptidos en superficies: Química prebiótica en superficies	Eva Mateo-Marti	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
Sara Gómez de Frutos	Efecto de los ciclos de luz y oscuridad en poblaciones de microorganismos hiperhalófilos	José Eduardo González Pastor		Ongoing	Evolución Molecular
Sofia Zurita Zurita	Application of signal processing methods to the Rover Environmental Monitoring Station data for the analysis of environmental processes on Mars	José Antonio Rodríguez Manfredi and Francisco Javier Escribano Aparicio	Universidad de Alcalá de Henares	Ongoing	Instrumentación Avanzada
Víctor Muñoz Hisado	Diversidad microbiana en ambientes permanentemente helados	Cristina Cid Sánchez	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular

Master Theses

Name	Title	Director	University	Date	Department
Adrián Hidalgo Pinilla	Simulaciones de observaciones con el Telescopio Espacial James Webb (JWST) con modelos de toro y viento para núcleos galácticos activos en el Universo	Almudena Alonso Herrero		sep-22	Astrofísica
Antino Jimenez Alcazar	Detección de galaxias infrarrojas con formación estelar extrema a distancias cosmológicas mediante JWST	Luis Colina	Universidad Complutense de Madrid	feb-22	Astrofísica
Carmen San Nicolás Martínez	Índice de Tolerabilidad a la Vida en exoplanetas conocidos. Aplicación a planetas rocosos	Patricia Cruz	Universidad Complutense de Madrid	Ongoing	Astrofísica
David Fernández Cava	Efecto de metales pesados en la actividad fotosintética de microalgas acidófilas extremófilas	Ángeles Aguilera Bazán	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
David Tacero Puerto	Galaxies in a cosmological context	Luca Costantin	Universidad Complutense de Madrid	sep-22	Astrofísica
Enrique Goitia díaz	Búsqueda de sistemas binarios de componentes tardías con Gaia	Maricruz Gálvez-Ortiz and Patricia Cruz	Universidad Complutense de Madrid	Ongoing	Astrofísica
Enrique Moya Sánchez	Caracterización de estrellas AGB no detectadas en el catálogo Gaia EDR3 usando herramientas de Observatorio Virtual	Francisco Jiménez, Belén López	Universidad Internacional de Valencia	abr-22	Astrofísica
Fátima Ruiz Blas	Effect of climate change on microbial communities	Cristina Cid Sánchez	Universidad Complutense de Madrid	19/06/2022	Evolución Molecular
Gytha Mettepenningen	Measuring interstellar ice analog thickness with laser interferometry	G. M. Muñoz Caro & C. González Díaz		ene-22	Astrofísica
Ignacio Carrasco Ropero	Five new uncultured species of the phylum Thermoplasmatota detected in the extreme environment of Rio Tinto. A bioinformatic analysis	Dr. Felipe Gómez Gómez	Universidad Complutense de Madrid	Ongoing	Planetología y Habitabilidad
Irene Forcada Casares	Spectroscopic Analysis of Individual Stars in the Sagittarius Dwarf Irregular Galaxy	Miriam García García and Francisco Najarro de la Parra	Universidad Autónoma de Madrid	sep-22	Astrofísica
Irene Molina	Efecto de metales pesados en la actividad fotosintética de Chlamydomonas acidophila	Ángeles Aguilera Bazán	Universidad Autónoma de Madrid	Ongoing	Evolución Molecular
Iris Bermejo Lozano	Hacia las primeras estrellas del Universo: LeoA	Miriam García García and Francisco Najarro de la Parra	Universidad Complutense de Madrid	feb-22	Astrofísica
Jesús Muñoz Bulnes	The environmental influence on the incidence of ionized outflows in galaxies	Bruno Rodríguez Del Pino		oct-22	Astrofísica
Laura López Ibáñez	Exomoon formation through giant impacts originated from unstable coorbitals	Jorge Lillo-Box	Universidad Complutense de Madrid	jun-22	Astrofísica
Lorena Amaya Ruiz	Galaxias tipo Vía Láctea según las observaciones: Caracterización mediante el programa galaXYZ	Luca Costantin	Universidad Complutense de Madrid	sep-22	Astrofísica

Lucía Gómez Miguel	Análisis y modelado de datos marcianos de la estación medioambiental MEDA	Eduardo Sebastián Martínez	Universidad de Alcalá de Henares	Ongoing	Insrumentación Avanzada
Michelangelo Pantaleoni González	The ALS catalog of massive stars	Jesús Maíz Apellániz	Universidad Complutense de Madrid	sep-22	Astrofísica
Miguel Román	Masas de cúmulos vs. la estrella con mayor masa	Miguel Cerviño		sep-22	Astrofísica
Núria Matey Delgado	Galaxias tipo Vía Láctea según las simulaciones: Caracterización de barras mediante modos de Fourier-Bessel	Luca Costantin	Universidad Complutense de Madrid	sep-22	Astrofísica
Paula Brcic	Spectro-astrometry with MEGARA at the GTC: a pilot study to search for protoplanets	Nuria Huélamo and Ignacio Mendigutía	Universidad Autónoma de Madrid	sep-22	Astrofísica
Pedro Hernández Cascales	The limits of the Universe: detecting high-redshift galaxies with JWST	Luca Costantin	Universidad Complutense de Madrid	Ongoing	Astrofísica
Rachel Brown	Space Sustainability: A glimpse into the governmental, economic and social transitions within the global space sector	M.-P. Zorzano	University of Aberdeen, UK	sep-22	Planetología y Habitabilidad
Rafael Navarro Carrera	Simulating NIRCam imaging of ALMA [OIII]88um emitter in the EoR	Javier Álvarez-Márquez	Universidad Complutense de Madrid	jun-22	Astrofísica
Rut Nicolás Lloveres	Life tolerability index for known exoplanets. Application to exomoons	Jorge Lillo-Box and Patricia Cruz Gamba	Universidad Complutense de Madrid	jun-22	Astrofísica
Sergio Jiménez Fernández	Hybrid, strongly-coupled superconducting-magnetic resonators (a materials study)	Alicia Gómez and Jesús Mª González	Universidad Autónoma de Madrid	Ongoing	Insrumentación Avanzada
Stefan Georgiev	Molecular and isotopic survey on the sedimentary organic matter of a glacial lake in the SW coast of Greenland with an interest for the search of life on Icy Worlds	Laura Sánchez-García	Ludwig-Maximilians-Universität München	Ongoing	Evolución Molecular
Victor de la Fuente Treceño	Looking for planets in formation around young stars	Ignacio Mendigutía and Nuria Huélamo	Universidad Autónoma de Madrid	sep-22	Astrofísica

Degree Works

Name	Title	Director	University	Date	Department
Agustin Carbajo Usano	Análisis de diversidad microbiana en dos acuíferos bajo la mina Cobre Las Cruces	Elena G-Toril	Universidad Autónoma de Madrid	2022	Evolución Molecular
Alejandro González Albarrán	Desarrollo de nuevos recubrimientos poliméricos inspirados en química prebiótica	Marta Ruiz Bermejo y José Luis de la Fuente	Universidad de Alcalá de Henares	sep-22	Evolución Molecular
Alejandro Suárez Gordo	Modelos numéricos para el estudio hidrodinámico del sistema de acuíferos subterráneos del Río Tinto (Huelva)	I. Herreros y C. Escudero		jul-22	Planetología y Habitabilidad
Andrea Hidalgo Arias	Study of endolithic microorganisms in volcanic rocks from Antarctica	Cristina Cid Sánchez	Universidad Complutense de Madrid	Ongoing	Evolución Molecular
Guillermo Roldán Caselles	Reconstrucción de procesos hidrogeológicos en el pasado de Marte	M.Á. de Pablo, A. Molina e I. Herreros		sep-22	Planetología y Habitabilidad
Javier Cámara Martos	Geochemical analysis analysis of water samples	Cristina Cid Sánchez	Universidad de Alcalá de Henares	2022	Evolución Molecular
Marina Manjavacas Ropero	Efecto del disolvente y las condiciones térmicas en la polimerización del diaminomaleonitrilo	Marta Ruiz Bermejo y José Luis de la Fuente	Universidad Rey Juan Carlos	jul-22	Evolución Molecular
Paula García Martinez	Efecto de metales pesados en la actividad fotosintética de microalgas acidófilas extremófilas	Ángeles Aguilera Bazán	Universidad Autónoma de Madrid	2022	Evolución Molecular

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Name	Title	Director	University	Date	Department
Dª Abigail Elvira Cruz Hernández	Uso de espectroscopía de emisión de rayos X (XPS) en estudios de sorción de moléculas orgánicas en superficies minerales complejas. El caso de la sorción de adenina, timina y fenilalanina en minerales y rocas		Universidad Nacional Autónoma de Mexico	14/04/2022-14/07/2022	Evolución molecular
Sofia Backlund	Complexity in the present biosphere: Study of the interaction between the protein co-expression networks of DNA viruses and human cells during a viral infection	Jacobo Aguirre		sept 2021-march 2022	Evolución molecular

Ongoing Funded Projects

IP	Title	Funding source	Code Nº	Ammount	Department
A. Alonso Herrero	A multiscale view of AGN: from the torus to the circum-galactic medium		PID2021-124665NB-I00	237.765 €	Astrofísica
A. Alonso Herrero and M. Villar Martín	Unraveling galaxy and black hole evolution at high angular resolution: feedback, the obscuring torus and star formation activity		PGC2018-094671-B-I00	169.400 €	Astrofísica
AGF	The physicochemical nature of water on early Mars	European Research Council		2.000.000 €	Planetología y Habitabilidad
AGF	Mars Phosphorus and Life	ERC H2020, Marie Sklodowska-Curie Individual Fellowships	101022397	173.000 €	Planetología y Habitabilidad
Alicia Gómez Gutiérrez	Development of Hybrid Graphene-Superconductor Detectors for Quantum and Space Applications-DEFROST	Office of Naval Research-Global		150.082 $	Instrumentación Avanzada
Alicia Gómez Gutiérrez	FAult Tolerant MOLecular Spin processor (FATMOLS)	H2020 FET-Open		53.751 €	Instrumentación Avanzada
Alicia Gómez Gutiérrez	Tecnologías Cuánticas – Circuitos Superconductores	Plataforma Temática Interdisciplinar CSIC		105.374 €	Instrumentación Avanzada
Alicia Gómez Gutiérrez / Jesús Martín-Pintado	SUPERconducting circuits for HYbrid QUantum Processing unit (SUPERHYQUP)	Agencia Estatal de Investigación, Proyectos de Transición Ecológica y Transición Digital		150.650 €	Instrumentación Avanzada
Ana Belén Galán Abellán	Precipitación mineral en medios ácidos y sus implicaciones en la habitabilidad.	Ayudas a proyectos de i+d dentro del programa de estímulo a la investigación de jóvenes doctores financiada en el marco del convenio entre la universidad autónoma de madrid y la comunidad de madrid relativo a los años 2019-2024	SI3/PJI/2021-00328	37.090 €	Evolución Molecular
Ana Moreno Caballud	Las cuevas de hielo del Parque Nacional de Ordesa y Monte Perdido: dinámica actual ante el cambio global y reconstrucción paleoambiental (ORCHESTRA)	Red de Parques Nacionales. Ministerio para la Transición Ecológica y el Reto Demográfico 2552/2020			Evolución Molecular
Ángeles Aguilera	Microbiological Control in the Formation of Mineral Deposits	MINECO	RTI2018-094867-B-I00		Evolución Molecular
Antonio Molina Jurado	Equipamiento y difusión de resultados para la reconstrucción hídrica iterativa en Marte. EDRIM	Education and Science Ministry	VPAC 202250I104	5.000 €	Planetología y Habitabilidad
B. Maté Naya	LInking ice, gas, and dust: Laboratory AstroChemistry (LILAC)	MCIN	LINKA20353	24.000 €	Astrofísica

Ongoing Funded Projects

C. Sánchez Contreras	Génesis de Nebulosas Planetarias: vientos, pérdida de masa y lanzamiento de chorros rápidos	MICINN	PID2019-105203GB-C22	104.060 €	Astrofísica
Carlos Briones	'Graphene aptasensor bioelectronics: a neural interface for neurotransmission probing in neurological disorders'	"La Caixa" Foundation, Health Research 2021 Call	HR21-00410	908.539 €	Evolución Molecular
Carlos Briones	'Development, characterization and applications of aptamers as new biotechnological tools for virus detection and antiviral therapy'	Ministerio de Ciencia, Innovación y Universidades; Programa Estatal I+D+i Orientada a los Retos de la Sociedad	PID2019-104903RB-I00	100.000 €	Evolución Molecular
D. Carrizo	Extreme Environments in Planetary Exploration: Geolipids, Stable Isotopes and Minerals in King Gorge Island, Antarctica	IAU (Uruguayan Antarctic Institute)		20.000 €	Planetología y Habitabilidad
Daniel Carrizo	Science and Instrumentation for the study of (bio)geochemical processes in Mars	MINECO	RED2022-134726-T	20.000 €	Planetología y Habitabilidad
Daniel Puyol	Fundamentals and applications of purple bacteria biotechnology for resource recovery from waste (PURPLEGAIN)	COST Action	060/22 CA21146		Evolución Molecular
David Hochberg	MIRROR-SYMMETRY BREAKING IN CONTINUOUS FLOW CHEMICAL PROCESSES: THEORETICAL ANALYSIS AND APPLICATIONS TO CATALYSIS	Ministerio de Ciencia e Innovación	PID2020-116846GB-C22	28.798 €	Evolución Molecular
Elena González Toril and Cristina Cid Sánchez	Ciclo de aerosoles en Marte y La Tierra, estudio comparativo. Implicaciones para la vida y protección planetaria (CAMELIA-MICRO)	Ministerio de Ciencia e Innovación	PID2019-104205GB-C22		Evolución Molecular
Enrique Solano Márquez	El Observatorio Virtual Español. Explotación científico-técnica de archivos astronómicos	Ministerio de Ciencia e Innovación	PID2020-112949GB-I00	209.935 €	Astrofísica
Ester Lázaro	Experimental evolution of an RNA bacteriophage: Influence of contact networks, external environment, and pre-existing mutations (EVOLCEM)	MCIN/AEI	PID2020-113284GB-C22	91.960 €	Evolución Molecular
Eva Villaver	On the rocks II	Ministerio de Ciencia e Innovación	PGC2018-101950-B-I00	121.000 €	Astrofísica
Francisco J. Manjón and Olga Prieto-Ballesteros	MALTA-CONSOLIDER TEAM	Agencia estatal	RED2018-102612-T	14.000,00 €	Planetología y Habitabilidad
Francisco Najarro de la Parra	Desarrollo y explotación de nuevas tecnologías para instrumentación espacial en la Comunidad de Madrid.	Comunidad de Madrid	TEC2SPACE. S2018/NMT-4291	895.232 €	Astrofísica
Francisco Najarro de la Parra and Izaskun Jiménez Serra	Contribución del CAB a SPICA, desarrollo de instrumentación criogénica y explotación científica multilongitud de onda	Ministerio de Ciencia e Innovación	PID2019-105552RB-C41	1.108.965 €	Astrofísica
G. M. Muñoz Caro	Astrophysical ice processes	MICINN	PID2020-118974GB-C21	70.180 €	Astrofísica
Giovanni Lamanna and Enrique Solano	European Science Cluster of Astronomy & Particle physics ESFRI research Infrastructure	European Commission. H2020 Programme	INFRA-EOSC-4-2018	126.469 €	Astrofísica

Ignacio Mendigutía	Star and planet formation across different astronomical scales	Agencia Estatal de Investigación	RYC2019-026992-I	40.000 €	Astrofísica
Isabel Herreros	Rotura de simetría en espejo en procesos químicos de flujo continuo: análisis teórico y aplicaciones a la catálisis (CHIRFLOWCHEM)	Ministerio de Ciencia e Innovación	PID2020-116846GB-C22	28.798 €	Planetología y Habitabilidad
J. Ormö, K. Wünnemann, M. Jutzi, E. Sturkell and Isabel Herreros	Contribution to the DART-Hera (NASA/ESA) missions: a combined capacity of numerical and experimental simulations of heterogeneous materials	CSIC	ILINK22061	22.554,40 €	Planetología y Habitabilidad
J.A.R. Manfredi	Science and technology of space instruments for characterizing the Martian environment within multiple NASA missions: REMS, TWINS and MEDA	MINECO	RTI2018-098728-B-C31		Planetología y Habitabilidad
J.E. González Pastor	Closing the circle: from cultures and function to genomes and metagenomes and back in a salinity gradient (METACIRCLE)	Ministerio de Ciencia e Innovación	PID2021-126114NB-C43	231.110 €	Evolución Molecular
J.E. González-Pastor	Innovative tools for sustainable exploration of marine microbiome innovative tools for sustainable exploration of marine microbiomes: towards a circular blue bioeconomy and healthier marine environments (BlueTools)	Programme: Horizon	HORIZON-CL6-2022-CIRCBIO-01	623,382.5 €	Evolución Molecular
Jacobo Aguirre and Raúl Guantes.	Interacción entre redes complejas: Teoría y aplicaciones en el ámbito de la astrobiología (NetWorld)	Ministerio de Ciencia e Innovación	PID2021-122936NB-I00	36.300 €	Evolución Molecular
Jesús Maíz Apellániz	Ocultas a plena vista: encontrando estrellas galácticas calientes masivas en el espectro visible	Agencia Estatal de Investigación	PGC2018-095049-B-C22		Astrofísica
Jesús Manuel Sobrado Vallecillo	Imitando el subsuelo planetario en el laboratorio (MPSL)	PLAN ESTATAL I+D	PID2020-114047GB-100	96.500 €	Instrumentación Avanzada
José Antonio Rodríguez Manfredi	Caracterización y estudio de la dinámica atmosférica de Marte con el instrumento MEDA, a bordo del rover Perseverance de NASA	INTRAMURAL CSIC	202250E145	104.000 €	Instrumentación Avanzada
José Antonio Rodríguez Manfredi /Eduardo Sebastián Martínez	Ciencia y tecnología de instrumentos espaciales para la caracterización del ambiente marciano en múltiples misiones de NASA	PLAN ESTATAL I+D	RTI2018-098728-B-C31	2.372.205 €	Instrumentación Avanzada
José Antonio Rodríguez Manfredi /Eduardo Sebastián Martínez	M3LEC Ciencia y tecnología de instrumentación para la caracterización del entorno marciano en múltiples misiones de NASA -IV: REMS (Fase E), TWINS (Fase E) y MEDA (Fase E)	PLAN ESTATAL I+D	PID2021-126719OB-C41	968.000 €	Instrumentación Avanzada
Juan Miguel González Grau	Red Nacional de Microorganismos Extremófilos (REDEX)	MINECO	RED2018-102734-T. 2020/22		Evolución Molecular
Kevin Freedman, Armando Azua-Bustos	Evolutionary puzzles: Do microbes in the Atacama Desert harvest UV as an energy source?	Human Frontier Science Program	RGY0066/2018	750.000 $	Planetología y Habitabilidad
L. Colina	Instrumentación MIRI Telescopio Espacial James Webb	The Science and Technology Facilities Council	MIRI2015	513.824 €	Astrofísica

Ongoing Funded Projects

Laura Sánchez-García	Forensic Geochemistry: on the search for biosignatures in extreme environments by exploiting molecular and isotopic tools (RyC Project)	Ministerio de Ciencia e Innovación (MICINN)	RYC2018-023943-I	308.600 €	Evolución Molecular
Luis Ignacio Pastor Pérez and Susana Mata Fernández	Técnicas transversales para la visualización y análisis de datos complejos y multimodales. VADIS	Ed. and Sci. Ministry	PID2020-113013RB-C21	108.295 €	Planetología y Habitabilidad
M. Cerviño	Estallidos de formación estelar a lo largo de la evolución del Universo	Ministerio de Ciencia e Innovación	PID2019-107408GB-C41	121.000 €	Astrofísica
M. Giustini	Unveiling Black Hole Winds from Space	Programa de Atracción de Talento de la Comunidad de Madrid	2018-T1/TIC-11733	143.000 €	Astrofísica
María Rosa Zapatero Osorio, Jorge Sanz Forcada	Enanas marrones y planetas aislados y alrededor de estrellas	Agencia Estatal de Investigación	PID2019-109522GB-C51	217.800 €	Astrofísica
Maria-Paz Zorzano	CAMELIA (the cycle of aerosols on Mars and Earth, a comparative study. Implications for life and planetary protection).			165.200€	Planetología y Habitabilidad
MARIA-PAZ ZORZANO MIER and CARMEN CORDOBA JABONERO	Ciclo de aerosoles en marte y la tierra, estudio comparativo. Implicaciones para la vida y proteccion planetaria-atmosferas (camelia-atm)	Ministerio de Ciencia e Innovación, PLAN ESTATAL de I+D+I	PID2019-104205GB-C21	88.000 €	Evolución Molecular
OLGA PRIETO BALLESTEROS and DANIEL CARRIZO GALLARDO	Operacion Tecnica Y Explotacion Cientifica de Datos En Rls De Exomars, y Contribucion Al Rax De Mmx	Ministerio de Ciencia e Innovación, PLAN ESTATAL de I+D+I	PID2019-107442RB-C32	665.379 €	Planetología y Habitabilidad
Olga Prieto-Ballesteros	PANGAEA Portable Handheld Spectrometer for Geological Characterisation	ESA and INTA	4000138579/22/NL/AT	599.800,00 €	Planetología y Habitabilidad
R. Martín Doménech	Linking laboratory simulations and astronomical observations to constrain the Sulfur and Phosphorus	La Caixa Junior Leader		297.900 €	Astrofísica
Roberto Rosal García	Red Temática de Micro y Nanoplásticos en el Medio Ambiente (EnviroPlaNet)	MINECO	RED2018-102734-T. 2020/22		Evolución Molecular
S. Arribas & A. Labiano, L. Colina as col	Participación española en el proyecto JWST. Actividades previas al lanzamiento, caracterización en órbita y preparación de programas científicos de tiempo	Ministerio de Ciencia e Innovación	PID2019-106280GB-I00	221.793 €	Astrofísica
S. Arribas, Luis Colina	Participación española en el Telescopio Espacial James Webb: Actividades técnicas posteriores al lanzamiento y programas científicos asociados	Ministerio de Ciencia e Innovación	PID2021-127718NB-I00	484.000 €	Astrofísica
V. Parro	Past and present signs of life detection in planetary exploration (SOLID)	Ministry of Science and Innovation-AEI	PID2021-126746NB-I00		Planetología y Habitabilidad
V.M. Rivilla	Cosmic Origins of Life (COOL)	Atracción de Talento Investigador (Doctores con experiencia)	2019-T1/TIC-15379	192.000 €	Astrofísica

Víctor Parro y Laura Sánchez-García	Detección de señales de vida actual y pasada en exploración planetaria (SOLID)	Agencia Estatal de Investigación (AEI, MICINN)	PID2021-126746NB-I00	181.500 €	Evolución Molecular
Victorino Parro and Mercedes Moreno-Paz	SOLID: Detección de Señales de Vida en Exploración Planetaria	Agencia Estatal de Investigación (AEI, MICINN)	RTI2018-094368-B-I00	482.000 €	Evolución Molecular
Xavier Luri	Red Española de Explotación Científica de Gaia	Ministerio de Ciencia, Innovación y Universidades	RED2018-102672-T	15.000 €	Astrofísica
Enrique Solano	The Gaia DR3 Catalogue of Galactic AGB Stars	European Space Agency	4000139151/22/ES/CM	60.000 €	Astrofísica

Mars Sample Return Concept Illustration. Credits: NASA/JPL-Caltech.

Publications
(Articles and Reviews)

Publications

Publicaciones

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Books

"101 Conceptos Básicos de Astrobiología"

(eds. D. Barrado y S. Cabañero)

INTA, Ministerio de Defensa (2022)

Deposito legal: M 31082-2022

ISBN: 978-84-9091-727-5

Contribuited by almost all CAB researchers

Descubriendo Galaxias, Almudena Alonso Herrero y Jesús Romero, Editorial: Next door Publishers. ISBN: 978-84-125659-6-6

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Outreach

Ester Lázaro. ¿Qué implicaciones científicas y morales tendría descubrir vida extraterrestre? Filosofía and Co (2022).

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Ester Lázaro. Conference: "La búsqueda de vida en otros mundos". Jornadas de la Red Andaluza de Astronomía. Sevilla (2022)

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Ester Lázaro. Conference: "La búsqueda de vida en otros mundos". TEDxSaintLouisUniversityMadrid (2022)

Ester Lázaro. Organization of the event "Ellas son CAB" (2022), held at CAB to celebrate the "Día Internacional de la Mujer y la Niña en la Ciencia".

Ester Lázaro. Member of the central team of the Project "Cultura con C de Cosmos" (II Edition). Among the most noteworthy activities are the participation in a discussion at Café Gijón. (Vida en otros mundos: un diálogo entre ciencia y filosofía) and a live performance on YouTube (Vida (extra)terrestre).

Ester Lázaro. Interview for the radio program Sapiens (RNE, 2022)

Ester Lázaro. Interview for the radio program La rosa de los vientos (Onda Cero, 2022)

Ester Lázaro. Intervention in the program Cámara abierta (TVE, 2022)

Ester Lázaro. Participation in the round table organized by AFI Escuela "MujeresQueTransforman: La presencia femenina en las carreras STEM". (February, 2022)

Ester Lázaro. Collaboration in the series of scientific conferences of the CSIC for the educational system of the Community of Madrid.

Ester Lázaro. Contribution to the book "101 Conceptos Básicos de Astrobiología" (eds. D. Barrado y S. Cabañero), Ed. INTA/Ministerio de Defensa (2022), ISBN: 978-84-9091-727-5

Carlos Briones. Scientific advisor and scriptwriter (in Spanish and English) for the animation video 'El origen de la vida' / 'The origin of life', produced in 2022 by the company Labestiaproduce (https://labestiaproduce.com/) for the CSIC LifeHUB.CSIC initiative. Links: https://www.youtube.com/watch?v=ZhFz9BgkJAAS (Spanish), https://www.youtube.com/watch?v=i2dmNGNG3rE (English).

Carlos Briones. Participation in the Round Table '¿Estamos solos en el universo?' at the Valladolid Book Fair, together with Juan Ángel Vaquerizo, Eva Villaver and Inés Rodríguez (June 12, 2022; https://www.youtube.com/watch?v=rocsg7ITQeU).

Carlos Briones. Public outreach talk (together with José Antonio Rodríguez Manfredi) 'En busca de vida en Marte: nuevas misiones y nuevos retos', as part of the cultural activities of the Universidad Internacional Menéndez Pelayo (Palacio de la Magdalena, Santander, June 29, 2022; https://uimptv.es/en-busca-de-vida-en-marte-nuevas-misiones-y-nuevos-retos/).

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Carlos Briones and Luis Colina. Interview by Lorenzo Milá in the program ‘Objetivo Planeta’ (Televisión Española, Canal 24 horas): ‘Telescopio James Webb: ¿Qué avances aporta a la búsqueda de vida en el Universo?’ (July 21, 2022; https://www.youtube.com/watch?app=desktop&v=_60jg5JOD9c).

Carlos Briones. Public outreach talk (together with Ricardo Amils) ‘Extremófilos… ¿y extraterrestres?’ at the event ‘Ciencia Contigo’, organized by the Centro de Biología Molecular Severo Ochoa (CBMSO, CSIC-UAM) at the Residencia de Estudiantes CSIC (November 26, 2022; https://www.cbm.uam.es/images/eventos/seminarios/2022/programainfo.pdf).

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Junio 2022: EL DESCONOCIDO CICLO DEL CARBONO EN MARTE

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Autor del prólogo del libro “Marte. El enigmático planeta rojo” de Antonio Pérez-Verde

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https://www.eldebate.com/sociedad/20220206/jorge-garcia-pla-miembro-misiones-nasa-marte-colonizar-marte-siglo-xxii-xxiii-vez.html

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Fairén. El rover Curiosity no ha encontrado vida en Marte, pero eso hay que demostrarlo. El País, 8 de febrero.

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Fairén. Metanógenos en la Tierra (¿y en Marte?) hace 3.500 millones de años (Astronomía, Nº 272. Marzo 2022).

Fairén. Las mutaciones genéticas no son del todo aleatorias (Astronomía, Nº 273. Abril 2022).

Reflections of the Cosmos in the Museo del Prado

In a perfect symbiosis with science, this route reflects how the art of the past recorded the changes that our perception of the cosmos has undergone over the centuries. Designed by the astrophysicist Montserrat Villar, it proposes a journey through 21 works from the permanent collection of the Museo Nacional del Prado, that was shown from July 11 to October 16, 2022. The book “Reflections of the Cosmos” authored by Villar accompanies the itinerary. With the support of American Friends of the Prado Museum and the Arthur & Holly Magill Foundation.

WEAVE First Light, CAB Press Release (12/2022). Luca Costantin, Jesús Maiz Apellániz

Entrevista en el programa Objetivo Planeta de Lorenzo Milá en el canal TVE 24h, Luis Colina

Entrevista en el programa Objetivo Planeta de Lorenzo Milá en el canal TVE 24h, Montserrat Villar

Entrevista en el programa A hombros de gigantes de Manuel Seara en el canal de Radiotelevisión española Radio 5, Luis Colina

Publicaciones

Entrevista en el programa Sapiens de Paula Aller de Radio Nacional, Almudena Alonso Herrero

Entrevista en el programa de radio Principio de Incertidumbre de Canal Extremadura, Bruno Rodríguez Del Pino

Colaboración habitual de Montserrat Villar en el programa A Hombros de Gigantes. Responsable de la sección de Astronomía.

Entrevistas en El Mundo, ABC, RNE, Cadena Cope, Onda Cero, etc a Montserrat Villar, así como en podcasts diversos

Dirección de la tercera edición de "Cultura con C de Cosmos" por Montserrat Villar celebrada de marzo a junio de 2022.

Entrevista radiofónica en el Canal UNED sobre la exposición AstrónomAs, Miguel Cerviño, 24-03-2022

Cuando la Luna perdió su pureza, Montserrat Villar Martín, curso "Enfoques", Museo del Prado.

Una mirada española en el telescopio espacial James Webb, Almudena Alonso Herrero, Actividades 11F – SOMMA, on-line

Las galaxias y sus agujeros negros, Almudena Alonso Herrero , Ciclo "Ventanas del Universo", CaixaForum, Madrid

El telescopio espacial James Webb: una nueva era para la astronomía infrarroja, Almudena Alonso Herrero , IACTec, Tenerife

Primeras observaciones del telescopio espacial James Webb: de los exoplanetas a las galaxias más lejanas, Almudena Alonso Herrero, Real Academia de Ciencias Exactas, Físicas y Naturales, Madrid

Preparándonos para observer galaxias y agujeros negros supermasivos con el telescopio espacial James Webb, Almudena Alonso Herrero , Ciclo "Cita con las Estrellas", Málaga

Descubriendo un nuevo universo con el telescopio espacial James Webb, Almudena Alonso Herrero, Planetario de Madrid

Pequeña introducción a la astronomía: un paseo por el Universo, Giovanni Miniutti, Catálogo de conferencias científicas del CSIC dirigidas a centros educativos de la Comunidad de Madrid

IES Humanes, 13/02/2022

IES Miguel de Cervantes, 10/02/2022

IES Francisco de Quevedo, 14/03/2022

CEPA Buen Gobernador, 17/02/2022

CEIP Pedro Muñoz Seca, 27/04/2022

CEPA El Pontón, 20/10/2022

IES Palomeras Vallecas, 15/12/2022

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Agujeros Negros: un viaje al borde del abismo, Giovanni Miniutti, Catálogo de conferencias científicas del CSIC dirigidas a centros educativos de la Comunidad de Madrid

IES Altaír, 25/03/2022

IES San Cristóbal de los Ángeles, 19/05/2022

CEIPSO Príncipe don Felipe, 26/10/2022

IES Prado de Santo Domingo, 09/12/2022

Asomándonos al origen del Universo: el telescopio espacial James Webb, Bruno Rodríguez Del Pino, Catálogo de conferencias científicas del CSIC dirigidas a centros educativos de la Comunidad de Madrid

IES Marqués de Suances, 22/12/2022

IES Humanes, 21/20/2022

Asomándonos al origen del Universo: el telescopio espacial James Webb. Javier Álvarez-Márquez y Bruno Rodríguez Del Pino, V Semana de la Ciencia del Valle de Benasque. Centro de Ciencias Pedro Pascual. 19/11/2022.

- Ignacio Mendigutía: Press release CAB (June/2022): "Las inmensas 'guarderías de formación estelar y planetaria"

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https://cab.inta-csic.es/noticias/primer-catalogo-extenso-de-estrellas-masivas-muy-bajas-en-metales/39/

- Marta Lorenzo and Miriam García: interview at Radio Exterior Marca España

https://www.rtve.es/play/audios/marca-espana/marca-espana-cab-lidera-estudio-sobre-estrellas-masivas-25-10-22/6721012/

- Miriam García, interview for Radio show “Entre probetas”

https://www.rtve.es/play/audios/entre-probetas/entre-probetas-planetas-para-todos-gustos/6736371/

- Marta Lorenzo: science nugget for CAB’s website

https://cab.inta-csic.es/wp-content/uploads/2022/11/SexACat_ScienceNugget_vFF.pdf

https://cab.inta-csic.es/noticias/las-inmensas-guarderias-de-formacion-estelar-y-planetaria/52/

- José A. Caballero, Hoy no es 29 de febrero, Longitud de Onda, Radio Clásica https://www.rtve.es/play/audios/longitud-de-onda/hoy-no-29-febrero/6819225/

- José A. Caballero, Antonio Arias, Anni B Sweet, JJ Machuca, Isabel Daza, “Astrobioconcierto”, Fuencaliente, La Palma https://www.eltime.es/isla-bonita/44201-la-palma-sera-esta-primavera-la-capital-mundial-de-la-astrobiologia.html

- José A. Caballero, Carlos Briones, “Astrobioconferencia”, Santa Cruz de La Palma https://www.eltime.es/isla-bonita/44201-la-palma-sera-esta-primavera-la-capital-mundial-de-la-astrobiologia.html

- José A. Caballero, CARMENES DR1 press release: Telediario 1 &2 (La 1), La rosa de los vientos (Onda Cero), Longitud de onda (Radio 3), Gente despierta (Radio 1) https://carmenes.caha.es/ext/pressreleases/GJ486/

- David Barrado y Susana Cabañero (eds). 2022. “101 Conceptos Básicos de Astrobiología”,

Instituto Nacional de Té.cnica Aeroespacial. ISBN 978-84-9091-727-5

https://cab.inta-csic.es/libros/101-conceptos-basicos-de-astrobiologia/ DESCARGA GRATUITA

- Cultura con C de Cosmos: Spring 2022 edition of this activity on the topic “Life”

https://culturaccosmos.es/

- David Barrado: “James Webb: la joya de la corona”

https://www.abc.es/ciencia/abci-david-barrado-james-webb-joya-corona-202112250029_noticia.html

- David Barrado and Victor Parro: “La primera vuelta al mundo desde la perspectiva del siglo XXI y la exploración espacial”

https://www.abc.es/ciencia/primera-vuelta-mundo-perspectiva-siglo-exploracion-espacial-20220909160124-nt.html

- David Barrado: The Conversation, all articles in:

https://theconversation.com/profiles/david-barrado-navascues-524504/articles

- David Barrado: “Hoy empieza todo”, Radio 3, RTVE, interview about his book “Peligros cósmicos”

https://www.rtve.es/play/audios/hoy-empieza-todo-2/peligros-cosmicos-2022-01-17t10-29-39660/6295597/

- David Barrado: “La entrevista de Radio 5”, RTVE. Interview about the James Webb Space Telescope.

https://www.rtve.es/play/audios/la-entrevista-de-radio-5/entrevista-radio-5-david-barrado/6366798/

- David Barrado: “A hombros de gigantes”, RTVE: “¿Qué tiempo hace en el exoplaneta WASP-39”

https://www.rtve.es/play/audios/a-hombros-de-gigantes/hombros-gigantes-tiempo-hace-exoplaneta-wasp-39-03-12-22/6750225/

SASDABA:

The SASDABA project (Star Analyser Spectroscopic DataBAse) is an All Sky Bright Stars (V<5) spectroscopic survey from both hemispheres. The project is being developed by the Spanish Virtual Observatory and the Garraf Astronomical Observatory (OAG). It aims at providing raw and reduced data from original observations to be used in basic spectroscopic analysis and stellar classification by teachers, students, and amateur astronomers. Our activity in 2022 has focused on the ingestion of new datasets and the implementation of new functionalities ("search by observer") in the data archive.

Virtual Observatory schools go virtual.

Since 2009 the Spanish Virtual Observatory group has been actively participating in the organization 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.

In 2022 we organize two schools focused on master/PhD students and early-career researchers:

XXII SVO School

II ESCAPE science with interoperable data

and participate in two other schools.

I Escuela Latinoamericana de Gaia

Eclipsing binaries and Asteroseismology

Other VO school-related activities

Micro-curso VOV: "Taller remoto sobre Observatorio Virtual III. VOSA" (P. Cruz).

Development of a new tutorial: VO with Python: working with PyVO and MOCPy (P. Mas).

Papers

ProAm Commission of the Spanish Astronomical Society: assessment of ProAm collaboration in Spain and how to improve it

Talks.

"Actividades Pro-Am en el marco del Observatorio Virtual" (E. Solano)

"O Universo é mais incrível ainda - James Webb" (P. Cruz)

"Exoplanetas: mundos fuera de la Tierra" y "Un día en la vida de un astrónomo" (M. Cruz Gálvez).

Courses

Title: "Experto en Astronomía" (Universidad Católica de Murcia)

Subject: "Observatorio Virtual" (E. Solano).

Women promotion in STEM

Chatea con una astrónoma (P. Cruz)

Co-coordination "Astrominas 2022" (P. Cruz)

Participation in the "II Premio Javier Gorosabel de Colaboración ProAm".

Contribution to Astroparsec (P. Cruz)

Management of the @obsvirtesp Twitter account

Press releases

Las inmensas "guarderías" de formación estelar y planetaria.

Primera detección de moléculas con silicio y azufre en eta Carina, una potente estrella de granmasa a punto de explotar como supernova

¿Puede una estrella desaparecer sin dejar rastro?

Radio Euskadi

Onda Regional de Murcia

Citizen-science: near-Earth asteroid precovery

Ingestion of a new survey: JPLUS-DR2

Collaboration with high schools

27/10/2022 - El Confidencial https://www.elconfidencial.com/tecnologia/ciencia/2022-10-27/meteoritos-marte-insight-planeta-sistema-solar-nasa_3513814/

27/10/2022 - El País https://elpais.com/ciencia/2022-10-27/dos-meteoritos-caidos-en-marte-en-2021-desvelan-los-secretos-de-su-estructura-interna.html

05/12/2022 - El País https://elpais.com/ciencia/2022-12-05/hallada-en-marte-una-zona-volcanica-tan-grande-como-europa-que-puede-entrar-en-erupcion.html

05/12/2022 - Science Media Centre https://sciencemediacentre.es/reaccion-al-hallazgo-de-una-pluma-del-manto-activa-en-marte

M.I. Herreros, J. Ormö, “Misión DART: Cuenta atrás para el primer ensayo de defensa planetaria de la Tierra, artículo en la revista digital “The Conversation”, 2022; https://theconversation.com/mision-dart-cuenta-atras-para-el-primer-ensayo-de-defensa-planetaria-de-la-tierra-189495

M.I. Herreros, J. Ormö, “¡DART dio en el blanco! La primera misión de defensa planetaria de la historia ha impactado en el asteroide Dimorphos”, artículo en la revista digital “The Conversation”, 2022, https://theconversation.com/dart-dio-en-el-blanco-la-primera-mision-de-defensa-planetaria-de-la-historia-ha-impactado-en-el-asteroide-dimorphos-190360

M.I. Herreros, J. Ormö, “DART ha desviado a Dimorphos de su órbita natural: podemos dormir más tranquilos ante el posible impacto de un asteroide en la Tierra”, artículo en la revista digital “The Conversation”, 2022; https://theconversation.com/dart-ha-desviado-a-dimorphos-de-su-orbita-natural-podemos-dormir-mas-tranquilos-ante-el-posible-impacto-de-un-asteroide-en-la-tierra-192150

M.I. Herreros, J. Ormö, “Evitar lo inevitable: la misión DART, un experimento a escala planetaria para desviar asteroides”, artículo en el boletín de invierno de 2022 de la Sociedad Española de Astronomía, 2022; https://www.sea-astronomia.es/boletin/evitar-lo-inevitable-la-mision-dart-un-experimento-escala-planetaria-para-desviar-asteroides

Reacciones a la propuesta de que el relieve de la luna Europa puede deberse a la presencia de agua líquida Nombre del evento: reacciones smc.es Tipo de evento: Entrevistas en medios comunicación Fecha de celebración: 19/04/2022 Entidad organizadora: Science Media Centre (SMC) Disponible en Internet en: <https://sciencemediacentre.es/reacciones-la-propuesta-de-que-el-relieve-de-laluna-europa-puede-deberse-la-presencia-de-agua

El instrumento español para buscar vida en Marte se queda en tierra por la guerra en Ucrania Nombre del evento: noticia en SINC Tipo de evento: Entrevistas en medios comunicación Fecha de celebración: 18/03/2022 Entidad organizadora: Fundación Española para la Ciencia y la Tecnología “https://www.agenciasinc.es/en/view/content/302094/full/1/131601

Cañadas. English: 24 January 2022: UCL website, British Geological Survey website.

Cañadas: 28 January: CAB website, CAB linkedin and facebook profiles, Diario de Sevilla, Investopi website.

Fairén. El rover Curiosity no ha encontrado vida en Marte, pero eso hay que demostrarlo. El País, 8 de febrero.

Fairén. El origen de los elementos en la Tierra (Astronomía, Nº 270. Enero 2022).

Fairén. Revelados los primeros 200 metros de la subsuperficie de Marte (Astronomía, Nº 271. Febrero 2022).

Fairén. Metanógenos en la Tierra (¿y en Marte?) hace 3.500 millones de años (Astronomía, Nº 272. Marzo 2022).

Fairén. Las mutaciones genéticas no son del todo aleatorias (Astronomía, Nº 273. Abril 2022).

International Congress committees – Session Conveners

--AbSciCon 2022 session organizer (Dr. F. Gómez): Acid Brines as Possible Habitable Environments and Organic Preservatives: Low Water Activity Niches. Atlanta (GA), May 2022.

--Sessions organizer (Dr. F. Gómez): EPSC LF1: Earth Analogues Session and EPSC AB1: Astrobiology Session

Short visits:

Alberto Rebassa Mansergas (Universidad Politécnica de Cataluña). November 2nd-4th.

Formation

XVIII International School of Astrobiology «Josep Comas I Solà»: *Searching for Life on Mars: Techniques and Challenges*

Organizer: UIMP Santander

Place: Santander - Península de la Magdalena (Hall Real)

Direction: Rosaly M. Lopes (*Jet Propulsion Laboratory NASA, USA*) and Víctor Parro (*Centro de Astrobiología, Spain*)

Secretary: Carlos Briones (*Centro de Astrobiología, Spain*)

Teachers:

- **Mike Malaska:** Jet Propulsion Laboratory, NASA, USA
- **Melissa Rice:** Western Washington University, USA
- **Frances Westall:** CNRS, France
- **José Antonio Rodríguez Manfredi:** Centro de Astrobiología, CAB (INTA-CSIC), Spain

In 2021, three different space missions successfully arrived at Mars, including the landing in Jezero crater by the NASA's Perseverance rover, which is expected to significantly advance our search for life on the Red Planet. Perseverance is the first step of the Mars Sample Return (MSR) mission and will collect and cache samples for future return to Earth, where they can be analyzed in our laboratories. The Perseverance rover carries seven instruments to conduct important science and technology investigations while on the surface, including for the first time measurements using a Deep UV fluorescence and Raman mapping spectrometer able to detect organic molecules and their spatial distribution. Although the results alone cannot prove that biosignatures are present, they will be able to identify carbon-containing compounds and help classify contained organic functional groups. In parallel, the planned European Space Agency (ESA) ExoMars mission will include the Rosalind Franklin rover. ➛

➛ The 2022 Summer School will review and assess the types of techniques that are necessary for detection of biosignatures on Mars, including Raman spectroscopy, the isotopic and chirality analyses that Rosalind Franklin rover will perform, and the advanced techniques needed to analyze samples both in-situ and in Earth-based laboratories. The central question will be “how can we unequivocally detect biosignatures on Mars?” and the discussions will involve in-situ rovers, sample collecting and return, laboratory analyses on Earth, and the experiments that future human explorers may be able to perform. The lectures will be focused on instrumentation, techniques, and the science they provide. In addition to them, during the week the students will participate in discussions about the theme, prepare and present group projects, and take part in an excursion to a relevant geological site near Santander..

EAI Academy 2022:

Organizers: EAI and CAB

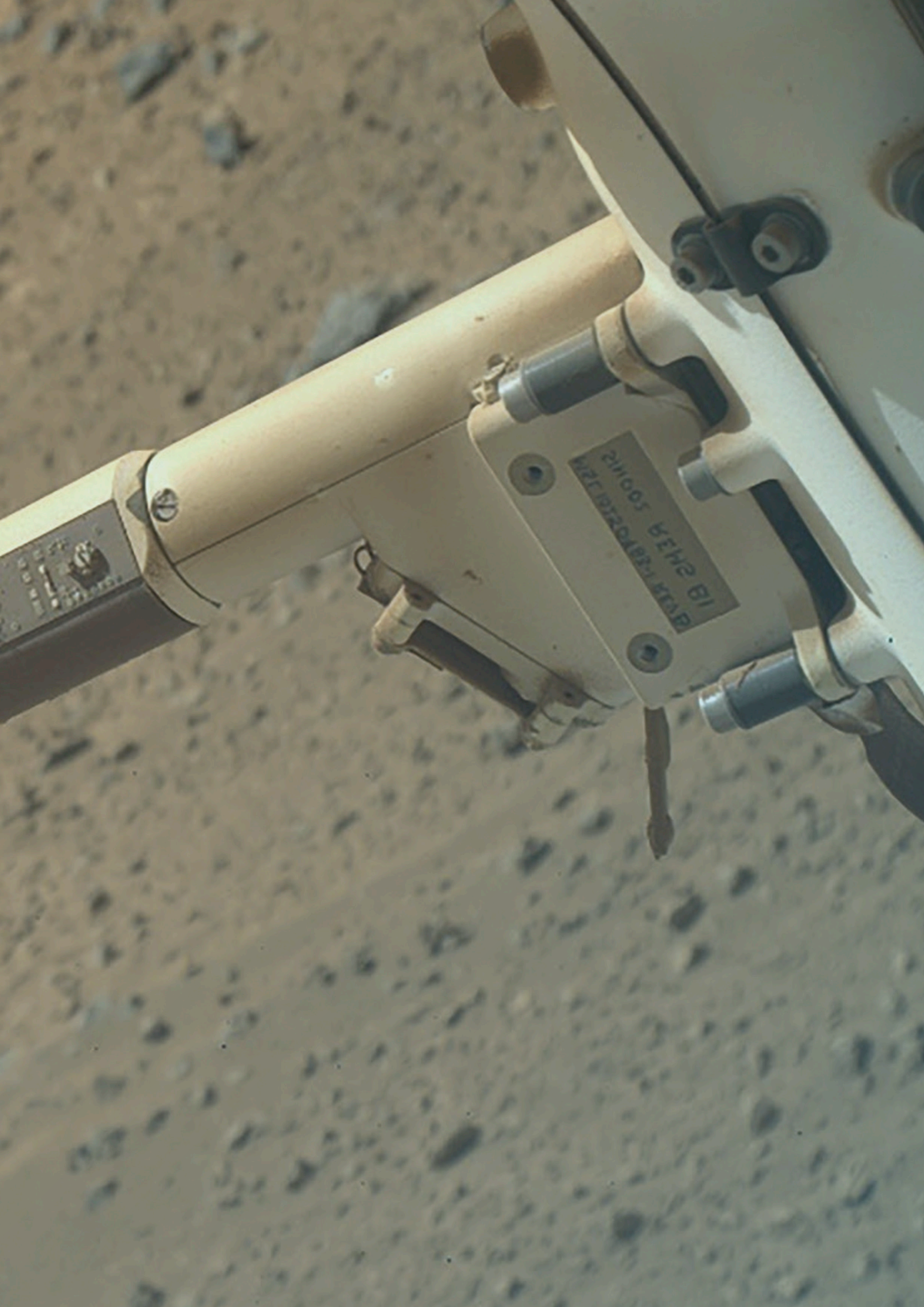
Directed by: María Paz Zorzano, CAB

Classes:

- Exoplanet biomarkers: José A. Caballero Astrophysics Department CAB (Spain)
- The Pathway to Prebiotic Chemistry: molecular precursors from space: Victor Rivilla Astrophysics Department CAB (Spain)
- The Hidden Microbial Life in Earth’s Lava Caves: Implications for Life Detection on Extraterrestrial Bodies: Diana E. Northup Biology Department University of New Mexico (USA)
- Liquid water on Exoplanets and the Habitable Zone: Amri Wandel University of Jerusalem (Israel)
- The marine deep-subsurface biosphere: Jan Amend University of Southern California (USA)
- Hydrothermal systems - life in the dark: Anna Neubeck Uppsala University (Sweden)
- From the thermodynamic evolution of the protosolar nebula to the present-day composition of Jupiter: Olivier Mousis Aix-Marseille Université (France)
- Searching for evidence of life on subterranean Mars: Prospects and Challenges: Charity Philips-Lander South West Research Institute (USA)
- The habitability of Mars: a geophysical approach: Doris Breuer Institute of Planetary Research, DLR (Germany)
- Life inside the rocks: microbial diversity and metabolisms in the deep subsurface: Victor Parro Molecular Evolution Dpt. CAB (Spain)
- Deciphering Ocean Worlds in the lab: Olga Prieto-Ballesteros Planetology & Habitability Dpt. CAB (Spain)
- Under too little pressure - Hypopiezotolerant microorganisms as potential model organisms in Astrobiology: Dr. Petra Schwendner University of Florida (USA)
- Microbial life in extreme and dry environments on Earth: Dr. Kristina Beblo-Vranesevic DLR Cologne (Germany)
- Effect of saltation and abraded silicates on the survival of bacteria and as a sink of methane and carbon dioxide: Dr. Kai Finster Aarhus University (Denmark)
- The near surface environment of Mars: observations, laboratory simulations and Mars sample return: Dr. María-Paz Zorzano CAB (Spain)
- Acidophiles: low pH lovers. The Rio Tinto case and the Mars connection: Dr. Felipe Gómez CAB (Spain)

Roque de los Muchachos Observatory.

Detail of the REMS wind and temperature sensors on Mars Credits: NASA/JPL-CALTECH/CAB



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Conjunto de antenas de ALMA, el proyecto de astronomía más grande que existe, ubicado en la meseta de Chajnantor en los Andes chilenos. © Clem y Adri Bacri-Normier (wingsforscience.com) / ESO