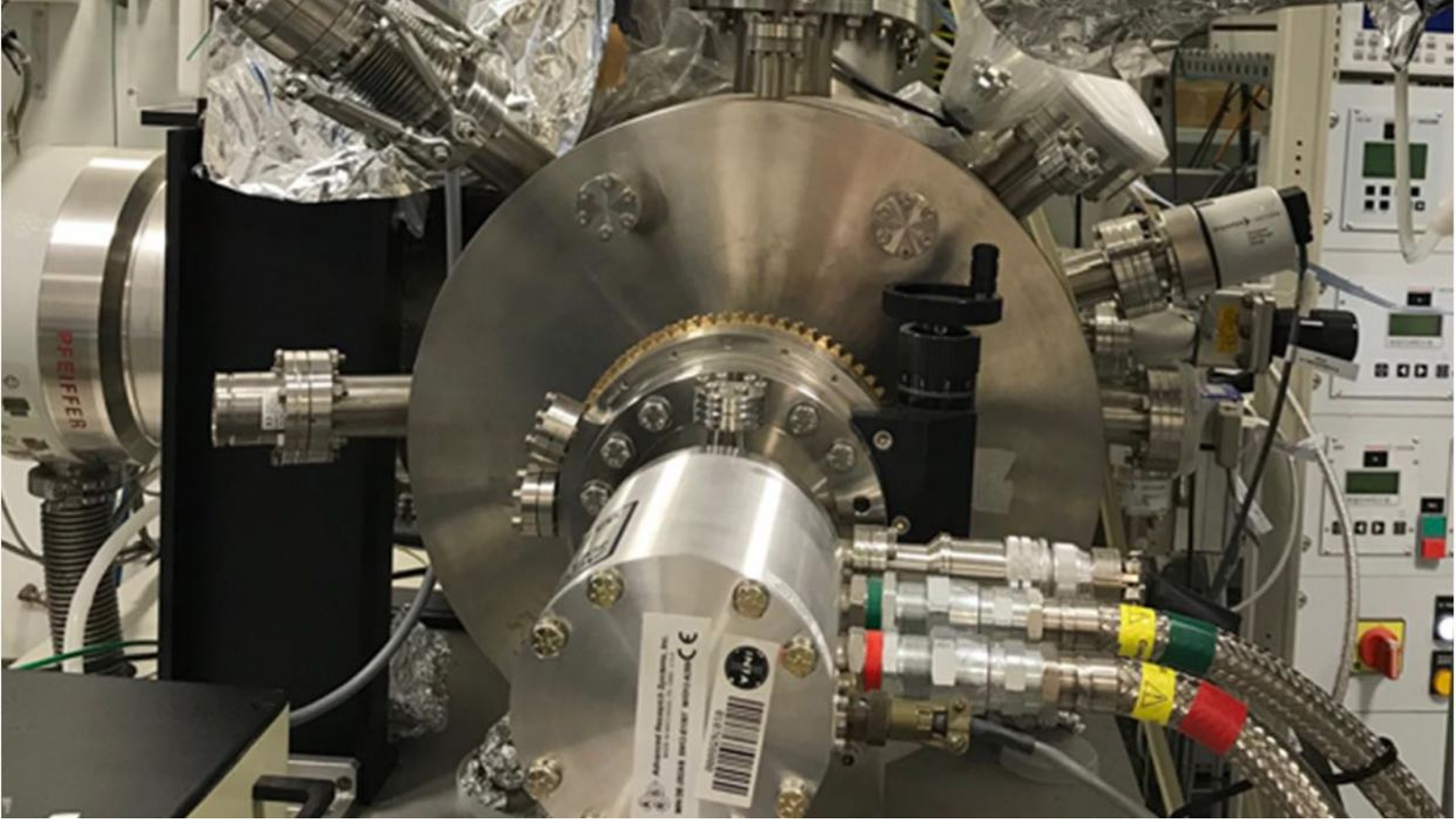


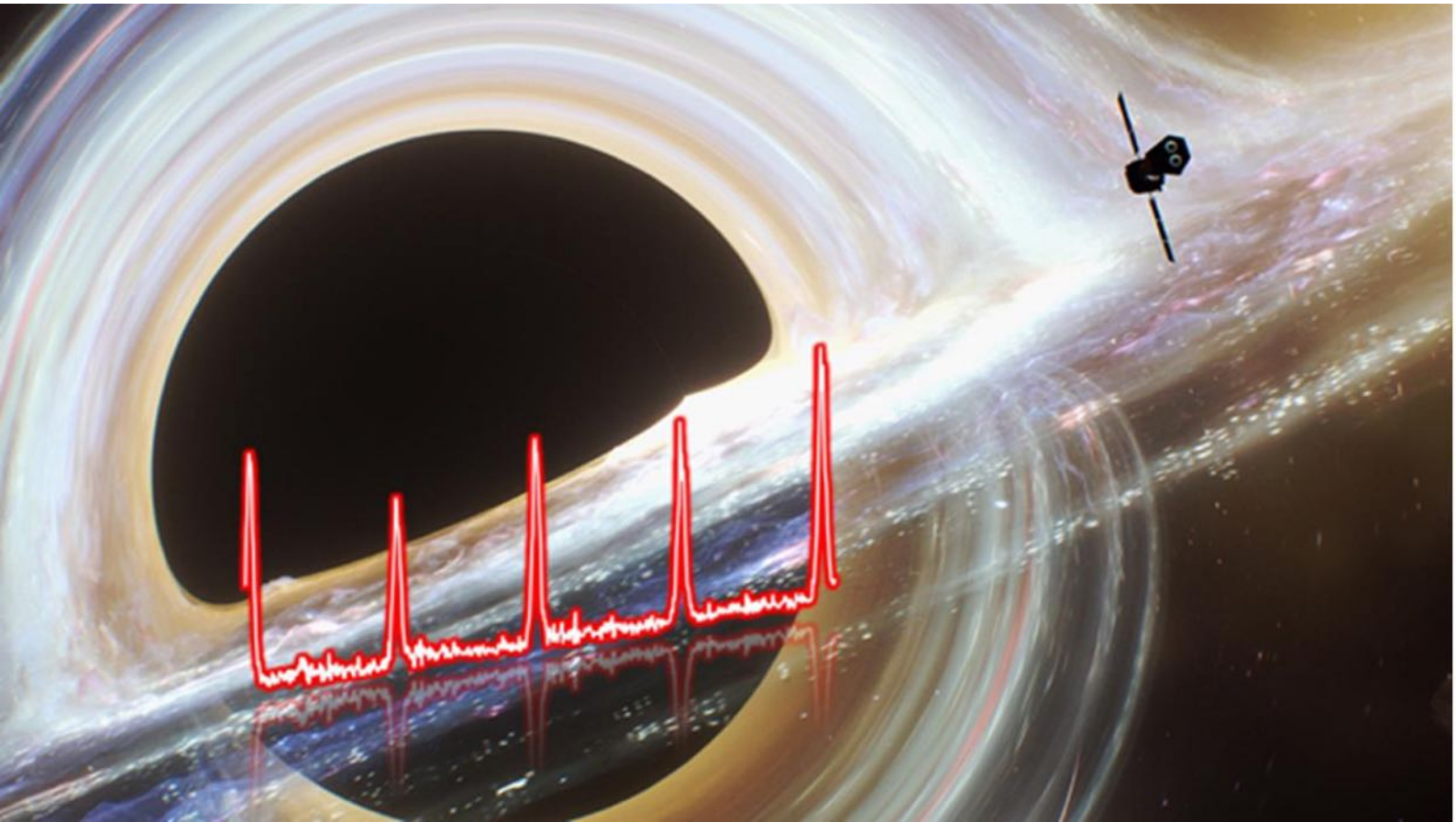
CENTRO DE ASTROBIOLOGÍA · CAB

ASOCIADO AL NASA ASTROBIOLOGY PROGRAM

CSIC INTA

EXCELENCIA MARÍA DE MAEZTU

Annual Report 2019



CENTRO DE ASTROBIOLOGÍA

CSIC - INTA

Molecular Biomarkers under the Atacama Desert soils

INTRODUCCIÓN

El Centro de Astrobiología (CAB) se fundó en 1999 como un Centro Mixto entre el Consejo Superior de Investigaciones Científicas (CSIC) y el Instituto Nacional de Técnica Aeroespacial (INTA). Localizado en el campus del INTA en Torrejón de Ardoz (Madrid), el CAB se convirtió en el primer centro fuera de los Estados Unidos asociado al recién creado NASA Astrobiology Institute (NAI), convirtiéndose en miembro formal en el año 2000. La Astrobiología considera la vida como una consecuencia natural de la evolución del Universo, y en el CAB trabajamos para estudiar el origen, evolución, distribución y futuro de la vida en el Universo, mediante investigaciones en la Tierra como en entornos extraterrestres. La aplicación del método científico a la Astrobiología requiere la combinación de teoría, simulación, observación y experimentación. Esta aplicación de la Ciencia fundamental a las cuestiones de la Astrobiología es el principal método de trabajo en el CAB. La organización multi- y transdiciplinar del Centro fomenta la interacción de los ingenieros con investigadores experimentales, teóricos y observacionales de varios campos: astronomía, geología, bioquímica, biología, genética, teledetección, ecología microbiana, ciencias de la computación, física, robótica e ingeniería de las comunicaciones.

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

A destacar durante el ejercicio 2019 es la celebración del 20º aniversario del Centro de Astrobiología, que quedó constituido como centro mixto del CSIC y de INTA el 19 de noviembre de 1999. La efeméride fue celebrada con un acto especial el 19 de noviembre en el que contamos con destacados representantes de ambas instituciones, el director científico de la ESA, Profesor Günter Hasinger, así como el impulsor clave y fundador del CAB, el profesor Juan Pérez Mercader y otros miembros fundadores. Asimismo, organizamos el curso “20 años de Astrobiología en España” en el marco de los cursos de verano de El Escorial de la Universidad Complutense.

A mediados de diciembre de 2019 se lanzó con el éxito CHEOPS (CHaracterising ExOPlanet Satellite - Satélite de caracterización de exoplanetas, una misión de ESA y la Agencia espacial suiza dedicada a la caracterización de exoplanetas de tamaños comprendidos entre la Tierra y Mercurio. El CAB forma parte del equipo científico que seguro aportará información valiosa sobre planetas similares a la Tierra. Dos meses antes recibimos en el CAB al recién premiado con el Nobel de Física, el Prof. Michel Mayor, descubridor del primer exoplaneta e impulsor de CHEOPS.

El descubrimiento de un agujero negro que se comporta como un metrónomo de rayos X; La descripción de nuevos microorganismos que habitan los lugares más extremos de la tierra; la entrega a NASA del instrumento MEDA (Mars Environmental Dynamics Analyzer) para la misión Mars 2020; o la elaboración de un servicio meteorológico marciano gracias a los datos ya recibidos y procesados por el CAB del instrumento TWINS a bordo del módulo Insight de NASA, son algunos de los resultados más destacables de 2019. Finalmente, el 24 de mayo de 2019 nos dejó para siempre Murray Gell-Mann, Premio Nobel de Física 1969 por sus descubrimientos sobre partículas elementales, amigo del CAB y figura clave en la génesis y creación del Centro.

INTRODUCTION

The Centro de Astrobiología (CAB) was founded in 1999 as a joint centre between the National Research Council (CSIC) and the National Institute for Aerospace Technologies (INTA). Located within the INTA campus in Torrejón de Ardoz (in Madrid), CAB became the first astrobiology organization outside the United States to be associated with the NASA Astrobiology Institute (NAI), formally becoming an associate partner in the year 2000. Astrobiology considers life as a natural consequence of the evolution of the Universe, and CAB aims to study the origin, evolution, distribution, and future of life in the Universe, through investigations on Earth and in extraterrestrial environments. Application of the scientific method to astrobiology requires the combination of theory, simulation, observation and experimentation. This application of fundamental science to the questions of astrobiology is the most important goal for CAB. The multi- and transdisciplinary setting available at CAB allows engineers to interact with experimental, theoretical and observational scientists from various fields: astronomy, geology, bio-geochemistry, biology, genetics, remote sensing, microbial ecology, computer science, physics, robotics and communications engineering.

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

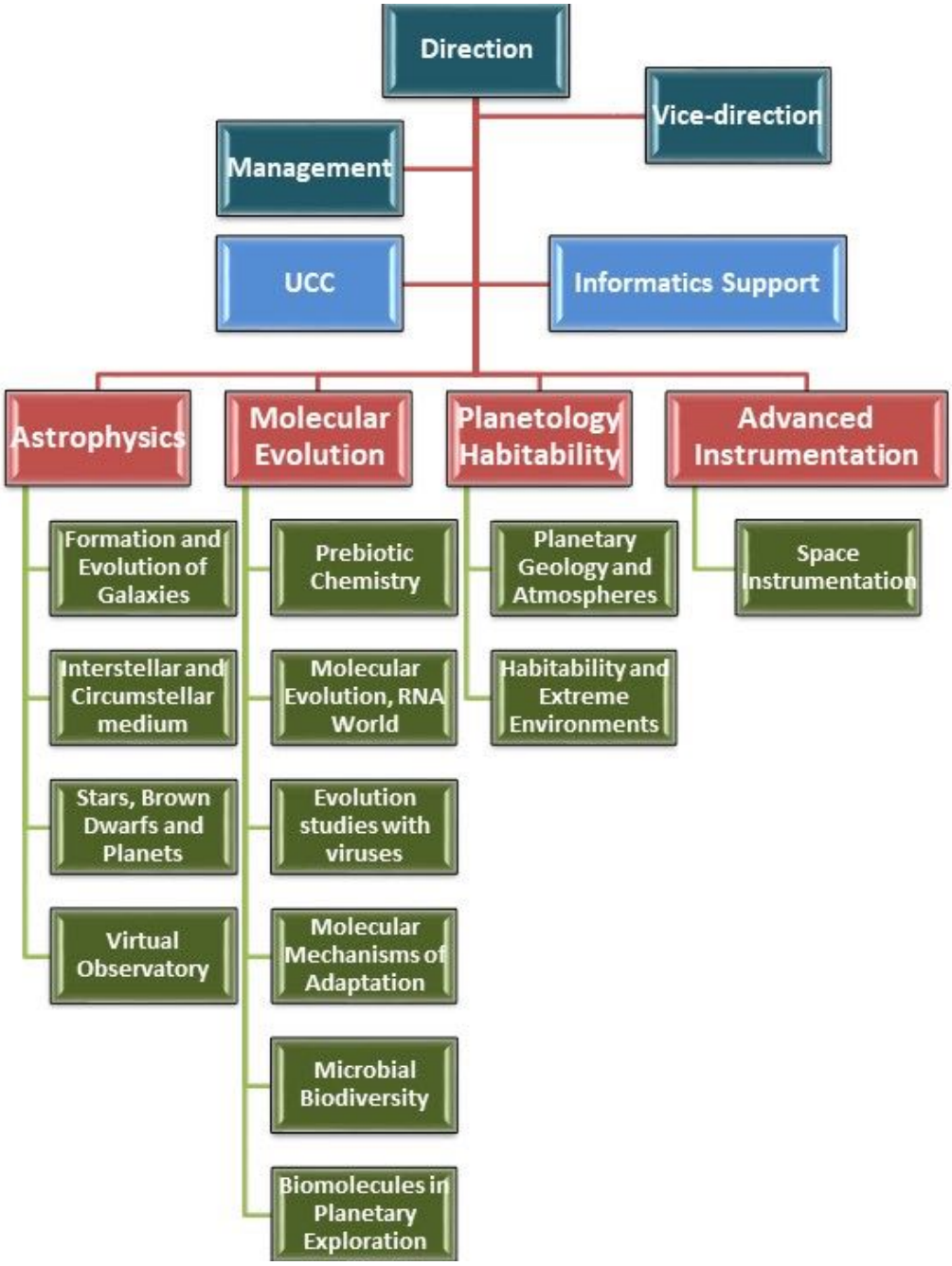
To highlight during 2019 is the celebration of the 20th anniversary of the Centro de Astrobiología, which was constituted as a joint center of CSIC and INTA on November 19th, 1999. The event was celebrated with a special act on November 19 in which we had prominent representatives from both institutions, the ESA Scientific Director, Professor Günter Hasinger, as well as the key promoter and founder of CAB, Professor Juan Pérez Mercader, and other founding members. Likewise, we organized the course "20 years of Astrobiology in Spain" within the framework of the El Escorial summer courses at the Complutense University of Madrid.

In mid-December 2019, CHEOPS (Characterizing ExOPlanet Satellite), a mission from ESA and the Swiss Space Agency dedicated to the characterization of exoplanets of sizes between Earth and Mercury, was successfully launched. The CAB forms part of the scientific team that will surely provide valuable information on Earth-like planets. Two months earlier we received at CAB the recently awarded Nobel Prize in Physics, Prof. Michel Mayor, discoverer of the first exoplanet and promoter of CHEOPS.

The discovery of a black hole that behaves like an X-ray metronome; The description of new microorganisms that inhabit the most extreme places on earth; the delivery to NASA of the MEDA (Mars Environmental Dynamics Analyzer) instrument for Mars 2020 mission; or the elaboration of a Martian meteorological public application thanks to the data already received and processed by CAB from the TWINS instrument on board the NASA Insight module, are some of the most remarkable results in 2019. Finally, on May 24th sadly passed away Murray Gell-Mann, Nobel Prize in Physics 1969 for his discoveries on elementary particles, friend of CAB and key figure in the genesis and creation of the Centre.

INSTITUTE 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 2019. Centro de Astrobiología was organized in four Research Departments (red), each of them having different research groups (green). Additional units such as the Unidad de Cultura Científica (UCC), the Informatics Support, or the DNA Sequencing service, provide the required support for the operations of CAB. The departments operate a number of laboratories and facilities covering the very different areas of activities.

GOVERNING COUNCIL

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

D. Ángel Olivares Ramírez, Secretario de Estado de Defensa, Ministerio de Defensa.

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

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

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

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

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

ADVISORY BOARD

The former Directors of CAB constitute its Advisory Board:

- 1999 – 2008: Juan Pérez Mercader (CSIC)
- 2008 – 2010: Álvaro Giménez Cañete (CSIC)
- 2010 – 2015: Javier Gómez Elvira (INTA)
- 2015-2019: Miguel Mas Hesse (CSIC)

DIRECTION AND CENTER EXECUTIVE BOARD

Victor Parro

Francisco Najarro

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

RESEARCH DEPARTMENTS

Astrophysics

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ALFONSO	GARZON	JULIA
ALLER	EGEA	ALBA
ALONSO	HERRERO	ALMUDENA
ALVAREZ	SAAVEDRA	ALBERTO
ÁLVAREZ	MÁRQUEZ	JAVIER
ARRIBAS	MOCOROA	SANTIAGO
BARCELÓ	FORTEZA	SEBASTIÁ
BARRADO	NAVASCUÉS	DAVID
BLANCO	SANCHEZ	CARME MARIA
CABALLERO	HERNANDEZ	JOSE ANTONIO
CABAÑERO	RODRIGUEZ	SUSANA
CALERO	DE ORY	MARINA
CARRASCOSA	DE LUCAS	HÉCTOR
CATALAN	TORRECILLA	CRISTINA
CERVIÑO	SAAVEDRA	MIGUEL ANTONIO
CIFUENTES	SAN	ROMAN CARLOS
COLINA	ROBLEDO	LUIS
COSTANTIN		LUCA
CRESPO	GOMEZ	ALEJANDRO
CUENDA	MUÑOZ	DIEGO
DOMINGO	GARAU	ALBERT
ESTRADA	PIQUERAS	ALBERTO
FUENTE	GUILLEN	DIEGO DE LA
GARCIA	CASTRO	MIGUEL
GARCIA	GARCIA	MIRIAM
GARCIA	TAVORA	VICENTE
GIUSTINI		MARGHERITA
GONZÁLEZ	ÁLVAREZ	ESTER
GONZALEZ	DIAZ	CRISTOBAL
GORGUES	VALENCIANO	ALEJANDRO
GUZMAN	DIAZ	JORGE
HOLGADO	ALIJO	GONZALO
HUELAMO	BAUTISTA	NURIA
JIMENEZ	SERRA	IZASKUN MAITE
LABIANO	ORTEGA	ALVARO
LILLO	BOX	JORGE
MAIZ	APELLANIZ	JESUS
MARCOS	ARENAL	PABLO
MARQUES	COELHO CHAVES	RUI JOSE
MARTIN	GUERRERO DE ESCALANTE	EDUARDO L.
MARTIN-PINTADO	MARTIN	JESUS
MAS	HESSE	JOSE MIGUEL
MENDIGUTIA	GOMEZ	IGNACIO ANTONIO

MÉRIDA	GONZÁLEZ	ROSA MARÍA
MINIUTTI		GIOVANNI
MONTESINOS	COMINO	BENJAMIN
MORALES	CALDERON	MARIA
MUÑOZ	CARO	GUILLERMO
NAJARRO	DE LA PARRA	FRANCISCO
PEREIRA	SANTAELLA	MIGUEL
PÉREZ	GARCÍA	ANA MARÍA
PEREZ	GONZALEZ	PABLO GUILLERMO
PERNA		MICHELE
PIQUERAS	LOPEZ	JAVIER
RICO	VILLAS	FERNANDO
RODRIGO	BLANCO	CARLOS
RODRIGUEZ	DEL	PINO BRUNO
SANCHEZ	CONTRERAS	MARIA CARMEN
SANCHEZ	GARCIA	MARIA
SANZ	FORCADA	JORGE
SANZ	FENÁNDEZ DE CÓRDOBA	LOURDES
SOLANO	MARQUEZ	ENRIQUE
VELASCO	TRASMONTE	ALMUDENA
VILLAR	MARTIN	M.MONTSERRAT
ZAPATERO	OSORIO	M.ROSA

Planetology and Habitability

AMILS	PIBERNAT	RICARDO
AZUA	BUSTOS	ARMANDO JAVIER
CARRIZO	GALLARDO	DANIEL ALEJANDRO
DIOS	CUBILLAS	ANA DE
ESCUDERO	PARADA	CRISTINA
FERNÁNDEZ	SAMPEDRO	MARÍA TERESA
GÓMEZ	GÓMEZ	FELIPE
GONZALEZ	FAIREN	ALBERTO
HERREROS	CID	MARIA ISABEL
LOPEZ	JIMENEZ	ALICIA
MARTÍNEZ	SARMIENTO	PALOMA
MOLINA	JURADO	ANTONIO
MUÑOZ	IGLESIAS	MARIA VICTORIA
OLOF	ORMO	JENS
PRIETO	BALLESTEROS	OLGA
RINARDO	BELMAR	VICTOR ALFONSO
ROBAS	GARCÍA	CRISTINA
RODRIGUEZ	GONZALEZ	NURIA
VEGA	GARCIA	SONIA MARIA
ZORZANO	MIER	MARIA PAZ

Molecular Evolution

AGUILERA	BAZÁN	ÁNGELES
ALONSO	RAVELO	FELIPE RUYMAN
ARRIBAS	HERNÁN	MARÍA
BENGUIGUI	DE LA CAMARA	MACARENA
BRIONES	LLORENTE	CARLOS
CID	SÁNCHEZ	CRISTINA
CUETO	DIAZ	EDUARDO JOSE
DOS SANTOS	SEVERINO	RITA SOFIA
FERNÁNDEZ	ALGAR	MARÍA
FRANCISCO	MARTINEZ	PATRICIA DE
GALVEZ	MARTINEZ	SANTOS
GARCIA	LOPEZ	EVA
GARCIA	VILLADANGOS	MIRIAM
GOMEZ	FRUTOS	SARA
GONZALEZ	DE FIGUERAS	CAROLINA
GONZALEZ	PASTOR	JOSÉ EDUARDO
GONZÁLEZ	TORIL	ELENA
HERMIRA	HERRANZ	MARGARITA
HOCHBERG	NEWMAN	DAVID
JIMENEZ	BONALES	LAURA
LÁZARO	LÁZARO	MARÍA ESTER
LAMPRECHT	GRANDÍO	MARÍA
LEZCANO	VEGA	MARIA ANGELES
MATEO	MARTÍ	EVA
MIRETE	CASTAÑEDA	SALVADOR
MORENO	PAZ	MERCEDES
NAÑEZ	CABRERO	ALMUDENA
OCHOA	DE ERIBE	JON
PARRO	GARCIA	VICTORINO
PEREZ	FERNANDEZ	CRISTINA
POSTIGO	CACHO	MARINA
RAYO	PIZARROSO	PEDRO
RUIZ	BERMEJO	MARTA
SANCHEZ	GARCIA	LAURA
TORRES	VAZQUEZ	BEATRIZ
WHITE		JOSEPH

Advanced Instrumentation

FERRANDIZ	GUIBELALDE	RICARDO
GIMENEZ	TORREGROSA	SILVIA
GOMEZ	GUTIERREZ	ALICIA
LEPINETTE	MALVITTE	ALAIN
LOPEZ	JIMENEZ	ALICIA
MAGAZ	PEREZ	MARIATERESA
MARIN	JIMENEZ	MARIA DE LAS MERCEDES

MARTIN	SOLER	JAVIER
MORA	SOTOMAYOR	LUIS
NAVARRO	LOPEZ	SARA
PEINADO	GONZALEZ	VERONICA
PLA	GARCIA	JORGE
RODRIGUEZ	MANFREDI	JOSE ANTONIO
ROMERAL	PLANELLÓ	JULIO JOSÉ
ROMERO	GUZMAN	CATALINA
SAEZ DE	TERESA	JORGE LUIS
SEBASTIÁN	MARTÍNEZ	EDUARDO
SOBRADO	VALLECILLO	JESUS MANUEL
TORRES	REDONDO	JOSEFINA
URQUI	O'CALLAGHAN	MARIA DEL ROSARIO
VIUDEZ	MOREIRAS	DANIEL
ZURITA	ZURITA	SOFIA

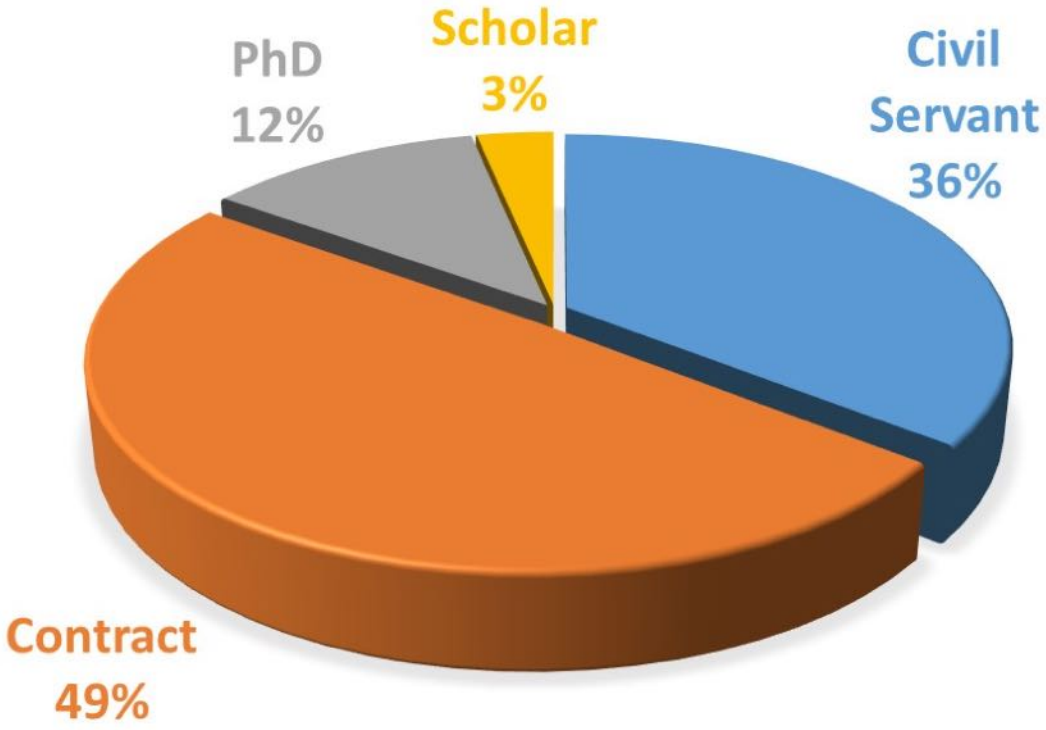
Management and other supports

BERMUDEZ	CASTILLO	ESTER
DEL	OLMO	ANDRÉS ROSA
FRAILE	NORIEGA	TATIANA
GARCÍA	MARTÍN	MARÍA TERESA
GUITART	MARTÍN	MARGIE
GUTIERREZ	ORTEGA	MACARENA
MONCAYO	ORTEGA	CONSUELO
SALADO	REY	M.SAGRARIO
SUAREZ	MARSA	VIRGINIA
MARTINEZ	DE LLERA	CARMEN
GARCÍA	CLIMENT	INMACULADA

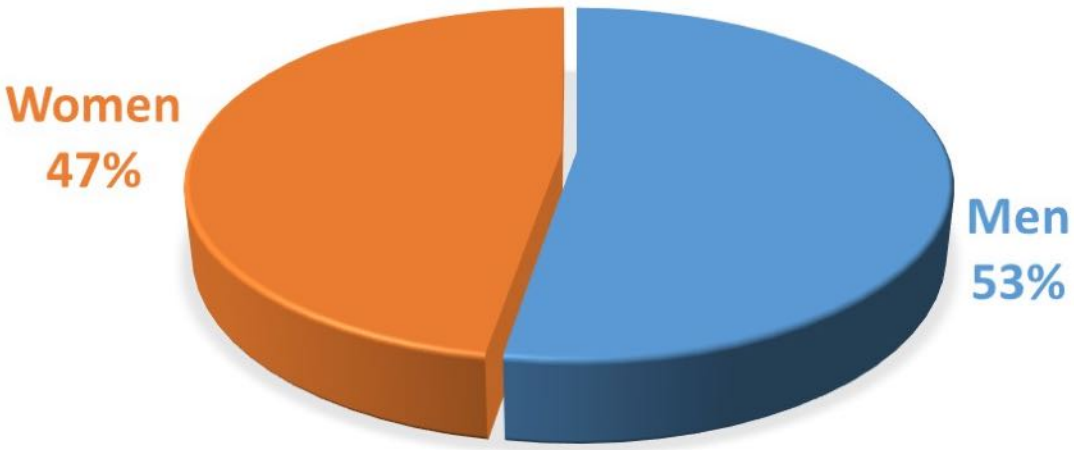
Services Unit

ALONSO	DEL VAL	PILAR
ALONSO	VALDIVIESO	MIGUEL ANGEL
PARRAS	RICO	ANTONIO
SANCHEZ	NARRILLOS	PAULA
SUÁREZ	CARRASCO	SERGIO
VAQUERIZO	GALLEGO	JUAN ANGEL
VARA	PINEDO	JESUS ANSELMO

Personnel



Gender Balance



ASTROPHYSICS

Head of Department: Pablo G. Pérez González

Throughout the history of the Universe, generations of stars have created in their interior all the heavy elements that we know. The atoms of these chemical elements formed molecules, dust grains and ice sheets in the interstellar and intergalactic medium to condense into planetary systems with rocky planets. Liquid water, as on the Earth, allowed the conditions in which life arose more than 3.5 billion years ago and must have been repeated in a large number of planetary systems.

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

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

The Department is organized in 4 Research Groups:

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

Galaxies Formation and Evolution

Coordinator: Giovanni Miniutti

Obscuring material around Active Galactic Nuclei

We have studied the properties of the obscuring material around nearby Active Galactic Nuclei (AGN), the so-called dusty molecular torus. For our first approach we used ALMA high angular resolution observations of several molecular gas transitions and the (sub)millimeter emission at 850micron and 1.3mm of two nearby Seyferts. On scales of hundreds of parsecs, the kinematics of the molecular gas reveals both circular and non-circular motions, with the latter related to the presence of ionized gas outflows. The torus (10-20pc scales) of the prototypical Seyfert 2 galaxy NGC1068 is both rotating and outflowing. Its size depends on the molecular gas transition used, with those tracing denser gas revealing a more compact size. The complicated nuclear CO(3-2) and CO(2-1) morphology and kinematics of NGC3227 can only be explained with a nuclear warped disk and a molecular outflow. The AGN wind in NGC3227 appears to have excavated the molecular gas and possibly the dust in regions close to the AGN. This created a cavity-like structure, which is similar to that observed in NGC1068. Our second approach was to model high angular resolution infrared observations of a volume-limited (d < 40Mpc) sample of X-ray selected Seyfert galaxies using clumpy torus models. We confirmed that type 2s have larger values of the torus covering factor than type 1s. These findings were independent of whether we used an optical or an X-ray classification. On the other hand, the torus covering factor remains essentially constant within the errors in the luminosity range of our sample and there is no clear dependence with the Eddington ratio, as found in X-rays.

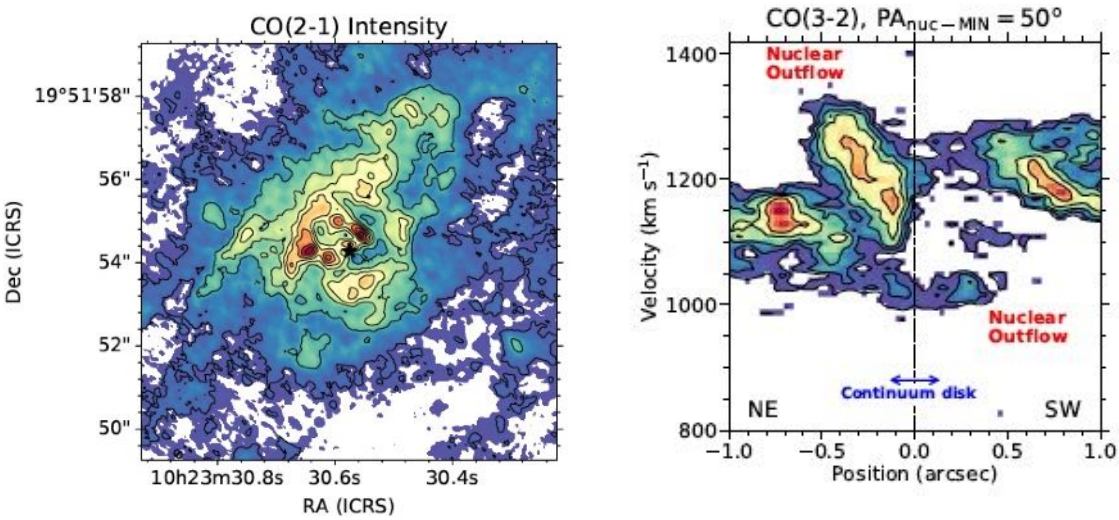


Figure 2-1 - The left panel is the ALMA CO(2-1) integrated emission of the central 10" (approximately 700pc) of NGC3227. The right panel is a CO(3-2) position-velocity diagram of the central 1" taken along the kinematic minor axis of the nuclear disk of NGC3227, revealing the presence of a nuclear molecular outflow.

Detection and analysis of 3 ULXs in the low-metallicity starburst galaxy ESO 338-4

Combining Chandra and XMM-Newton X-ray observations we have uncovered three ultraluminous X-ray sources (ULXs) in ESO 338-4. The brightest among them, ESO 338-4 X-1, has X-ray luminosity in excess of 10^{40} erg s^{-1}. We speculate that ESO 338-4 X-1 is powered by accretion on an intermediate-mass (300 M_{sun}) black hole. We show that X-ray radiation from ULXs and hot superbubbles strongly contributes to HeII ionization and general stellar feedback in this template starburst galaxy.

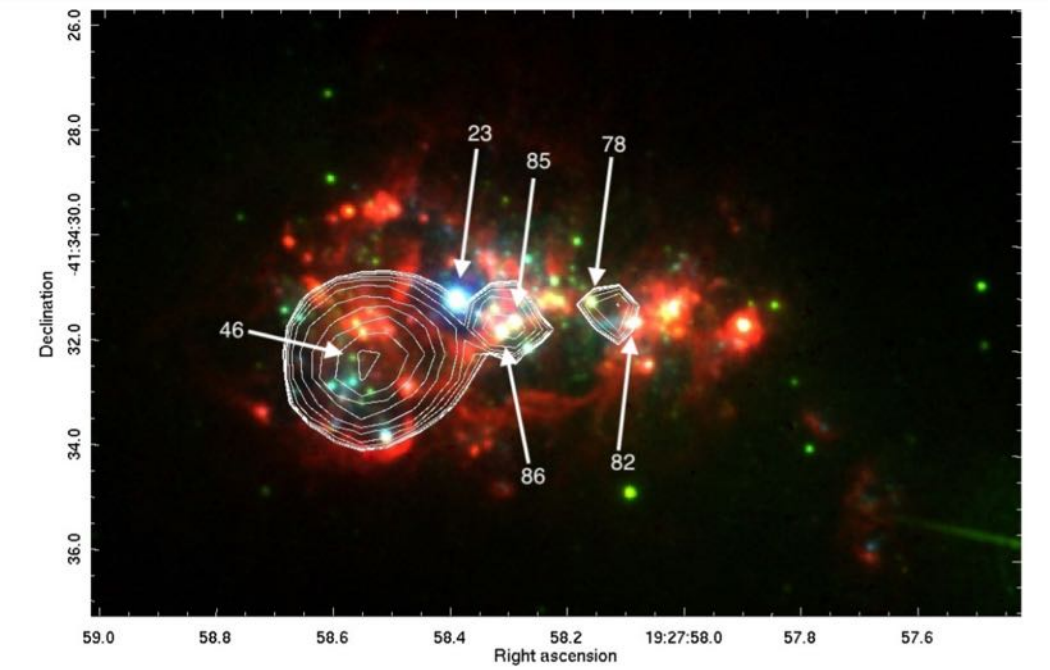


Figure 2-2 - HST colour composite image of ESO 338-4 (UV, optical, H), with logarithmically spaced contours tracing the smoothed Chandra X-ray image.

Spectrophotometric detection of protocluster candidate galaxies at z= 6.5

We combined multiband photometry with follow-up observations via multi-object spectroscopy of 16 Lyman alpha emitter (LAE) candidates discovered in the Subaru/XMM Newton Deep Survey. We have securely confirmed 10 LAEs with sufficient signal-to-noise ratio of the signature Ly emission lines. The inferred star formation rates of the confirmed LAEs are on the low side. However, they show the evidence of high Ly rest frame equivalent widths. These are pieces of evidence for low-mass star-forming galaxies, which are thought to be responsible for the re-ionisation of the Universe. Furthermore, this group of LAEs exhibits a sign of possibly virialised core of a protocluster at this high redshift.

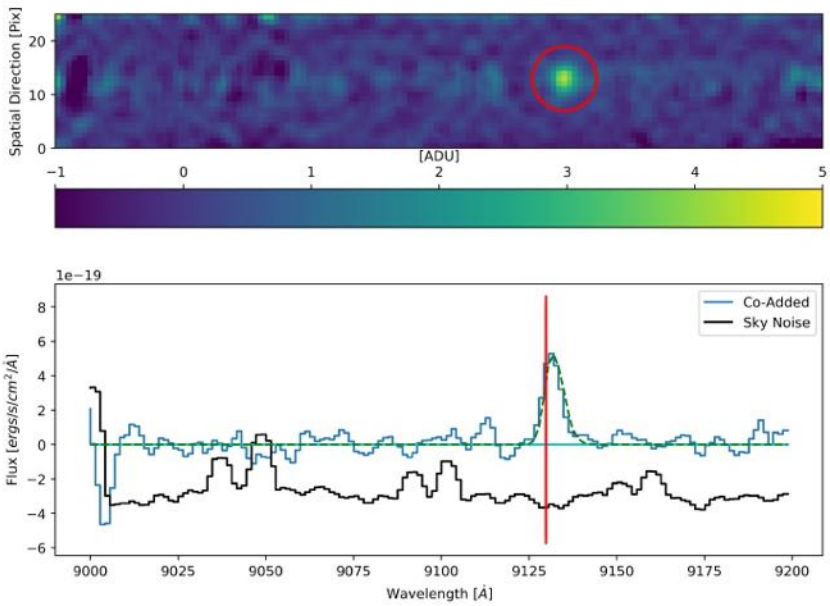


Figure 2-3- The co-added 2D and 1D spectrum of the 10 LAEs at z=6.5 with reliable detections.The blue solid line is the 1D spectrum,while the black solid line is the sky background.

Discovery of Quasi Periodic Eruptions (QPEs) in an active galaxy

Using ESA's XMM-Newton X-ray observatory, a CAB-led study has discovered some unprecedented X-ray flashes from the active black hole at the core of the galaxy GSN 069, about 250 million light years away.

The source suddenly increases its X-ray brightness by large factors, dims back to its normal level within one hour, and lights up again approximately nine hours later. Further observations, performed with XMM-Newton as well as NASA's Chandra X-ray observatory in the following couple of months, confirmed that the distant black hole was still keeping the tempo, emitting nearly periodic bursts every nine hours that were dubbed 'Quasi-Periodic Eruptions', or QPEs. The Figure shows the X-ray brightness as a function of time during three different observations (XMM-Newton in red, Chandra in green).

There are various mechanisms that could give rise to this type of quasi-periodic signal, potentially linked to instabilities in the accretion flow close to the central black hole. Alternatively, the eruptions could be due to the interaction of the disc material with a second orbiting body – another black hole or perhaps the remnant of a star that previously torn apart by the central black hole. Further observations and theoretical modelling is needed to establish the physical nature of this completely new phenomenon in active galactic nuclei. Understanding this unprecedented behaviour will certainly significantly improve our view of supermassive black hole accretion in general.

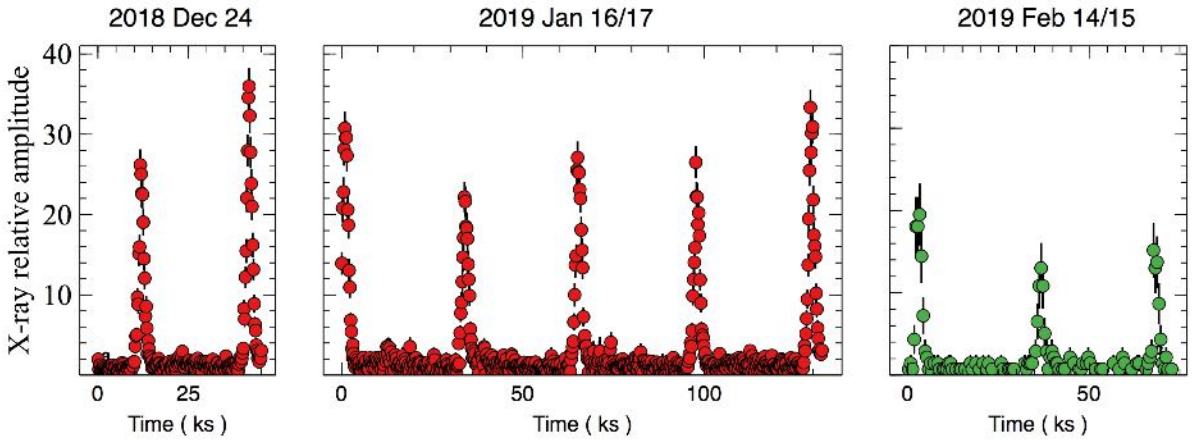


Figure 2-4 - X-ray brightness as a function of time within three different X-ray observations of GSN 069. The actual count rate has been normalized to the nearly constant quiescent (non-flaring) level to show the X-ray amplitude evolution more clearly (Miniutti et al. 2019, Nature, 573, 381)

Preparing for the James Webb Space Telescope

Luis Colina has continued his work on the preparations of the scientific exploitation of the James Webb Space Telescope (JWST) Mid-IR Instrument (MIRI). Together with Javier Álvarez, Álvaro Labiano and Rui Marques have developed realistic simulated spectra of galaxies at cosmological distances, during the Epoch of Reionization of the Universe. In addition, together with other international members of the MIRI high-z working group, has investigated the expected accuracy in the determination of the stellar masses of high-redshift galaxies with JWST broadband photometry. The results of these works had been published in a couple of refereed papers.

Luis Colina continues his activities as coordinator of the European MIRI high-z working group. The group has been involved in the revision and preparation of the Guaranteed Observing Time (GTO) in response to NASA and STScI requirements. The full program including the prime imaging in. the Hubble UltraDeep Field, as well as the spectroscopy of selected high-redshift quasars and galaxies is now completed and available for the astronomical community.

Luis Colina has been investigating the AGN and starburst activity in the nuclear regions of low-redshift galaxies using the millimeter wavelength interferometer ALMA, and the VLT near-IR integral field spectrograph, SINFONI. Detailed studies of the stellar populations in the circumnuclear ring of the galaxy NGC 4303 was published in collaboration with scientists from the Universidade Federal Rio Grande do Sul /N. Dametto & R. Riffel). In addition, the calibration and preliminary analysis of ALMA data taken from a large sample of Luminous and Ultraluminous Infrared Galaxies (U/LIRGs) continues.

Álvaro Labiano has continued his involvement in the JWST as the international coordinator of the JWST/MIRI-MRS instrument. He has published 4 technical documents in collaboration with CAB scientists and the MRS team. He has been invited to present his work in two international workshops, and organized two international meetings for the MIRI and MRS teams. Álvaro Labiano has been responsible of the supervision of the commissioning activities for the MIRI-MRS instrument, the implementation of MRS capabilities in proposal preparation tools, and the update of the Calibration Data Products needed for the MRS data reduction pipeline developed by STScI. As part of the JWST commissioning preparations, he participated in the Science Instrument Rehearsal 4.0 at the Space Telescope Science Institute, aiming to update the actuation protocols for JWST operations and spacecraft failures.

Álvaro Labiano has published seven scientific papers including White Papers for the NASA Decadal Survey 2020, and presented his results in four (two invited) international workshops and conferences. He has also co-organized one scientific international workshop. As part of his involvement in the SPICA mission, he has contributed to several articles on the SPICA Yellow Book.

Concerning outreach, Álvaro Labiano published in 2019 two Science Nuggets (short outreach presentations) on JWST, under the María de Maeztu CAB program, and gave a colloquium for middle school students about space science and exploration.

Álvaro Labiano was awarded a contract under the Programa de Garantía Juvenil (MICINN) to hire a computer scientist to work on JWST analysis tools. He also applied (co-IP) for funding (granted in 2020) to the Plan Nacional de Espacio to support CAB's involment in the JWST mission.

Javier Álvarez has continued his involvement in the JWST as a member of MIRI European Consortium, where he has actively participated in the test, calibration, and commissioning team. He has been deeply involved in the wavelength calibration and resolving power of the MRS and the characterization of the MRS PSF, together with testing of the MIRI simulator and JWST calibration pipeline. He has published 3 technical documents in collaboration with CAB scientists and the MRS team. He has been invited to present his work in 2 international workshops, and has participated in 3 international MIRI Consortium meetings. As part of the JWST commissioning preparations, he participated in the Science Instrument Rehearsal 4.0 at the Space Telescope Science Institute, aiming to update the actuation protocols for JWST operations and spacecraft failures.

Javier Álvarez has participated in the MIRI high-z GTO working group, where he is co-PI of the star-forming galaxies and quasar GTO programs. He has continued the revision of the GTO programs, data simulations and analysis. In parallel, he has continued with his project on characterizing the dust attenuation in Lyman break galaxies at $z\sim3$. He has published 2 first author scientific papers.

Rui Marques has started his work on performing realistic simulations and reduction of JWST Near-Infrared Imager and Slitless Spectrograph (NIRISS) wide field observations targeting very high redshift emission line galaxies.

In parallel, Rui Marques has continued his research on gravitational lensed sources at high redshift within the BELLS GALLERY project, investigating the rest-frame UV properties of Lyman-alpha emitters and Lyman break galaxies. He has published one first author scientific paper on the discovery of one of the most luminous Lyman-alpha nebulae known so far. He has also participated in several high-ranked observer proposals (HST, GTC, NOEMA, WHT) including two as a PI using GTC. He has been part of the seminar organizing committee at CAB and acted as an external proposal reviewer for the China Telescope Access Program.

Interstellar and circumstellar medium

Coordinator: Guillermo M. Muñoz Caro

The field known as Astrochemistry or Molecular Astrophysics is approached from three main different perspectives: i) Observational (ALMA observations, preparation of SAFARI spectrometer on board the future SPICA mission, Robledo de Chavela antennas, and access to other multi-wavelength observatories), ii) Theoretical (development of molecular excitation, radiative transfer, chemical evolution models, and MADCUBA code for data analysis), iii) Instrumentation (design and construction of SAFARI spectrometer, development of KID detectors to observe from mm to far-infrared, and iv) Experimental (laboratory experiments dedicated to ice processes using the ultra-high vacuum InterStellar Astrochemistry Chamber (ISAC), and use of external radiation facilities abroad such as the NSRRC synchrotron in Taiwan).

This line of research is dedicated to the four-fold study mentioned above (observational, theoretical, instrumentation, and experimental) aiming to understand the physico-chemical processes that occur in interstellar and circumstellar environments, in particular the reactions leading to complex organic molecules (COMs) of interest for astrobiology. More than 200 molecules have been detected in these regions, every year a few new species enlarge this list. Large circumstellar envelopes around evolved stars and the chemistry in protoplanetary disks are investigated. The complex region toward the Galactic Center with a rich chemistry is also a subject of research within our group. In diffuse clouds, some chemical reactions take place, but most of the molecules are dissociated by the strong radiation field. In dense clouds like Taurus or Orion, the sites of new stars formation, the detection of numerous molecular species results from a complex network of chemical reactions and the interplay between dust grains and gas-phase species. In dense cloud interiors dust grains are covered by ice mantles composed of H_2O, CO, CO_2, CH_3OH, CH_4, NH_3, etc. Irradiation (energetic photons and cosmic rays) of the ice generates COMs of prebiotic interest that are incorporated into comets and other minor bodies of the primitive solar system.

In summary, the chemistry of different environments in the Galaxy is often determined by the presence of intense UV fields from nearby stars, cosmic rays, shocks, turbulence, and other phenomena that are often not well characterized. The main goal of this research group is to obtain a detailed description of the above environments, to understand the gas and dust lifecycle in our Galaxy, and to determine the limits of chemical complexity before the appearance of life on Earth.

Observational studies using different telescopes at different wavelengths:

Circumstellar envelopes around evolved stars: We continued our studies of circumstellar envelopes around low-to-intermediate mass evolved stars (AGB, post-AGB, pPNe, and PNe) through observations of these systems at multiple wavelengths, from the X-rays to the radio regime. For instance, we carried out a series of molecular line and continuum emission studies in the submm/mm-wavelength range with ALMA. The unique capabilities of ALMA (very high sensitivity and angular resolution) have enabled us to characterize the nebular morphology and dynamics of several AGB/post-AGB/PNe and related objects with unprecedented detail and to improve our understanding of the origin of the remarkable morphological and kinematical differences between AGB circumstellar envelopes, and their more evolved counterparts, post-AGB and PNe. Our team is leader in the search and direct characterization of rotating disks in these systems. Disks are postulated to play a major role in the wind collimation responsible of PN-shaping.

Using ALMA spectroscopy, in 2019 we reported the discovery of a molecular ejecta in Eta Carina, one of the most active LBV stars, and a puzzling chemistry in this object (Bordiu & Rizzo 2019).

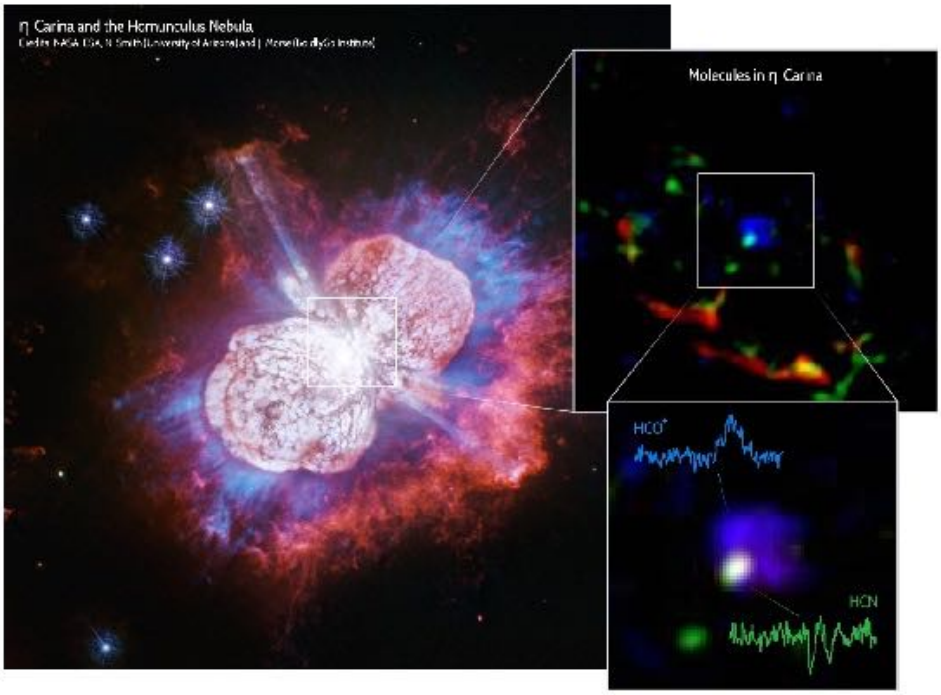


Figure 2-5. ALMA observations of a molecular ejecta in Eta Carina (Bordiu & Rizzo 2019).

Interferometric observations with ALMA of the free-free continuum and recombination line emission at 1 and 3 mm of the Red Square Nebula surrounding the B[e]-type star MWC 922 were reported (Sánchez Contreras et al. 2019). The unprecedented angular resolution (up to 0."02) and exquisite sensitivity of these data reveal for the first time the structure and kinematics of the nascent compact (<150AU) ionized region at its center. We resolve the spatio-kinematic structure of a nearly edge-on disk rotating around a central mass of 10-15Msun and discover a fast (100 km/s) bipolar ejection (possibly a jet) orthogonal to the disk – see Fig. 2-6. *This represents the first empirical proof of rotation in a bipolar wind expanding at high velocity (100 km/s)*. The fast bipolar wind is actively launched in regions closer than 29AU most likely by a disk-mediated mechanism.

J. Ramos defended his PhD thesis in 2019, working under the supervision of C. Sánchez Contreras. As part of his thesis work, we published a second paper of a series making use of Herschel/PACS spectroscopy of evolved stars in the THROES catalogue to study the inner warm regions of their circumstellar envelopes (CSEs) (da Silva Santos et al. 2019). We used the CO emission spectra, including a large number of high-J CO lines (from J=14-13 to J=45-44, ν = 0), to derive rotational temperatures, masses, and mass-loss rates of the envelope layers where the CO transitions observed with PACS arise.

As part of our extensive studies of the properties of AGB CSEs we also published in Quintana-Lacaci et al. 2019 a study of the properties of a particular type of evolved stars, C-rich evolved stars with high expansion velocities. We have obtained single-dish line profiles and interferometric maps of the CO J = 1-0 and J = 2-1 emission lines with IRAM-30m and IRAM/

NOEMA for the two best studied objects within this group, IRC+10401 and AFGL 2233. We have modeled this emission using a LVG radiative transfer code to determine the kinetic temperature and density profiles of the gas ejected by these stars. We have found that the luminosities obtained for these objects (log(L/L) = 4.1 and 5.4) locate them in the domain of the massive asymptotic giant branch stars (AGBs) and the red supergiant stars (RSGs). In addition, the mass-loss rates obtained (1.5×10^{-5}-6×10^{-3} Myr^{-1}) suggest that while IRC+10401 might be an AGB star, AFGL 2233 could be an RSG star.

This group is also active in spectral surveys, FUV/X-ray observations of AGBs with HST, XMM, Chandra, and GALEX, and optical spectroscopy with GTC/MEGARA.

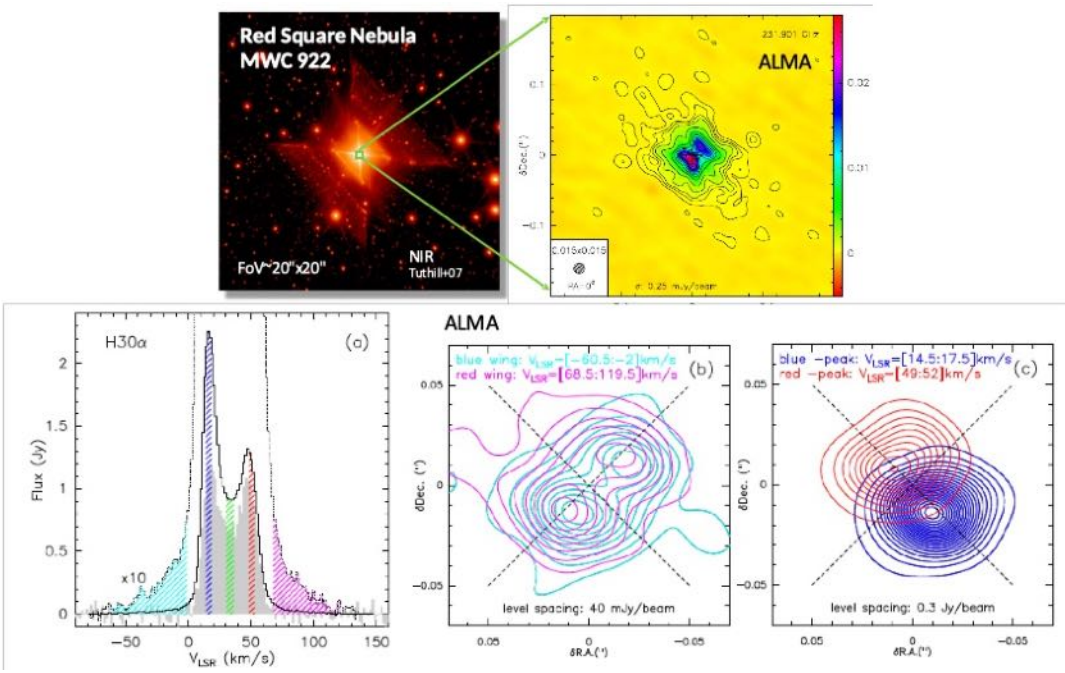
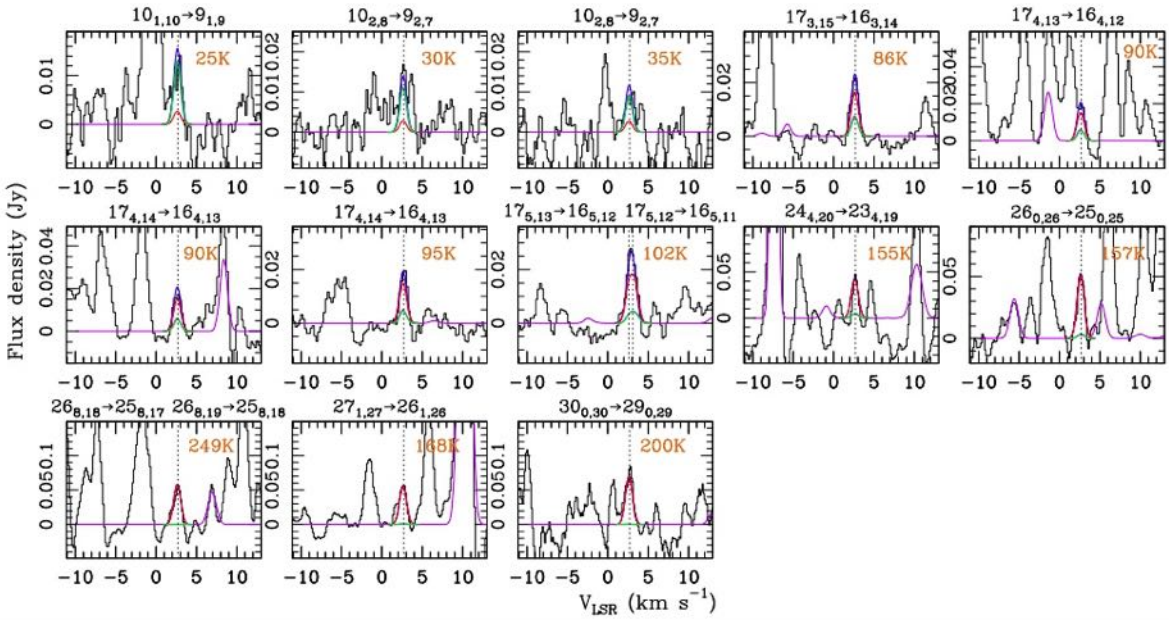


Figure 2-6. Summary of ALMA observations of a rotating disk and a fast bipolar wind at the core of the Red Square Nebula around the B-type star MWC 922 (Sánchez Contreras et al. 2019). Top panels show the image of the extended nebular in the NIR (left) and 1mm-continuum emission map of the compact X-shaped ionized core at the center (right). Bottom panels show (a) the integrated spectrum of the H30 line obtained with ALMA (black line) and with the IRAM-30m antenna (gray histogram); (b-c) the H30 emission maps integrated over the line wings and the peaks, showing the presence of the fast bipolar wind and the rotating disk, respectively – see Sánchez Contreras et al. 2019 for more details.

Interstellar Medium:

Several studies to characterize interstellar regions have been carried out. The goal is to understand the chemistry in these environments, and in particular, the formation of complex organic molecules of interest for Astrobiology. One example is the search of RNA precursor molecules such as glycolonitrile ($HOCH_2CN$) and cyanomethanimine ($HNCH_2CN$). During 2019, these species were detected in the interstellar medium by our group members. A new inventory of Nitrogen-bearing complex organics has been established toward the Center of our Galaxy, stressing the chemical richness of this region in prebiotic species. Glycolonitrile, detected for the first time in the interstellar medium and around a proto-Sun using ALMA (see Fig. 2-7), is a key intermediate species in the production of C_3/C_4 sugars. In the pre-RNA world, glycolonitrile is essential for the assembly of ribonucleotides, which are thought to be precursors of nucleic acids. The formation of this species occurs presumably in icy dust

mantles, the seeds of planetary systems and cometesimals. The detection of these species are pieces of evidence for prebiotic reactions in space.



Fureg. 2-7. First detection of pre-biotic glycolonitrile ($HOCH_2CN$) in the interstellar medium (Jimenez-Serra et al. 2019).

Izaskun Jiménez Serra co-supervised two PhD students based in University College London (Giuliana Cosentino) and Queen Mary University of London (Shaoshan Zeng) who defended their thesis in 2019.

Members of this team have worked on

- Analysis of spectral lines surveys in a variety of objects observed with 30m and ALMA in cold cores (low mass-stars), Hot cores (massive stars), Galactic center and extragalactic nuclei.
- Star formation (both high and low mass).
- Proposals to international facilities at mm/submm wavelengths: ALMA, e-VLA, GBT, IRAM, APEX.

New astronomical facilities both on ground and space (SKA, SPICA, …) During 2019, the CAB team has been working on the definition of the science cases. In particular, it has been very active on the field of prebiotic chemistry in the interstellar medium in the context of future searches with the SKA, and in the study of feedback and feeding in the Context of Galaxy Evolution with SPICA.

Laboratory astrochemistry

This research line continued its activity regarding the experimental study of physico-chemical processes in icy dust grains present in dense interstellar clouds, circumstellar regions and pre-cometary material. The comparison of the effects of UV versus X-rays in irradiated H_2O:CO:NH_3 ice mixtures was published in two papers. This work serves to explore the formation of prebiotic species in protoplanetary disks where both types of radiation are at work. We found that the prebiotic chemistry induced by UV and X-ray irradiation led to similar products, which include amino acids like glycine, formamide, and other prebiotic

species. A follow up work provides an explanation for the non-detection of these species (known as complex organic molecules or COMs) in the gas phase of protoplanetary disks, suggesting that COMs are formed in the ice but remain depleted in the dust.

The need for a non-thermal desorption mechanism of ice molecules, which accounts for the gas phase abundances observed toward cold regions, has triggered the experimental study of photon-induced desorption (photodesorption) of ice species. Since 2008, we have largely contributed to the study of photodesorption in pure ices or ices composed of 2 or more different species. In collaboration with the NCU in Taiwan and Palermo Observatory, in 2019 we published papers that report i) the photodesorption of CO_2 and the formation of atomic C, which is an important coolant that triggers star formation, ii) the photodesorption in $CO:N_2$ and $CO_2:N_2$ ice mixtures with interesting implications for our understanding of photon-energy transfer between ice molecules see Fig. 2-8), and iii) the photodesorption yield of CO molecules as a function of the angle of CO ice deposition, where we found evidence for a column structure of the ice formed at large incidence angles of deposition.

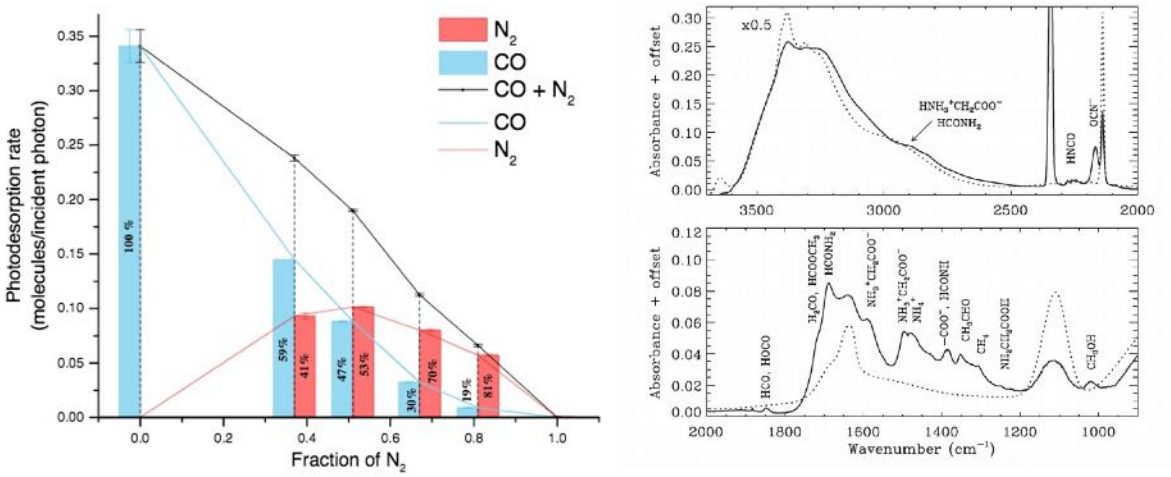


Figure 2-8. ***Left*****: Photodesorption is the process that occurs upon ice irradiation, leading to the ejection of molecules from the ice surface to the gas phase. In the $CO:N_2$ ice mixture, representative of the ice surface in cold interstellar dust, the relative proportion of these species fully determines their desorption. This observation might appear straightforward if both species absorb UV radiation with the same efficiency. But in reality this is not the case, only CO absorbs UV photons, and must donate a fraction of their absorbed photon energy to the neighboring N_2 molecules to explain the observed photodesorption (Carrascosa et al. 2019).** ***Right*****: Infrared spectra of a $H_2O:CO:NH_3$ = 1.5:1.3:1 ice mixture irradiated with soft X-rays to study the formation of prebiotic species in protoplanetary disks. The bands of several COMs are clearly seen. Although this identification of glycine in the infrared is only tentative, this species was confirmed by chromatography of these samples (Muñoz Caro et al. 2019).**

The teams led by E. Mateo, O. Prieto, and G. M. Muñoz Caro published a joint article that reports the most relevant scientific results of the Laboratory for the Simulation of Interstellar and Planetary Environments (LSAIP), published in the astrobiology journal Life. A Report for the European Space Astronomy Centre (ESAC) with title ¨Measurements of thermal and dielectric properties of ices in support to future radar measurements of Jovian Icy moons¨ was delivered. This report contains the WP01 of the project: Ice growth and characterisation, reporting fabrication of the ice samples containing salts, and the first measurements that showed the viability of the determination of ice thermal conductivity (C. González Díaz, G. M. Muñoz Caro, ITEFI-CSIC team) and electric conductivity (O. Prieto, V. Muñoz, UCM team) .

Data analysis

In 2019, work on the development of MADCUBA (Madrid Data Cube Analysis) was continued. The implemented capabilities of this code are:

- Data cube visualization and reduction. The visualization and analysis (soothing, crop, extract spectrum, etc.) of spatially synchronized cubes has been implemented during 2019.
- Automatic import data cubes from ALMA and cubes and spectra from all Herschel instruments was incorporated.
- Advanced LTE analysis of molecular line profiles using the JPL and CDMS catalogs and recombination lines is possible.

Instrumentation

In order to observe at lower frequencies than ALMA, several researchers coordinated the construction and integration of new instrumentation for the Robledo de Chavela antennas (Host Country). A new intermediate frequency processor and a broadband backend were installed. In the last 6 years the scientific results have been very satisfactory, leading to several publications.

Figure 2-9. (a) Example of large format array of Ti/Al KIDs fabricated as a demonstrator for the KISS instrument (b) Single pixels (c) *S21 transmission at 15 mK showing 296 pixels.*

During 2019, this group contributed to the preparation of SAFARI, a new far infrared spectrometer for SPICA Space Telescope. SPICA is an international project led by the JAXA (Japan), ESA (Europe) and several European institutions, including CAB. In the framework of this consortium, CAB contributes with the optical and mechanical design of the SAFARI instrument.

We are also focused on the development of state-of-the-art superconducting Kinetic Inductance Detectors (KIDs) for future mm/sub/FIR space missions and quantum applications. In this context, the activities in 2019 were:

- Development of titanium/aluminum based KIDs for future Cosmic-Microwave-Background radiation studies which include sensitivity to both polarizations in the W-band (75-110 GHz).

- Participation in the commissioning of the KISS instrument, which is a 80-300 GHz spectrometer for the Quijote Telescope. We have also continued our collaboration in the NIKA2 instrument.
- Development of hybrid 2D-Materials/Superconducting KIDs for low frequency detection (<75 GHz) and quantum applications (quantum key distribution).
- Development of lumped element resonators as superconducting circuits for molecular spin qubits quantum processors.

Formation and evolution of stars, brown dwarfs and planets

Coordinators: María Rosa Zapatero Osorio and Benjamín Montesinos Comino.

As in the past years, our group has been very active, addressing a significant number of scientific objectives, all of which are related to the formation and evolution of massive and low-mass stars, brown dwarfs, and planets.

The main areas the group is pursuing are:

- Search and identification of low-mass stars, brown dwarfs and isolated planets in star forming regions and young stellar clusters. Search of massive stars in our Galaxy and in low-metallicity galaxies.
- Study of the stellar and substellar mass functions: upper and lower limits and influence of the surroundings.
- Protoplanetary and debris discs.
- Search for brown dwarfs, planets and comets around stars, using direct and indirect techniques.
- Characterization of the physical and chemical properties of stars, brown dwarfs and planets using photometry, spectroscopy and astrometry, covering all the electromagnetic range.

Several projects funded by different Agencies are lead or with active participation of members of the group:

- Spanish contribution to phase B SAFARI/SPICA (F. Najarro, PNE)
- Brown dwarfs and planets in clusters and around stars (M.R. Zapatero Osorio, J. Sanz, PNAyA).
- Surveys of massive stars in the Galaxy (J. Maíz, PNAyA)
- Herbig AeBe stars and their connection with planet formation (I. Mendigutía, CAM)

On-going space- and ground-based instrumental projects with active involvement of some members of the group are: INTEGRAL/OMC (since 2002), CHEOPS (ESA small mission launched in December 18th 2019), MIRI/JWST (NASA mission to be launched in 2021), PLATO (adopted mission by ESA, expected launch in 2026), ARIEL (recommended as M4 mission of ESA, expected launch 2025), SAFARI/SPICA (proposed M5 space mission to ESA, ~2029); CARMENES/CAHA-3.5 (planet-hunter spectrograph operating at visible and near-infrared wavelengths on Calar Alto Observatory), and ESPRESSO/VLT (planet-hunter spectrograph operating at visible wavelengths on Paranal Observatory). There is also an active participation in long-term space projects, such as LUVOIR (LUMOS, POLLUX), the Habitable Exoplanet Observatory (HabEX) and the Large Interferometer For Exoplanets (LIFE), and ground based GTC-AO, J-PLUS, MEGARA, WEAVE and CARMENES+.

- We make emphasis that a large amount of projects and science cases that will be tackled with the above missions/telescopes/instruments are devoted to the search and/

or characterization of planets discs and small bodies orbiting stars of the Galaxy, i.e., with clear implications in several fields of Astrobiology.

- In what follows, some scientific highlights produced by group members are summarized:

- We led two white papers, one submitted to ESA's Voyage2050 call for long-term planning, and the other to the Astro2020 survey launched by the National Academies of Sciences, Engineering, and Medicine of the United States. The papers gathered international teams of experts on massive stars. They convey the need for a large telescope in space for further developments on the field of massive stars in metal-poor environments, a key topic to understand star formation at high redshift and the epoch of reionization (Fig. XX). The papers support the construction of LUVOIR and propose that ESA joins as a partner. (Garcia+ 2019 arXiv:1903.05235; Garcia+ 2019 arXiv: 1908.04687).

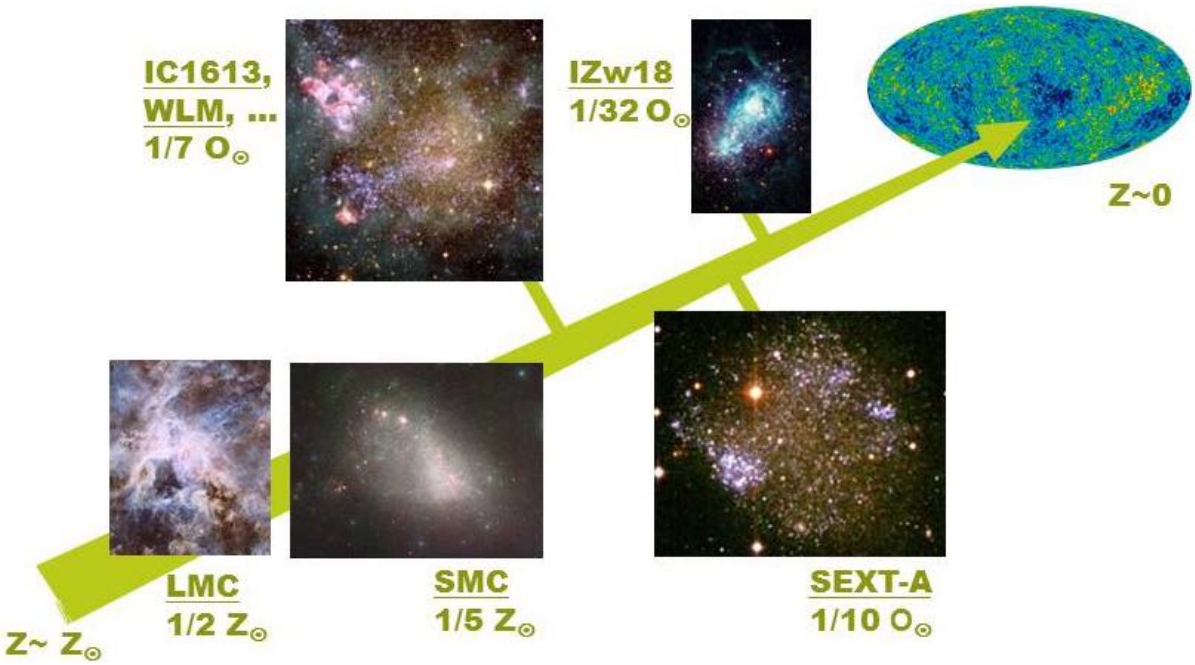


Figure 2-10: Local Group and nearby dwarf irregular galaxies make a sequence of decreasing metallicity that emulates the chemical composition of the Universe at past stages. By studying the physical properties of massive stars in these galaxies, we can better estimate the contribution of massive stars in terms of ionizing radiation, mechanical energy and yields along Cosmic History (From arXiv:1903.05235).

- Martínez-Rodríguez, Caballero, Cifuentes et al. (2019 ApJ, 887, 261) estudiaron la hipotética presencia y estabilidad dinámica de lunas alrededor de planetas en zonas habitables alrededor de estrellas enanas M, las más abundantes en la Galaxia.

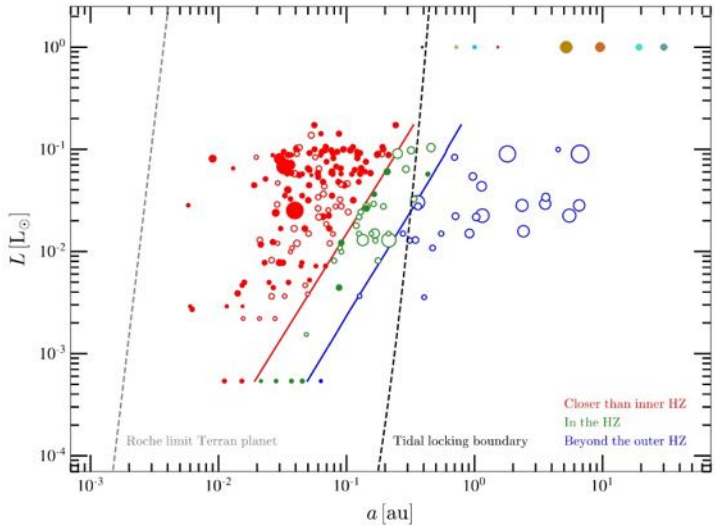
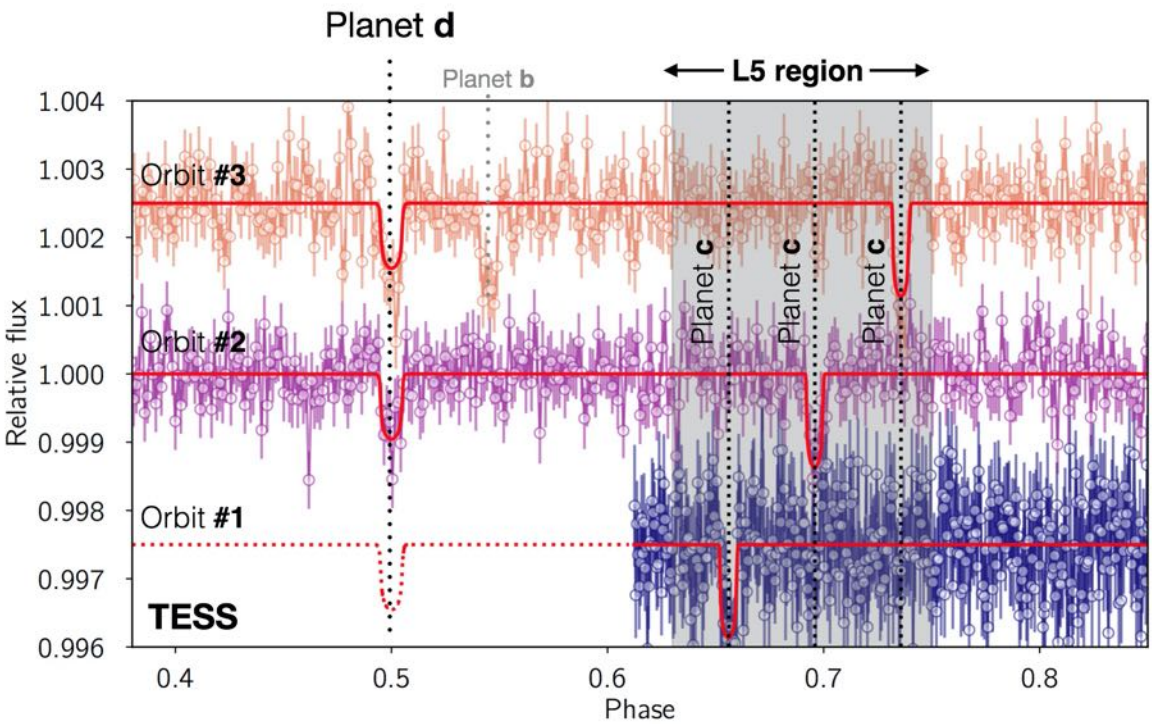


Fig.2-11 MR19: conservative habitable zone (HZ) for all the M dwarfs in Martínez-Rodríguez et al. (2019; inner HZ, "recent Venus," in red; outer HZ, "maximum greenhouse," in blue). Their hosted exoplanets are depicted with sizes proportional to their masses in logarithmic scale, with filled circles if they have been detected by transit and with open circles if they have been detected by radial-velocity measurements. Exoplanets closer than the inner HZ, in the HZ, and beyond the outer HZ are shown in red, green, and blue, respectively. Thedashed, gray line is the Roche limit for an Earth-like planet (Aggarwal & Oberbeck 1974). The dashed, black line represents a "constant-time-lag" tidal locking model for a 10M⊕-planet with rapid initial rotation after 1 Gyr (Barnes 2017). The eight solar system planets are depicted in the upper part of the plot.

- Co-orbital exoplanets from close-period candidates: the TOI-178 case (Leleu, Lillo-Box, et al., A&A): as part of the efforts of the TROY project (www.troy-project.com) led by J. Lillo-Box, this paper shows the best candidate to have a co-orbital configuration, this is, two planets sharing the exact same orbit. Detected by TESS with precision photometry, follow-up efforts from ground and space continue in 2020 to unveil this intriguing system. Pie de figura:



TESS lightcurve in phase of TOI-178 showing planet "d", and potential transits of planet "c".

- The discovery with CARMENES by Morales et al. (2019 Science, 365, 1441) of GJ 3512 b, a Jovian planet around a tiny, very low-mass star in an eccentric, long-period orbit, imposed a serious challenge to planet formation models, as it was expected that protoplanetary discs around such very low-mass star do not have enough mass to allow the formation of Jupiter-mass planets.

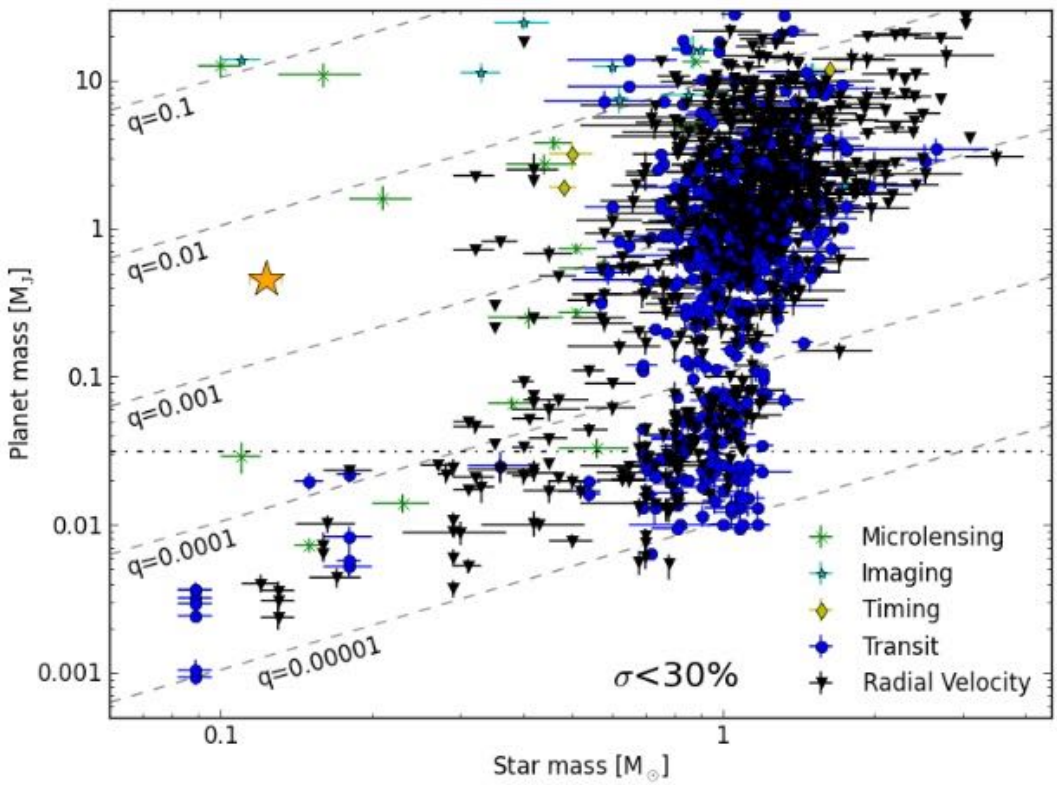


Fig. 2-12 Mor19: GJ 3512 b minimum planet mass and host stellar mass compared to known planetary systems. Data for known exoplanets come from the NASA exoplanet archive. Only systems with star and planet mass uncertainties below 30% are displayed. Different exoplanet detection techniques are shown as labelled and GJ 3512 b is depicted with an orange star symbol. The planet minimum mass is plotted in the case of planets detected by radial velocities and timing. The dashed lines indicate different host star-to-planet mass ratios (q) as labelled, and the horizontal dot-dashed line corresponds to 10 M⊕.

- CAFE2: an upgrade to the CAFE high-resolution spectrograph. Commissioning results and new public pipeline (Lillo-Box et al., MNRAS). Here we present the upgraded CAFE instrument at the 2.2m telescope of Calar Alto Observatory and the new public pipeline. The instrument is now capable of reaching 8 m/s precision intra-night and provides science-ready data.

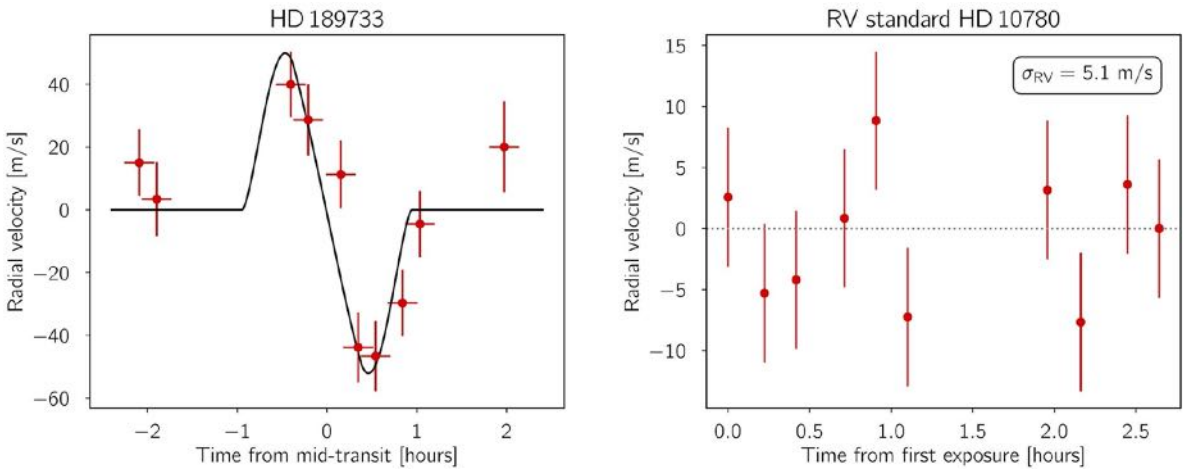


Figure 2-13 Scientific verification of the instrument CAFE with the detection of the Rossiter-MacLaughlin of the exoplanet around HD 189733 (left) and the stability and precision of the instrument through the radial velocity of a standard star (right).

- For determining precise masses and radii of planets, from which estimating bulk composition or basic atmospheric properties, one needs first precise masses and radii of their host stars. Schweitzer, Passegger, Cifuentes et al. (2019 A&A, 625, A68) set up the methodology for determining masses and radii of the M-dwarf stars being monitored by CARMENES in its search for exoearths.

- Based on Gaia DR2 data, we have searched for high velocity stars, unbound by the galactic potential, which might be in the process of been expelled due to interactions with primordial black holes (Montanari, Barrado & García-Bellido, 2019, MNRAS 490, 5647).

- Currently, the exoplanet with the highest Earth similarity index (i.e., the planet that looks like the most to Earth based on mass, expected radius and insolation) is Teegarden b, an exoearth discovered by CARMENES around a nearby ultracool dwarf by Zechmeister et al. (2019 A&A, 627, A49).

- The collaboration with the Bordeaux University (COSMIC-DANCe) has produced a significant number of results: New low mass members in the open cluster IC4665 (Miret-Roig et al. 2019, A&A 631, 57) and the old cluster Rupretch 147 (Olivares et al. 2019; A&A 625, 115). In addition, we have prepared the spectroscopic exploitation of our catalogs, and the study of the disk population in the youngest clusters.

- With the help of CARMENES and the TESS NASA space mission, Luque et al. (2019 A&A, 628, A39) discovered GJ 357 b, one of the most suitable Earth-sized planets for atmospheric characterisation with the forthcoming James Webb Space Telescope.

- SUCANES database: we have started building SUCANES, a database to study the early phases of substellar formation. This is a project aiming at compiling and exploiting all the data available for the youngest brown dwarf candidates (the so-called pre- and proto-BDs). It is part of our effort to understand the formation of brown dwarfs, and a continuation of our observational works in different star forming regions (e.g. Barrado+2018, Huélamo+2017).

- We continued our search of young accreting planets within the gaps of transitional disks, using the H line and spectro-astrometric techniques (Cahill et al. 2019, MNRAS 484, 4315). We studied the young star T Chamaleontis through the analysis of multi-epoch optical spectroscopy. Currently, we are leading the only survey in the northern hemisphere devoted to find such planets, using ISIS/WTC and MEGARA/GTC ("BORN"; Baby planets ORigiNs; PIs Mendigutía & Huélamo).

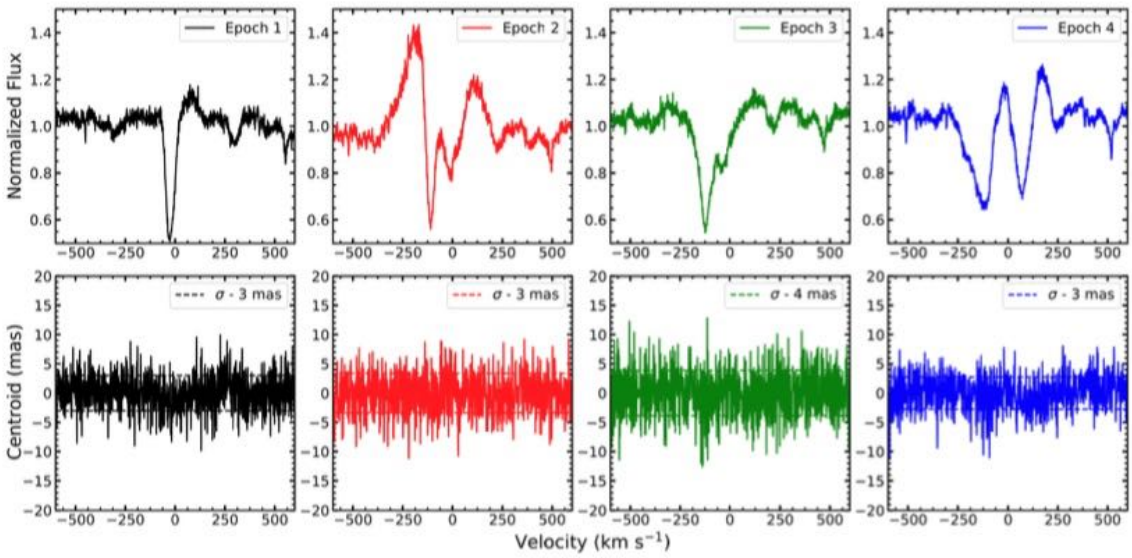


Figure 2-14 Spectro-astrometric (SA) analysis of the H line of the young star T Cha in four different epochs. The upper panels show the observed line, and the lower panels the SA signals. On average, the accuracy achieved was 3.6 mas, or 0.3 au at the distance of the star (110 pc). We did not report any signal from a possible accreting protoplanet.

- We continue our high-spatial resolution observational studies of relevant young stars with protoplanetary disks, using MUSE/VLT (Schneider et al. 2020, A&A, 638, L3) and GRAVITY/VLTI (Marcos-Arenal, in prep)

- Intermediate-mass Herbig Ae/Be stars with protoplanetary disks: We have contributed with the most complete characterization of the stellar and circumstellar properties of all Herbig Ae/Be stars known to date (Wichittanakom et al. 2020, MNRAS, 493, 234; Guzmán-Díaz et al. submitted). The data derived in this last paper are already available in a Virtual-Observatory complaint archive (see Fig. and link below). Combining Gaia DR2 data and machine learning techniques, we have also provided a new catalogue of potential Herbig Ae/Be stars that is an order of magnitude larger than the current sample (thousands of such sources, instead of hundreds; Vioque et al. 2020, A&A, 638, A21). An invited review paper on the accretion properties of Herbig Ae/Be stars has been accepted and published (Mendigutía, 2020, Galax, 8, 39).

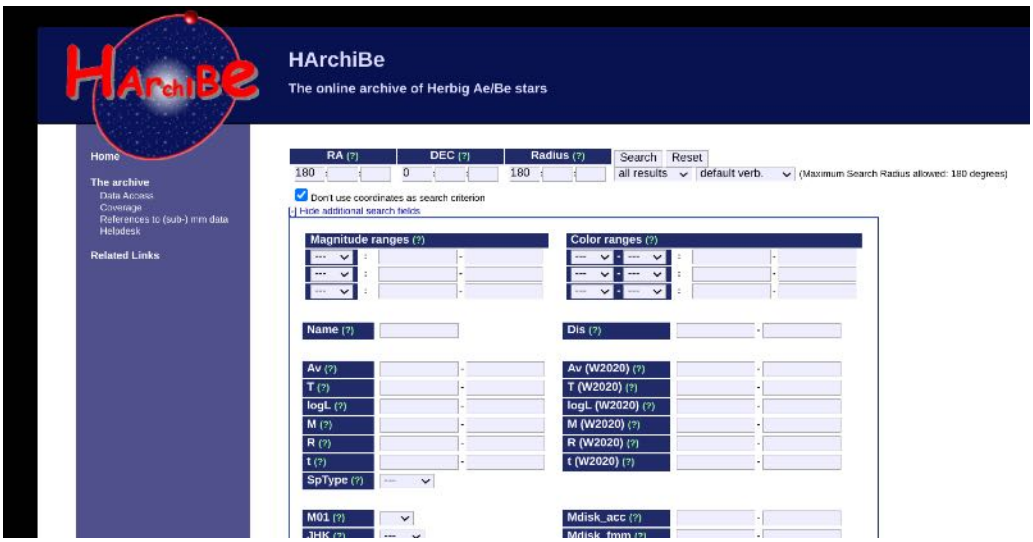


Figure 2-15 Screenshot of HArchiBe, the online archive of Herbig Ae/Be stars, made in collaboration between the Groups "Formation and Evolution of Stars, Brown Dwarfs and Planets" (Guzmán-Díaz et al, submitted) and "Data Archive Unit. Spanish Virtual Observatory":

- Sanz-Forcada et al. (2019, A&A 631, A45) confirmed the shortest (1.6 yr) coronal cycle determined to date in iota Hor. This star is a solar analogue with 600 Myr of age, ideal to study the radiation environment at the time when life appeared on Earth. The cycle is very regular, keeping the same amplitude and duration after 5 cycles (more than those monitored in the Sun to date). The paper use not only the X-rays, but also UV, and TESS light curves to determine other results, like rotation period, flares occurrence, coronal abundances, etc.

- A complete study of HR 10, slightly evolved binary (the first of its class discovered), with individual circumstellar envelopes around each component, was completed (Montesinos et al., 2019, A&A, 629, A19). Dedicated campaigns with six telescopes, using echelle spectroscopy and interferometric VLT/PIONIER observations. This was a byproduct of the study of a large sample (~120) of main-sequence stars of spectral types A and F, devoted to the search for exocomets. The work, which was the core of Isabel Rebollido's PhD thesis, co-supervised by Eva Villaver (UAM) and Benjamín Montesinos (CAB) has increased from 20 to 26 the number of stars with exocometary-like events. Detailed analysis of some stars is underway.

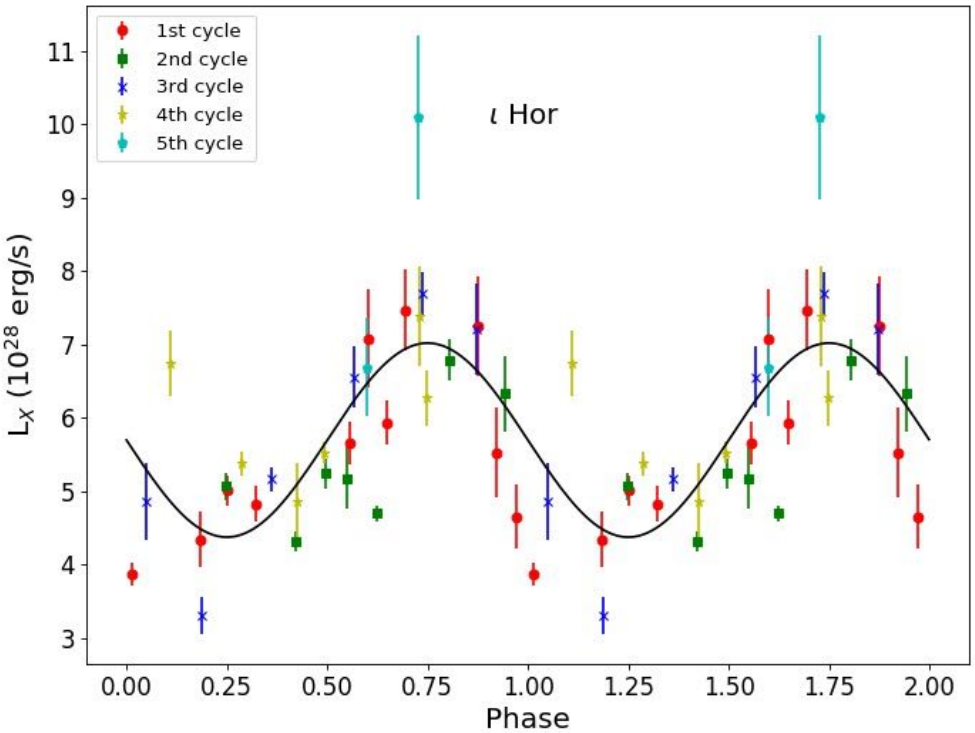


Figure 2-16 Phase-folded long-term X-ray (coronal activity) light curve of Hor based on the period of 588.5 d, obtained from the GLS periodogram analysis. Superposed is the corresponding sine curve.

- The PanCET collaboration (incl. J. Sanz-Forcada) to observe exoplanet atmospheres with HST is giving great results. Sing et al. (2019, AJ 158, 91) observe for the first time Mg II and Fe II in a planet atmosphere, partially escaping from WASP 121b. Dos Santos et al. (2019, A&A 629, A47) search for metallic ions in GJ 436 b.

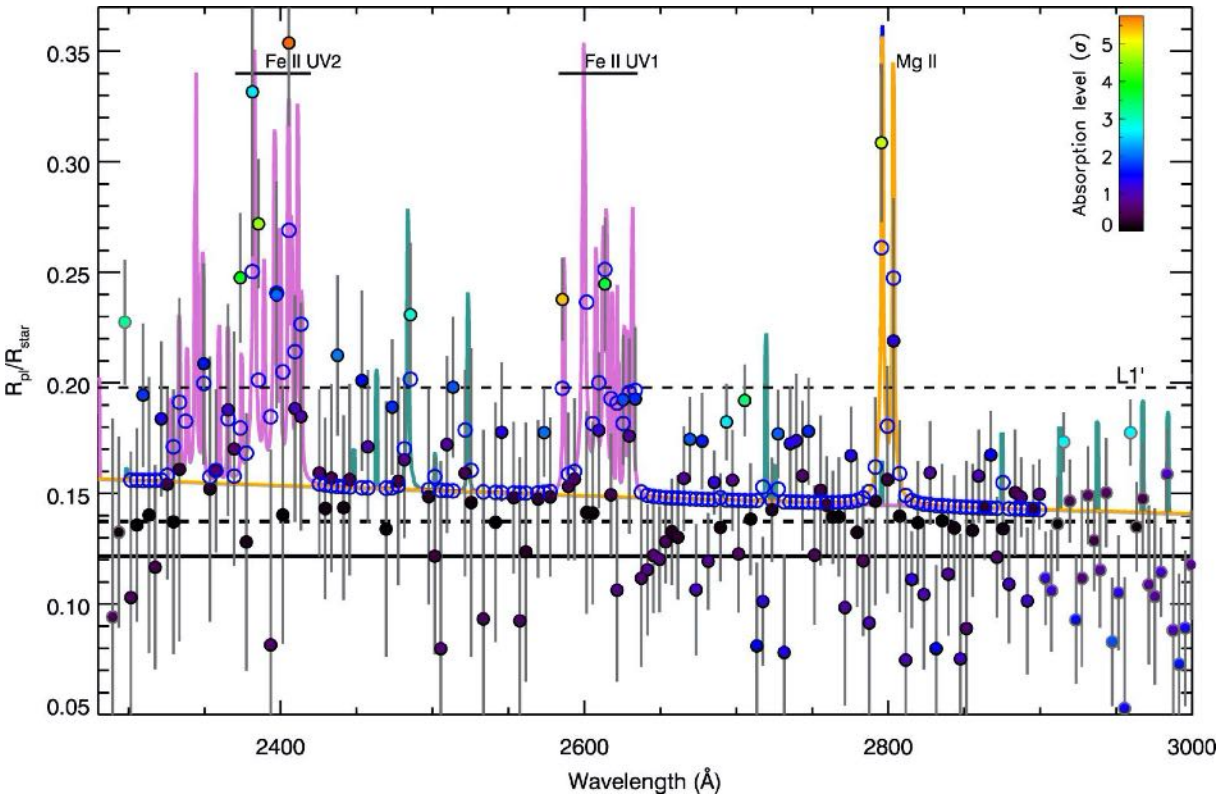


Figure 2-17 WASP-121b NUV transmission spectrum in unique 4 Å passbands. The data points have been colored with the significance in transit depth above that of the NUV spectrum, which is indicated by the black dashed line at $R_{pl}(NUV)/R_{star}$ = 0.1374. A model fit that includes Fe I (green), Fe II (purple), and Mg II (orange) absorption is shown, with the complete model integrated over the spectral passband shown with (blue) open circles. The Lagrange point distance L1 is also indicated.

- In Miles-Páez et al. (2019, MNRAS, 484, L38, includes M. R. Zapatero Osorio), we presented the linear polarimetric observations of the transits of two small planets of the TRAPPIST-1 system. Some polarimetric signal is observed, which agrees with the theory and confirms the existence of dust in the atmosphere of the parent star.

- The ambitious multiplicity study of stars O-type stars (MONOS) has its first article published (Maíz Apellániz et al. 2019) which provide spectral classifications for objects with previous spectroscopic and/or eclipsing binary orbits. The massive compilation and reprocessing required for this endeavour enables the creation of LiLiMaRlin, a library of high-resolution spectroscopic libraries adding our own+collaborators programs and public archives.

- The GALANTE project is presented, including in its first article (Lorenzo-Gutiérrez et al. 2019) the characterization of the GALANTE photometric system. It describes a twelve broad-to-narrow filter system designed to measure the physical parameters and extinction of all stars along the northern Galactic plane, plus several off-plane interesting pointings.

- With the expertise derived from the general reanalysis of Gaia photometric sensitivity curves and applying the precise technique of lucky imaging, Maíz Apellániz 2018 presents distances and orbits to Galactic stellar groups containing O stars within 1 kpc of the Sun: Collinder 419 and NGC 2264.

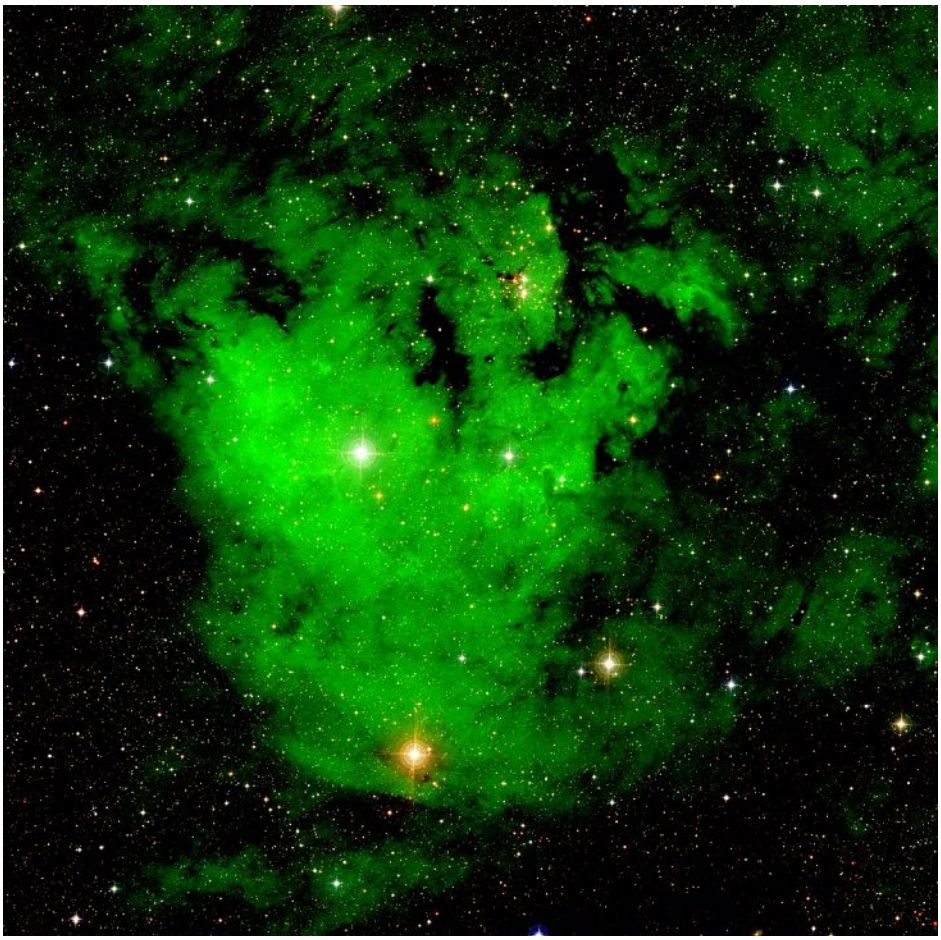


Figure 2-18 The Berkeley 59 prototype GALANE field as imaged by GALANTE. The RGB mosaic has a field size of 1.4°x1.4° with North towards the top and East towards the left and uses a three filter combination including an ~y Strömgren, Halpha, and the Calcium Triplet band.

- We continued our studies of massive stars in Galactic massive obscured clusters. In Westerlund-1 we found two early/mid-O hypergiants with luminosities, temperatures and masses significantly in excess of other early stars of the cluster, hence qualifying as massive blue stragglers (Clark, Najarro et al 2019).

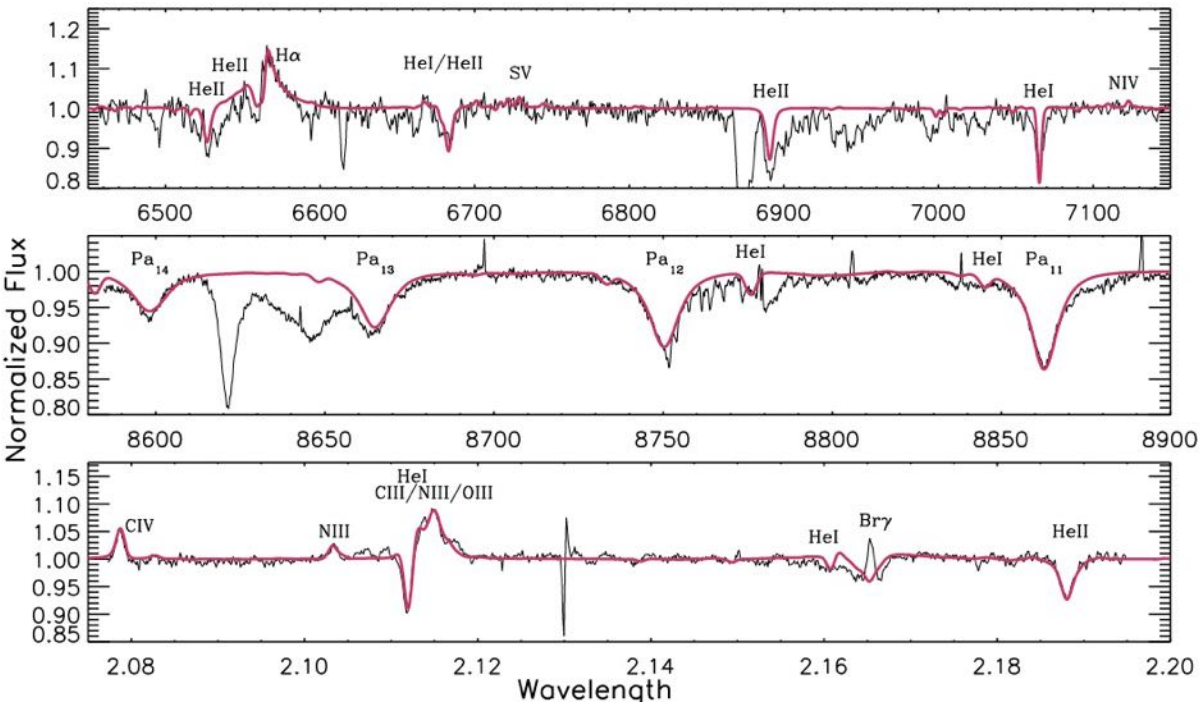


Figure 2-19 Comparison of the synthetic spectrum of Wd1-27 derived from model-atmosphere analysis (red dashed line) to observational data (black solid line) (Clark, Najarro et al. 2019).

In our research of the Galactic Center and it's massive stellar population, we continued our collaboration with the IAA-CSIC within the frame of the GALACTICNUCLEUS project. We found variability in the near infrared extinction curve (Nogueras-Lara, Schödel, Najarro et al 2019). We have also significantly revised the census of massive stars in the region (Geballe et al 2019 and Clark et al, including Najarro) and investigated the unusual initial mass function of the Arches Cluster (Hosek, Lu, Anderson, Najarro, Ghez et al 2019).

Virtual Observatory: Scientific exploitation of astronomical archives

Coordinator: Enrique Solano

The Virtual Observatory (VO) is an international initiative whose main goal is to guarantee an easy and efficient access and analysis of the information hosted in astronomical archives and services. VO is a world-wide community-based initiative with the potential to open new research methodologies in Astronomy. The importance of the Virtual Observatory as a research e- infrastructure has been clearly identified by the European Union (which has supported the development and operation of the European VO through different FP6, FP7 and H2020 projects), as well as by other international consortia like Astronet or the Research Data Alliance (RDA). The Virtual Observatory is also fully aligned with the principles expressed in H2020 EU funding program regarding open access to scientific data and the development of the European Open Science Cloud.

The Spanish Virtual Observatory (SVO, http://svo.cab.inta-csic.es) is a project successfully working since 2004. The project is led at CAB. SVO coordinates and collaborates with the Spanish astronomical groups with interest in the VO and acts as the national contact point for the international VO initiatives, in particular the International Virtual Observatory Alliance (IVOA) and the Euro-VO project.

The project is structured in four major lines of work, namely:

- Improve the CAB Data Centre and provide support to other Spanish data centres.
- Develop VO standards and tools with special emphasis on data mining tools.
- Foster collaborations in VO-science.
- Develop of Education and Outreach activities.

The main activities carried out in 2019 have been the following:

The CAB Astronomical Data Centre

- Work on the implementation of reduction pipelines in the GTC archive system.
- Maintenance and development of new functionalities in the CARMENES and Calar Alto data archives.
- Development of archives using our VO-publishing tools (SVOCat).
- Building of a catalogue of sources from the GTC OSIRIS Broad Band images.V

Virtual Observatory tools

- Implementation of new functionalities in VOSA, a VO tool to estimate physical parameters of thousands of stars by comparing their spectral energy distribution with theoretical models. VOSA is a robust and well-tested tool as demonstrated by the more than 1800 users who have analysed almost 6 000 000 objects and have published 140 refereed papers.
- Improvement of Clusterix, a tool that allows to estimate the membership probability of a list of objects to a given stellar cluster.

- Improvement of SVO Discovery Tool, a tool that, given a list of objects, discovers all the information available in VO services.Implementation of an alert system.

Data Mining tools

- Application of machine learning techniques to the estimation of physical parameters of M stars using spectroscopic (CARMENES) data.
- Development of a supervised classifier to identify ultracool objects in the J-PLUS survey.

VO-science projects

- Identification and characterization of solar system objects in astronomical survey.

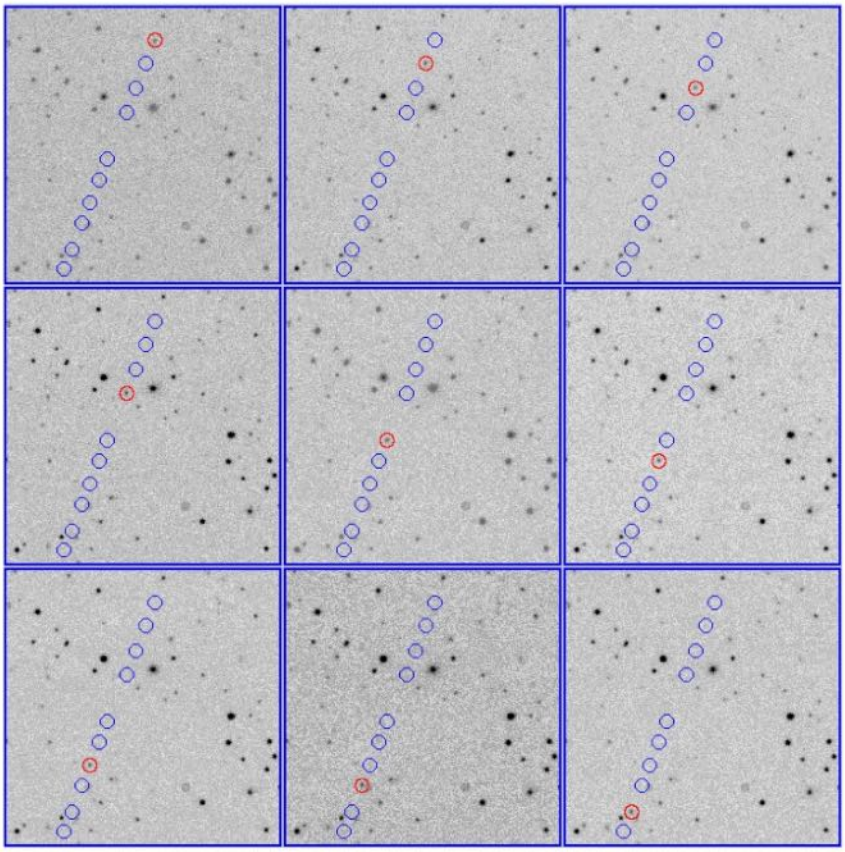


Figure 2-19: Example of linear motion of the Main Belt asteroid 1997 UK9 during nine consecutive images. The temporal coverage is almost 3 h. The epoch increases from left to right and from top to bottom in intervals of near 20 minutes. The proper motion of the asteroid is 42.8 / h. Blue circles indicate the trajectory of the asteroid. Red circles indicate the current asteroid position in the image .

- Identification and characterization of wide binaries using Gaia DR2.

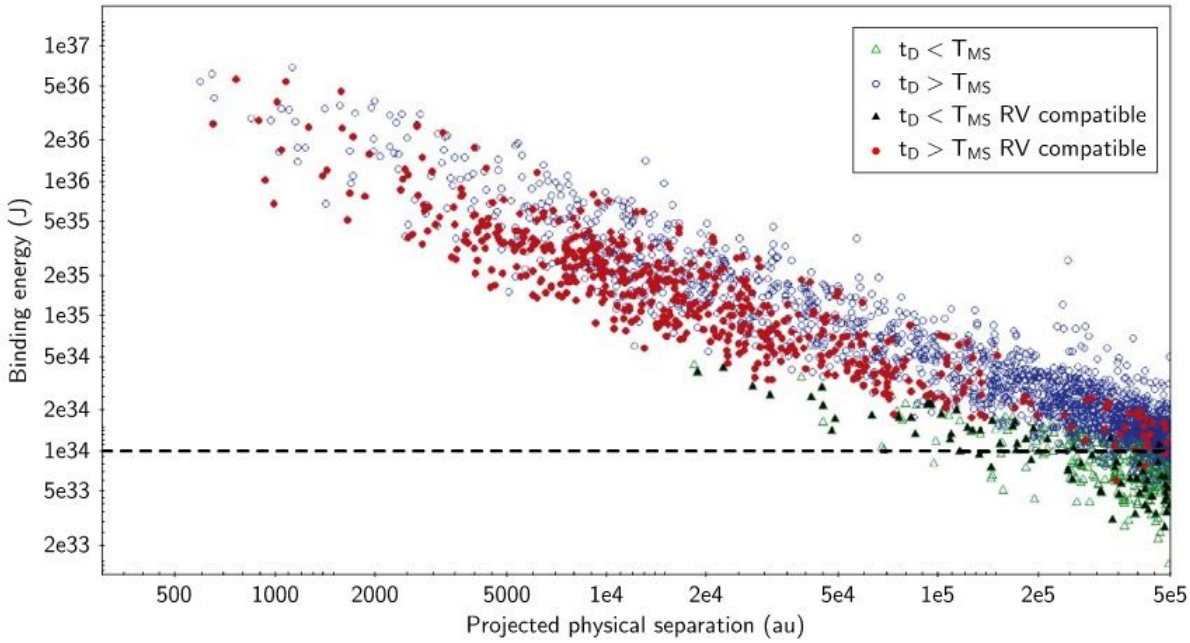


Figure 2-20: Binding energy as a function of the projected physical separation for the comoving candidate pairs of our catalog. TD and TMS indicate the dissipation time of the binary system and the time in the Main Sequence, respectively ()

- Identification and characterization of ultracool dwarfs in the J-PLUS survey.

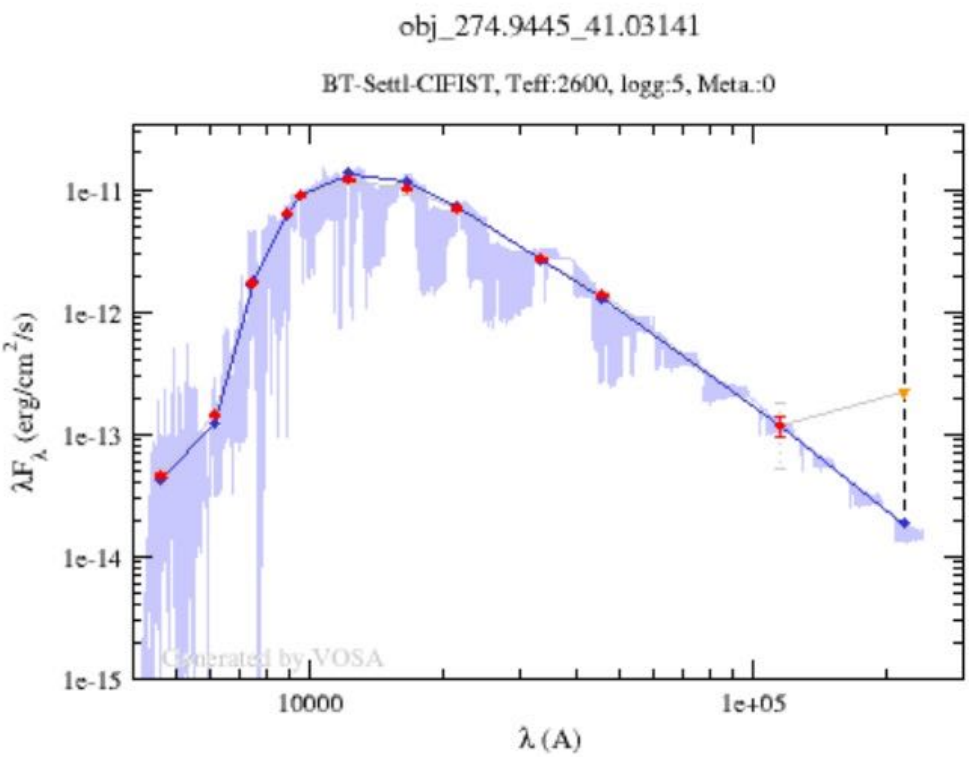


Figure 2-21:Determination of the physical parameters of one of the new ultracool dwarfs uing VOSA. The blue spectrum represents the theoretical model that fits best, while red dots represent the observed photometry. The inverted yellow triangle indicates that the photometric value corresponds to an upper limit. The vertical dashed line flags a possible excess in the spectral energy distribution. ()

- Identification and characterization of white dwarfs at less than 100 pc.

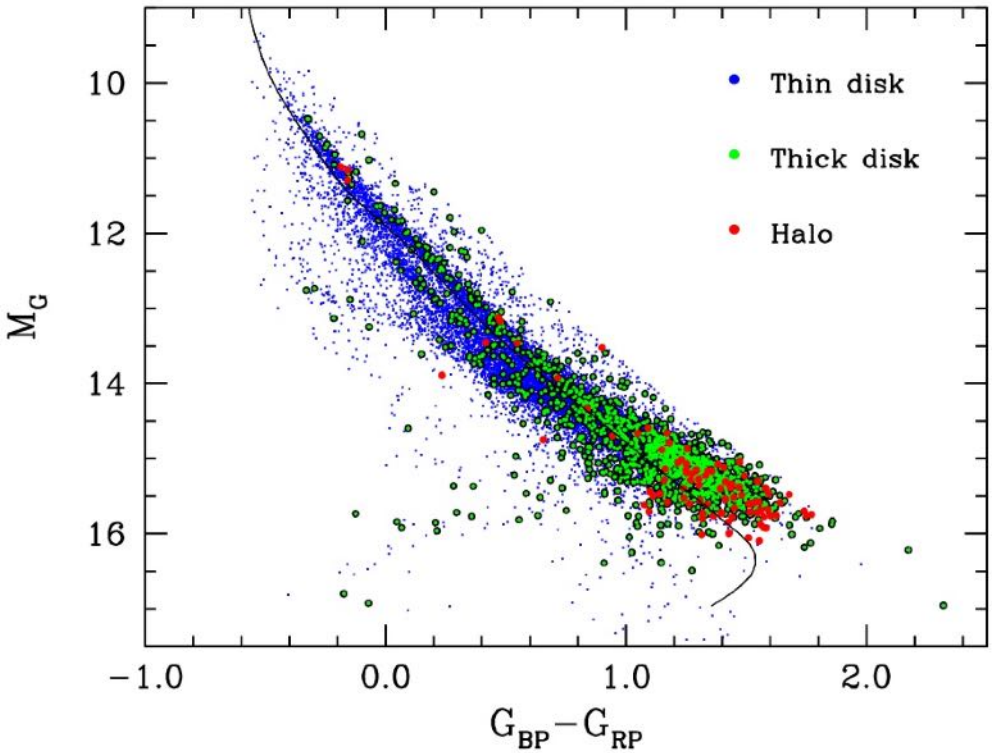


Figure 2-22: Color-magnitude diagram for the 100 pc Gaia sample as resulting after applying our Random Forest classification algorithm. The three Galactic components have been disentangled, obtaining 12 227, 1410 and 95 white dwarf candidates for the thin and thick disk, and halo population, respectively. ()

Education and Outreach activities

- Organisation of three SVO School: Universidad Complutense de Madrid (March and November 2019) and III ProAm Meeting (Huesca, December 2019).
- Supervision of one Master Thesis.
- Participation in the I Foro de Ciencia Ciudadana en España
- Participation in the ESAC Open Day.
- Participation in the IX Jornadas de Astronomía de Astrocuenca.
- Preparation of flyers on the Spanish Virtual Observatory project.
- One press release.
- New design of the SVO portal.

Figure 2-23: The new SVO portal.

Planetology and Habitability

Head of Department: Felipe Gómez

The Department of Planetology and Habitability has developed a transdisciplinary activity since its creation.

During 2019 and displaying this transdisciplinary nature, the research activity run in our department has focused on the understanding and study of life and its interaction with both the atmosphere and the geological part of the environment. Therefore, the main lines of research during 2019 have focused on the study of life under extreme conditions, lipidic biomarkers and in planetary atmospheres and geology.

Planetary Geology is the study of solid Surface planetary objects in the Universe, including Earth. Specifically, this scientific discipline investigates the composition, structure and processes and agents by which planets, satellites, comets, asteroids and meteorites evolve since its formation. The understanding of life in extreme conditions and the biodiversity present at these extreme ecosystems by other side will give us some clues about the limits of life on Earth and the potential habitability out of planet Earth.
The planetology and habitability department is composed of 2 Research Groups

- Planetary Geology and Atmospheres
- Habitability and Extreme Environments

Planetary Geology group

Coordinator: Olga Prieto Ballesteros

This group has as the main goal to determine the astrobiological potential of planetary objects of the Solar system, such as Mars and Ocean Worlds, through geological studies. We have special interest to assess the habitability requirements that future missions under development could detect. Investigations involve laboratory activities, fieldwork, and participation in the supporting science of development of exploration instruments and space missions.
Among the activities performed during the 2019 period are the participation in the Voyage 2050 call proposing a white paper titled "Searching for (bio)-chemical complexity in icy satellites, with a focus on Europa". The international team, led by CAB investigators stated in this work that in order to advance the goal of searching for evidence of life beyond Earth we must focus on the detection of large macromolecular material capable of structural and functional plasticity, as well as cell-like morphologies indicative of an extant biosphere. We described this new strategy, and propose a mission with the goal of revealing the different levels of prebiotic/biotic chemical and structural complexities on planets and satellites of the Solar System following a non-Earth centric approach, as well as their potential compatibility with terrestrial life. This might clarify the nature of the (bio)-chemical complexity of the Solar System, both now and in the past. We prioritize Jupiter's moon Europa as the mission target due to its energetic state, activity, and the presence of liquid water and chemical elements, which all suggest it may have developed as a chemical complexity reactor.

In 2019, researchers of this group started a contract with the European Space Agency (ESA) to conduct measurements of the thermal and dielectric properties of ices in support to future radar observations of Jovian Icy moons from JUICE and Europa Clipper missions (ESA Contract 4000126441/19/ES/CM). Our results will be useful to interpret the interior structure of Europa and Ganymede moons, in particular the distribution of aqueous reservoirs within the crust.

The investigation of the mineralogy and structures of cold seeps samples and their astrobiological implications on Europa was developed during 2019. The rock mantle-ocean interaction would provide the necessary compounds and energy to sustain a habitable environment and to enable the development of chemosynthetic life, similar situation to our oceans´ cold seeps. However, the physical conditions of the seabed could favour gas clathrate hydrate formation from volatiles produced by gas-water-rock reactions. This clathrate dissociation could be behind the origin of some geomorphological structures observed in its icy crust. A carbonate chimney from Gulf of Cadiz cold seeps was studied as terrestrial analogue to understand the processes associated with the gas release in an oceanic environment and extrapolate these results to Europa. The sample was analysed by X-ray diffraction and X-ray fluorescence, FT-IR and Raman spectroscopy and optical microscopy. The results allowed distinguishing allochthonous components from autochthonous, both subject to fluid emission process. In this way, fluids constitute an energy source and a carbon source, and therefore their presence in Europa would hypothesize the possible development of biogeochemical cycles.

Studies on the light-toned materials that crop out in the Coogoon Valles area of Mars was done as part of the activity of 2019. This area is located between the two final selected landing sites for the ExoMars 2020 Rosalind Franklin rover, Mawrth Vallis and Oxia Planum. Our study concludes that not only the sequence of materials in Coogoon is similar to that of Mawrth Vallis, but that, according to the characteristics of the materials, their contact and altitude of these contacts they are part of the same lithostratigraphic units that correlate across 500 km. These clay-bearing materials at Coogoon Valles were later exposed through erosion and incorporated into the Coogoon Valles fluvial system, that fed up the sedimentary

deposits located at the end of the fluvial system in Oxia Planum, were the final selected site for the landing of the ExoMars rover is located. This makes of Coogoon an area of great importance to establish the regional context for the data that will be obtained by the rover, and to help to their interpretation in a broader geologic context.

Some members of the group were involved in the organization of the CPESS6 - VI Reunión de Ciencias Planetarias y Exploración de Sistema Solar (in both, the SOC and the LOC). This meeting were celebrated at CAB during the days May 27th – 29th of 2019.

Atmospheres group contribution led by Dr. Maria Paz Zorzano Mier

As part of the activities of the María de Maeztu Excellence project of CAB, within this year a new research line has been initiated to investigate the role of mineral aerosols on the atmospheric chemistry and cloud nucleation on Mars. In particular, we are comparing the transport of aerosols on Earth with those on Mars and have implemented a methodology to validate remote-LIDAR observations of the Earth atmosphere provided by CALIPSO, with the existing surface-based LIDAR instrumentation of INTA. Our research has also demonstrated through experiments and theoretical quantum mechanical calculations, that minerals may have a critical role on atmospheric photochemistry and can, for instance, break and fix atmospheric nitrogen, by interaction with UV, or interact with amino-acids or perchlorates and water producing the abiotic absorption and release of atmospheric volatile molecules on the regolith. This may have played a role on the prebiotic chemistry on Earth as well as on the present-day Mars.

The Department of Planetary Geology and Habitability, has two representatives in the COSPAR (Committee On SPAce Research) Planetary Protection Panel: Scientific Commissions B – Space Studies of the Earth-Moon System, Planets and Small Bodies of the Solar Systems. This year the panel has discussed the MMX sample return program, and the on-going analysis of criteria/needs for industry, as well as the plans for moon exploration and Icy worlds. The panel has met several times during the year to provide advice, analyse new existing scientific results and new proposed exploration missions.

The HABIT (HabitAbility: Brines, Irradiance and Temperature) instrument for ExoMars 2022, for the ExoMars Surface Platform, has been finally assembled, qualified, calibrated and tested. HABIT, as all the other instrument payloads was integrated in the Surface Platform and the preliminary data of nominal operation and communication with the spacecraft software have been successfully analysed. As for ACS, on-board the ExoMars TGO, it has been monitoring the atmosphere of Mars, and has provided new insights into the effects of dust storms on Mars, and its impact on water scape. The science team of the ExoMars 2022 mission has launched also the activities of Data Archiving Working Group, as all the data need to be archived and released at the Planetary Science Archive of ESA, and the Rover Surface Operation Working Group. As part of the Mars Science Laboratory science operation group, the group has also continued analysing the observation of REMS and other instruments on board the Curiosity rover and has contributed to the detection of an unexpected O_2 atmospheric seasonal variability on the surface of Mars.

Geodynamical modeling group contribution led by Dr. Isabel Herreros Cid

Other research activity during 2019 was the development of numerical models for the study of geodynamical processes in the Solar System.

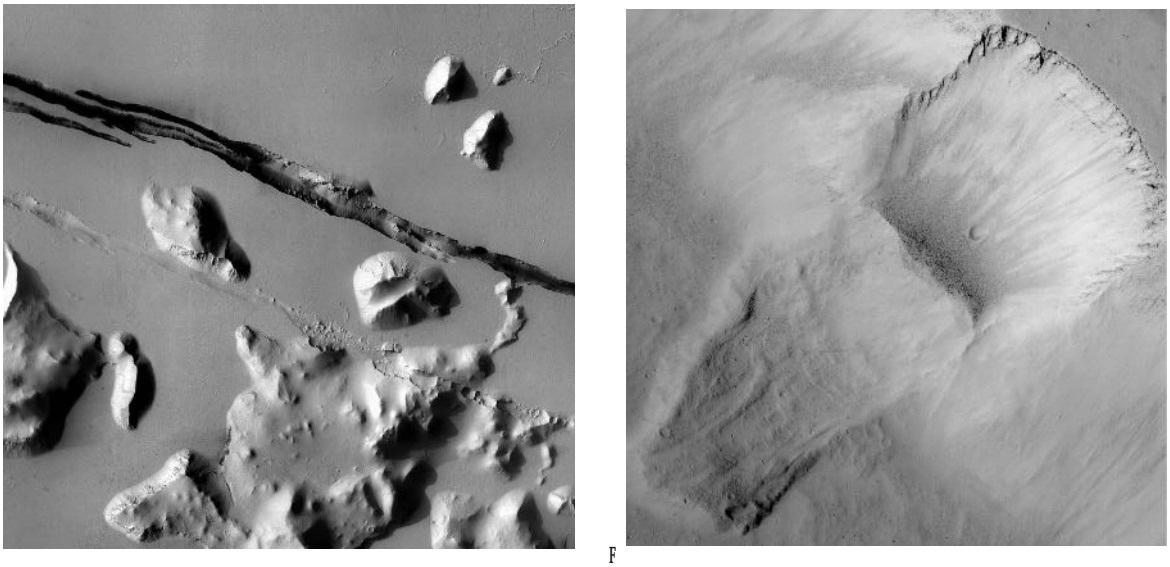


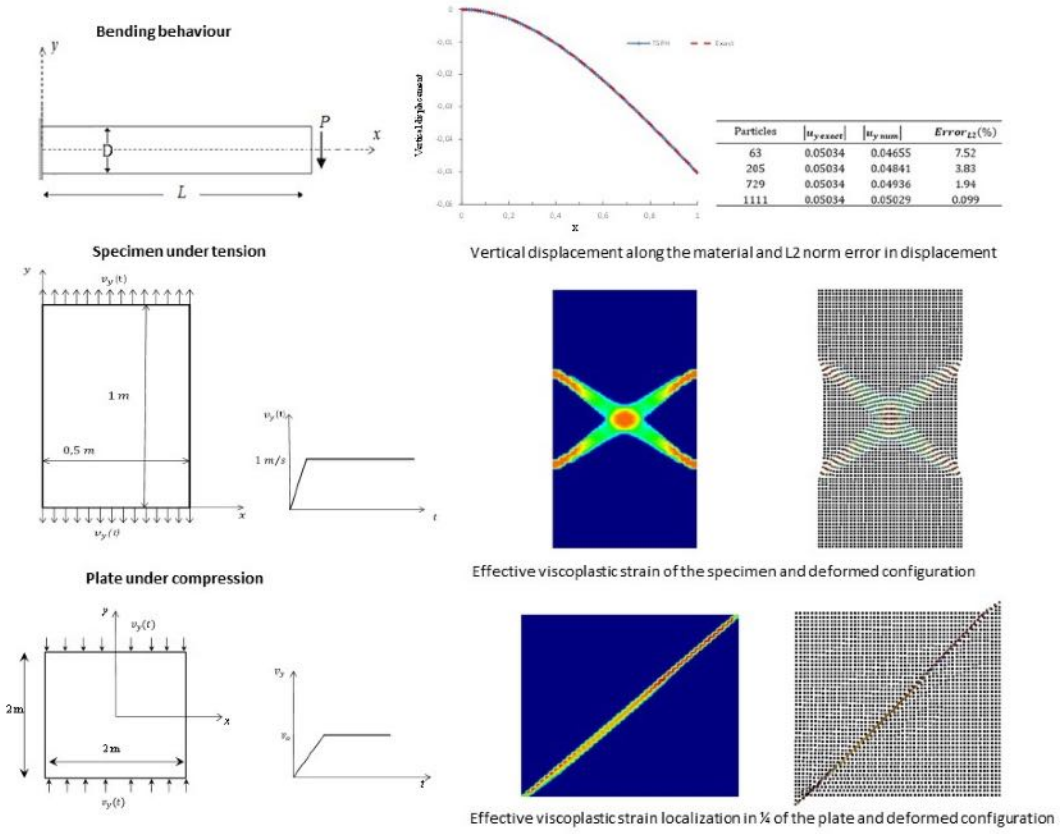
Figure 1: (a) Crack in Cerberus Fossae (Mars) (Image credit: NASA/JPL-Caltech/ASU); (b) Landslide in Kasei Valles (Mars) (Image Credit: NASA/JPL/Malin Space Science Systems)

Geodynamical processes are responsible for the relief in planetary bodies, giving rise to different geographical accidents and structural forms of the crust.

External geodynamical processes that affect planetary surfaces may produce changes in the terrain of different characteristics: landslides, sinking, subsidence, fractures. These modifications are often associated with various factors such as gravity, weakening of materials or variations in effective stresses, as well as other natural and environmental agents (erosion, earthquakes, rain, chemical degradation, biological or human action, etc.). Research into the physical phenomena involved in these processes, as well as the causes that produce them, can help us understand the conditions in which the crust of the rocky bodies of our Solar System has been shaped, shedding information on their geological past, evolution and environmental conditions in which these changes took place.

Development of models allowing to reproduce these phenomena are of paramount importance in order to draw conclusions about the conditions under which the changes observed in the field occur or have ever occurred. A mathematical model consists of a set of equations describing the behaviour of the studied system, for instance, the mass balance and linear momentum equations. These equations are obtained after understanding the Physics of the phenomena and after a set of simplifications. These are, in general, systems of partial differential equations whose unknowns are the variables used to describe the problem under study. However, the overall predictability of the model will never be greater than that of the worst component, which must be taken into account when choosing the most suitable model for the study of the particular phenomenon.

When the geodynamical process involves the soil deformation or the localized failure of the terrain (Figure 1a), the mechanism can be described within the frame of the Solid Mechanics. To this end, the UL TSPH (Updated Lagrangian Taylor-SPH) has recently been developed at CAB in collaboration with the Université Abdelmalek Essaâdi. It consists of a meshless numerical model capable of reproducing the deformation and failure of materials under dynamic conditions. This model has been validated by comparing the obtained results with well-known mathematical solutions (Figure 2), demonstrating that the UL TSPH is accurate, efficient and easy to implement, thus becoming a useful tool for the study of certain geodynamical processes such as fracture and fragmentation of the crust, sinking and land subsidence.



Particles	$\lvert u_{y\,exact} \rvert$	$\lvert u_{y\,num} \rvert$	$Error_{L2}(\%)$
63	0.05034	0.04655	7.52
205	0.05034	0.04841	3.83
729	0.05034	0.04936	1.94
1111	0.05034	0.05029	0.099

Figure 2: UL Taylor-SPH results (HK Serroukh, M Mabssout, MI Herreros,"Updated Lagrangian Taylor-SPH method for large deformation in dynamic problems", Applied Mathematical Modelling, 2019; (https://doi.org/10.1016/j.apm.2019.11.046).

However, the failure mechanism can be described as diffuse, and in this case the soil mass may flow similarly to that of a liquid (Figure 1b). This is the case for landslides of loose, collapsible or metastable materials. Once material fluidization occurs, the constitutive behaviour changes and it is necessary the use of a rheological model within the frame of Fluid Mechanics.

From a numerical point of view, the main problem is how to continuously represent the transition from solid to fluid and vice-versa, when the mobilized material stops and it returns to its solid state. Most studies focus on using a lagrangian model for solids with a constitutive law suitable for the initial phase of the failure thus identifying the mass of terrain being mobilized. The values obtained with this model will serve as initial conditions for a second eulerian model which will be used to study the propagation phase of the moving soil.

The purpose of this line of research is to help close the gap between these two formulations, developing models in both Solid Mechanics and Fluid Mechanics in order to explain the different geodynamical processes to which it is subjected the crust of planetary bodies.

Geology of craters group contribution led by Dr. Jens Ormö

The work of Dr. Ormö is focused on the geology of craters formed by cosmic impacts and how they can be used to reconstruct the paleoenvironment in which they formed. This is of significance in the search for Life habitats elsewhere in the Solar System.

Main activities during 2019 include laboratory experiments of projectile impacts, analysis of drill core data from various impact craters, as well as fieldwork.

The geological work during 2019 has mainly focused on impact craters. However, the first geological fieldwork of the year illustrates the various ways the scientists at CAB INTA-CSIC assist the scientific community and the public. As a specialist on evaluating what physical features in nature that may be caused by natural geological processes and what may have an anthropogenic origin members of the department were called in to assist an archaeological research project in the so-called 'Sacred Mountain of Thebes', at Luxor, Egypt. The team is made up of researchers from Spain, the United Kingdom, and Egypt, but it is articulated on the collaboration between the Complutense University of Madrid and the Documentation Center of the Egyptian Ministry of Antiquities. The object of the investigation is a Wadi, adjacent to the temple of Deir-el-Bahari, in which at the end of the 19th century a series of extraordinary funerary finds from the Pharaonic period were made. The goal is to reconstruct the history of the locality and to understand the reasons why this place was chosen to safeguard the - after the tomb of Tutankhamen - the most important funerary find of ancient Egypt. In an area packed with temples and other structures, the ancient Egyptians left this single wadi seemingly pristine. However, well hidden in an unmarked tomb nearly 80 mummies had been stashed after being moved from their original locations in the Valley of the Kings. The archaeologists believe the wadi may have been too holy to even allow the location of a temple. Nature itself was divine, but some morphological alterations may have been made nevertheless. There is a basic need for documentation of the wadi's geomorphology and geology. Especially the stratifies limestones that make up the Wadi walls show large forms in the rock with an anthropogenic appearance. In other parts of Egypt these forms have been detected and their cultural significance confirmed, but in the case of Wadi C-2 "La Cachette", it presents serious identification difficulties for which Dr. Ormö's expertise is of fundamental importance. Fieldwork to the site was carried out during approximately one week of February.

Figure 3: Half-space experiment in the Experimental Projectile Impact Chamber (EPIC) at the CAB INTA-CSIC showing an irregular ejecta curtain developing after the impact into a heterogenous target consisting of sand with inter-bedded ceramic plates. Also the resulting crater and ejecta layer differ from an impact into homogenous medium. Width of frame 70cm.

In connection with the participation in the 50th Lunar and Planetary Science Conference in Houston, Texas, Dr. Ormö stopped for a week's fieldwork at first the Wetumpka crater, Alabama, and then the Flynn Creek crater, Tennessee. The work is carried out in collaboration with colleagues at the Auburn University, Alabama. The two craters are important representatives of craters from cosmic impacts into shallow-marine conditions. The fieldwork included documentation and sampling of special lithologies and geomorphological features formed by the resurging ocean water into the freshly formed craters. Craters with similar features have been detected in satellite images from Mars, and may hold valuable information on the potential past oceanic phases early during the history of the planet, at times when life was evolving in the oceans on our own planet.

Habitability and Extreme Environments group

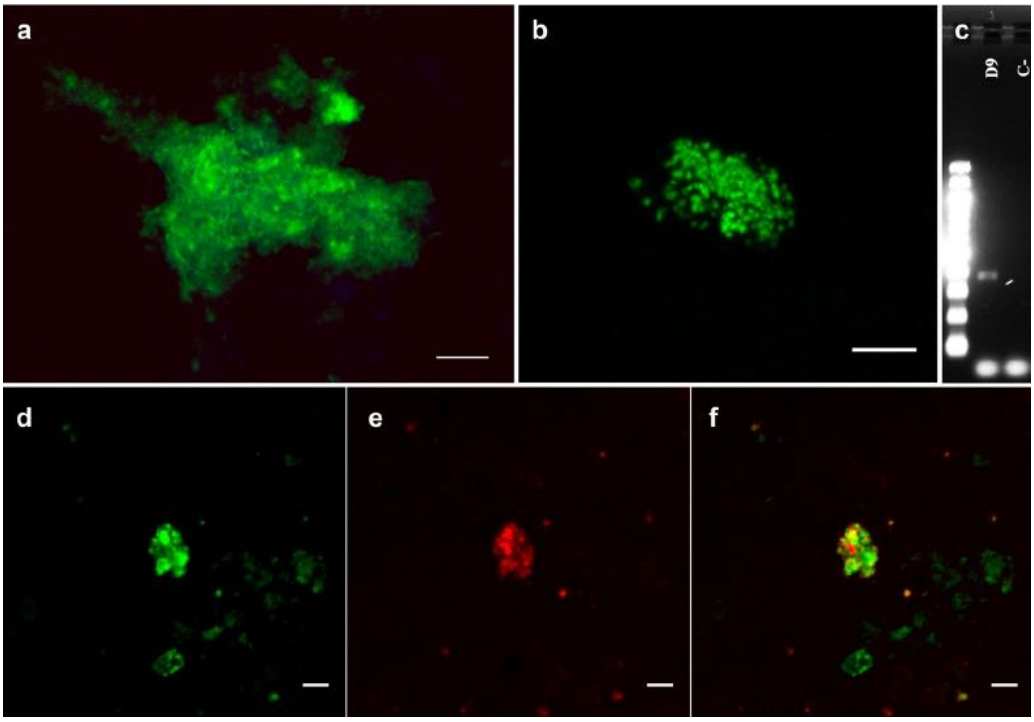
Coordinator: Felipe Gómez Gómez

The activity of the Extremophiles and habitability group during 2019 has focused on the study of the biodiversity and life presence under very extreme conditions in the terrestrial analogues of Dallol and Rio Tinto. The Dallol geothermal area in the northern part of the Danakil Depression (up to 124 – 155 meter below sea level) is deemed one of the most extreme environments on Earth. In fact, it is the hottest place on Earth. This multi extreme environmet is located at the Afar Depression, an incipient seafloor spreading center located at the triple junction, between Nubian, Somali and Arabian Plates (it is characterized by an attenuated continental crust, which is less than 15 km thick with zones shallow (3–5 km deep) magma chambers beneath its axial) , and for hosting environments at the very edge of natural physicalchemical extremities. This is a narrow lowland salt plain (up to 124 m below sea level) running inland, quasiparallel to the coast of the Red Sea, which formed when part of the Red Sea was isolated during the Pleistocene. Just in the north of the area a salt plain accumulation of marine evaporite deposits has been deposited and host the Dallol volcano. The interaction between the evaporitic deposit and the volcanic activity have created the unique Dallol hot springs, which are highly acidic (pH. 0) and saline (saturation) with maximum temperatures ranging between 90 and 109ºC. At the surface, the water temperature at the source is above 100 ÆC and highly acidic (pH~ 0) . The resultant hot pools vary in color depending on the high metal concentration(e.g., iron 35.6 g/L, copper 93 mg/l) . A combination of these extreme chemical and physical parameters (e.g. temperature, pH, salinity and heavy metals) has resulted in a unique multiextreme environment. In this so extreme conditions, high temperatura, high acidity (pH below 0) , salt content and metals we report for the first time evidence of life existing with these hot springs using a combination of morphological and molecular analyses.

F
igure 4: Mineral deposits and pools associated with them in the hydrothermal emergence of Dallol in the Danakil depression (Ethiopia).

Ultrasmall structures are shown (which seems at the first look to be mineral precipitates) to be entombed within mineral deposits, which are identified as members of the Order

Nanohaloarchaea. The results from this study suggest the microorganisms can survive, and potential live, within this extreme environment, which has implications for understanding the limits of habitability on Earth and on (early) Mars. During 2019 the group published for the first time the presence of microorganisms in Dallol geothermal area (Gómez et al., 2019). At the same time, it was reported that those microorganisms were active at that poli-extreme environment. At the same time, we were able to publish the preservation of lipid biomarkers in the Dallol salt deposits (Carrizo et al., 2019)



Ultra-small microorganisms identified in the salt deposits of the chymneis in Dallol (Gomez et al., Scientific Reports 2019).

Rio Tinto is an extreme acidic river located at the South of Spain. The interest of the group in this environment has been centered in the microorganisms inhabiting the interstitial space and metal covers (rock varnish) of rocks deposited in the very acidic conditions of this environment. Rocks are the matrix in which microorganisms inhabit in subsurface environments. Mineralogy, as one of the main energy sources, affects the distribution of the microbial populations, and conversely, microbial activity affects the mineralogy of the system. Thus, microorganisms-mineral interaction studies are essential to understand how subsurface ecosystems works.

During 2019 deeper studies on rio Tinto has been focused in the study of the iron burnish

precipitated over the rocks present in the river bed. This study has important astrobiological implications since the interaction of the microorganisms with the minerals and its role in the precipitation patterns of them have been reported. The results were compiled in a Thesis defended during 2019 (José Jordán PhD).

By other side, in the Iberian Pyrite Belt subsurface, understanding the microbes-geo interaction become even more relevant. The Mars Astrobiology Research and Technology Experiment (MARTE) and the Iberian Pyrite Belt Subsurface Life Detection (IPBSL) projects, point out that Río Tinto's peculiarities may be the direct consequence of the existence of a subterranean bioreactor. According with the obtained results, subsurface microorganisms would dissolve pyrite deposits through the generation of Fe^{3+} by iron-oxidizing metabolic processes. In fact, correlative fluorescence and confocal Raman microscopy analyses carried out on native subsurface samples from the Iberian Pyrite Belt, showed how the distribution of Acidovorax, an anaerobic nitrate reducing Fe oxidizing bacteria, seems to be associated with the presence of pyrite and Fe^{3+}, which strongly suggests that this microorganism is involved in the dissolution of this mineral in the IPB subsurface. Curiously, variations on the pyrite Raman spectra in terms of changes on both the relative intensity and position of its characteristic bands were detected along the complete surface.

To study the interaction microorganisms-mineral, we carried out Acidovorax cultures on natural and synthetic pyrite. Pyrite was then analyze exhaustively by correlating confocal Raman microscopy and X-ray photoemission electron microscopy (XPEEM) in the CIRCE beamline at ALBA synchrotron, the cyclic particle accelerator located in Barcelona. XPEEM allowed, by X-ray Photoelectron Spectroscopy measurements of C 1s, O 1s, N 1s (bacteria) and S 2p and Fe 2p (pyrite) regions and X-ray Absorption Spectroscopy measurements of S 2p and Fe 2p regions on pyrite surfaces, to analyze the local chemical modification produced by Acidovorax microorganisms on the pyrite surface and associated them to pyrite Raman spectra changes.

During 2019, Felipe Gómez advised 3 postdocs 2 and 2 PhD students.
Another of the activities carried out by this group in 2019 was the continuation of scientific collaborations in the NASA space missions framework. Several members of this group belong to the MSL-Curiosity and Mars2020-Perseverance NASA rovers science teams. Both Dr. Felipe Gómez and Dr. González-Fairén are Co-I of the REMS and MEDA instruments on board these missions.

Early Mars Group contribution led by Dr. Alberto G. Fairén

During 2019, the "early Mars" group, led by Dr. Fairén, finished the development of the European Research Council Starting Grant "icyMARS" (up to may 31), and started a new ERC Grant, the Consolidator Grant "MarsFirstWater" (from June 1).

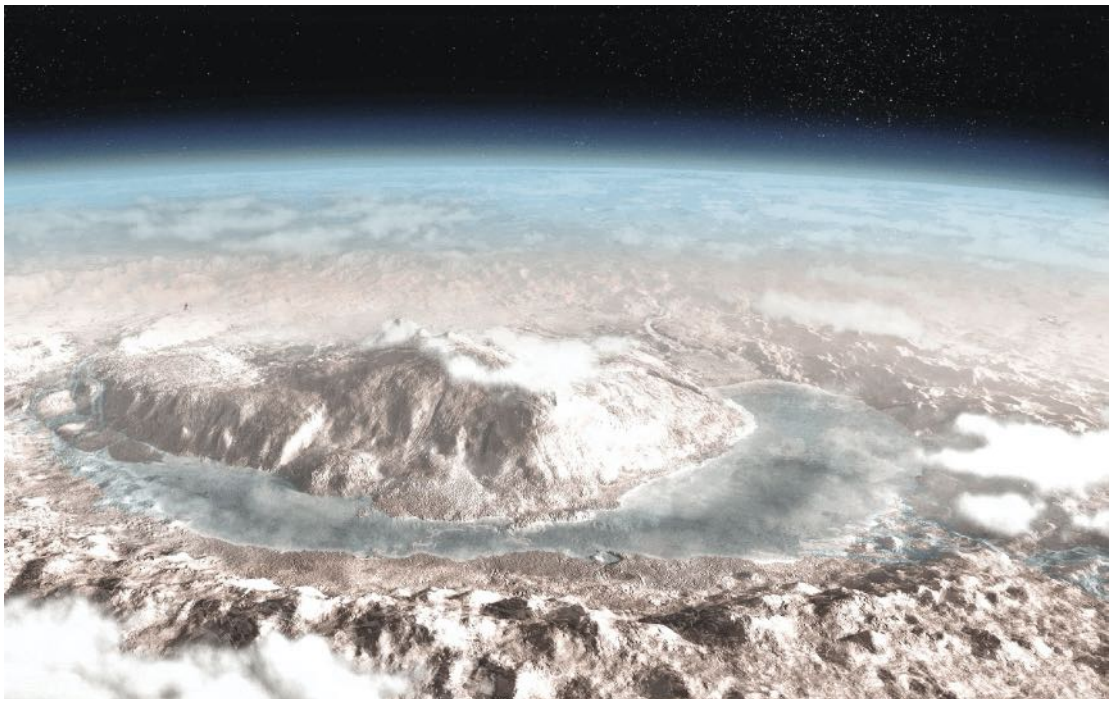


Figure 4: Ice and water depsits on Gale crater during Hesperic

Major achievements of this group during 2019 were:

Analyzing the aeolian transport of microbial life on dust in the Atacama Desert and its implications for Mars.

The group found that bacteria and fungi are able to unscathed traverse the Atacama desert, the driest desert on Earth, using wind-transported dust particles, particularly in the afternoon hours. By setting a simple experiment in two transects crossing the hyperarid core of the Atacama, we described how life is able to arrive and potentially colonize the driest places of the Atacama, despite its extreme aridity, highly saline soils and extremely high UV radiation levels. This finding suggests that any potential microbial life on Mars, extant or in the past, could have benefited from aeolian transport to wander across the planet and find suitable environments to thrive.

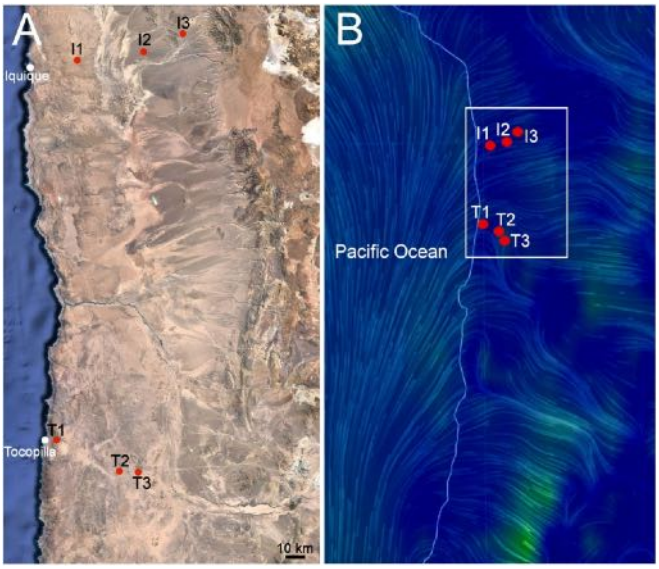
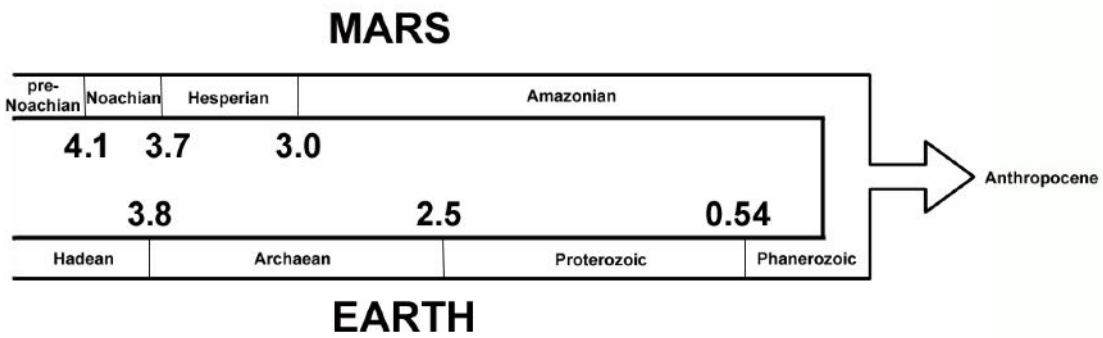


Figure 5: Sampling site locations and wind conditions at the Atacama. (A) Map of the two transects nalyzed, Iquique (three sites, I1, I2 and I3) and Tocopilla (T1, T2 and T3). (B) Usual wind flow conditions on the two transects analyzed at 5 PM using the Earth visualization tool. *Proposing a "Mars Anthropocene".*

During the next few decades, and for the first time in History, the impact of human activities and technologies could be analyzed and quantified not only on Earth, but also on other planetary bodies. Probably it is still too soon to propose a new epoch defining the geology of other planets of the Solar System on the basis of the impact of human activities. However, the case of Mars deserves initial consideration, and therefore our group proposed that the impact of human activities on Mars will soon be quantifiable as they are on Earth. On Earth, this impact is serving to propose the inception of a new geological time interval: the Anthropocene. As a consequence, we proposed that the Anthropocene may be soon debuting as the first multiplanetary geological period.



The Mars Anthropocene.

Other areas of research by the "early Mars" group during 2019 included:
Analysis of the Arabia Terra region of Mars. The group used orbital datasets and GIS to analyze the transition of landforms in Arabia Terra, searching for evidences for paleoshorelines and contributing to the analysis of Oxia Planum, the landing site for the Rosalind Franklin rover.
Instrument proposal. It was proposed a suite of first-order, in situ analytical instruments and sensors essential to determining different levels of prebiotic/biotic chemical and structural complexities in planets and satellites of the Solar System. The critical instruments would be: (1) a microscope to resolve microscale evidences for life; (2) a Raman spectrometer to detect signatures of organic (bio)molecules of different sizes and complexities, even different from those operating in terrestrial biochemistry; and (3) a biomarker detector equipped with a biosensor containing multiple bioaffinity probes (including antibodies and aptamers) for relevant biochemical compounds.
Requesting a re-evaluation of Planetary Protection policies for Mars. Under current policies, spacecraft are sent to visit Mars to look for "habitability", but they are not allowed to investigate the regions that might be especially likely to harbor life, and as a result there is not a dedicated strategy to search for life on Mars. Last year, we started a public debate with NASA's Planetary Protection officers, and this year we concluded proposing proactive steps to implement new specific policies and moving forward.
During 2019, Alberto Fairén advised 5 postdocs (Armando Azua, Antonio Molina, Carolina Gil, Laura García and Miguel Ángel Fernández) and 1 PhD student (Cristina Robas). He also presented 21 abstracts/posters at national and international meetings, and published 18 popular science articles in different newspapers and magazines (in Spanish).

MOLECULAR EVOLUTION

Head of Department: Ester Lázaro Lázaro

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

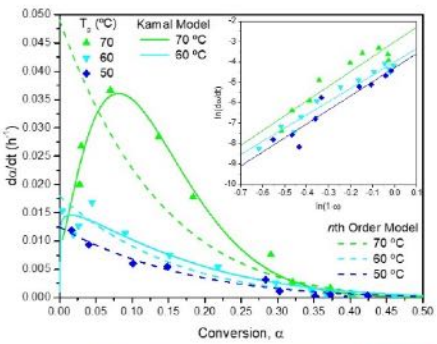
The research coordinated among these groups aims to give answers to fundamental questions related to the generation of the precursor molecules of life - including those responsible for storing and transmitting genetic information -, the mechanisms that direct biological diversification, or the simulation 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.

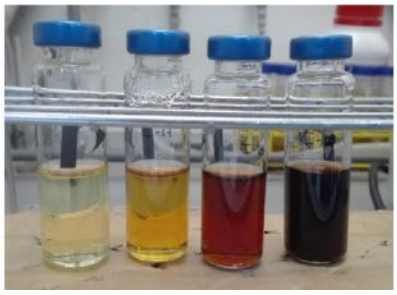
PREBIOTIC CHEMISTRY

Coordinator: David Hochberg

Kinetic and structural studies of HCN-derived polymers (Marta Ruiz Bermejo)

A compound is considered as a prebiotic reactant when it is available in adequate concentrations on the primitive Earth, or elsewhere, and when it can lead to the formation of other more complex molecules by compatible reactions with the geochemical and geophysical constraints of a particular environment, planetary or interstellar. These prebiotic transformations most likely occurred in water (oceans, lagoons or lakes) or in solid-state conditions caused by the slow evaporation of water. In this context, HCN can be considered as an excellent prebiotic reagent because it is a ubiquitous molecule in the Universe. This compound has been observed in planetary and interstellar locations and is easily produced in plausible prebiotic environments. HCN has been detected in remote galaxies, in interstellar clouds, notably in star-forming regions, in reflection nebulae, in planetary nebulae, in interplanetary dust, in circumstellar envelopes and discs, in comets, in meteorites, in the atmospheres of the outer planets and their moons and, in a terrestrial context, in volcanic gases and hydrothermal vents. HCN is the major product when appropriate gas mixtures are subjected to intense physical energy, such as from electric discharges, UV radiation or shock waves. In addition, currently there is an increasing number of publications about the formation and concentration of HCN in the atmosphere of the early Earth as well as in alkaline environments.





More than fifty years ago, J. Oró claimed the first prebiotic synthesis of adenine from refluxed solutions of concentrated ammonium cyanide. Since then, HCN oligomerization/polymerization has been considered as a preferential prebiotic route for the synthesis of purines and pyrimidine derivatives. Thus, numerous studies were carried out over the last fifty years to define the molecules present in the HCN oligomers/polymers and important bioorganics have been identified such as amino acids, heterocycles containing nitrogen (hidantoins, purines, pyrimidines, imidazoles and pteridines) carboxylic acids involved in the rTCA cycle and also glyoxylic acid, which opens a door to the "glyoxylate scenario" proposed by Eschenmoser. Additionally, HCN polymers have recently received great attention in the field of material sciences because they have been proposed as coatings and adhesives with potential biomedical applications, and HCN-based polymers have also been suggested to serve as valuable models for functional materials with emergent properties, including semiconductors, ferroelectricity, catalysis and photocatalysis. In addition, there is a growing interest in HCN polymeric clusters due to the generation of an energized charge carrier with light irradiation to induce photo redox reactions for stable hydrogen production and heterogeneous organosynthesis, which may enrich the discussion of chemical reactions under prebiotic conditions. However, their structural characteristics and, by extension, their final properties and hence their potential applications depend directly on

the experimental synthetic conditions used for their production, such as initial pH, the salinity of the aqueous environment, temperature, presence of oxygen, or the reaction time. Therefore, a comprehensive knowledge of the kinetic history of HCN polymer formation and their respective structural features are prerequisites to properly tune the properties of the desired reaction products. Thus, the effect of the temperature was systematically studied for aqueous NH_4CN polymerization considering several approaches and models to explain the kinetics of this precipitating reaction as well as its influence on the structural nature of the insoluble polymers synthesized. As a result, high temperatures lead to highly conjugated and oxidized and relatively largely ordered HCN-derived polymeric structures. It is also likely that high temperatures might lead to changes in the morphology, size and density of the final cyanide polymerization products (preliminary results of further work in progress are in agreement with this assumption). In addition, the temperature had a significant influence in the kinetics of the production of HCN-derived polymers and subsequently in the mechanistic pathways. The great complexity of the cyanide polymerization pathways in aqueous environment is well-known, but we demonstrate and for the first time, that this complexity is greater than expected, since the mechanisms of HCN-derived polymer production are temperature dependent.

On the other hand, the pioneering works of Ferris and co-workers about the role of the HCN in the abiotic generation of the first and primaeval bioorganic molecules, demonstrated the relevance of the DAMN, diaminomaleonitrile (the formal tetramer of the HCN), in the HCN oligomerization/polymerization processes. In addition, Mamajanow and Herzfed, also under a prebiotic perspective, reported the solid-state reaction of crystalline samples of DAMN, obtaining a dark polymer, electrically conductive on doping, and resistant to hydrolysis. Starting from this point, we began to study the bulk polymerization of DAMN by means the use of thermoanalytical techniques, such as termogravimetry (TG), differential scanning calorimetry (DSC), and coupled with mass spectrometry (MS), since these techniques have demonstrated to be an essential tool in the complicated task to analyzing plausible prebiotic polymers.

Adsorption and reactivity of biomolecules on surfaces(Eva Mateo-Martí)

Understanding the common guidelines that govern molecular adsorption on surfaces, particularly preferential adsorption and reactive sites, has significant implications in catalysis and prebiotic chemistry. Iron sulfides are central to our understanding of the evolution of the Earth, they have been described as catalysts in a number of key biochemical reactions associated with the “iron-sulfur world” hypothesis for the development of life.

Our studies on pyrite surface evidence the importance of sulfur surface vacancies, as it has shown that the formation of such point defects has a significant impact on the reactivity of this surface and the chemical evolution of adsorbate species, such as amino acids. Then, pyrite surface is shown to be a suitable substrate for facilitating the chemical evolution of the amino acid glycine, even under inert conditions, due to unstable surface charges. Furthermore, we conclude, the breaking-up of bonds in the sulfur-sulfur dimers due to sputtering process, the variations of the coordination number of iron atoms, and the creation of defects drives molecular adsorption and chemical evolution. Our work supports that molecules can be adsorbed and evolve on pyrite surfaces having implications for the sulfur-iron world theory.

In addition, we have demonstrated that pyrite catalyses the fixation of atmospheric nitrogen, the efficiency of this process increases with UV irradiation and atmospheric molecular density (see Figure 4-1).

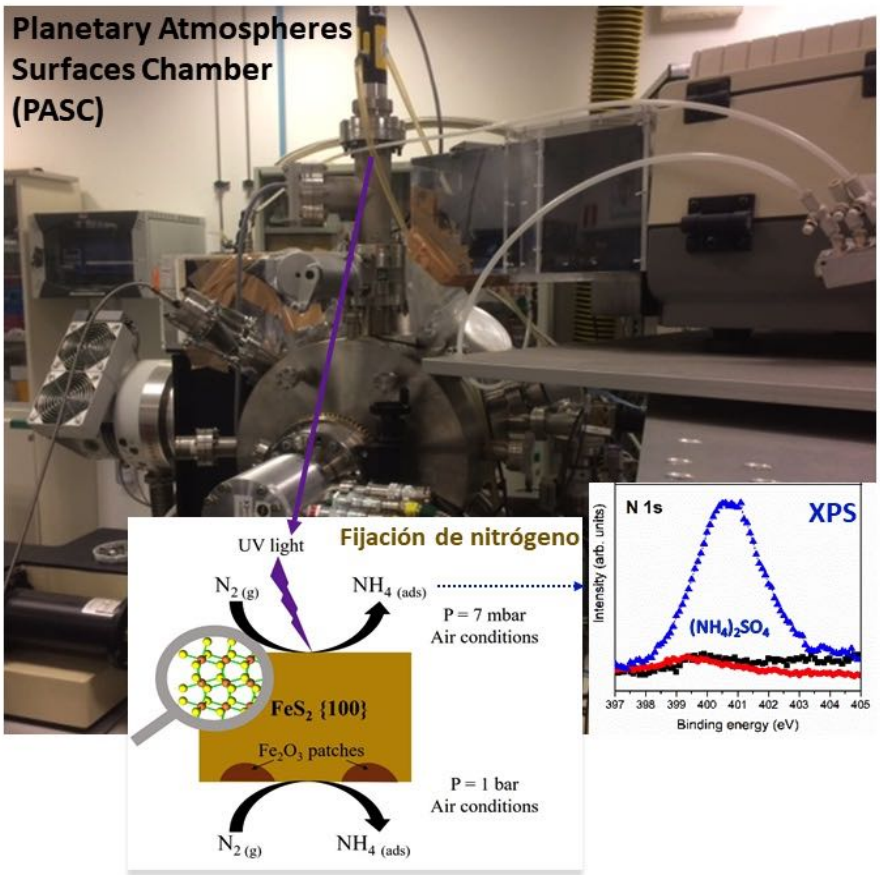


Figure 4-1: Photo of the Planetary Atmospheres and Surfaces Chamber (PASC), scheme of the uv-photocatalytic abiotic nitrogen fixation process on pyrite surface: XPS spectroscopy identify the presence of ammonium salts on the surface of pyrite, easily release from the surface upon contact with liquid water.

Our experimental results showed that the UV-irradiated pyrite surface, inside the Planetary Atmospheres and Surfaces Chamber (PASC), is able to fix N_2 and form NH_4+ in a few hours. The presence of oxides and carbonates species play a crucial role as intermediated species in the process, as they are the responsible species for nitrogen fixation, whereas in the absence of these intermediated species the adsorption phenomenon is not observed. We hypothesized that the sulfur vacancies on FeS_2 surface destabilize the neighbor iron allowing to cleavage the N_2 molecule and transforming to NH_4+ in the presence of the adsorbed H_2O. Indeed, previous works have proved that these defect sites are capable of forming reactive oxygen species (ROS) by water splitting under anaerobic conditions. XPS and IR spectroscopies have been used to identify independently the presence of ammonium salts on the surface of pyrite. This is furthermore confirmed by the easy release from the surface of the formed product with water. This kind of experiments can be used in the future to identify the most favourable conditions (in terms of temperature, atmospheric composition, absence or presence of liquid phases, UV ranges, rates of production etc.) to enhance the nitrogen fixation processes, to investigate other prebiotic or planetary environments. This process has furthermore implication for the abiotic nitrogen fixation on other planetary environments, and it has critical implications for the habitability of planet and the origin of life. We conclude that UV photocatalysis on pyrite may have been a natural mechanism of prebiotic fixation of nitrogen into ammonium sulfates which is then easily released upon contact with liquid water. This property of pyrite may have been incorporated naturally in the prebiotic chemistry evolution, leading to the inclusion of pyrite nano-clusters as reaction centres to generate ammonia from nitrogen, and then from ammonia to generate ammonium sulfates salts in the presence of oxygen.

Our findings contribute to the understanding of chemical reactivity and of the role that minerals might have played in prebiotic and surface chemistry. They also add to the knowledge of the interfacial processes of amino acids in prebiotic chemistry surface reactions, iron-sulfur scenarios and biomolecule/surface interactions.

Open Prebiotic Environments Drive Emergent Phenomena and Complex Behavior (David Hochberg)

Complex systems in nature are most appropriately modeled as open networks, where energy, raw materials and reactants are continuously being pumped in, and reactants and products are prone to dissipation and decay. The ecosystem, for example, exists far from equilibrium, in a continuous state of flux. Living organisms, in order to stay alive, are constantly importing nutrients and energy in various forms and exporting waste products and heat. Individual cells within organisms also interact with their local environment. Similarly, many natural and artificial non-living systems, such as rivers, fountains and reactors, exist far from equilibrium, at times exhibiting steady-state behavior but always interacting with their environments.

Studying synthetic networks exhibiting emergent phenomena is at the focus of Systems Chemistry research. The design and analysis of such networks may shine light on early chemical evolution processes that led to emergent properties in prebiotic environments, while at the same time they might be useful for the construction of synthetic cells. Simple (prebiotic) replicators and networks may be open or closed, namely, interacting with their environments, or alternately, chemically and thermally isolated. Both systems have therefore been studied, enabling precise modeling and rigorous analysis, and allowing crucial insight into the minimal requirements for various emergent phenomena. In collaboration with Gonen Ashkenasy's group from the Ben-Gurion University (Israel), we have reviewed several of the simple replicators and catalytic networks based on replicating templates T (see Fig. 4-1) previously investigated as prototypes for modelling replication, complexification and emergence.

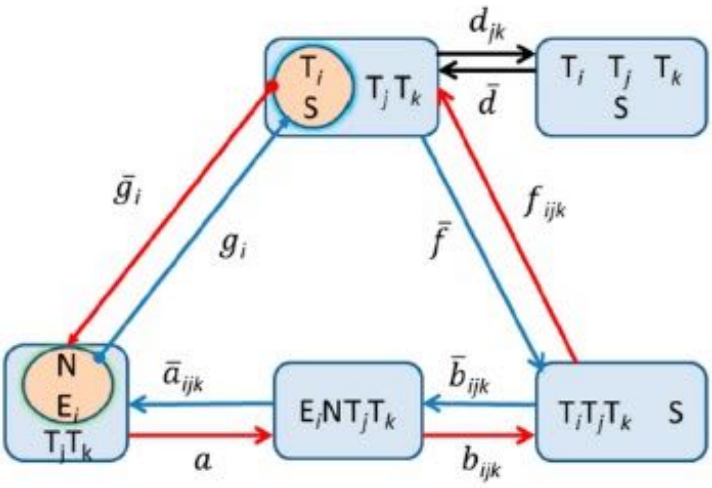


Fig. 4-2. The fully reversible replication network reviewed here, emphasizing the closed cycles involved in the corresponding Wegscheider condition for which the product of the equilibrium constants around any closed reaction pathway must be equal to unity. The clockwise sense is depicted by the blue pathway, whereas the counter-clockwise path is indicated in red. Note that since the dissociation of template dimers into single templates is not involved in these cycles (see upper right corner), the corresponding rate constants d and djk are not constrained.

Catalytic reaction networks, based on simple models of minimal self-replication and higher order catalysis, consist of molecular arrays interconnected by autocatalytic and cross catalytic pathways among reactants and templates (Fig 4-2). These synthetic networks have been studied in order to unravel complex system behavior, and can serve as "bottom-up" models for the design and understanding of molecular evolution and emergent phenomena. In the context of Systems Chemistry, catalytic reaction networks have been studied theoretically and computationally, and have been realized experimentally in several distinct chemical systems, including nucleic acids, fatty acids, peptides, organic abiotic molecules and enzymatic networks. Subsequent studies have shown how small catalytic networks may be designed to perform Boolean logic operations, and to mimic computational modules and network motifs, and they may further display oscillations and circadian rhythms, bistability and bifurcations and control competition and cooperation.

Entropic Analysis of Mirror Symmetry Breaking in Chiral Hypercycles (David Hochberg)

Replicators are fundamental to the origin of life and evolvability. Biology exhibits homochirality: only one of two enantiomers is used in proteins and nucleic acids. Thermodynamic studies of chemical replicators able to lead to homochirality shed valuable light on the origin of homochirality and life in conformity with the underlying mechanisms and thermodynamic constraints. In line with this framework, enantioselective hypercyclic replicators may lead to spontaneous mirror symmetry breaking (SMSB) without the need for additional heterochiral inhibition reactions, which can be an obstacle for the emergence of evolutionary selection properties. We have analyzed the entropy production of a two-replicator system subject to homochiral cross-catalysis (Fig. 4-3) which can undergo SMSB in an open-flow reactor. The entropy exchange with the environment is provided

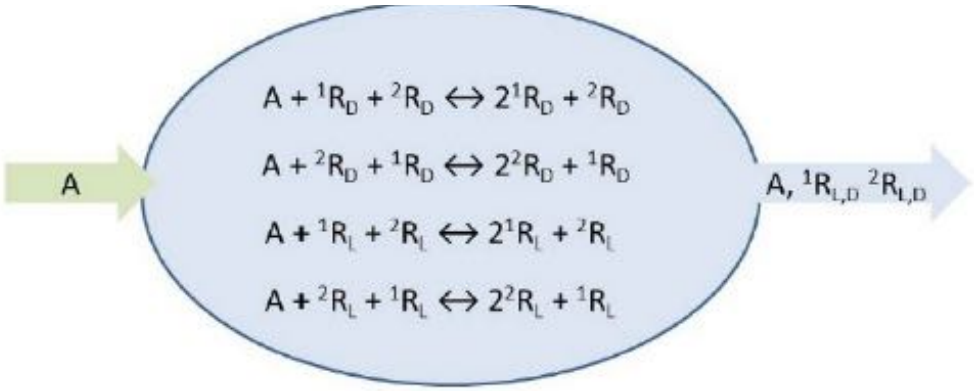


Figure 4-3. Reaction network for the two cross-catalyzed chiral replicators 1R and 2R in an open flow reactor at constant volumn V.

by the input and output matter flows (Fig 4-3), and is essential for balancing the entropy production at the non-equilibrium stationary states. The partial entropy contributions, associated with the individual elementary flux modes, as defined by stoichiometric network analysis (SNA), describe how the system's internal currents evolve, maintaining the balance between entropy production and exchange, while minimizing the entropy production after the symmetry breaking transition. We have validated the General Evolution Criterion, (Fig 3)

which states that the change in the chemical affinities proceeds in a way as to lower the value of the entropy production.

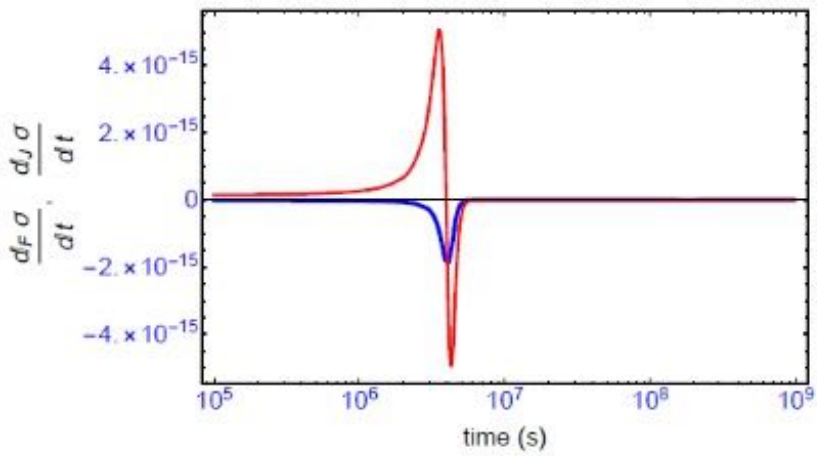


Fig. 4-4 Blue curve: the change in the entropy production with respect to changes in the chemical forces F (the affinities), which is negative definite thoughout the entire time course and reaches zero at the final stable chiral NESS, and thus obeys the general evolution criterion (GEC). Red curve: the change in the entropy production with respect to changes in the flows J, starts off positive, then becomes negative after SMSB and then reaches zero from below on the approach to the final stable chiral NESS.

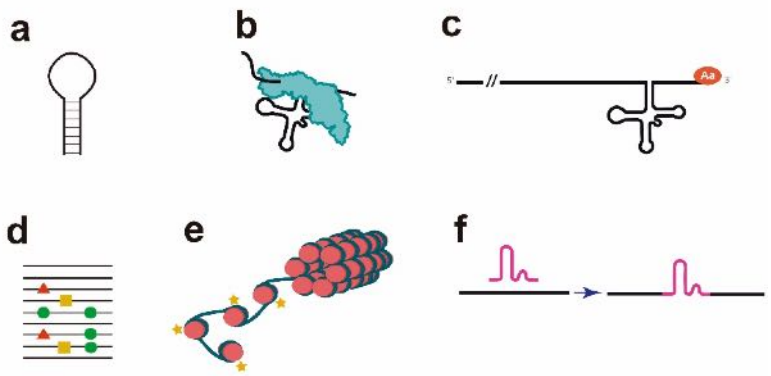
The question of biological homochirality requires an understanding of the non-equilibrium thermodynamic conditions that may lead to stable deviations from the racemic composition. The purpose of this work is to place a strong emphasis on the entropic changes and exchanges associated with SMSB. In so doing we have understood how such chemical dynamical systems can be conceived and in strict obeyance of the thermodynamic laws. This approach is developed in detail employing a model of two cross-catalyzed chiral replicators (Fig 4-4). This may be regarded as a primitive infrabiological system built out of two coupled (auto)catalytic systems. This will lead to a description of entropy production, entropy exchange, and the balance of the former and the latter at a non-equilibrium stationary state (NESS), for non-equilibrium systems in terms of the extreme flux modes, such as are defined by stoichiometric network analysis

Molecular Evolution, RNA world and Biosensors

Carlos Briones

The research group "Molecular Evolution, RNA world and Biosensors" is focused on the origin and early evolution of life (including experimental and theoretical approaches to the RNA world hypothesis), in vitro selection and evolution of nucleic acids (RNA and ssDNA aptamers), biosensor development (DNA microarray technology, aptamer-based sensors, bionanotechnology-inspired biosensors), and the study of sequence-structure-function relationships in viral or viroidal RNA (including their visualization and characterization using AFM). We also collaborate with interdisciplinary research projects devoted to the analysis of the microbial biodiversity of extreme environments.

In 2019, we have investigated [in collaboration with Instituto de Parasitología y Biomedicina "López Neyra" (IPBLN, CSIC) and Centro de Biología Molecular "Severo Ochoa" (CBMSO, CSIC-UAM)] possible pathways towards the origin of RNA (and, in particular, mRNA) via the concatenation and expansion of proto-tRNA-like structures. We define this method as "archaeological", as it has been designed to discover evolutionary patterns through a non-phylogenetic and non-representational strategy. As an example, tRNA-like elements were found in structurally and/or functionally relevant positions in viral and cellular mRNAs. This suggested that the concatenation of such RNA motifs was an activity likely present in the RNA pools, that might have been relevant in the RNA world. The extensive alteration of sequences that eventually triggered the transition from the predecessors of coding RNAs to the first fully functional mRNAs (which was not the case in the stepwise construction of noncoding rRNAs) hinders the phylogeny-based identification of RNA elements (both sequences and structures) that might have been active before the advent of protein synthesis.



The "archaeological" approach towards the origin of the RNA world considers different RNA elements and functional interactions, including the following: a) RNA secondary structures, such as stem-loops, which provide the basis for RNA cooperation and evolution; b) ribozymes, here exemplified by RNase P (in blue), which processes the precursor of tRNA (black); c) tRNA-like elements present at the 3' end of the genomic RNA of plant viruses; d) quasispecies structure, which provide the broad adaptive potential of RNA viruses; e) epigenetic marks changing chromatin into active or inactive states; f) self-replicative (RNA or DNA) elements that invade host (viral or cellular) genomes.

Aptamers are RNA or single-stranded DNA (ssDNA) oligonucleotides selected in vitro from large libraries of synthetic random oligonucleotides, using an amplification-selection method termed Systematic Evolution of Ligands by EXponential enrichment (SELEX). They can bind with high affinity and specificity to the desired target molecule. In vitro selection methods

have contributed to unveil the functional versatility of RNA. Such a functionality, together with other relevant evidences, have suggested that the appearance of RNA likely preceded that of proteins and DNA. This is the basis of the RNA world hypothesis, which, in its current formulation, is a relevant model in the field of the origin and early evolution of life.

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

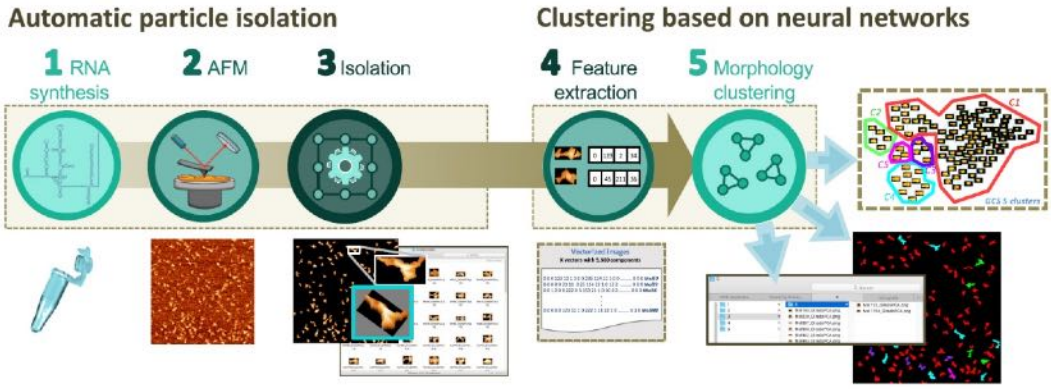
In 2019, we have focused on the in vitro selection and characterization of RNA and ssDNA aptamers specific for low molecular weight compounds useful as biomarkers in astrobiology as well as in biotechnology. The investigated target molecules include amino acids and related molecules, short peptides of different sequence and structure, and proteins such as the poly(C)-binding protein 2 (PCBP-2) and the core protein of hepatitis C virus (HCVcore). To characterize the affinity and specificity of the selected aptamers, we have developed Enzyme-Linked OligoNucleotide Assay (ELONA) coupled to either real-time, quantitative PCR (qPCR, for ssDNA aptamers) or reverse transcription followed by quantitative PCR (RTqPCR, for RNA aptamers), as well as colorimetric ELONA.

In particular, we have accumulated experience in the development of RNA and ssDNA aptamers against HCV core protein (belonging to genotypes 1, 2, 3 and 4), with the aim of developing new biotechnological tools focused on HCV diagnosis, genotyping and anti-HCV therapy. With that aim, recombinant HCV core protein belonging to each of the four genotypes (full-length proteins as well as 122 aa-long variants which contain only the D1 domain) were produced in baculovirus-insect cell expression systems, including a terminal 6xHis-tag to purify and, afterwards, to attach it to the copper-covered plates used in SELEX. Up to 14 rounds of in vitro selection of 76 nt-long, RNA and ssDNA aptamers were carried out in parallel for each of the four target HCV core proteins. Enriched populations resulting from each selection process were sequenced by NGS, and the most abundant aptamer sequences and structures were identified. The applicability of HCVcore-specific aptamers is currently being investigated.

Regarding PCBP-2-specific ssDNA aptamers, one of those showing the highest affinity has been used to develop novel graphene-based biosensors, in collaboration with researchers from the Instituto de Ciencia de Materiales de Madrid (ICMM, CSIC) and Instituto de Microelectrónica de Barcelona (IMB-CNM, CSIC). A straightforward and highly controlled route has been used to form atomic vacancies on graphene sheets in ultra-high vacuum systems, followed by the covalent chemical functionalization with a stable p-aminothiophenol (p-ATP) molecule at such vacancies. This functionalization protocol largely preserves the pristine electronic properties of graphene, while the thiol group of p-ATP remains available to react with different molecules, including thiol-modified aptamers with

which a stable bisulphide bridge is formed. The graphene-conjugated aptamer retains the functionality required to recognize the target PCBP-2 protein in solution, and such hybrid nanostructures open a new route towards the integration of high-quality graphene layers into advanced biosensing platforms. Their applicability is currently being investigated.

Finally, in the field of atomic force microscopy (AFM) of biomolecules, our group and collaborators [from ICMM and the Instituto de Biología Molecular y Celular de Plantas (IBMCP, CSIC-UPV, Valencia)], have analysed viroids, which are short (typically, 250-430 nt long) and non-protein-coding circular RNAs able to infect and replicate in plants. Three different species of viroids belonging to the families Pospiviroidae and Avsunviroidae were imaged by AFM at single molecule resolution. Our work showed their compact conformations at 0 and 4 mM Mg2+ and highlighted the role played by some elements of RNA tertiary structure in their structural stabilization. Additionally, in collaboration with Universidad Politécnica de Madrid (UPV), we have developed a novel morphology clustering software for AFM images, which is based on particle isolation and artificial neural networks. It allows to automatically analyse the different conformations of the biomolecules imaged by AFM, as well as to cluster them in groups based on their morphology. Such a novel software is currently being used to study AFM images of RNA regions of viruses and viral genomes, RNA-RNA complexes, as well as aptamer-protein complexes on biosensor surfaces.



Workflow of the morphology clustering software developed for AFM images, based on particle isolation and artificial neural networks.

Experimental evolution studies with viruses and microorganisms

Coordinator: Ester Lázaro Lázaro

Despite the great advances made in biological sciences in the last decades, there is still considerable ignorance concerning the molecular mechanisms and the general principles underlying evolution. The answers to these questions cannot be easily obtained observing the natural world, where multiple variables whose values are beyond our control establish complex interactions. Instead of that, it might be more informative to re-create the evolutionary process in the laboratory, by means of experiments in which variables could be finely controlled, allowing in this way the identification of relationships between environmental parameters, genetic changes and specific adaptations. This kind of experiments requires the use of simple systems that evolve rapidly, not difficult to handle, and in which correspondences between genotype and phenotype can be easily determined. RNA viruses meet most of these requirements. They have short generation times and replicate their genomes with very high error rates, giving rise to large, highly heterogeneous populations that adapt rapidly to most changes in environmental conditions.

Our experimental system is a bacteriophage, Qβ, that infects the bacterium *Escherichia coli*. It has a single-stranded, positive-sense RNA genome of only 4217 nucleotides, which facilitates the establishment of genotype-phenotype relationships. Like all viruses, it does not have a metabolism, which brings it closer to the world of primitive replicators, being also an adequate system for the study of evolution prior to the generation of cellular life.

Evolutionary experiments carried out in our group are usually focused on determining the changes in fitness experienced by Qβ when it is propagated under the particular conditions whose influence on evolution we want to analyze. One of the experimental variables more used in our studies is temperature, which probably is one of the most relevant selective pressures influencing biological processes from the origin of life. Fitness determinations are complemented with genetic studies aimed not only to the analysis of consensus sequences but also to the characterization of the changes that occur in the internal structure of populations, which may be determinant for the evolutionary outcomes.

The main research lines that we carried out in 2019 and the most relevant results obtained are summarized in the following sections:

Influence of the pre-existent genetic diversity on adaptation

A highly relevant question in evolutionary studies is how pre-existent genetic diversity influences subsequent adaptation. To analyze this issue, we prepared two populations of bacteriophage Qβ (Qβp2 and Qβp25) that differed in the number of serial passages (2 or 25 respectively) that they had experienced at optimal temperature (37ºC) from a clonal origin. It is expected that the difference in the number of passages, and therefore in the opportunity to generate mutations, leads to differences in the complexity and degree of diversity of both populations.

A next generation sequencing (NGS) analysis of three amplicons of each population showed that the frequency distributions of the haplotypes represented above a 0.05% threshold contained a few that were present in high amounts and a very long tail of others whose frequencies were very low (Fig.). The number of haplotypes normalized by the number of sequences was always higher for Qβp25, which also presented higher values for all the diversity indexes analyzed (maximum and minimum mutation frequencies, Shannon entropy and nucleotide diversity).

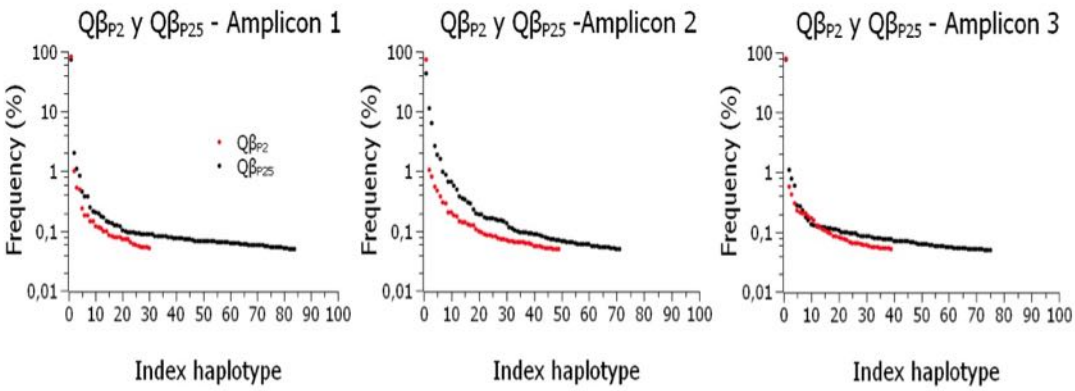


Figure 4-5: Frequency distributions of haplotypes in populations Qβp2 and Qβp25. In all cases, the number of sequences included in the analysis was above 200000.

Evolution at 43ºC of both populations Qβp2 and Qβp25 for a number of 60 serial passages (in triplicate) led to fitness gains that, at the last passage, were quite similar. However, the lineages whose ancestor was Qβp25 increased fitness more rapidly, which was accompanied by the selection at early passages of a broader set of mutations than those selected in the lineages whose ancestor was Qβp2. All these results suggest that the greater diversity contained in population Qβp25 favours rapid adaptation to the increase in temperature. Analysis of mutations that were represented above 0.5% in ancestral populations, an amount that does not allow detection by traditional Sanger sequencing techniques, showed that several of these pre-existent mutations were used for the subsequent adaptation of the virus, which can explain the faster adaptation of the most diverse population.

Analysis by massive sequencing of the populations corresponding to a representative lineage of each set showed that the lineage whose ancestor was Qβp2 reached higher values for all diversity indexes evaluated than the lineage whose ancestor was Qβp25.The result is remarkable since population Qβp25 had higher values than Qβp2 for the same parameters.

Adaptation to alternating values of temperature

In general, selective pressures in nature do not remain constant for long periods of time, but fluctuate among different values, a fact that probably contributes to shaping the evolutionary process. To analyze this question, population Qβp2 was propagated for 60 serial passages that alternated the temperatures of 30ºC and 43ºC. In parallel, the same population was also propagated constantly at 30ºC or 43ºC. All evolutionary lineages were triplicated. The analysis of the fitness values obtained at passage number 60 showed that the alternating lineages failed to adapt to 30ºC, while their fitness did improve at 43ºC, although to a lower extent than lineages propagated constantly at 43ºC. This result shows that alternation of two values of a particular selective pressure interferes with adaptation to each of them.

An NGS analysis of a representative lineage of each set described above showed that the fluctuating lineage and the one constantly evolved at 30ºC presented lower values for all diversity indexes evaluated than the lineage evolved at 43ºC. This finding suggests that there could be a relationship between the temperature of evolution and the generation of diversity, something that we proceeded to analyze.

Relationships between temperature of evolution and generation of diversity

We carried out an experiment in which population Qβp2 was propagated for 60 passages at 5 different temperatures: 30ºC, 33ºC, 37ºC, 40ºC and 43ºC. The populations obtained were then subjected to an NGS analysis that allowed us to evaluate the genetic diversity contained in a particular genomic region (between nucleotides 1060 and 1331) of each of them. Remarkably, for all the diversity indexes analyzed, a good correlation was obtained between the evolution temperature and the diversity value (Fig.)

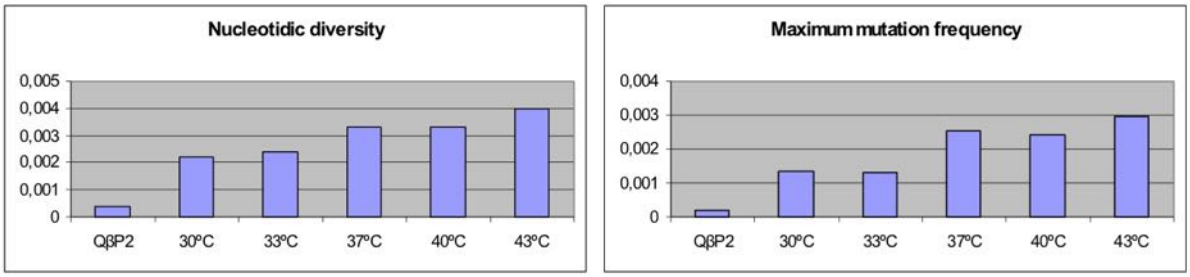


Figure 4-6. Variation of two representative diversity indexes as a function of the temperature of evolution. The Qβp2 bars represent the values obtained for the ancestral population. The rest of bars correspond to the populations obtained upon propagation of Qβp2 for 60 serial passages at the temperature indicated.

Mechanisms of adaptation in liquid and semisolid medium

The structure of the physical environment in which populations evolve is another important factor that may condition the adaptive pathways. The good knowledge we have about the adaptation of Qβ to high temperatures when it replicates in liquid medium motivated us to carry out an experiment in which the virus was propagated in semi-solid medium at 37ºC and 43ºC in parallel. The results obtained showed a series of common mutations to both temperatures, and also another (U830C), which was exclusive to the lineages evolved at 43ºC, that conferred a phenotype of small plaques. This mutation had not been identified in any of the previous experiments carried out in liquid medium. We are currently studying why this phenotype provides advantages at high temperatures when the virus evolves in semi-solid medium. Some preliminary results indicate that it could be related to variations in the rate of virus adsorption.

Intra-population dynamics of adaptation at high temperature

Finally, we have also continued the characterization of the within-population dynamics that takes place during the adaptation of Qβ to increased temperature. The results showed that, even at early stages of the process, populations were composed by a highly diverse ensemble of mutants containing different combinations of mutations that provided beneficial effects. Competition among mutants, together with epistatic interactions among mutations located in the same genome, delayed the emergence of a defined consensus sequence and made it difficult to predict the mutations that fixed at later stages. Artificially reconstructed populations containing a fraction of the diversity present in actual populations fixed mutations more rapidly, illustrating how population bottlenecks may contribute to determine the adaptive pathways. The conclusion is that although high error rates and large population sizes facilitate adaptation in RNA viruses, when the availability of beneficial mutations under a particular selective condition is elevated, the final outcome is more dependent on interactions occurring within the mutant spectrum than on the selective value of particular mutations.Microbial biodiversity

Microbial biodiversity

Coordinator: Ángeles Aguilera

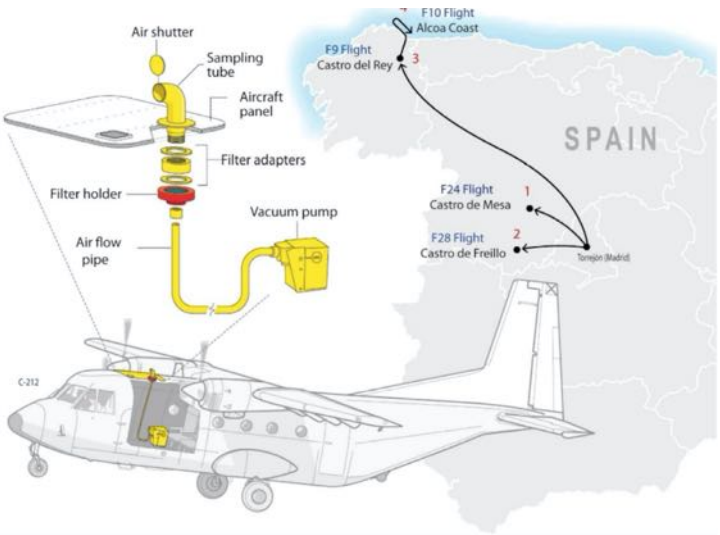
Microbiological Control in the Formation of Mineral Deposits (MINLIFE) (Ángeles Aguilera, Elena González-Toril)

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

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

Scientific missions from manned and unmanned flying research platforms (MICRAS) (Elena González Toril, Ángeles Aguilera and Susana Osuna Esteban)

MICRAS is a multidisciplinary project for the study of atmospheric aerosols, using flying research platforms. From the interaction between disciplines such as chemistry, physic, microbiology and a clear support of engineering, will allow us to cover a complete study of microbial ecology of aerosols. INTA aircrafts will be the basic tool in our research, and represent a huge advantage in the study of atmospheric microbial ecology and the different environments that we could find. Most studies to date on



the atmospheric microbiome are restricted to samples collected near the Earth's surface. The tropospheric microbial ecology at high altitudes and in open air masses, where long-range atmospheric transport is more efficient, remains poorly characterized. This fact is mostly due to difficulties associated with obtaining enough biomass for analysis, not to mention the difficulty to access to aerial platforms to sampling the air from the microbiological point of view. In this regard, to our knowledge, there are only four references regarding microbial ecology in the troposphere by using aircrafts, one related to tropical storms, another to the airborne bacteria in the lower stratosphere and two reporting changes in the microbial atmospheric composition during Asian dust events in Japan. Increasing our knowledge of this field will also contribute to improved models of microbial dispersal and microbial biogeography.

Development and implementation of sampling equipment for the study of airborne microorganisms at altitude: one stage electrostatic precipitators in Aerial Research Platforms (ELECTRO-BIOTA) (Ángeles Aguilera, Elena González-Toril, Susana Osuna)

ELECTRO-BIOTA will be devoted to the study of atmospheric aerosols, using flying research platforms. At this moment, the sampling of external air is carried out by means of an isokinetic probe which will be the first thing we developed. The isokinetic probe avoids accelerating and decelerating the air current in the inlet to ensure that the actual concentration of particles is being measured. This system is equipped with pressure and temperature devices as well as the mass flow. A Venturi tube or a Pitot-static system measures the volumetric flow. Finally, a system to drive the flow by means of a suitable aspirator is connected to the system. The whole set must have the highest degree of automation possible; to achieve an on-board system on a remotely piloted aerial platform that allows the automatic acquisition of biological samples. In addition, there is the asepsis requirement of the sampling system, which is fundamental for the collection of biological samples. Thus, the system must be able to be adequately sterilized to ensure that it has not been contaminated before or during sample collection.

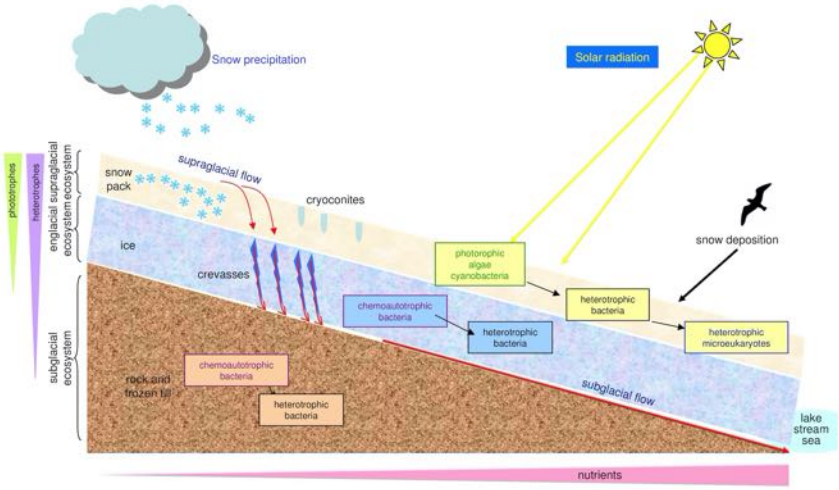
ELECTRO-BIOTA has a scientific and engineering duality: the study of microbial ecology of the atmosphere and the adequacy of manned and unmanned flying platforms for the study of atmospheric microbial ecology. The main objectives are (i) Study of the microbial ecology of the atmosphere using manned and unmanned flying research platforms (ii) Correlation database by multivariate statistics and model development, (iii) Development of sampling equipment and software suitable for the proposed objectives.

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

So far, three types of samplers have been developed (Electrostatic, Impactor, Coriolis-type liquid impregnator). Although we are collecting enough biomass, we still need to increase the efficiency of these. Also, the air intake isokinetic probe has been developed. 16S rRNA gene libraries have been developed and sequenced using Illumina. Sampling was carried out during the second half of the year (16 hr flight time) in both rural and urban areas (flying over Madrid and Guadalajara) at two altitudes (ca. 100m to 3,000m). The samples were also collected for the study of nano and microplastics in height and were analyzed by optical microscopy and Fourier Transform Infrared Transmission Spectroscopy (FTIR), which is

commonly used in the characterization of different compounds. Microplastics from industrial origin have been detected at 3,000 m, with a distribution capacity of more than 1,000 km, according to 36h modelling carried out in HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT), which is something that had not been described until now.

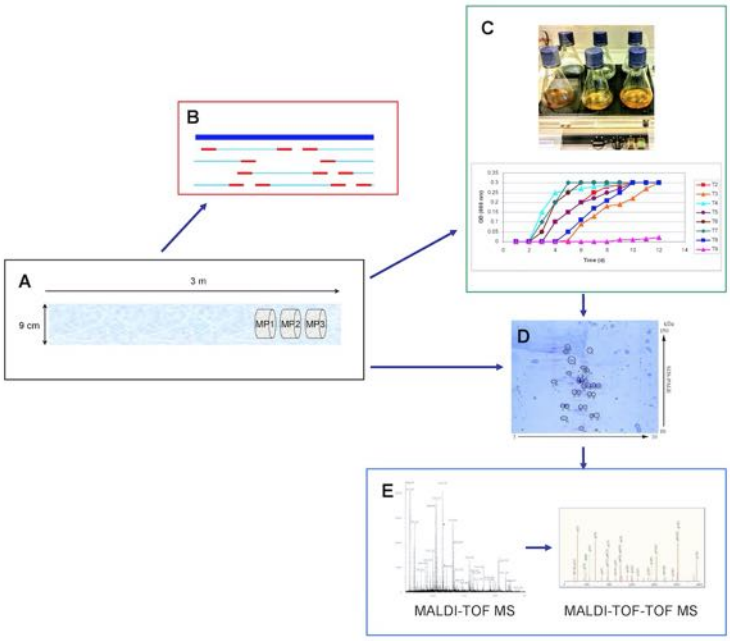
Taxonomic and functional characterization of microbial communities from volcanic englacial ecosystems (Cristina Cid Sánchez and Eva García López)



Ice from glaciers occupies approximately 11% of the Earth's surface. Although glaciers were traditionally considered to be an uninhabitable environment, it has been proven that they are populated by a large number of microorganisms including bacteria, archaea and microeukaryotes. Among them, microorganisms inhabiting the Antarctic glaciers are much more unknown than those living in other frozen environments. Three ecosystems can be differentiated in glaciers: supraglacial, subglacial and englacial ecosystems. Little is known about the persistence, physiology, and ecology of microbial communities inhabiting the englacial ecosystem. It has been reported that microorganisms enclosed in ice present very low metabolic rates, using energy only to repair damaged biomolecules, and not to grow and reproduce. More research is necessary in order to define their importance.

Functional culturomic and metaproteomic analysis are ideally suited to englacial ecosystem studies for several reasons. Firstly, species that have not yet been recognized by 16S rRNA sequencing can be identified by the sequences of their proteins, and moreover, it is a way of verifying that microorganisms are alive and have the capacity for metabolism and growth. Taking into account that proteins are synthesized only when they are required, the detection of whole essential proteins is an indicator to detect living cells. Secondly, culturing can also increase the abundance and activity of microorganisms, enabling metaproteomic studies to model the structure of the potential microbial community. In addition, the knowledge of the proteins used by these microorganisms makes it possible to find out their metabolic pathways and how microorganisms are able to survive in this extreme environment.

This project has have provided new results through 16S rRNA sequencing, culturomics (a culturing process that uses multiple culture conditions) and metaproteomics. Several interesting questions are addressed: (i) what are the microorganisms that inhabit the englacial ecosystem?, (ii) are they alive or quiescent?, (iii) if these microbial communities are alive, what are their survival mechanisms, their physiology, and their ecology? This study details a strategy for the identification of the englacial microbial community from an Antarctic glacier combining genomic and metaproteomic techniques. Firstly, samples from the innermost end of an ice core from an Antarctic glacier were analyzed by a 16S rRNA gene survey in order to identify microbial species. Secondly, microorganisms were cultured in



various culture media and at various temperatures. Lastly, metaproteomic techniques were used to verify that englacial microorganisms present an active metabolism and to elucidate their potential metabolic routes.

MOLECULAR MECHANISMS OF BIOLOGICAL ADAPTATION

Coordinator: José Eduardo González Pastor

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

Currently we are interested in studying the molecular mechanism of adaptation to perchlorate and UV radiation in microorganisms that inhabit hypersaline environments. Hypersaline environments can be considered analogous to Mars and icy satellites such as Europa (Jupiter) and Enceladus (Saturn). In addition, we are developing molecular tools for the screening of metagenomic libraries in mesophilic and hyperhalophilic microorganisms using microfluidics. This work is funded by the European Project: METAFLUIDICS (H2020, GA685474) and the Coordinated Project: PGC2018-096956-B-C42 (MICINN, Spain)

Search for perchlorate resistance genes in microorganisms of a hypersaline lake of Atacama

In 2008, the NASA Phoenix Mars Lander discovered the presence of perchlorate anions in the Martian surface regolith. This finding questioned the possible presence of life on Mars, since perchlorate is toxic for most of known microorganisms, including humans. In addition, perchlorate ion is very soluble in water leading to very low eutectic temperatures ranging from −74 to −34°C, which would allow the presence of seasonal flows of brine liquid water on Mars. For these reasons, perchlorate has a major astrobiological interest at present. However, little is known about how microorganisms can resist against perchlorate. Thus, the aim of this project was to identify novel genes and molecular mechanisms responsible for perchlorate resistance using functional metagenomics and transcriptomics.

Metagenomic DNA was isolated from sediments of Salar de Marincunga, a hypersaline lake in Atacama Region (Chile) which is considered to contain high perchlorate levels. Extracted DNA was partially digested with Sau3AI enzyme, and DNA fragments (2-8 kb) were cloned into the high-copy vector pBluescript SKII+ hosted in E. coli DH10B strain. The metagenomic library was screened for resistance to perchlorate on solid medium containing 125 mM sodium perchlorate, lethal for the host strain. Nine perchlorate resistant clones were identified and their environmental DNA fragments were sequenced. A total of 17 individual ORFs were identified and cloned to determine which genes were directly responsible for perchlorate resistance. We found nine individual genes that increased perchlorate-resistance when cloned into *E. coli* DH10B cells (Fig. 4-7). These genes encoded for proteins not previously reported to be involved in perchlorate resistance, and they were related to different cellular processes such as RNA metabolism, DNA protection, protein turnover or membrane lipid composition.

pJR10-*orf2*, pJR12-*orf2* and pJR35-*orf2* were related to RNA metabolism and encoded for

proteins similar to a Sm-like domain containing hypothetical protein, a QueF enzyme and a RNase E, respectively. Sm-like proteins are involved in a variety of RNA processing events, such as regulation of translation of mRNAs. QueF is one of the enzymes required for queuosine biosynthesis, a modified nucleoside present at the wobble anticodon position of some tRNAs that alters codon bias. RNaseE plays a critical role in tRNA processing, maturation of the 5' end of 16S RNA and mRNA decay.

Other genes encoded for proteins previously reported to conferred resistance to different stress, such as DNA-binding protein HU (pJR56-*orf2*) or ClpP protease (pJR157). HU plays a role in DNA replication, recombination, and repair, and is essential for induction of genes related to survival under stress conditions. ClpP protease is involved in removal of misfolded and dysfunctional proteins, and regulation of short-lived proteins. Another 4 perchlorate-resistant genes encoded for proteins similar to a putative alanine dehydrogenase (pJR37-*orf2*), a IMP dehydrogenase (pJR72), a MlaC domain-containing protein (pJR76-*orf2*) and a hypothetical protein with unknown function (pJR125). Furthermore, some of the perchlorate-resistant genes also conferred resistance against UV-radiation, 4-nitroquinoline-N-oxide and hydrogen peroxide.

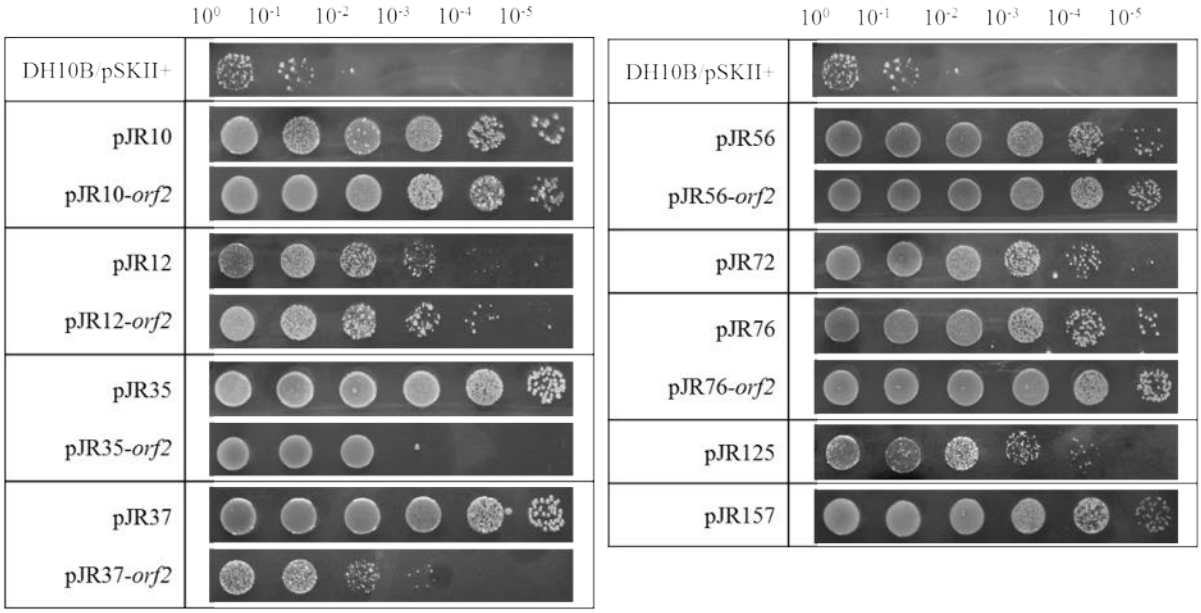


Figure 4-7. Drop assay of the individual predicted ORFs responsible for perchlorate-resistance and their complete clones. Cultures were grown on solid medium containing 125 mM sodium perchlorate and incubated for 48h at 37 °C. E. coli DH10B bearing empty pSKII+ vector was used as a negative control.

Screening for genes involved in DNA damage protection from hypersaline environments using metagenomic libraries expressed in the hyperhalophilic archaea Haloferax volcanii

To search for genes involved in protection against DNA damage in microorganisms from hypersaline environments, which are exposed to high doses of UV radiation, we have explored a metagenomic library from the Es Trenc salterns (Mallorca, Spain) hosted in the hyperhalophilic archaea *H. volcanii*. This library consists of a total of 1.46x106 independent clones with an average insert size of 1.4 Kbp (2.04 Gbp of cloned metagenomic DNA in the pAJ bifunctional vector). The library was exposed to the compound 4-nitroquinoline (4NQO) that mimics the biological effects of UVB radiation in the DNA. A total of 1.00x106 recombinant cells from the amplified library were grown on solid medium containing 0.8 μM 4NQO, and one clone pAJ-21 showed significant growth differences to control cells

when exposed to 0.8μM 4NQO (Fig. 4-8).

This clone has been completely sequenced and was found to correspond to a 2.8 Kbp region of the genome of the hyperhalophilic bacterium *Salinibacter ruber*. The sequence contains a total of three annotated ORFs, of which two encode for DNA repair exonucleases and one for a hypothetical protein of unknown function (Figure 4-9). As a result, ORF3, which encodes a DNA exonuclease, was assigned as providing resistance to 4NQO in *H. volcanii* DS70.

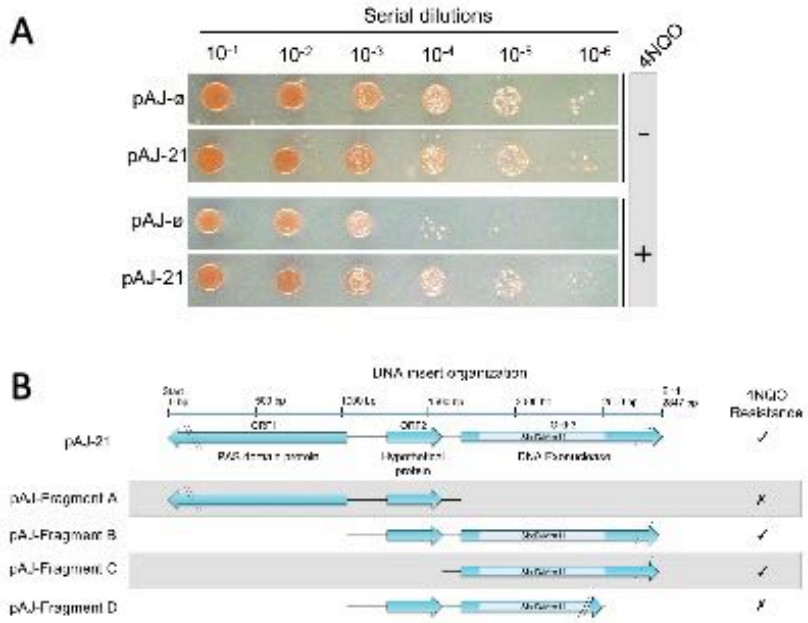


Figure 4-8. (A) Serial dilutions of H. volcani strain DS70 cells harboring empty control plasmid (pAJ-ø) or nitroquinoline resistant clone plasmid (pAJ-21). In each case 10 μl of each serial dilution starting from a cell suspension with an OD600 of 0.6 was spotted on YPC Nv0.3 agar medium supplemented with or without 0.8 μM 4NQO. (B) Schematic representation of the DNA sequence of clone pAJ-21 and mapping of 4NQO resistance. Annotated ORFs on each DNA fragment are represented as blue arrows. The marks on the right correspond to the 4NQO resistance phenotype of each construction.

Life support systems: UV resistant plants

The main goal is to generate plants more resistant to UV radiation, to improve their capabilities to survive in space conditions. Five genes from bacteria and archaea involved in UV resistance were introduced in the genomes of different *Arabidopsis thaliana* plants. Those genes were retrieved in a previous study from microorganisms of a saltern (Es Trenc, Spain) and from hypersaline ponds from the Andean Highlands (4.300 m altitude) in Argentina, environments exposed to high UV-B doses of radiation. Those genes were cloned in the plasmid pCAMBIA 3500 (from Carlos Alonso, CNB), and then introduced in *Agrobacterium tumefaciens*, which were used to transfer the genes by floral dipping to the genome of *Arabidopsis thaliana* Columbia-0. Several independent transgenic lines were obtained for each construction, and the third generation of two different constructions were exposed to UV-C (450mJ) radiation or to 20-30 M of 4-nitroquinoline 1-oxide (4-NQO), a compound that mimics the DNA damage effect produced by UV radiation. The results indicate that plants expressing the conserved hypothetical genes pML6-*orf1* and pML84-*orf1* improve their resistance to UV radiation, although only those expressing pML84-*orf1* exhibited more resistance to 4-NQO (Fig. 4-9).

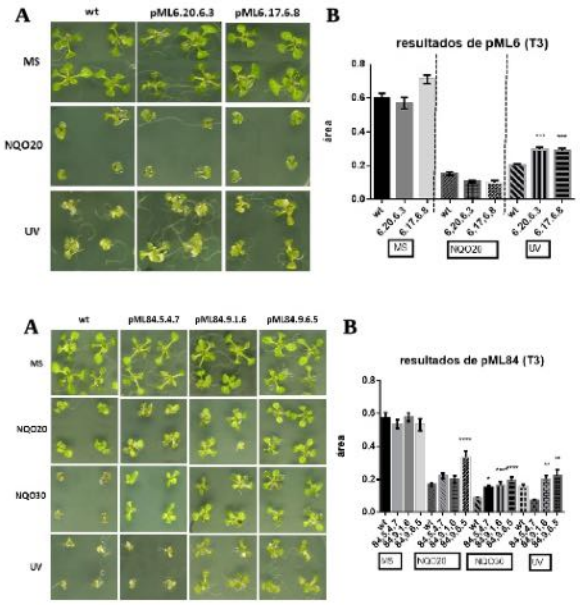


Figure 4-9. Results of UV radiation and nitroquinoline resistance of plants expressing the conserved hypothetical genes pML6-orf1 (upper panel) and pML84-orf1 (lower panel). (A) Images of wt and transgenic lines after two weeks growing in: i) MS (without treatment); ii) 4-NQO treatment (20 and/or 30 μM); and iii) exposed to 450mJ of UV-C radiation after one week of growth. (B) Average values of the rosette area (ImageJ) of each of the experiments, taking into account the biological replicates (3 replicates, 24 plants per replica)

Biomolecules in Planetary Exploration

Coordinator: Victor Parro García

Microbial communities and biomarkers in terrestrial analogues of Mars: from Atacama Desert to Andean and Antarctic hydrothermal areas

Searching for molecular biomarkers in planetary exploration requires a deep understanding of the metabolic potential and the production and the preservation of biomolecules in terrestrial analogues of other planetary environments. Among these analogues, the Atacama Desert (Northern Chile), one of the oldest and driest deserts on Earth, is considered as a polyextreme environment dominated by extreme aridity, high UV radiation, elevated salinity, and extreme temperature fluctuations. On the other hand, early Mars had an active volcanism that could have lasted to relatively recent periods. Then, terrestrial hydrothermal environments constitute good scenarios to study the associated microbial life and its metabolic and molecular fingerprints. The high altitude Andean hydrothermal areas such as El tatio, or the Antarctic volcanic regions are considered as a window to the past that emulate (at least in several parameters) other environments in early Martian periods.

1. Prokaryotic Community Structure and Metabolisms in Shallow Subsurface of Atacama Desert Playas and Alluvial Fans After Heavy Rains: Repairing and Preparing for Next Dry Period

The Atacama Desert is known for this extreme aridity, although displays significant rains only once per decade. To investigate how microbial communities take advantage of these sporadic wet events, we carried out a geomicrobiological study a few days after a heavy rain event in 2015. For this purpose, we selected five sample sites in playa soils and one in alluvial fan site which covered a longitudinal (West to East) transect. To explore the microbial diversity and the presence of biomarkers at each sampling site, we conducted different physicochemical and microbial community analyses in a vertical profile from the surface to 80 cm depth at each sampling site.

We measure the gravimetric moisture content peaks in 10 and 20 cm depth samples (from 1.65 to 4.1% w/w maximum values). Anions such as chloride, nitrate, and sulfate concentration increased with depth, with maximum values of 13–1,125; 168–10,109; and 9,904–30,952 ppm, respectively. Small organic anions such as formate and acetate reached maximum concentrations from 2.61 to 3.44 ppm and 6.73 to 28.75 ppm, respectively.

Microbial diversity was inferred from DNA analysis and showed Actinobacteria and Alphaproteobacteria as the most abundant and widespread bacterial taxa among the samples, followed by Chloroflexi and Firmicutes at specific sites. DNA sequencing of archaeal 16S rRNA showed OTUs belonging to Euryarchaeota and Thaumarchaeota Phila. Ordination of the bacterial community showed a clear association of samples with depth, and, in a lesser extension, between playas and alluvial fun. A similar pattern was observed for Archaea, were mainly dominated by Methanobacteria class at the surface while deeper samples had the highest abundance of Haloarchaea, Methanomicrobia and Nitrososphaera classes.

Metaproteomics showed a high and even distribution of proteins involved in primary metabolic processes such as energy production and biosynthetic pathways, and a limited but remarkable presence of proteins related to resistance to environmental stressors such as

radiation, oxidation, or desiccation.

The biomarker profiling with the sandwich microarray immunoassay (LDCHIP) confirmed the trends elucidated above with the DNA analysis and demonstrated the presence of two universal bacterial proteins, the chaperone GroEL and FTsZ also found with metaproteomics. The combination of geochemical, DNA sequencing, and metaproteomic analysis in this study allowed us to infer about the structure and nature of the microbial populations, their diversity, and their putative metabolic states in Atacama playas and the alluvial fun after a sporadic but large-scale rain event. The results indicated that extra humidity in the system allows the microbial community to repair, and prepare for the upcoming hyperarid period. Additionally, it supplies biomarkers to the medium whose preservation potential could be high under strong desiccation conditions and relevant for planetary exploration.

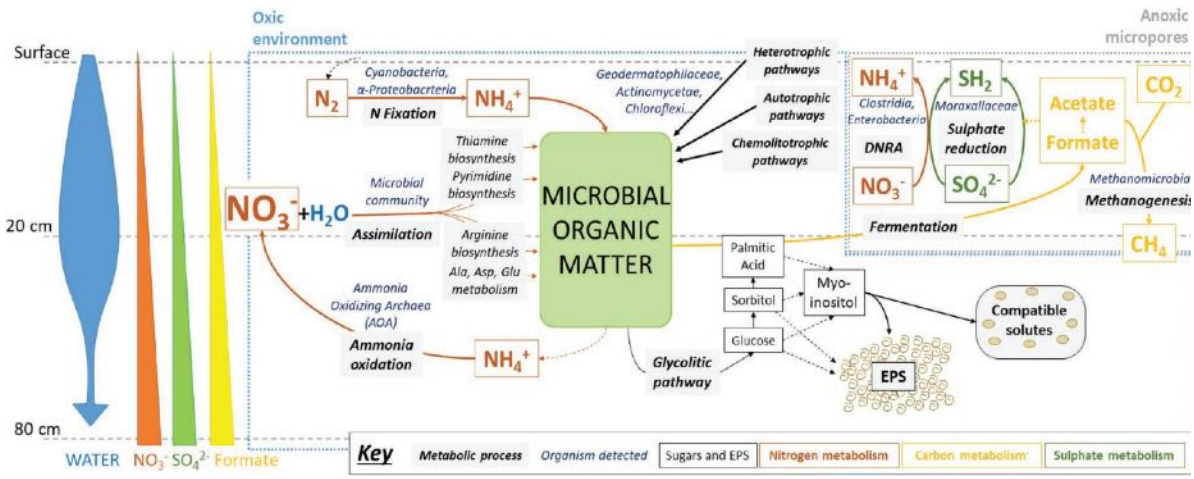


Fig. 4-10. Microbial metabolisms in swallow subsurface of Atacama Desert playa environment after rainfall. Metabolic pathways were inferred from the results obtained after multi-analytical approach. Water input seems to be the main driver of microbial activity in oxic environments, mainly for N-cycling (orange arrows) and glycolytic pathways (dark thin arrows), as well as in creating anoxic environments, where S- (dark green arrows) and C-cycles (yellow arrows) could be operating, including CH4 production and consumption. Microbial groups referred to as putatively responsible for metabolic pathways are based on both 16S rRNA sequencing findings and previous studies that determined their metabolic capabilities.

2. Microbial biomarker profiling with SOLID-LDChip in a Mars drilling simulation campaign in the Atacama Desert (Chile).

The study of the metabolic potential and conservation of biological information in extreme environments on Earth is crucial to explore the feasibility of detecting extant or extinct life on Mars. For this purpose, we stablished a twofold objective: first, the identification of new molecular biomarkers in samples from the Atacama desert with both the immunological biosensor LDChip (Life Detector Chip) and the SOLID (Signs Of Life Detector) instrument. Secondly, the implementation and improvement of the LDCHip immunosensor as well as developing new concepts of instrumentation for planetary exploration. To accomplish these goals, we search for microbial biomarkers in the Atacama desert during a field campaign carried out in winter 2018 within the framework of the project entitled Atacama Rover Mars drilling Studies (ARADS) led by NASA Ames Research Center.

Geomicrobiological studies were applied to characterize the microbial diversity present in GP7 and P12 drills at the core of the Atacama Desert, in the Antofagasta region. X-ray diffraction (XRD) revealed that sampling points consisted of alluvial and colluvial sand deposits, with significant differences between two drills. Thus, GP7 was dominated by halite

while in P12 dominated sulfate rich-layers (gypsum and anhydrite). Although Both drills showed similar values for total organic Carbon, the higher values were at the surface for GP7drill and in depth for P12 drill, respectively.

The taxonomic analysis by DNA sequencing revealed in GP7 drill a bacterial community that was dominated by the phylum Proteobacteria represented mainly by the beta-Proteobacteria class, followed by Actinobacteria and Firmicutes phyla. Conversely, Actinobacteria was the dominant phylum in drill P12 (60%-80% OTUs) followed by alfa and beta-Proteobacteria classes, along with the Firmicutes phylum. These results were confirmed both manually at the field-lab and in situ with SOLID instrument by using the LDChip immunosensor and demonstrate the scarce carbon content and biomass present in the samples for these types of soils. In addition, the possibility to perform autonomous and remote operations in terrestrial analogs can play an important role in future space missions.

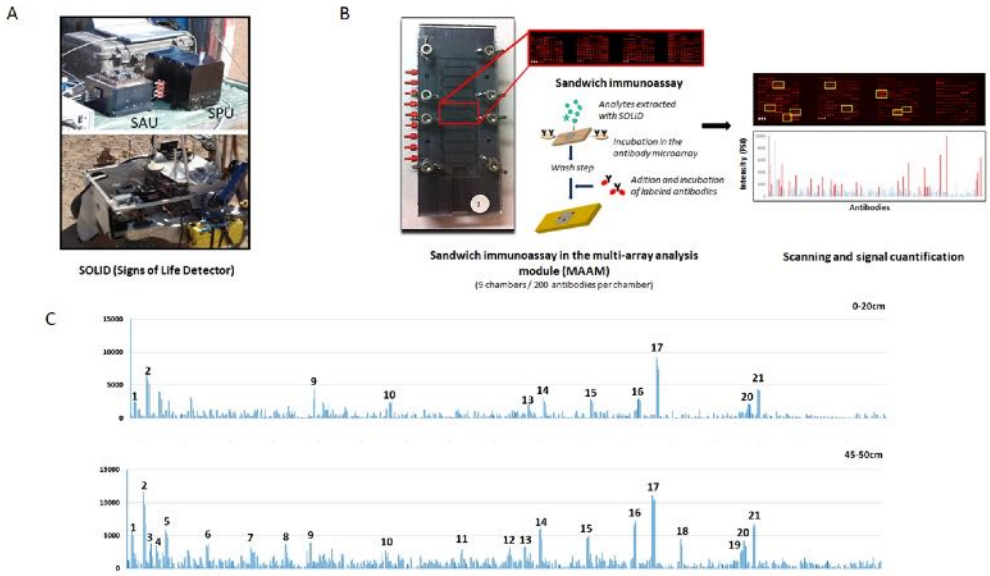


Fig 4-11. (A) SOLID instrument analysis carried out in situ in the K-REX2 rover at the Atacama Desert. (B) Fluorescent sandwich microarray immunoassay (FSMI) performed manually in the field-lab and (C) Immunograms obtained with the SOLID instrument for GP7 drill at the surface and 40-50cm depth. Numbers indicate positive signals for some of the antibodies printed in the microarray.

Microbial biomarker transition in high-altitde sinter mounds from El Tatio (Chile) through different stages of hydrothermal activity

We investigated molecular fingerprints of microbial life in three geyser mounds from El Tatio geysers field (Atacama, Chile) for the astrobiological relevance of this unique geothermal system with certain similarities to Martian environments (high UV radiation, high atmospheric dryness, extreme daily temperature oscillation). Multiple biomarkers (lipids, DNA, proteins and biopolymers) were were investigated in three morphologically similar geyser mounds characterized by differences in water activity (i.e., episodic liquid water, steam, and inactive geyser lacking hydrothermal activity) in order to determine (past and present) biological signatures and dominant metabolism. Altogether, they provided biogeochemical evidence for habitability and preservation in silica sinter at the high altitude, hyper-arid environment of El Tatio.

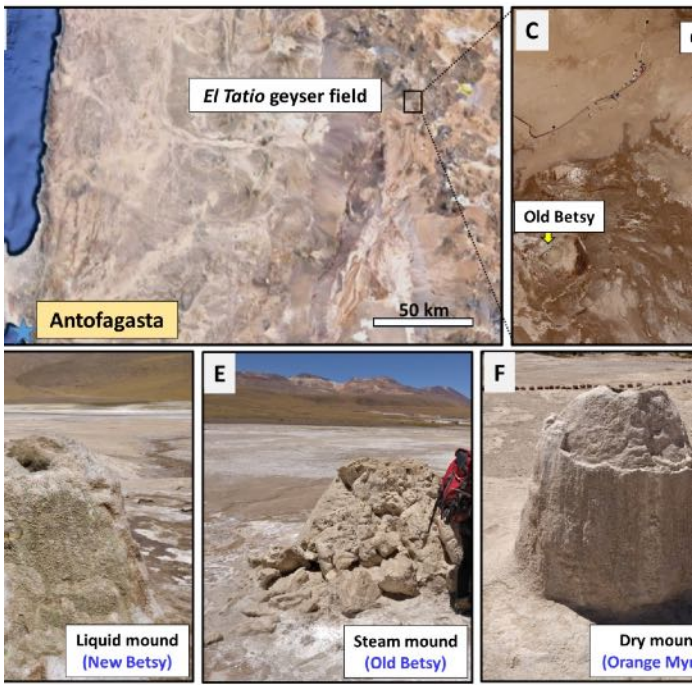


Fig. 4-12. Site of study and sampling. Map of northern Chile (A), showing the location of the El Tatio geysers field (B), including the three geysers studied here (New Betsy, NB; Old Betsy, OB; and Orange Myrtle, OM) (C). Both pictures in B,C are satellite images from Google Maps. The general appearance of the three sinter mounds (liquid NB, steam OB, and dry OM) is shown in D–F, respectively.

Lipid biomarkers indicated relative abundance of thermophiles and sulfate reducing bacteria in the liquid water mound; photosynthetic microorganisms such as cyanobacteria, in the steam sinter mound; and archaea and purple sulfur bacteria in the dry sinter from the inactive geyser. Sequencing of environmental 16S rRNA genes and immuno-assays generally corroborated the lipid-based microbial identification. A life detector chip based on multiplex immunoassays (LD-chip) and the compound-specific isotopic analysis of carboxylic acids, alkanols, and alkanes indicated that the principal microbial pathway for carbon fixation in the three sinter mounds was through the Calvin cycle, with a relative larger contribution of the reductive acetyl-CoA pathway in the dry system. Other inferred metabolic traits varied from the liquid mound (iron and sulfur chemistry), to the steam mound (nitrogen cycle), to the dry mound (perchlorate reduction). The three sinter structures preserved biosignatures representative of primary (thermophilic) and secondary (including endoliths and environmental contaminants) microbial communities.

The combined results revealed different stages of colonization that reflect differences in the lifetime of the mounds, where primary communities dominated the biosignatures preserved in sinters from the still active geysers (liquid and steam mounds), in contrast to the surviving metabolisms and microbial communities at the end of lifetime of the inactive geothermal mound.

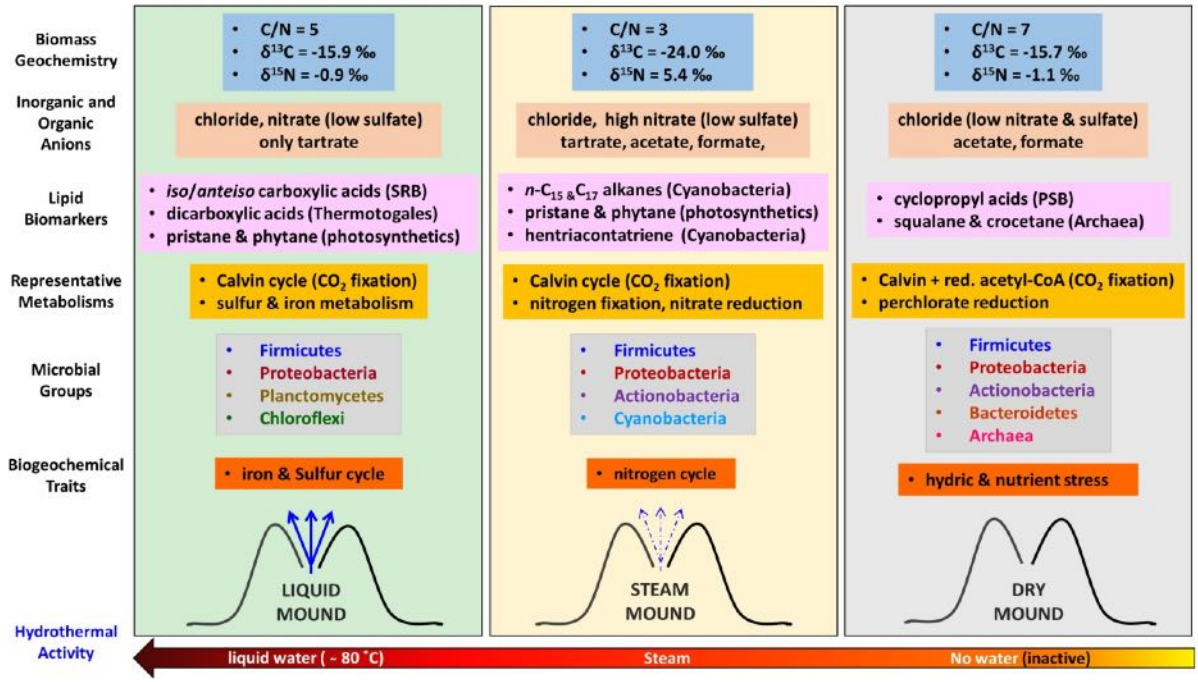


Fig. 4-13. Schematic of the biogeochemical reconstruction of the three geothermal systems (liquid, steam, and dry) at El Tatio as a function of the hydrothermal activity based on bulk elemental and isotopic geochemistry, characteristic lipid biomarkers (source diagnosis in brackets), compound-specific isotopic analysis (metabolism), DNA sequencing (phylogeny), and LDChip immunoassays (phylogeny, metabolism, and biogeochemical traits). SRB means Sulfur Reducing Bacteria, GnSB Green non-Sulfur Bacteria, and PSB Purple Sulfur Bacteria. Red, acetyl-CoA stands for the reductive acetyl-CoA pathway for autotrophic CO2 fixation..

Biomarker profiling of microbial mats in the geothermal band of Cerro Caliente (Deception Island, Antarctica)

We investigated three microbial mats thriving on the polar geothermal site of Cerro Caliente, a hill located in Deception Island (Antarctica). Deception Island is an active stratovolcano from the South Shetlands Islands that harbors both extremely cold and hot habitats and is comprised within the Antarctic Specially Protected Area No. 140. The geothermal activity in Cerro Caliente comprises a narrow band of warm substrate affected by hydrothermal fluids ascending from a fault and extending along ca. 40m length and 3m wide along the summit ridge. The objective of the study was to characterize the community structure and major metabolic traits of three microbial mats located in Cerro Caliente registering 88ºC, 8ºC and 2ºC at the time of collection.

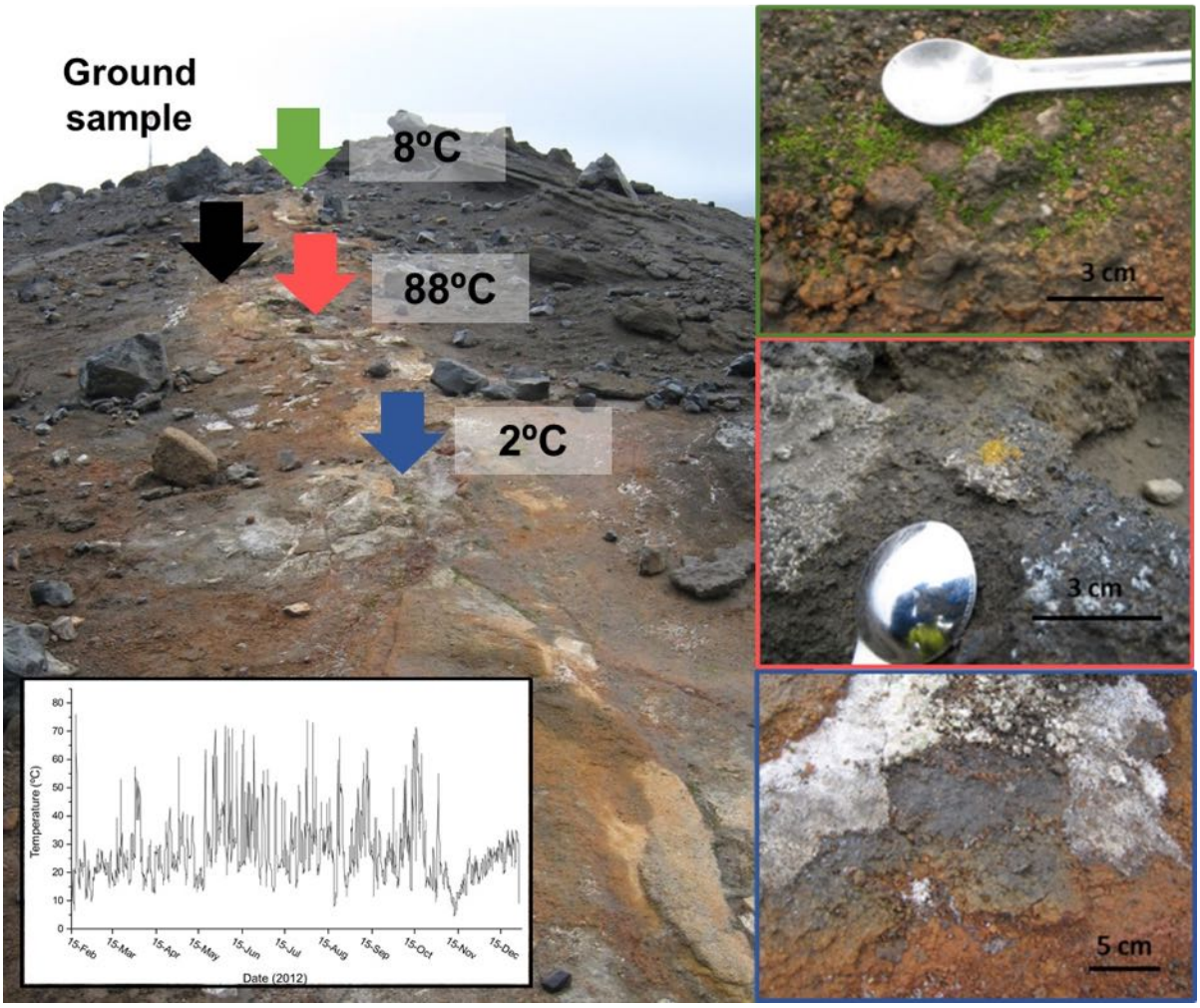


Fig. 4-14. Sampling location at Cerro Caliente, Deception Island. Color arrows indicate the location of the microbial mat samples and the black arrow indicates the site for ground sample and location of a thermocouple for temperature measurements over a year. On the right, pictures showing the appearance of the microbial mats and, on the bottom, the graph showing the ground thermal oscillations over a year.

Massive sequencing analysis of SSU rRNA genes (16S and 18S), multiplex immunoassays and stable isotope composition (13C and 15N) revealed the presence of microorganisms with different thermal tolerances and metabolisms as a function of the prevailing temperature of each mat. The mat at 88ºC showed a higher proportion of thermophiles and the Reductive Tricarboxylic Acid or the 3-Hydroxypropionate cycle as major carbon fixation pathways. In contrast, the mats at 8ºC and 2ºC showed a higher proportion of psychrophiles and the Calvin-Besson-Bassam cycle for CO2 fixation. Beyond this thermal pattern, the three mats shared main microbial phyla, most likely explained by the strong thermal oscillations recorded in the ground over the year. Therefore, thermal factors must be considered to explain the overall microbial community structure and operating metabolisms in Cerro Caliente.

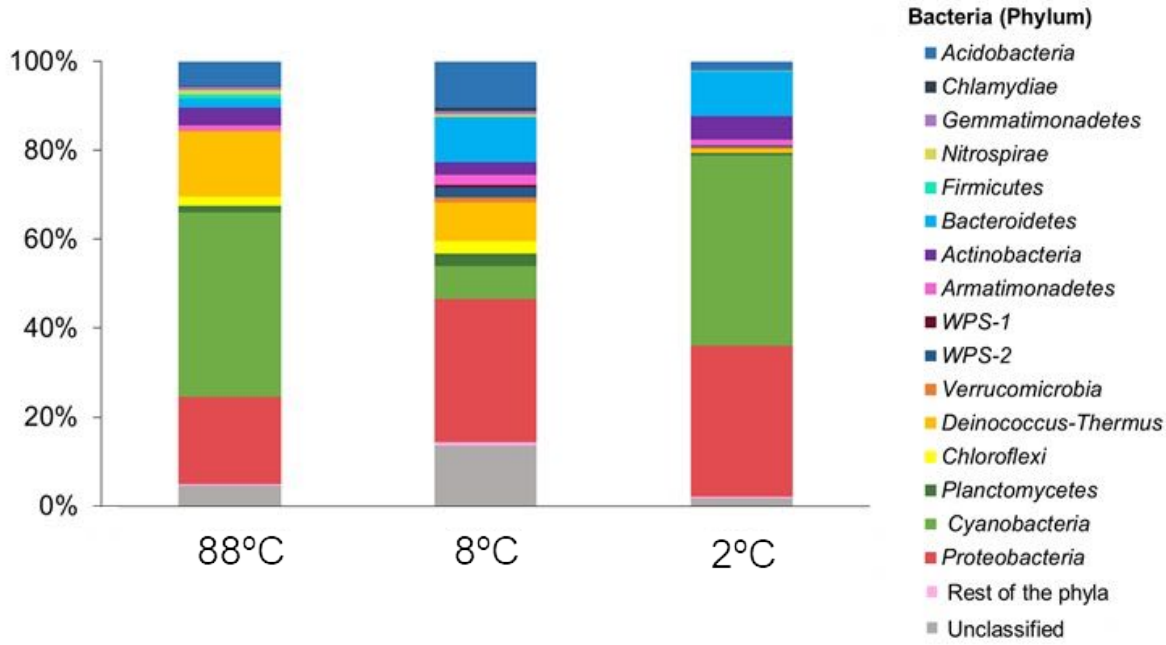


Fig. 4-15. Bacterial community composition of the microbial mats in terms of relative abundance. The phyla with relative abundances <0.5% are comprised within the "rest of the phyla" group.

The interest of glaciovolcanic environments as potential habitable sites on early Mars highlights Cerro Caliente as a relevant analogue for the study of molecular microbial markers. The coexistence of evolutionarily distant microorganisms with different thermal tolerances (some adapted to extreme high and cold temperatures) and metabolisms (different CO2 fixation pathways) in Cerro Caliente provides diverse molecular biomarker signatures useful to interpret extant or extinct life in current or future planetary missions to Mars.

ADVANCED INSTRUMENTATION

Head of Department: Eduardo Sebastián Martínez

Experimentation and simulation play a fundamental role in the accomplishment of the different research lines in the Center. In many cases they are carried out in the laboratory, in others during field campaigns by studying natural processes, and in other cases in space, either by remote observation or by in situ analysis and measurements on the surface of planetary bodies.

The Department devotes its research activity to the development of space instrumentation technologies for planetary and astrophysical exploration, as well as the development of simulation chambers for planetary environments. In this last aspect, the Instrumentation Department has different infrastructures, planetary simulation chambers and vacuum technologies to scientifically and technologically support the researchers of the group. All the 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 technological aspects of this development range from the conception of prototypes and new concepts of instrumentation, the design and supervision of the industry specialized in the manufacture of flight models, through the execution of testing campaigns for the validation and maturation of the instrumentation and developed technologies, either in simulation chambers or in representative environments (so-called terrestrial analogues). Within the framework of the group's activity, the operation and exploitation of the scientific data collected by the technological developments is also carried out, in direct collaboration with the rest of the center's staff and associated units.

During the year 2019 the department continued with the leadership, development and operation of different flight instruments. The clearest examples are the REMS (Rover Environmental Monitoring Station) aboard the Curiosity rover, the TWINS (Temperature and Wind Sensors for InSight mission) aboard the lander of the InSight mission, and the MEDA (Mars Environmental Dynamics Analyzer) of the Mars2020 mission, all of them from NASA. Other examples of the European Space Agency (ESA) are the RLS (Raman Laser Spectrometer) for the ExoMars program and the far-infrared spectrometer SAFARI for the SPICA telescope. In addition to that, in the field of simulation of planetary and interplanetary environments, the department contributed to the design and set-up of the StarDust chamber, within the European ERC NANOCOSMOS project and led the experiments of the WLOM project to simulate the poles of the planet Mars.

The Advanced Instrumentation Department is organized in 1 Research Group:

Space Instrumentation

Space Instrumentation

Coordinator: Jose Antonio Rodriguez Manfredi

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

The main activities carried out during the year 2019 were:

Instrumentation for space missions: MEDA.

The Center for Astrobiology leads the development of the space instrument MEDA (Mars Environmental Dynamics Analyzer) for NASA's Mars 2020 mission.

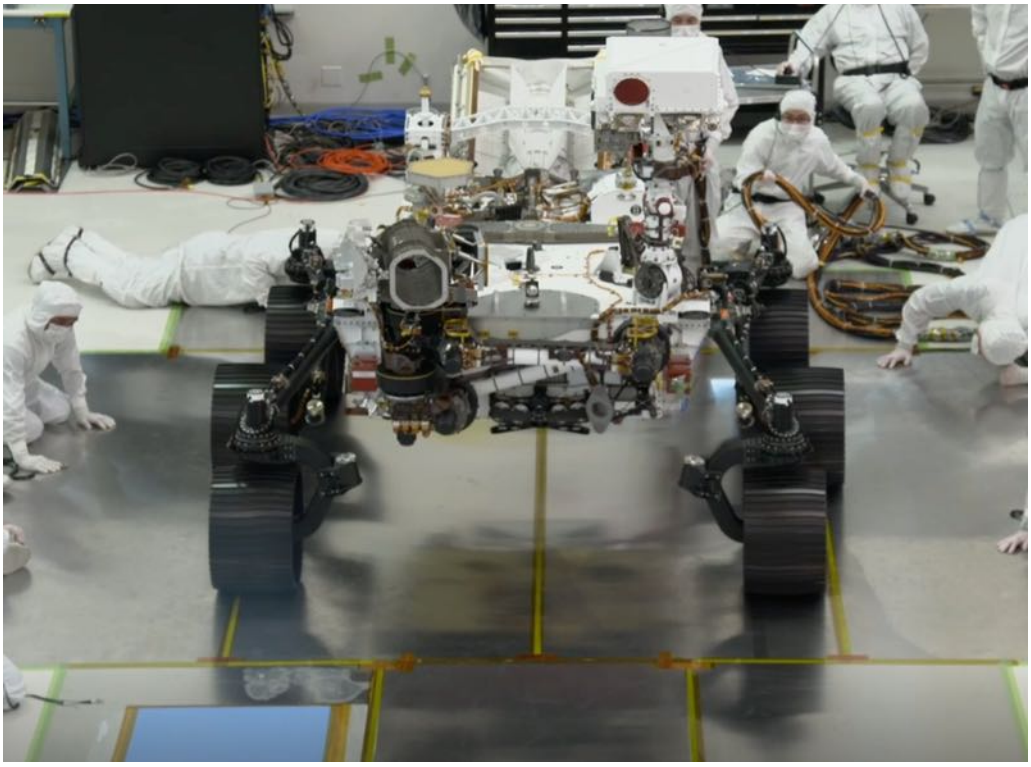
Together with the CAB, the Departamento de Cargas Útiles at Instituto Nacional de Técnica Aeroespacial, CRISA Airbus Defense and Space, AVS Added Value Solutions, ALTER Technology, the University of the Basque Country, the Rocasolano Physics-Chemistry Institute (CSIC) and the University of Alcalá participate in this development as Spanish partners. Additionally, the Finnish Meteorological Institute, the Jet Propulsion Laboratory, the University of Michigan, Aeolis Research, the University of Texas A & M, NASA Goddard Space Flight Center, and the John Hopkins APL as international partners.

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

Throughout the year 2019, the international team delivered the two remaining flight subsystems, the RDS (which also includes the SkyCam system, a CCD dedicated exclusively to observing the Martian sky) and the WS, which, due to their complexity, required a few more months before being delivered to JPL.

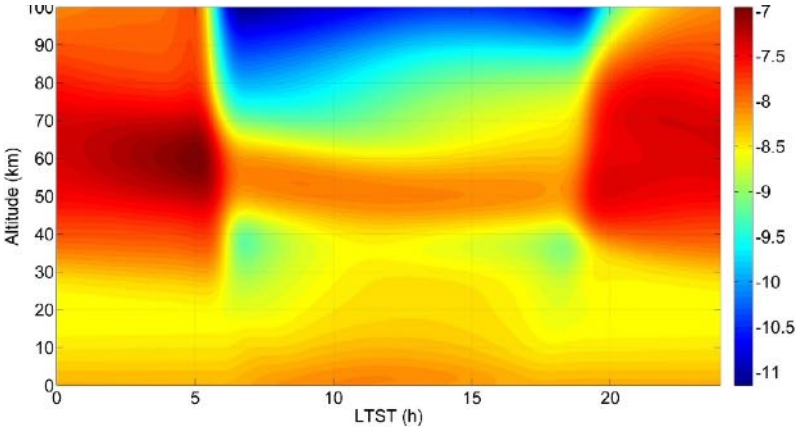
Also, as part of the latest phase D activities, the team worked intensively on completing the development and validation of the instrument's flight software, and the interface to the rover's on-board computer.

With all the elements delivered, JPL proceeded to integrate them all into the rover, and to conduct global system tests, the compatibility tests between instruments, and those others checking the performance of the rover and her systems in representative Martian environments (in simulation chambers). After all those, Perseverance was almost ready to be shipped to Florida for her latest tests and activities before proceeding with the final stacking.



Perseverance rover mobility test at JPL (Dec 2019), with all MEDA sensors installed (Yellow circle, wind sensor).

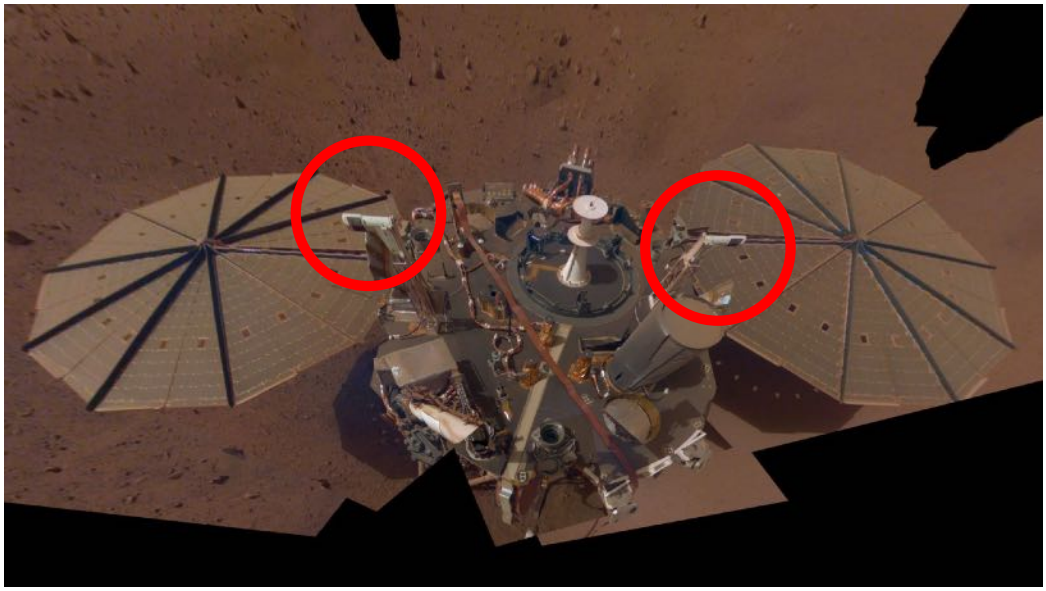
In parallel with all this technological activity, scientific studies have been carried out for the future interpretation of the data from the MEDA station once it is on Mars. An example of them is the use of photochemical models in order to simulate the chemical mechanisms that drive odd oxygen's diurnal budget and its variability on Mars atmosphere. The Martian ozone vertical distribution and its diurnal variation for equatorial latitudes are studied. The chosen equatorial latitude-region is based on the recent and future plans of NASA and other agencies to study this region by different surface missions. The diurnal variation shows large differences in the abundance between daytime and nighttime; and variable behavior depending on the atmospheric layer. The photolysis-driven ozone diurnal profile is obtained at the surface, whilst a sharp decrease is obtained in the upper troposphere at daytime, which originates from the large differences in atomic oxygen abundances between atmospheric layers. Finally, no clear anticorrelation between ozone and water vapor is found in the diurnal cycle, contrary to the strong correlation observed by orbiters on a seasonal timescale.



Diurnal variability for the vertical profile of ozone (logarithm of ozone mixing ratio) at the southern fall equinox.

Instrumentation for space missions: TWINS.

The Department of Instrumentation of the CAB is responsible of the TWINS (Temperatures and Winds for InSight), an instrument dedicated to environmental characterization of the Martian atmosphere. TWINS is part the mission InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) of NASA, for the characterization of the interior of the planet Mars through a lander.



NASA's Insights lander on Mars (May 2019) with the two TWINS booms (red circles).

Since its landing on Mars in November 2018, both InSight and TWINS have been working and doing their jobs with great success.

The scientific data provided by TWINS are allowing discarding false seismic readings caused by the strong winds of the environment, and also being of a great scientific value given the detailed record that it is carrying out. TWINS is providing a continuous log of the local winds and temperatures at the landing site (Elysium Planitia), being a perfect complement to those other data provided by REMS in the Martian Gale Crater, thus constituting the first mini meteorological-environmental network on the surface of Mars.

Instrumentation for space missions: REMS.

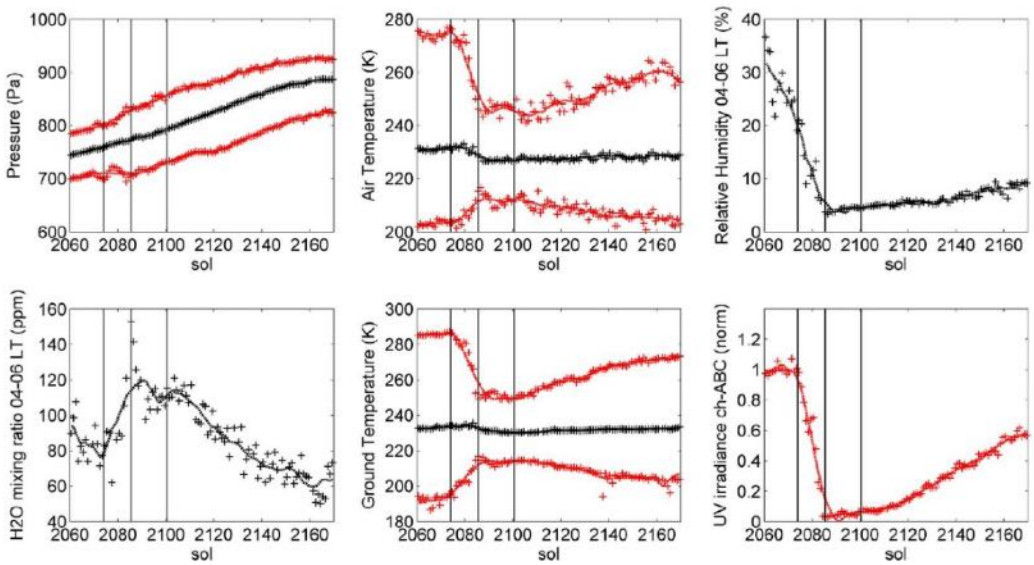
During 2019, the successful operation of the REMS (Rover Environmental Monitoring Station) on Mars, aboard Curiosity, continued. Curiosity, NASA's exploration vehicle, has been since August 2012 recognizing and characterizing the habitation environment of the Martian Gale Crater. REMS is the instrument in charge of the characterization of the environment, continuously collecting data on pressure, air and ground temperatures, wind speed and direction, atmospheric humidity and incident ultraviolet radiation. During all this time, the instrument has collected more than 75 million readings from each of the sensors.

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

Curiosity, with REMS on it, at Glen Etive (Oct 2019)

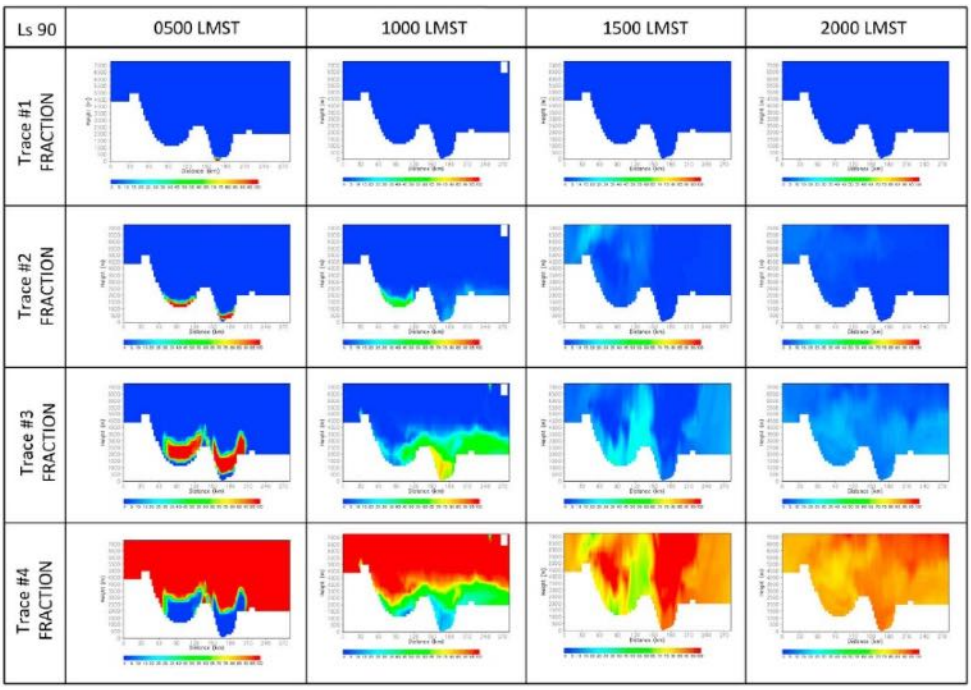
Within the framework of the REMS project, scientific research activities are also carried out. Throughout the year 2019, there was an important contribution to the characterization of the MY34/2018 Global Dust Storm, including a detail analysis of the effects and measurements of different REMS sensors. REMS offers a unique opportunity to better understand the impact of a global dust storm on local environmental conditions, which complements previous observations by the Viking landers and Mars Exploration Rovers. All atmospheric variables measured by REMS are strongly affected albeit at different times. During the onset phase, the daily maximum UV radiation decreased by 90% between sols 2075 (opacity ~1) and 2085 (opacity ~8.5). The diurnal range in ground and air temperatures decreased by 35 and 56 K, respectively, with also a diurnal average decrease of ~2 and 4 K respectively. The maximum relative humidity, which occurs right before sunrise, decreased to below 5%, compared with prestorm values of up to 29%, due to the warmer air temperatures at night, while the inferred water vapor abundance suggests an increase during the storm. Between sols 2085 and 2130, the typical nighttime stable inversion layer was absent near the surface as ground temperatures remained warmer than near surface air temperatures. Finally, the frequency domain behavior of the diurnal pressure cycle shows a strong increase in the strength of the semidiurnal and terdiurnal modes peaking after the local opacity maximum, also suggesting differences in the dust abundance inside and outside Gale.

Dust deposition on the ultraviolet sensor: comparison between Mars Science Laboratory sols 2036 (prestorm) and 2216 (after the storm)



Evolution of REMS variables (sols 2060–2170) for the period encompassing the onset (sols 2075–2084), highly dusty (sols 2085–2100), and decay phases of the dust storm. Daily mean (black) and daily maximum and minimum (red)

Another relevant scientific contribution of the REMS research team was the study of methane on Mars. The detection of methane at Gale crater by the Tunable Laser Spectrometer–Sample Analysis at Mars instrument aboard the Curiosity rover has garnered significant attention because of the implications for the presence of Martian organisms. Methane should be well mixed except when near a source or shortly after a release. Nevertheless, the observed spikes measurements of several parts per billion by volume or greater and a subsequent return to the background level are intriguing. The REMS team makes use of the Mars Regional Atmospheric Modeling System to simulate, via passive tracers, the transport and mixing of methane released inside and outside of the crater. Instantaneous and steady state releases were studied to test whether the results are consistent with in situ observations made by the Mars Curiosity rover. The simulations indicate that the mixing time scale for air within the crater is approximately 1 Martian day. While the observed low background levels can be reproduced by the model under some circumstances, it is difficult to reconcile the measured peaks with the modeled transport and mixing.



Fraction of the four tracers at four different times (0500, 1000, 1500, and 2000 LMST) at Ls 90° in a north south cross section view of the crater for the instantaneous methane release scenario.

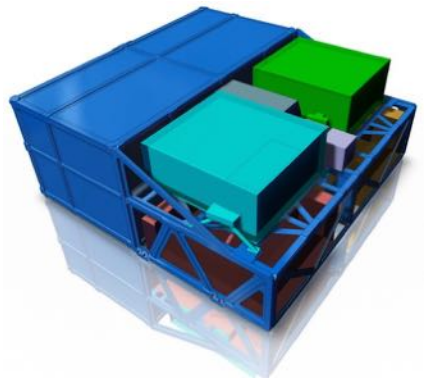
Technological developments of the SAFARI / SPICA project.

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

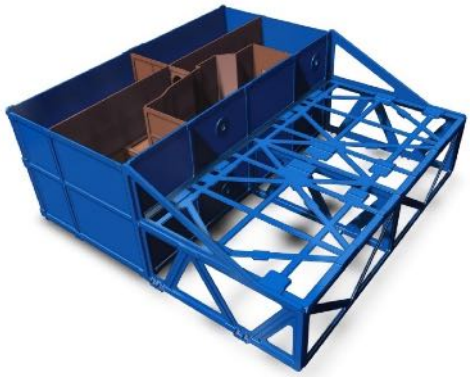
During the year 2019 the work that has been performed in SAFARI is a complete new design and analysis of the focal plane Unit (FPU) within the established ESA-JAXA requirements.

Safari is a far infrared spectrometer operating at 4K, 150Kg of weight and a volume of de 1,5x1,5x0,5 m, which houses all of the optical subsystem units, calibration source, FTS(Fourier transform system) optics, cryocooler and the four 1,7K grating modules which houses the TES detector .

The mission was postposed and was chosen as an ESA M5 candidate. In December 2019 we have reached the mission critical review (MCR) were we had to deliver a comprehensive documentation on the design and mechanical analysis. The M5 selection will resolve at the beginning of the year 2021.



Open frame module to allocate the four 1,8 K grating modules



Front closed box, for straylight control and closed with structural departments, in order to allocate the optical subsystems.

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

Technological developments of the European project NANOCOSMOS.

The Spatial Instrumentation Group has been part of the design and development team of the vacuum system known as StarDust, within the NANOCOSMOS project (ERC-2013-SyG Grant Agreement No. 610256).

During the year 2019, it was continued with the commissioning phase of the Stardust machine. In addition to that, first tests using rotational spectroscopy were carried out with the chemical chamber included in the astrophysics laboratory of the machine. These tests show that carbonaceous dust analogues formed from low-pressure gas-phase condensation of carbon atoms in a hydrogen atmosphere, in a ratio of carbon to molecular hydrogen similar to that reported for evolved stars, lead to the formation of amorphous carbon nanograins and aliphatic carbon clusters. Aromatic species and fullerenes do not form effectively under these conditions, raising implications for a revision of the chemical mechanisms taking place in circumstellar envelopes.

Image of the StarDust vacuum system at the ICMM-CSIC facilities

WLOM Project (Water Liquid On Mars).

This is a project led by researchers of the Space Instrumentation Group. Its main objective is to recreate the water cycle inside a Mars simulation vacuum chamber, analysing the existence of liquid water and its implications to facilitate the survival of a biological sample. Throughout the year 2019 the first testing prototype was built, using a moss sample to validate the proposed technological solution.

Images of the WLOM set-up inside MARTE chamber. (Cyanobacterial mat after the cooled water cycle, "simulate" the mars poles)

Education & Public Outreach

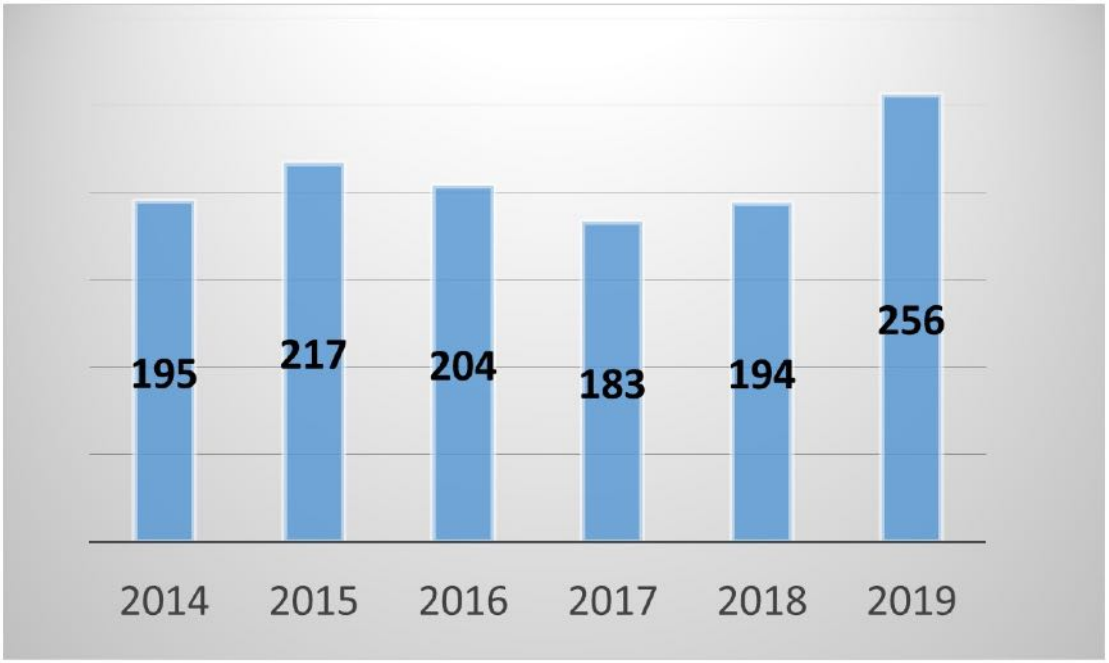
Juan Angel Vaquerizo

Unidad de Cultura Científica (UCC)

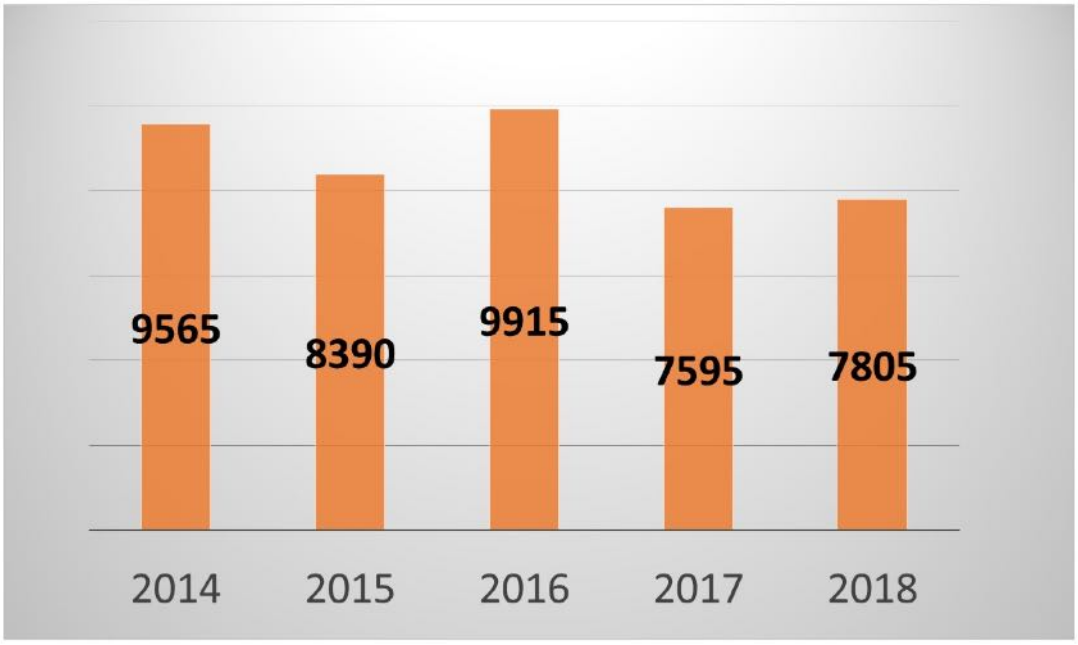
The UCC is responsible for the dissemination of scientific advances in the field of astrobiology. It does so by optimizing the existing internal and external communication channels, as well as enabling an effective interaction between the CAB´s Research Community and the general public. The UCC develops a Communication Plan consisting of the drafting and publication of press releases, the relationship with mass media (press, radio and television), the participation in social networks and collaboration with scientific outreach magazines, such as AstronomiA magazine. Also it develops an Annual Disclosure Activities Plan. Listed below are the activities carried out during the year 2019.

- Production of press releases and other forms of media related materials. 24 press releases.
- Attention to the mass media. 225 media impacts.
- Curation of CAB website contents.
- Social networks maintenance.
- Twitter: 6105 (followers)
- Facebook: 3238 (followers)
- YouTube channel: 485 (subscriptors)
- Attention to the CAB school and public visits. 2470 visitors.
- Planning and conducting outreach activities, talks, courses and workshops. 80 activities, 3500 people.
- Participation in education & public outreach events:
- Madrid Science Week (Semana de la ciencia). 250 people.
- International Day of Women and Girls in Science Event at CAB. 80 people
- “City Science” Project (Ciudad Ciencia). More than 800 students.
- “Science in the Neighbourhood” Project (Ciencia en el Barrio). 300 students.
- Organization and support for scientific, social or outreach events in the CAB:
- CAB’s 20th Anniversary Event. More than 200 attendees.
- Support for outreach projects:
- Culture with the C of Cosmos C3. Astronomy & Art as part of our Cultural Heritage. 43 activities.
- Active participation in the FECYT’s Network of Scientific Culture and Innovation Units (FECYT is the Spanish Foundation for Science & Technology).

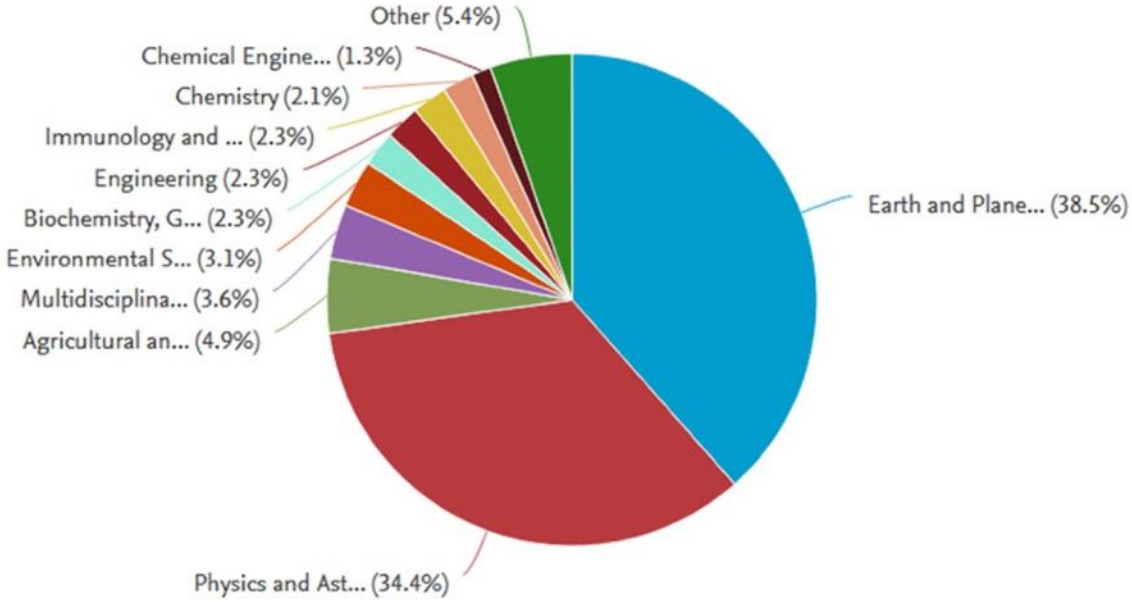
Articles (last 6 years)



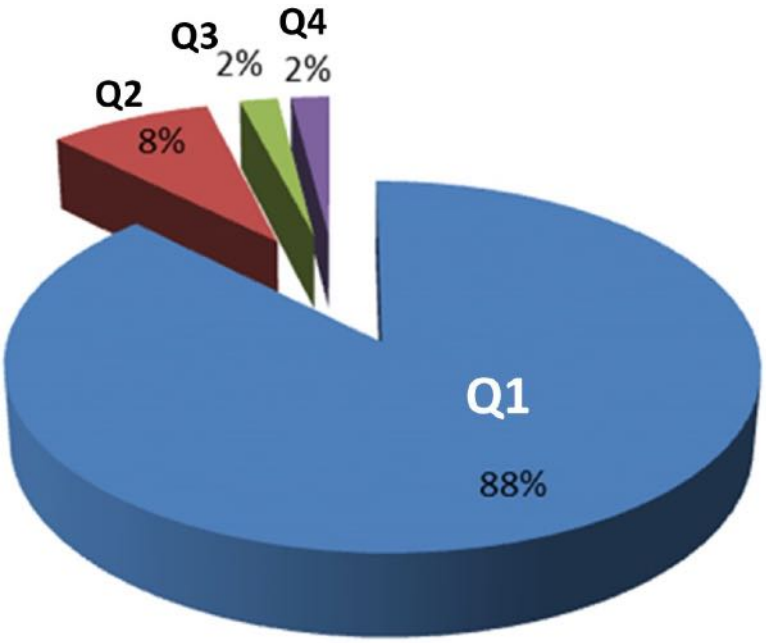
Citations (last 5 years)



Articles by subject Area in 2019



Distribution by Quartils in 2019



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Congresses

At least 100 communications to international meetings and congresses.

Teaching activities

CAB researchers participate actively in different official master and PhD programs by several universities.

PhD Theses

1. A FAR-INFRARED STUDY OF LOW AND INTERMEDIATE MASS EVOLVED STARS USING HERSCHEL PACS AND SPIRE SPECTROSCOPY. ***Jesus Ramos Medina.*** TESIS DOCTORAL. Facultad de Ciencias Físicas, Universidad Complutense de Madrid (UCM). 18/10/2019

2. GALANTE: PHOTOMETRIC SYSTEM AND GALACTIC PLANE SURVEY. ***ANTONIIO LORENZO GUTIERREZ.*** TESIS DOCTORAL. Universidad de Granada (UGR). 17/12/2019

3. GEOMICROBIOLOGÍA DE REVESTIMIENTO EN ROCAS EN UN AMBIENTE ÁCIDO EXTREMO: RÍO TINTO. ***José Jordán Soria.*** TESIS DOCTORAL. UNIVERSIDAD AUTONOMA DE MADRID (UAM). 11/10/2019

4. Nitrogen chemistry in the interstellar medium: fractionation and molecular complexity across the galaxy. ***Shaoshan Zeng .*** TESIS DOCTORAL. Queen Mary University of London (QMUL). 26/09/2019

Master theses

1. A Virtual Observatory methodology to identify and characterize asteroids in wide-field images. ***Cédric Pereira .*** TRABAJO FIN DE MASTER. CENTRO DE ASTROBIOLOGIA (CAB). 28/02/2019

2. Caracterización geomicrobiológica de comunidades endolíticas de análogos terrestres de las etapas tempranas y frías de Marte.. ***Valentín Gangloff .*** TRABAJO FIN DE MASTER. Universidad Autónoma (UAM). 11/07/2019

3. Estudio de las superficies heladas de Europa, Ganímedes y Calisto, y medición de la conductividad térmica de hielos análogos en el marco de la misión JUICE. ***Blanca Soto de Viana.*** TRABAJO FIN DE MASTER. Universitat Internacional Valenciana (VIU). 25/11/2019

4. Estudio del cúmulo de las Pléyades utilizando herramientas de Observatorio Virtual y los datos de Gaia-DR2. ***Rubén Docasal .*** TRABAJO FIN DE MASTER. UNIVERSIDAD INTERNACIONAL DE VALENCIA -VIU-. 28/11/2019

5. Identification and characterization of Mira tipe variable stars with the Virtual Observatory. ***Joaquín González .*** TRABAJO FIN DE MASTER. UNIVERSIDAD INTERNACIONAL DE VALENCIA -VIU-. 22/05/2019

6. Identification and characterization of Mira tipe variable stars with the Virtual Observatory. ***Joaquín González .*** TRABAJO FIN DE MASTER. UNIVERSIDAD INTERNACIONAL DE VALENCIA -VIU-. 22/05/2019

7. Microwave-driven synthesis of cyanide polymers under hydrothermal conditions: Astrobiologycal implications. ***Lucía Hortal Sánchez.*** TRABAJO FIN DE MASTER. Universidad Autónoma de Madrid. Facultad de Ciencias (UAM). 17/07/2019

8. Search for high-mass companions to ultracool subdwarfs. ***Francisco Javier González Payo.*** TRABAJO FIN DE MASTER. Centro de Astrobiología (CSIC-INTA) (CAB). 04/02/2019

Grades

1. Caracterización de estrategias adaptativas a temperatura elevada en el bacteriófago Qß. ***Daniel Julián Alonso.*** TRABAJO FIN DE GRADO. Universidad Autónoma de Madrid (UAM). 28/05/2019

2. Estudio de la interacción de la proteína esencial del divisoma bacteriano, FtsZ, con ZapD y ZipA: análisis mediante las técnicas de velocidad de sedimentación e interferometría de biocapa. ***Jaime Jiménez Suárez.*** TRABAJO FIN DE GRADO. UNIVERSIDAD DE ALCALA. 02/07/2019

Research works

1. Prácticas de Grado: Estudio de la emisión Lyman alfa en galaxias primordiales mediante modelos teóricos y datos observacionales.. ***Sonia Torrejón de Pablos.*** TRABAJOS DE INVESTIGACIÓN. Universidad Complutense de Madrid. Facultad de Ciencias Físicas (UCM). 13/06/2019

2. Practicas extracurriculares realizadas por el estudiante Lucas Rodriguez Almeida durante los meses de Junio y Julio en el CAB bajo mi direccion. ***Lucas Rodriguez Almeida.*** TRABAJOS DE INVESTIGACIÓN. UCM-UAM-UAH. 26/11/2019

Outreach and Events

1. 20 años de Astrobiología en España. *Olga Prieto*. Curso de verano de El Escorial. El Escorial.08/07/2019

2. Astrobiología: Formación y Evolución del Universo y de la Vida. . Curso avanzado de Astronomía: "Ventanas al Universo". CaixaForum Madrid.04/06/2019

3. Astro-concierto. Del impresionismo al rock espacial: Clausura de Cultura con C de Cosmos. *Montserrat Villar; Carlos Briones; David Barrado; Susana Cabañero; Jose Caballero; Ester Lázaro; Eva Villaver*. Evento de clausura de ¿Cultura con C de Cosmos¿. Madrid.23/03/2019

4. Búsqueda de vida en el Sistema Solar y más allá. *Victor Parro*. Ciclos y Conferencias del Museo de las Artes y las Ciencias de Valencia. Valencia. 04/04/2019

5. CAB-07: De la quimica en el Espacio al origen de la Vida. . Charla de divulgacion en el Colegio Nazaret Oporto dentro del ciclo del programa del Catalogo de Conferencias del CSIC orientadas a colegios e institutos de la Comunidad de Madrid. Madrid.06/11/2019

6. CARMENES catalogue of M dwarfs: luminosities, colours, and spectral energy distribution. . Present and future science with CARMENES (RIA). Granada. 20/02/2019

7. Celebración del día internacional de la mujer y la niña en la ciencia. *Ester Lázaro*. Actividades de Cultura con C de Cosmos el 11 F. Centro de Astrobiología. 11/02/2019

8. Charla: 'La genética en el cine: mutantes, clones y superhéroes', impartida en CaixaFórum Lleida. *carlos briones*. Ciclo 'Tardes Cinetíficas'. .05/02/2019

9. Charla 'Todo lo que siempre quisiste saber sobre el origen de la vid". *Carlos Briones*. Ciclo de conferencias del Club de amigos de la UNESCO en Madrid. Madrid.15/03/2019

10. Charla y mesa redonda. *Carlos briones*. Pisar la Luna (50 aniversario del Apolo 11). Madrid.20/07/2019

11. Ciencia e imaginación en la búsqueda de vida extraterrestre. *Ester Lázaro*. Ponencias del Club Sicomoro (Dentro del proyecto Cultura con C de Cosmos). Sede de la Fundación Sicomoro.25/01/2019

12. Co-direccion y co-supervision de las actividades cientificas promovidas por el grupo de trabajo Cradle of Life dentro del instrumento Square Kilometer Array (SKA). *Jimenez-Serra, I.*. Co-chair of the SKA Cradle of Life Science Working Group. .01/01/2019

13. Conferencia "Búsqueda de vida en el Sistema Solar y más allá". *Victor Parro*. "Casi un siglo mirando al espacio". Sevilla.24/09/2019

14. Conferencia 'De la astrobiología a la inteligencia artificial: un viaje de cine' en la Fundación Telefónica. *Carlos Briones*. Cultura con C de Cosmos. Madrid. 22/02/2019

15. Conferencia: 'La historia del universo y la vida, lienzo a lienzo'. *Carlos Briones*. Cultura con C de Cosmos. Madrid.19/03/2019

16. Coordinador del Ciclo. *Carlos Briones*. Ciclo `Ciencia de cine'. Burgos.16/10/2019

17. Descubriendo el Universo en el siglo XIX con dibujos astronómicos. *Alonso Herrero, A.*. Cultura con C de Cosmos. Madrid.23/01/2019

18. Dibujando el Universo Nebuloso del Siglo XIX. *Alonso Herrero, A.*. Conectalks. Valencia.08/05/2019

19. Dirección del curso "20 años de Astrobiología en España". *Victor Parro*. Cursos de Verano de la UCM en El Escorial. El Escorial.08/07/2019

20. Dirección y presentación de la jornada. *Victor Parro*. Jornada conmemorativa 20º aniversario del Centro de Astrobiología. Torrejón de Ardoz.19/11/2019

21. Dos clases tituladas:
`Stellar evolution and astrochemistry`
`Technologies to detect molecules in space` *Jimenez-Serra, I.*. XVII INTERNATIONAL SCHOOL OF ASTROBIOLOGY JOSEP COMAS I SOLÀ . FROM ASTROCHEMISTRY TO THE ORIGIN OF LIFE. Santander.22/07/2019

22. El arte y la vida: un científico en el Museo del Prado. . Museo del Prado, 200 años. Madrid.06/04/2019

23. El nanomundo en la gran pantalla. . Tardes Cinetíficas. Zaragoza.21/05/2019

24. El Universo Violento: Astrofísica de Altas Energías. . Curso avanzado de Astronomía "Ventanas al Universo". Caixaforum Madrid.11/06/2019

25. Evaluacion de propuestas cientificas enviadas a la ANR (French National Research Agency). *Jimenez-Serra, I.*. Evaluador externo de propuestas cientificas enviadas a la ANR (French National Research Agency). .10/04/2019

26. Evento: 'Astros, notas y versos. Música y poesía en bajo la cúpula del Planetario'. *Carlos Briones; Miriam Ridruejo; Lola Barroso*. Cultura con C de Cosmos. . 16/03/2019

27. Evolución biológica. Virus emergentes. *Ester Lázaro*. Jornada del Día de la Mujer y la Niña en la Ciencia. .13/02/2019

28. Galaxias: las piezas del Universo. *Alonso Herrero, A.*. Play Tardes de Ciencia, Cine y Charla. Ponferrada.23/05/2019

29. La Astrobiología. Un viaje al origen de la vida en el Universo. *Ester Lázaro*. Conferencias Científicas del CSIC dirigidas al Sistema Educativo de la Comunidad de Madrid. IES Alpajés (Aranjuez).20/02/2019

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31. La astronomía en el arte: el espacio a través del tiempo. *Montserrat Villar*. Colaboración de Cultura con C de Cosmos con la Real Academia de Bellas Artes de San Fernando. Madrid.28/02/2019

32. La astronomía en el arte: el espacio a través del tiempo.. *Montserrat Villar*. VIII Cita con las Estrellas 2019. Malaga.07/02/2019

33. "La búsqueda de vida en Exploración Planetaria". *Victor Parro*. Cursos de Verano de la UCM en El Escorial "20 años de Astrobiología en España". El Escorial. 10/07/2019

34. La ciencia también es cosa nuestra. *Ester Lázaro*. Actividades día de la mujer y la niña en la ciencia. Museo Nacional de Ciencia y Tecnoología.12/02/2019

35. La genética en el cine: mutantes, clones y superhéroes. . Tardes Cinetíficas. Lleida. 05/02/2019

36. La química en el medio interestelar. *Jimenez-Serra, I.*. Profesor del Curso de verano de El Escorial "20 AÑOS DE ASTROBIOLOGÍA EN ESPAÑA". El Escorial.08/07/2019

37. Las Galaxias: qué son y cómo se clasifican. *Alonso-Herrero, A.*. Actividades 11-F Día de la Mujer y la Niña en la Ciencia. Colegio las Navas de Tolosa.11/02/2019

38. Local Committee. *victoria muñoz iglesias; olga prieto ballesteros, antonio molina*. VI Meeting of Planetary Science and Solar System Exploration. .27/05/2019

39. Los extremos se tocan. . Naukas Pamplona 2019: 'Otros mundos'. Pamplona. 25/05/2019

40. Los virus y el origen de la vida. . Ciclo de Conferencias `Ciencia para todos¿. Madrid.05/11/2019

41. Luna. . Naukas Bilbao 2019. Bilbao.21/09/2019

42. Miembro del Comité Científico Organizador. *Silvia Mateos; José A. Acosta Pulido; Montserrat Villar; Josefa Masegosa; Amalia Corral; Francisco J. Carrera; Almudena Alonso Herrero*. V Meeting of AGN research in Spain. Santander.11/07/2019

43. Moderador de la actividad sobre ciencia y fotografía 'Ambientes extremos: la vida y su reflejo', celebrada en la Biblioteca Municipal Eugenio Trías (Madrid). *carlos briones; Ricardo amils*. Cultura con C de Cosmos. Madrid.23/01/2019

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45. Organizador y moderador de la tertulia "Del Mito al Cosmos" en el espacio "Diálogos del Conocimiento". *Carlos Briones*. Cultura con C de Cosmos. Madrid. 25/03/2019

46. Reviewer of observing proposals.. *Margherita Giustini*. Chandra 2019 Observing Time Allocation Committee. tele-conference.25/06/2019

47. Space Girls, Space Women. *Olga Prieto Ballesteros; Asunción Fuente Juan; Susana Carballo; Marina Rodríguez Baras; María Santos-Lleo*. Dia Internacional de la mujer y la niña en la ciencia. Madrid.11/02/2019

48. Talk upon invitation.. *L. Sanchez-Garcia*. Arctic Polar Forum. Stockholm University, Stockholm (Sweden), 14-16 May. 2018. Stockholm.14/02/2019

49. Virus emergentes. Una amenaza global. *Ester Lázaro*. Tardes Cinetíficas IV. CaixaForum Palma.07/02/2019

Books

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