Conférence Nationale d'Exobiologie

25 – 28 Novembre 2025

Bordeaux

Planning Final

Mardi 25 Novembre

9h – 10 h30 : Enregistrement / accueil Café (***Haut-Carré, Talence – Salle Badiane***)

10h30 – 10h40 : Introduction - *V. Vinogradoff, A. Cario, T. Tassaing, P. Gratier, S. Marre* (***Auditorium)***

10h40 – 12h40 : **Briques du vivant et chimie prébiotique (1)** *(**Auditorium**)* – *Chair : H. Cottin*

10h40 – 11h20 : **Invited talk – *Grégoire Danger* (PIIM)**

11h20 – 11h40 : Valentin Moulay : « Investigation of geochemical and prebiotic processes under hydrothermal conditions: a multiscale approach. Part I. ».

11h40 – 12h : Fatma Ercicek : « Investigations of geochemical and prebiotic processes under hydrothermal conditions : a multiscale approach. Part II. ».

12h – 12h20 : Salomé Lagasse : « Laboratory experiments of sugar synthesis under prebiotic wet-dry cycling conditions ».

12h20 – 12h40 : Rapport moral et financier de la SFE - *V. Vinogradoff, F. Stalport* (***Auditorium)***

12h40 – 14h30 : Buffet déjeunatoire (***Haut-Carré, Talence – Salle Badiane***)

14h30 – 16h10 : **Briques du vivant et chimie prébiotique (2)** *(**Auditorium**)* - *Chair : V. Vinogradoff*

14h30 – 14h50 : Hervé Cottin : « IR-COASTER : une expérience d'exobiologie et d'astrochimie à l'extérieur de la Station spatiale internationale ».

14h50 – 15h10 : Cédric Bourseau : « Integrative analytical unit for the study of emergent catalytic systems ».

15h10 – 15h30: Manuel Robert : « Simultaneous Analysis of Sugar and Amino Acid enantiomers in Ryugu and Orgueil Samples ».

15h30 – 15h50: Grégoire Boé : « The multi-phasic hydrothermal vent chemistry investigated through an innovative millifluidic high-pressure thermal-gradient induced flow reactor ».

15h50 – 16h10 : Organisation de l'Exobiologie en France (PEPR, SFE, initiatives locales, ...) *(**Auditorium**)*

16h10 – 16h30 : Pause-café (***Haut-Carré, Talence – salle Badiane***)

16h30 – 17h : Science-fiction et Exoplanètes – ***F. Selsis*** (***LAB, Auditorium***)

17h – 18h : **Exoplanètes, climats et zone habitable (1)** *(**Auditorium**)* - *Chair : P. Gratier*

17h - 17h20 : Danial Almasian : « Investigating the exoplanet HD88986 b by using TESS & CHEOPS space telescope data ».

17h20 – 17h40 : André Debus : « PLATO : une mission à la recherche de nouvelles "TERRES" ».

17h40 – 18h : Cyrille Olou : « L'hypothèse djehoutyenne : la rotation rétrograde de Vénus et ses implications pour l'habitabilité planétaire et l'exobiologie ».

18h00 – 18h30 : **Présentations flash des posters** (***Haut-Carré, Talence – Auditorium)***

18h30 – 20h : **Session Poster (Galerie du cloître)**

+ Apéritif Dinatoire

Mercredi 26 Novembre

9h – 10h40 : **Exoplanètes, climats et zone habitable (2)** ***(Auditorium)*** - *Chair : F. Selsis*

9h – 9h40 : **Invited talk –** ***Jérémy Leconte (LAB)*** «Naissance et mort des océans : de la Terre... à Venus... aux exoplanètes »

9h40 – 10h : Guillaume Chaverot : « Calcul de l'influence clé des paramètres planétaires sur la taille de la zone habitable ».

10h – 10h20 : Alice Maurel : « Interpreting the JWST observations of TRAPPIST-1 b and c ».

10h20 – 10h40 : Ori Sohier : « Atmospheric chemistry of temperate exoplanets: a synergistic approach combining laboratory experiments, modeling, and observation to characterize habitability ».

10h40 – 11h : Pause-café

11h – 12h40 : **Exoplanètes, climats et zone habitable (3)** ***(Auditorium)*** - *Chair : M. Turbet*

11h – 11h40 : **Invited talk – Emeline Bolmont (Univ. Genève)**

11h40 – 12h : Sean Raymond : « Exotic orbital architectures as planetary system-scale technosignatures ».

12h – 12h20 : Yassin Jaziri : «Favored Great Oxidation Event on exoplanets around M-Stars ».

12h20 – 12h40 : Xavier Delfosse : « Quoi de neuf du côté des planètes du voisinage solaire ».

12h40 – 14h : Buffet déjeunatoire (Haut Carré, Talence – Salle Badiane)

14h – 16h : **Analogues et biosignatures (1)** ***(Auditorium)*** - *Chair : M. Millan*

14h – 14h40 : **Invited Talk -** ***Nina Zeyen (Univ. Genève)*** « Que nous enseignent les lacs actuels sur les mécanismes biologiques et non-biologiques lors de la minéralisation ? ».

14h40 – 15h : Clara Christiann « Etude de (Bio)signatures moléculaires dans des dépôts minéralogiques de tubes de lave riches en silice : implications pour l'exploration de la sous-surface de Mars ».

15h – 15h20 : Lawry Honold : « How Carbon Dioxide in Interstellar Ice Analogues Impacts Organic Matter Generated ».

15h20 – 15h40 : Malaury Luzet : « Quantification of microbial contribution to calcite dissolution using vertical scanning interferometry: progress towards the identification of traces of life on mineral surfaces ».

15h40 – 16h: Adeline Garcia : « Characterization of interstellar ice residues by GC-FT-Orbitrap-MS: A high-resolution approach ».

16h – 16h20 : Pause-café

17h – 18h : **Missions Habitées : Aspects éthiques, légaux** ***(Auditorium)*** **-** *Chair : M. Gargaud*

17h – 17h30 : **Invited Talk –** ***Jacques Arnould (CNES)*** « L'astronaute de Vitruve ou les défis éthiques des missions spatiales habitées ».

17h30 – 18h : **Invited Talk –** ***Yelena Esslinger (UBM)*** « La protection juridique des environnements planétaires du système solaire ».

18h – 19h30 : **Echange et séance dédicace du Grand Livre de l'Exobiologie -** Librairie Georges (Talence – à 5 min à pied)

19h45 – 20h45 : **Conférence grand public** *Haut Carré, Talence -* ***Auditorium)*** - *Chair : M. Gargaud*

Invited talk – ***Michel Viso*** « Peut-on, et doit-on, aller sur Mars ? »

20h45 – 22h **:** **Apéritif dinatoire** – réservé aux participants du congrès

Jeudi 27 Novembre

9h – 10h40 : **Organismes extrêmophiles et limites de la vie / habitabilité (1)** ***(Auditorium)*** - *Chair : A. Cario*

9h – 9h40 : **Invited talk – *Adrienne Kish (MNHN)***

9h40 – 10h : Andreas Elsaesser : « OREOcube and Exocube: Miniature Space Exposure Platforms for the ISS with In-Situ Analytics for Exobiology and Space Exploration ».

10h – 10h20: Océane Lazzeroni : « Culture of extremophilic microorganisms into Enceladus-like conditions: in search of biosignatures for future space missions ».

10h20 – 10h40: Elisa Ravaro : « Development of a Fluorescent Detection System to Analyze Cell Envelope Stability in Halophilic Archaea ».

10h40 – 11h : Pause-café (Haut Carré, Talence – Salle Badiane)

11h – 12h : **Organismes extrêmophiles et limites de la vie / habitabilité (2)** ***(Auditorium)*** - *Chair : G. Erauso*

11h – 11h40 : **Invited talk – *Purification Lopez-Garcia (ESE)***

11h40 – 12h : Romain Coudray : « Adaptation mechanisms of Thermococcales in response to metal-rich environments ».

12h – 12h40 : **Vulgarisation, diffusion des connaissances, enseignements** (Astrobio-éducation, Ecole RED, Site web SFE) ***(Auditorium)***

12h40 – 14h : Buffet déjeunatoire (Haut Carré, Talence – Salle Badiane)

14h – 15h40 : **Exploration du système solaire, Exobiologie et retours d'échantillons (1)** ***(Auditorium)*** - *Chair : S. Marre*

14h – 14h40 : **Invited talk – *Nicolas Mangold (LPG)*** « L'exploration et l'échantillonnage du cratère de Jezero (Mars) par le rover Perseverance ».

14h40 - 15h : Théo Govekar : «Investigation of a set of natural samples: preparing in situ research of organic matter at Mars' surface with the MOMA instrument onboard Rosalind Franklin ».

15h – 15h20 : John Carter : « Are clays on Mars good exobiological targets? »

15h20 – 15h40 : Coline Serra : « Altération aqueuse d'analogues chondritiques : co-evolution SOM-IOM entre héritages interstellaires et nébulaires. »

15h40 – 16h : Pause-café (Haut Carré, Talence – Salle Badiane)

16h – 17h : **Exploration du système solaire, Exobiologie et retours d'échantillons (2)** ***(Auditorium)*** - *Chair : J. Carter*

16h – 16h20 : Alexandra Perron : « Strecker Pathways and Mineral-Organic Co-evolution under Aqueous Conditions Simulating Carbonaceous Asteroids ».

16h20 – 16h40 : Alex Abello : « Optimization of the injection system of the gas chromatograph on board the Dragonfly mission to Titan ».

16h40 – 17h : Véronique Vuitton : «Interaction of water ions with Titan aerosol analogues».

17h – 18h50 : **Exobiologie et Sciences Humaines et Sociales** ***(Auditorium)*** - *Chair : P. Pitrou*

17h – 17h20 : Cyrille Jeancolas : « Mesures de consensus en exobiologie »

17h20 – 18h50 : **Table ronde** – Animée par Perig Pitrou : « Contribution des Sciences Sociales à une réflexion sur la vie dans l'Univers »

Avec : Florian Métral : historien au CNRS, Centre André-Chastel ; Sylvie Allouche : philosophe à l'Université catholique de Lyon ; Adrienne KISH : spécialiste en microbiologie des environnements extrêmes au Muséum National d'Histoire Naturelle

20h45 – 23h : **Diner de Gala (Le café du port - Bordeaux)**

Vendredi 28 Novembre

9h – 9h40 : **Exploration du système solaire, Exobiologie et retours d'échantillons (3)** *(**Auditorium**)* - *Chair : G. Danger*

9h – 9h20 : Brieuc Bouhier : «Development of SFE for organic matter in extraterrestrial samples: the SFERE project».

9h20 – 9h40 : Chloé Arthozoul : «Impact of secondary processes on the Soluble Organic Matter (SOM) of carbonaceous chondrites ».

9h40 – 10h40 : **Terre primitive et son environnement lors de l'émergence de la vie** *(**Auditorium**)* - *Chair : A. Kish*

9h40 – 10h20 : **Invited talk – *Vinciane Debaille (acad. Royale de Belgique) :*** *« The Early Evolution of Earth and Mars: Divergent Pathways from Common Origins »*.

10h20 – 10h40 : Louis Maratrat : « Deciphering the origin of organo-sulphur hazes: an exploration of the actual limits of Sulphur chemistry with potential implications for prebiotic chemistry and exoplanet characterization ».

10h40 – 11h : Pause-café (Haut Carré, Talence – Salle Badiane)

11h – 11h30 : **Prix de Thèse *(Auditorium)*** ***Sarah Joiret :*** « L'apport de comètes dans le système solaire interne »

11h30 – 12h : **Prix Jeune Chercheur** ***Jana Bockova*** *(**Auditorium**)*

12h – 13h : Récupération des paniers repas (si besoin) – Haut-carré – salle Badiane

12h30 – 15h : **Déplacement en bus (aller – retour) au laboratoire des 2 infinis à Gradignan et inauguration du Chemin du Temps**

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Optimization of the injection system of the gas chromatograph on board the Dragonfly mission to Titan

Alex Abello * [1], Caroline Freissinet [1], Théo Govekar [1], Arnaud Buch [2], Joel Casalinho [2], Cyril Szopa [1]

[1] Laboratoire Atmosphères, Observations Spatiales (LATMOS) – LATMOS/IPSL, Sorbonne université, UVSQ Université Paris-Saclay, CNRS – France

[2] Laboratoire de Génie des Procédés et Matériaux (LGPM) – CentraleSupélec, Université Paris-Saclay – France

Earth- and space-based observations, the Cassini-Huygens mission, and laboratory experiments have brought a wealth of valuable information on Titan's organic chemistry, making it a priority target for exobiology research (1). To better constrain the chemical complexity of this environment, the Dragonfly mission will explore Titan in the mid-2030's (2). This relocatable lander is equipped with the Dragonfly Mass Spectrometer (DraMS) instrument to investigate Titan chemistry at geologically diverse locations. DraMS gas chromatography-mass spectrometry (GC-MS) mode will assess organic molecule diversity and seek potential molecular biosignatures in surface samples.
In DraMS GC-MS mode, solid surface samples are thermally volatized or chemically derivatized in a pyrolysis cell. The evolved gases are concentrated in an injection trap containing a chemical adsorbent for the duration of the thermal or chemical treatment of the sample. Once this sampling step is done, the compounds are then desorbed all at once by flash-heating the trap to be quickly injected into the chromatographic column. After their chromatographic separation, the compounds can be identified with the mass spectrometer downstream.

As a compromise between technical constraints, scientific requirements, and the need for redundancy, the DraMS instrument includes two independent injection traps. One of them is necessarily filled with Tenax TA adsorbent for its known performance and heritage in space missions. However, Tenax TA has shown some decomposition products that challenge the interpretation of the origin of the molecules (3). We have thus investigated Carbograph 2TD and Carbotrap C adsorbents as a potential alternative for DraMS' second injection trap, by comparing their performance to that of Tenax TA based on three criteria.

Firstly, mechanical resistance of the three adsorbents when submitted to vibrations representative of mission launch was assessed using scanning electron microscopy and particle size analysis. The low resistance of Carbograph 2TD led to its exclusion from the rest of the study. Secondly, desorption capabilities in DraMS-like desorption conditions were evaluated for Tenax TA and Carbotrap C. To this end, the amount recovered after adsorption and desorption was compared for each adsorbent, with a set of organic compounds. These compounds were selected to mimic the ones expected in Titan surface samples or for their relevance to exobiology, such as linear alkanes, amines, amides, fatty acid methyl esters, amino acids and nucleobases. The main result is that the recovery was either similar or better with Carbotrap C than with Tenax TA for a majority of compounds. Carbotrap C was also better suited for the detection of long-chain

*Speaker

alkanes containing up to 27 carbon atoms. Finally, DraMS must be able to detect a potential enantiomeric excess in the samples since this could be a bioindicator (4). Analyses of amino acids showed that desorption from both Tenax TA and Carbotrap C led to partial but comparable racemization for three of the four amino acids that were enantiomerically resolved. These two adsorbents were therefore equivalent regarding this criterion, but further studies will need to evaluate this effect more thoroughly in preparation of Dragonfly operation phase.

The combination of those results led to the selection of Carbotrap C as the adsorbent of DraMS' second injection trap.

(1) C. A. Nixon, "The Composition and Chemistry of Titan's Atmosphere," *ACS Earth Space Chem.*, vol. 8, no. 3, pp. 406–456, Mar. 2024, doi: 10.1021/acsearthspacechem.2c00041.

(2) J. W. Barnes *et al.*, "Science Goals and Objectives for the Dragonfly Titan Rotorcraft Relocatable Lander," *Planet. Sci. J.*, vol. 2, no. 4, p. 130, July 2021, doi: 10.3847/PSJ/abfdcf.

(3) A. Buch *et al.*, "Role of the Tenax® Adsorbent in the Interpretation of the EGA and GC-MS Analyses Performed With the Sample Analysis at Mars in Gale Crater," *J. Geophys. Res. Planets*, vol. 124, no. 11, pp. 2819–2851, Oct. 2019, doi: 10.1029/2019JE005973.

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Investigating the exoplanet HD88986 b by using TESS & CHEOPS space telescope data.

Danial Almasian * [1]

[1] Shahid Beheshti University – Iran

The discovery of transiting planets with orbital periods exceeding 40 days has been exceptionally
rare among the 5000+ planets identified to date. This dearth of findings poses a significant
challenge to studying planetary demographics, formation, and evolution. In this study, we report
detecting and characterizing HD88986 b, a potentially transiting sub-Neptune with the longest
orbital period of any known transiting small planet. Our analysis drew on a combination of two
sectors of TESS data and a 7-day observation from CHEOPS. Additionally, TLS was utilized for
the analysis of HD88986 data. Our findings indicate that HD88986 b, exhibiting two likely single
transits on sector 21 and sector 48, both consistent with the predicted transit time from the RV
model, is a likely transit candidate. The wide orbit of HD88986 b suggests that the planet did not
experience significant mass loss due to XUV radiation from its host star, likely retaining its original
composition and offering insights into its formation. Furthermore, the cold nature of HD88986 b,
owing to its extended orbital period, presents exciting prospects for future studies on the
characterization of its cold atmosphere composition.

*Speaker

Investigating Abiotic Organic Synthesis in Archean Rocks from the Canadian Shield

Ariane Amat * [1], Bénédicte Ménez [1], Jonas Bruenjes [2], Min Song [2], Barbara Sherwood Lollar [2]

[1] Institut de physique du globe de Paris, Université Paris Cité, CNRS, 1 rue Jussieu 75005 Paris, France – Université Paris Cité, Centre National de la Recherche Scientifique - CNRS – France
[2] Dept. of Earth Sciences University of Toronto, 22 Ursula Franklin St., Toronto, ON 8 Canada M5S 3B1 – Canada

Observing abiotic organic synthesis is paramount to understand how inorganic matter can transform into organic matter of potential prebiotic interest, in contexts representative of the early Earth. Subsurface environments can generate abiotic organic compounds through water-rock reactions under various pressures, temperatures, and redox conditions, and from diverse lithologies. They are, however, difficult to detect on Earth due to the ubiquity of biological activity in the first few kilometers of the crust. Located in the Canadian Precambrian craton, the Kidd Creek subsurface observatory is a unique accessible window into upper lithosphere abiotic organic chemistry, where the high radioactive dose and long residence time of groundwaters near carbonate crystals provide an environment conducive to both serpentinization and radiolysis, the latter corresponding to the formation of small carboxylates from interactions between radiolyzed water and dissolved carbonates. Exceptionally high concentrations of formate and acetate were detected in Kidd Creek groundwaters, but no oxalate, though the three ions are the main products of radiolysis. Herein was conducted one of the first studies of carbon dynamics in 2.7 Ga old crustal rocks drilled at Kidd Creek, aiming at assessing if oxalate ions precipitate as organic minerals that can be found in the rock matrix. Using material characterization techniques such as optical and scanning electron microscopy, as well as Raman and (nano)FTIR spectroscopy and subsequent multivariate analysis, we show that no oxalate mineral could be detected in the ultramafic rock sampled 2.4 km below the surface. On the other hand, an abundance of organic compounds, omnipresent in the rock, and different for each type of host mineral, was detected and found to be highly oxygenated and polymerized. Moreover, a destructuring of calcite crystals along cleavage planes was observed, which can be related to the formation of organic matter in these reactive areas. Thus, the radiolytic generated abiotic organic matter could have evolved differently depending on the mineral host, through solid/liquid interactions such as adsorptions, catalysis, polymerizations, and redox reactions. This work presents new insights into abiotic organic synthesis through radiolysis and reveals a potential complex organic-mineral co-evolution.
Keywords: Prebiotic chemistry, Abiotic organic synthesis, Deep carbon cycle, Subsurface, Radiolysis, Carbonates, Carboxylates, Vibrational spectroscopy, Electron microscopy

*Speaker

Impact of secondary processes on the Soluble Organic Matter (SOM) of carbonaceous chondrites

Chloé Arthozoul * [1], Véronique Vuitton [1], Simon Ollivier [2], Lydie Bonal [1], Francois-Regis Orthous-Daunay [1], Carlos Afonso [2]

[1] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) – Institut National des Sciences de l'Univers, Centre National de la Recherche Scientifique, observatoire des sciences de l'univers de Grenoble, Université Grenoble Alpes – France

[2] Chimie Analytique et Réactivité Moléculaire En Normandie (Institut CARMeN) – Université de Caen Normandie, Ecole Nationale Supérieure d'Ingénieurs de Caen, Université de Rouen Normandie, Institut national des sciences appliquées Rouen Normandie, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France

Carbonaceous chondrites are remnants of the formation and evolution of our Solar System. These objects contain up to 3.5 wt% of carbon, mostly in organic form (1). The complexity of this organic matter has been a topic of interest for over 60 years (2). The recent use of Ultra-High Resolution Mass Spectrometry (UHRMS) has revealed the high molecular diversity of the soluble fraction of this organic matter (SOM), containing thousands of molecular formulas (3). On the other hand, the study of their mineralogical and petrological characteristics has made it possible to characterize their secondary history occurring on their parent bodies: aqueous alteration, impacts, thermal metamorphism, and combination of these processes (4–6). However, the modifications potentially induced by these processes on the molecular diversity of the SOM remains relatively unknown (7,8).

This study enters into this framework: our aim is to better understand the changes induced by secondary processes on the SOM of carbonaceous chondrites. Here, we focus on the molecular diversity observable by UHRMS. To do this, we selected a series of carbonaceous chondrites whose secondary histories are known : both in terms of aqueous alteration and thermal history (4–6). These chondrites also come from different groups: 7 CM chondrites, 3 CI chondrites, and 2 CR chondrites. The soluble organic matter was extracted in a methanol/toluene mixture and then analyzed by FT-ICR (UHRMS) at the CARMEN institute at Université de Rouen.

First results highlight significant differences both between chondrite families and within a single family (notably along the alteration scale of CM chondrites). These differences are observed through variations in the intensity of molecular families as well as in the diversity of compounds within them. First observations indicate that the molecular diversity of shock-processed chondrites is significantly lower than in other chondrites. The abundance and distribution of nitrogen also appear to be indicators of secondary alteration history, along with metalorganic compounds. These findings will be deepened and considered in a second step along carbon and nitrogen isotopic and elemental analyses performed using Isotope Ratio Mass Spectrometry (IRMS) on the same SOM extracts.

*Speaker

Exploring the influence of chemical extraction on the complexity of the Soluble Organic Matter (SOM) in carbonaceous chondrites

Chloé Arthozoul * [1], Imane Aftiss [2], Kathy Dubuc [2], Laurène Flandinet [3], Véronique Vuitton *

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[1] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[2] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[3] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[4] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France

The complexity and origin of organic matter in carbonaceous chondrites has been a topic of interest for over 60 years1. This organic matter has been studied as a bulk, and has been separated in the form of Soluble Organic Matter (SOM) and Insoluble Organic Matter (IOM) and characterized using different analytical techniques2,3. The procedures used for extracting the soluble fraction vary depending on the analytical approach (targeted or untargeted) and the analytical instruments used for the characterization4. They might significantly influence the quantity and diversity of extracted organic matter, thereby impacting the interpretation of the data in terms of origin and evolution.
In the present work, our objective is to better understand the influence of chemical extraction on the complexity of the Soluble Organic Matter of two CM chondrites: Murchison and Allan Hills 93100. We focused on studying three parameters: the polarity of the extraction solvent (methanol/toluene), the duration of extraction (6h - 5 days), and the pH of the extraction solvent (2 - 11). The solvent polarity was modified by adding an increasing fraction of toluene in methanol while the pH of the solution was changed by adding either an acid (formic acid) or a base (ammonia) to the solvent. The resulting SOM was analyzed at IPAG by Orbitrap Ultra-High Resolution Mass Spectrometry with electrospray ionization.

The results show that the polarity of the extraction solvent and the duration of the extraction do not influence the diversity of the extracted SOM. Meanwhile, the pH does modify the SOM as, in the positive ionization mode, only _˜50% of the extracted molecules are identical in the most acidic and basic solutions. A more basic solvent leads to the extraction of more molecules, and these molecules seem to exhibit a higher aromaticity and nitrogen content. These results are important because they show that a wide range of pH is necessary to access the entire molecular diversity of the SOM present in carbonaceous chondrites.

*Speaker

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(3) Alexander, C. M. O.; Cody, G. D.; De Gregorio, B. T.; Nittler, L. R.; Stroud, R. M. The Nature, Origin and Modification of Insoluble Organic Matter in Chondrites, the Major Source of Earth's C and N. *Geochemistry* **2017**, *77* (2), 227–256. https://doi.org/10.1016/j.chemer.2017.01.007.

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Development of SFE for organic matter in extraterrestrial samples: the SFERE project

Brieuc Bouhier * [1], Clara Azémard [1], Fabien Stalport [2], Hervé Cottin

[1] Laboratoire Interuniversitaire des Systèmes Atmosphériques (LISA (UMR$_7$583)) $--InstitutNationaldesSciencesdel'Univers, UniversitéParis-EstCréteilVal-de-Marne-Paris12, CentreNationaldelaRechercheScientifique, UniversitéParisCité--France$

[2] Laboratoire Interuniversitaire des Systèmes Atmosphériques (LISA) – CNRS UMR 7583, Université Paris Cité and Université Paris Est Créteil, 61 avenue du Général de Gaulle, Créteil, 94010, France – France

To understand the origin of life on Earth and consider its emergence elsewhere in the universe, it is essential to study organic molecules, such as amino acids, sugars, or fatty acids, which constitute the elementary building blocks of life on Earth. Among the celestial objects that may have enabled the delivery of these molecules to bodies in the solar system such as Earth or Mars, meteorites are among the most scientifically valuable samples, particularly carbonaceous chondrites, which can contain an organic fraction of up to 4% of their total composition(1,2). However, these molecules are strongly bound to meteoritic mineral matrices, making the extraction step of this small amount of organic matter crucial before their analysis.
The SFERE project (Supercritical Fluid Extraction for sample return) fits within this objective, aiming to develop extraction methods using supercritical fluids as solvents. This phase allows fluids to combine the properties of a gas (low viscosity, high diffusivity) and a liquid (high density, solvation power). Widely used with supercritical CO2 for the extraction of nonpolar molecules, recent innovations in SFE allow the addition of polar co-solvents to extract a wider range of molecules of interest(3). Already used and recognized in fields other than exobiology, SFE offers comparable or better efficiency compared to conventional methods while limiting contamination risks, in addition to being part of green chemistry.

Nevertheless, this extraction step must be developed for each different mineral matrix, which makes the optimization phase time-consuming given the number of parameters to consider (temperature, pressure, flow rate, co-solvent, duration...). Thus, implementing experimental designs(4) is essential to effectively reduce the number of experiments to be performed in order to optimize our parameters before validation by comparison with other extraction methods such as ASE, sonication, or Soxhlet.

The SFE extraction method will first be developed and optimized on a natural terrestrial mineral matrix using experimental designs before application to chondrites such as Murchison, Orgueil, or Oued Chebeika 002. Preliminary results using methanol as a co-solvent will be presented and compared to those obtained by liquid-solid extraction (ultrasound) and to the literature. The application of this technique will also be discussed in the context of extraterrestrial sample returns such as Ryugu or Bennu, or more hypothetically from Mars.

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Integrative analytical unit for the study of emergent catalytic systems

Cédrick Bourseau * [1], Anthony Cunha [2], Claude Geffroy [1], Sébastien Papot [2], Pauline Poinot [1]

[1] Eaux, Géochimie organique, Santé [E1 – IC2MP équipe 1] (E-BICOM) – Institut de chimie des milieux et matériaux de Poitiers [UMR 7285] – France

[2] Synthèse organique [E5 – IC2MP équipe 5] (OrgaSynth) – Institut de chimie des milieux et matériaux de Poitiers [UMR 7285] – France

Origin of life is a question which is the subject of much research in different fields. Therefore, several approaches have been used to try to answer this almost universal question. Among them, the analytical chemistry and the systems chemistry fields offer great prospects in understanding the characteristics and interactions between molecules present in a chemical, biochemical or biological system. Furthermore, with the emergence of "omics" sciences, ultra-sensitive and ultra-resolutive analytical instruments have been developed. Thanks to these technologies, our knowledge on biology fundamentals has deepened substantially at the molecular level. Despite their versatility, these analytical chemistry tools are very often optimized to investigate, at a given time, a given class of molecules belonging to either metabolites (volatile compounds, amino acids, sugars, etc.) or biopolymers (proteins, RNA/DNA, etc.). In this context, our objective is to develop a universal platform combining different analytical units with the aim to highlight, in a system chemistry approach, emergent properties specific to the first protocells such as self-replication, self-assembly, and self-organization. Within this framework, we will monitor the dynamic processing of mixes of precursors and identify subsystems with lifelike properties such as protometabolism through catalytic cycles, replication of polymers units in the presence or in the absence of molecular templates, and selection processes like Darwinian type selection allowing access to homochirality or information-bearing molecules. With molecular network data treatment, this integrative strategy would allow the investigation of complex systems chemistry and should catch the key patterns representative to a transition from chemistry to biology. These primitive molecular networks could then further be used as a template to discriminate a purely chemical system from a biochemical/biological system, in primitive or extraterrestrial samples (Mars Sample Return).

*Speaker

The multi-phasic hydrothermal vent chemistry investigated through an innovative millifluidic high-pressure thermal-gradient induced flow reactor

Grégoire Boé * [1], Jérôme Jansen [2], Arnaud Erriguible [2,3], Stéphane Glockner [2], Anaïs Cario [3], Samuel Marre [3], Thierry Tassaing [1]

[1] Institut des Sciences Moléculaires (ISM) – Université Sciences et Technologies - Bordeaux 1, École Nationale Supérieure de Chimie et de Physique de Bordeaux (ENSCPB), Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France

[2] Institut de Mécanique et d'Ingénierie de Bordeaux (I2M) – Université de Bordeaux, Institut polytechnique de Bordeaux, Centre National de la Recherche Scientifique, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement, Arts et Métiers Sciences et Technologies – France

[3] Institut de Chimie de la Matière Condensée de Bordeaux (ICMCB) – Université de Bordeaux, Institut polytechnique de Bordeaux, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France

Deep-sea hydrothermal vents are key environments for investigating the geochemical and prebiotic processes that may have contributed to the origin of life on Earth. To mimic the extreme conditions of these systems at lab scale, we developed a high-pressure millifluidic reactor that reproduces the dynamic multi-phasic and multi-component physicochemical environment of submarine hydrothermal systems. The device operates under a thermosyphon-driven flow regime, establishing stable and tunable thermal gradients across three vertically aligned compartments at pressures of 20 MPa. In situ and co-localized infrared and Raman spectroscopies enable real-time monitoring of multiphase fluid composition and phase behavior along the thermal gradient. System validation was achieved through stepwise experiments, from pure CO2 to multiphase CO2-H2O and quaternary CO2-H2-N2-H2O mixtures, supported by hydrodynamic simulations of supercritical CO2 circulation. Comparison of experimental and simulated velocity fields confirmed consistent flow dynamics, with differences attributed to multiphase drag effects. Application of the reactor to fluid–mineral interactions demonstrated the abiotic formation of reduced carbon species (CH4, CO, formate, acetate, methanol and pyruvate) and ammonia under continuous flow, highlighting the catalytic role of Fe- and S-bearing minerals. These results establish the platform as a versatile experimental tool to investigate hydrothermal fluid dynamics, gas solubility, and mineral-catalyzed synthesis under controlled high-pressure flow conditions, thereby providing a closer laboratory analogue to natural hydrothermal vents.

*Speaker

Adaptation mechanisms of Thermococcales in response to metal-rich environments

Romain Coudray * [1], Jade Planel [1], Mickaël Tharaud [2], Alexandre Gelabert [3], François Guyot [4], Aurore Gorlas [1]

[1] Institut de Biologie Intégrative de la Cellule (I2BC) – Université Paris-Saclay – France
[2] Institut de Physique du Globe de Paris (IPGP - UMR$_7$154) –
–InstitutNationaldesSciencesdel'Univers, InstitutNationaldel'InformationGéographiqueetForestière[IGN], Unive
–France
[3] Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement (CEREGE) – Institut de Recherche pour le Développement, Aix Marseille Université, Collège de France, Institut National des Sciences de l'Univers, Centre National de la Recherche Scientifique, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement – France
[4] Institut de minéralogie, de physique des matériaux et de cosmochimie (IMPMC) – Museum National d'Histoire Naturelle, Institut de recherche pour le développement [IRD] : UR206, Sorbonne Universite, Centre National de la Recherche Scientifique – France

Metals are essential for all living organisms, as they are required in many metabolic and structural functions. The metallome is defined as the internal metal composition of a cell, linked to the dynamics of metal exchanges with its environment. Due to the release of a fluid highly concentrated in metals, hydrothermal vents are particularly interesting in the study of life/metal interactions. Among their major inhabitants, hyperthermophilic archaea of the order Thermococcales, have developed mechanisms to cope with the toxicity of high metal concentrations (up to a few mM). In laboratory conditions, they promote the formation of iron sulfides (FeS2 pyrite), leading to a full biomineralization of the cell. Interestingly, a subpopulation is able to grow after few days, indicating a population-scale adaptation. To better understand the dynamics of metal resistance in these extreme environments, we are (1) determining the metallomes of Thermococcales exposed to different metals (Mn, Zn, Cu, Co, Ni, V) ; (2) monitoring the dynamic of minerals formation; and (3) determining genes involved in metal resistance.

*Speaker

Are clays on Mars good exobiological targets?

John Carter * [1]

[1] IAS -Université paris XI (IAS) – IAS Université paris XI – Centre universitaire d'Orsay Bât 120 – 121 91405 ORSAY CEDEX, France

The seminal discovery of widespread clays on Mars twenty years ago offered the daunting prospect that Mars harbored aqueous environments not unlike those of Earth, producing secondary clay minerals relevant for exobiology, in particular thanks to their potential to sequester and preserve organic matter on geological timescales.
Much has been said about Martian clays. That they are mostly formed under temperate or even tropical climates, alternatively that they formed in subglacial settings, or perhaps in short-lived post-impact hydrothermal systems, or perhaps in the subsurface out of contact of the atmosphere and independently of climate. Or even perhaps as magmatic clays in a vapor rich crust. The exobiological potential of such settings ranges from promising to zero, hence understanding how clays formed on Mars is of critical importance.
We will provide a quick review of clay formation environments as currently understood for Mars, from orbital and in-situ observations. We will attempt to debunk the detrimental generalizations which are often made regarding Martian clays, and focus on those settings which are most promising and warrant future exploration.

*Speaker

Calcul de l'influence clé des paramètres planétaires sur la taille de la zone habitable

Guillaume Chaverot * [1]

[1] Institut de Planétologie et d'Astrophysique de Grenoble – IPAG Grenoble – France

L'un des objectifs de l'étude des exoplanètes telluriques est la découverte d'eau liquide à leur surface, condition sine qua non à l'apparition de la vie telle que nous la connaissons. De tels objets tempérés sont inaccessibles aux instruments actuels, à l'exception de la contribution significative apportée par le JWST à notre compréhension du système TRAPPIST-1, par exemple. Les futurs instruments, tels que ANDES@ELT, PCS@ELT, HWO et LIFE, permettront d'aller encore plus loin dans la caractérisation de ce type de planète, avec Proxima-b comme cible privilégiée.
Le concept de zone habitable (ZH) est un outil générique qui regroupe tous les processus affectant la phase de l'eau à la surface d'une planète. Elle est définie comme une zone virtuelle dans laquelle une planète peut maintenir de l'eau à l'état liquide. Cependant, ce concept reste incomplet. En effet, l'intérêt de la communauté s'est jusqu'à présent principalement concentré sur l'effet du type stellaire sur la position des bords intérieur et extérieur de cette ZH (par ex. Kasting et al. 1993, Selsis et al. 2007, Kopparapu et. al. 2013,2014,2017).
Nous présenterons des résultats récents (Chaverot et al., en prép.), basés sur un modèle climatique 1D, mettant en évidence l'influence clé des paramètres planétaires (composition atmosphérique et pression totale, masse planétaire), pour différents types d'étoiles, sur la position de la ZH. Grâce à des mises à jour majeures des données d'opacité du CO2 (Chaverot et al., accepté), nous montrons que la ZH est significativement plus étendue que les estimations issues des travaux clés de Kopparapu et al. (2013, 2014). Nous présentons également l'effet des paramètres planétaires sous forme de tendances claires à l'intention des observateurs et des instrumentalistes. En effet, il est essentiel de comprendre les limites de l'habitabilité pour affiner les cas scientifiques de projets tels que PCS@ELT en estimant l'observabilité des cibles potentielles.

*Speaker

Etude de (Bio)signatures moléculaires dans des dépôts minéralogiques de tubes de lave riches en silice : implications pour l'exploration de la sous-surface de Mars

Clara Christiann * [1], Maëva Millan [1], Mathilde Mussetta , Dina M. Bower [2], Amy Mcadam [2], Sarah S. Johnson [3], Cyril Szopa [1]

[1] LATMOS, Laboratoire Atmosphères, Observations Spatiales, Guyancourt, France (LATMOS) – Laboratoire Atmosphères, Observations Spatiales (LATMOS), Université Versailles St-Quentin, UPMC Université Paris 06, CNRS, LATMOS, 11 Boulevard d'Alembert, 78280 Guyancourt, France – France
[2] NASA Goddard Space Flight Center – United States
[3] Georgetown University [Washington] (GU) – United States

Les environnements basaltiques souterrains martiens, tels que les tubes de lave, sont susceptibles d'offrir une protection contre les conditions hostiles de la surface (1). Ils présentent donc un intérêt majeur pour l'exobiologie car ils pourraient abriter une forme de vie actuelle ou avoir préservé des traces de biosignatures anciennes. Des tubes de lave ont été identifiés à la surface de Mars depuis son orbite (2), mais leur exploration à l'aide de futures missions spatiales est nécessaire afin d'évaluer leur potentiel d'habitabilité. Formés par des processus volcaniques, les tubes de lave terrestres peuvent être utilisés comme analogues pour étudier les processus biogéochimiques susceptibles d'opérer dans ces environnements (3).
L'étude présentée porte sur des échantillons de basalte et de dépôts minéralogiques secondaires prélevés dans trois tubes de lave du parc national *Lava Beds National Monument* (LBNM, Californie), formés par des coulées de lave datées de 10 000 à 65 000 ans (4). Une approche multidisciplinaire a été employée afin de caractériser les échantillons ciblés, combinant des analyses minéralogiques, biologiques et chimiques, et plus particulièrement : (1) de caractériser les biomarqueurs moléculaires associés aux communautés microbiennes, (2) d'étudier les interactions entre la minéralogie, la biologie et la chimie, et (3) d'évaluer les capacités et les biais des techniques analytiques spatiales actuelles et futures pour la détection de ces biosignatures.

Les résultats de minéralogie indiquent que les échantillons sont majoritairement constitués de silice amorphe opal-A, avec une proportion mineure de carbonates et de sulfates. Les analyses métagénomiques indiquent la présence de diverses communautés microbiennes chimiotrophes, dominées par des Actinobactéries et des Protéobactéries. Des analyses chimiques réalisées par chromatographie en phase gazeuse couplée à la spectrométrie de masse ont été conduites en laboratoire en conditions " classiques " et en conditions opératoires de vol simulant celles d'instruments spatiaux (pyrolyse et la thermochimiolyse TMAH) embarqués à bord de rovers martiens tels que *Curiosity* et *Rosalind Franklin* (5, 6). Les résultats obtenus montrent la détection de molécules organiques de familles chimiques variées, incluant des biomarqueurs (*e.g.* acides gras, bases nucléiques, sucres) associés aux communautés microbiennes présentes dans les minéraux. Ces résultats confirment la capacité des protocoles analytiques employés dans l'exploration spatiale à détecter des biomarqueurs moléculaires dans des échantillons analogues martiens riches en silice.

*Speaker

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IR-COASTER : une expérience d'exobiologie et d'astrochimie à l'extérieur de la Station spatiale internationale.

Herve Cottin * [1]

[1] Laboratoire inter-universitaire des systèmes atmosphèriques – Centre National de la Recherche Scientifique : UMR7583, Université Paris-Est Créteil Val-de-Marne - Paris 12, Université Paris Diderot - Paris 7, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers – 61 Av du général de Gaulle 94010 CRETEIL CEDEX, France

L'évolution de la matière organique exposée aux conditions spatiales et particulièrement aux photons solaires dans le domaine de l'ultraviolet du vide (120-200 nm), a été étudiée en orbite terrestre basse depuis les années 90 et mise en œuvre sur différentes plateformes spatiales. IR-COASTER (InfraRed-Cubic Orbital Astrobiology Exposure Research) est une charge utile de recherche conçue pour étudier la stabilité d'échantillons organiques ayant une pertinence astro-biologique dans des environnements astrophysiques. Par rapport aux installations d'exposition précédentes, IR-COASTER est le premier à disposer d'un spectromètre FT-IR compact intégré pour l'analyse régulière des échantillons pendant l'exposition. La gamme infrarouge moyen (4000-1000 cm-1) utilisée est particulièrement efficace pour suivre la plupart des fonctionnalités organiques. Cette fonctionnalité avancée sera également disponible sur la prochaine installation d'exposition de l'ESA, Exocube.
IR-COASTER fonctionne désormais à l'extérieur du module Columbus sur la plateforme Bartolomeo et devrait être renvoyé au laboratoire début 2026 après un an d'exposition.

La conception compacte d'IR-COASTER, inspirée de la technologie CubeSat, facilite sa mise en œuvre et son utilisation à proximité de la Station spatiale internationale ainsi que lors de futures missions CubeSat, ou en tant que " hosted payload " lors de missions planétaires ou sur des satellites de télécommunication. Cette charge utile sert également d'éclaireur pour des programmes d'exposition plus ambitieux en orbite lunaire ou à la surface de la Lune.

Nous présenterons la série de tests de qualification réussis d'IR-COASTER, la raison de la sélection des échantillons et les résultats attendus. En plus de l'expérimentation spatiale, des expériences de soutien au sol doivent être menées. Celles-ci seront présentées et discutées.

Contributeurs et contributrices :

Hervé Cottin1, Fabien Stalport1, Noel Grand1, Juliette Pastore1, Rachel Gonthier1, Nathalie Carrasco2, Anaïs Feron1, Maxime Feingesicht1, Cécile Gaimoz1, Sarah Gomes1, Mathieu Gourichon1, Kristian Harge1, Florian Huet3, Xavier Landsheere1, Inès Louison1, Noel Mombazet1,4, Florent Mignon4, Sylvain Triquet1, Lisa Viallon1, Pascal Zapf1, Isabelle Savin De Larclause5, Didier Chaput5, Christian Mustin5

1Univ Paris Est Creteil and Université de Paris, CNRS, LISA, F-94010 Créteil, France

*Speaker

2LATMOS, Université Paris-Saclay, UVSQ, Sorbonne Université, CNRS, Guyancourt, France

3 OSU EFLUVE, Univ Paris Est Creteil F-94010 Créteil, France

4 Campus Spatial UPEC, Univ Paris Est Creteil F-94010 Créteil, France

5 Centre National d'Etudes Spatiales (CNES), Toulouse/Paris, France

Discovery of Small Molecule Features in Martian Analogue Lava Tubes in Iceland

Joleen Csuka * [1,2], Lela Devine [3], Nina Kopacz [4], Oddur Vilhelmsson [5], Brent R. Stockwell [2,6]

[1] Laboratoire Atmosphères, Observations Spatiales (LATMOS) – Université de Versailles Saint-Quentin-en-Yvelines, Institut National des Sciences de l'Univers, Sorbonne Universite, Centre National de la Recherche Scientifique – France
[2] Department of Chemistry, Columbia University – United States
[3] Barnard College [Columbia University - New York] – United States
[4] Università degli studi della Tuscia = Tuscia University [Viterbo] (UNITUS) – Italy
[5] University of Akureyri – Iceland
[6] Department of Biological Sciences, Columbia University – United States

Identifying extraterrestrial analogue environments and reliable biosignatures on Earth is crucial for understanding potential forms of life beyond our planet. However, both these environments and the life forms within them are not yet fully understood. Lava tubes, formed by basaltic pahoehoe volcanic eruptions, are created by low-lying shield volcanoes, where surface lava flows cool and hardens while the lava inside continues to flow. This process results in cave-like structures that remain isolated from the surface environment, creating light-deprived and nutrient-poor (oligotrophic) conditions (1). Despite these challenging conditions, microbial life thrives within these caves. As such, lava tubes provide a unique analogue environment to explore the limits of life's sustainability in extreme conditions. Although the surface of Mars has not yet yielded evidence of life, its subsurface remains a protected environment where signs of past or present life could be preserved. Thus, lava tubes on Mars present a compelling opportunity to search for any potential life that may have once existed or still resides beneath the surface (2).

The process of lipid biosynthesis is energetically demanding and rarely occurs abiotically, making lipids a promising biosignature for life on other planets. Lipids are known for their relative resistance to non-biological degradation, their role in compartmentalization, and their importance in regulating extremophile survival in harsh terrestrial environments. Our previously published paper, "A Study in Blue: Secondary Copper-Rich Minerals and Their Associated Bacterial Diversity in Icelandic Lava Tubes", measured carotenoid signals using Raman spectroscopy in a blue colored microbial sample. Thus, we hypothesize that some classes of lipids, such as carotenoids, may provide protective functions to microbial life and could serve as useful, enduring biosignatures in analogue environments like lava tubes due to their chemical properties that make them easily identifiable (3). Utilizing liquid chromatography-mass spectrometry (LCMS), we identified specific lipids and lipid metabolisms present in bacterial samples collected from lava tubes in Iceland. Here, we report a primary abundance of carotenoids and coenzymes (Q10 & Q9) that may serve as promising biosignatures within these extremophile environments.

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*Speaker

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(2018)

The Early Evolution of Earth and Mars: Divergent Pathways from Common Origins

Vinciane Debaille * [1]

[1] Université libre de Bruxelles (ULB) – Belgium

The early histories of Earth and Mars provide a critical window into the processes that shaped terrestrial planet formation and habitability in the inner Solar System. Both planets accreted from similar materials within the protoplanetary disk and experienced rapid differentiation during the first tens of million years. However, their subsequent evolutionary trajectories diverged dramatically. Geochemical and isotopic evidence suggests that both planets possessed global magma oceans that facilitated early core formation and the establishment of primary crusts. Despite major events such as the great oxidation event or the onset of plate tectonics, temperature conditions on Earth remained quite stable, and the retention of surface water fostered a dynamic and habitable environment. In contrast, Mars underwent rapid crustal stabilization, early dynamo cessation, and significant atmospheric loss within its first billion years. Comparative analyses of ancient zircons, isotopic reservoirs (using short-lived radiochronometers Hf–W, Nd–Sm, and Mn-Cr isotopes), and martian meteorites reveal that planetary size, volatile inventory, and impact history critically influenced each planet's thermal and geodynamic evolution. This synthesis will underscore the importance of comparative planetology in unravelling the divergent fates of two worlds that began alike but evolved apart.

*Speaker

Rosalind Franklin Mission (RFM - programme Exomars): une mission pour la recherche de traces de vie sur Mars

Andre Debus * [1]

[1] CNES / DOA / SU (Direction des systèmes Orbitaux et des Applications / Sciences de l'Univers) – Centre National d'Etudes Spatiales - CNES (Toulouse, France) – France

La mission du rover martien Rosalind Franklin fait partie du programme Exomars de l'ESA. Son objectif principal est la recherche de biosignatures dans des échantillons analysés in-situ, issus du proche sous-sol de Mars. Après de très nombreux aléas qui ont conduit à plusieurs reports de lancement, la mission a finalement été reconfigurée dans le cadre d'un partenariat avec la NASA. Ce rover européen de 310 kg est équipé d'une foreuse capable de collecter des carottes d'échantillons jusqu'à deux mètres de profondeur. Il embarque en autres 8 instruments scientifiques et un laboratoire analytique permettant d'examiner et analyser les échantillons collectés dans des conditions ultrapropres et stériles. A l'heure actuelle le rover est en cours de ré-intégration après des activités de remise à niveau. La mission devrait être lancée depuis Cap Canaveral fin 2028. Après une entrée atmosphérique du module en injection directe et une descente sous parachutes, la plateforme d'atterrissage portant le rover devrait être déposée sur Mars fin 2030, peu de temps après l'épisode saisonnier de tempêtes de poussières. Le site d'atterrissage retenu est Oxia Planum, choisi pour sa surface recouverte en partie de minéraux hydratés.

*Speaker

PLATO : une mission à la recherche de nouvelles ”TERRES”

Andre Debus * [1]

[1] CNES / DOA / SU (Direction des systèmes Orbitaux et des Applications / Sciences de l’Univers) – Centre National d’Etudes Spatiales - CNES (Toulouse, France) – France

La mission PLATO (PLAnetary Transits and Oscillations of stars) est une mission de classe M3 (Moyenne) du programme ”Cosmic Vision 2015-2025” de l’Agence Spatiale Européenne (ESA) destinée à la recherche d’exoplanètes. Son objectif principal est la détection de planètes de type terrestres (telluriques) gravitant dans la zone habitable d’étoiles de type solaire.
Pour ce faire, PLATO détectera des milliers de systèmes planétaires au sein de notre galaxie et permettra de déterminer avec une précision inégalée l’ensemble des propriétés de masse et orbitales des exoplanètes découvertes, de caractériser les étoiles hôtes ainsi que l’âge des exo systèmes découverts. Le programme reposera sur trois piliers : la détection de planètes extrasolaires depuis le satellite PLATO par la méthode du transit, la caractérisation de l’étoile par astérosismologie, également depuis le satellite, et la mesure de la vitesse radiale des étoiles détectées par le satellite PLATO à partir de télescopes sol.

Le satellite PLATO observera de manière ininterrompue un ou deux immenses champs de la voûte céleste de chaque hémisphère. La durée d’observation sur chaque hémisphère sera au minimum de 2 ans.

Le satellite PLATO embarque un module charge utile constitué de 24 télescopes travaillant en lumière visible, offrant un champ de vision combiné extrêmement large couvrant une surface totale du ciel d’environ 2232 degrés carrés, soit environ 5% du ciel. A cela s’ajoutent 2 télescopes spécifiques supplémentaires qui seront utilisés pour le pointage fin du satellite et pour la détection d’une éventuelle atmosphère sur les planètes gravitant autour des étoiles les plus brillantes.
PLATO devrait être lancé par une fusée Ariane 62 depuis Kourou en décembre 2026 et positionné autour du second point de Lagrange (L2), situé à 1,5 million de kilomètres de la Terre, à l’opposé du Soleil.

*Speaker

Quoi de neuf du côté des planète du voisinage solaire

Xavier Delfosse * [1]

[1] Université Grenoble Alpes (UGA) – UGA – ., France

L'obtention de données spectrales de la lumière réfléchie par des exoplanètes rocheuses fait partie des grands objectifs de l'astronomie actuelle, et de l'ELT en particulier. Même si ces données resteront encore très partielles, elles pourraient permettre de commencer à explorer la diversité des atmosphères des planètes telluriques et de préparer l'avenir, lorsque seront déployés (peut-être) des instruments tels que LIFE ou HWO (Habitable Worlds Observatory).
Seuls la poignée de systèmes les moins complexes à caractériser seront accessibles pour l'ELT, en particulier les planètes orbitant autour des étoiles les plus proches de nous, permettant une meilleure résolution angulaire et un flux de photons un peu plus élevé. Il est nécessaire que ces planètes soient détectées en amont des observations ELT.
Au cours de cette présentation, je ferai le point sur l'état du recensement des planètes du très proche voisinage, pour lequel la technique dite de la vitesse radiale est essentielle : combien de planètes ont déjà été détectées, lesquelles manquent encore potentiellement à notre catalogue, et quelles sont les actions actuelles pour les découvrir. Un focus particulier sera consacré aux grands relevés en cours en vélocimétrie radiale infrarouge, notamment avec SPIRou@CFHT et NIRPS@ESO.

*Speaker

OREOcube and Exocube: Miniature Space Exposure Platforms for the ISS with In-Situ Analytics for Exobiology and Space Exploration.

Andreas Elsaesser * [1,2]

[1] Institut UTINAM (UTINAM) – Université Marie et Louis Pasteur, CNRS, Institut UTINAM UMR 6213, 25000 Besançon, France – France
[2] Freie Universitaet Berlin (FUB) – Germany

OREOcube and Exocube are novel in-situ space exposure platforms designed as autonomous miniaturized laboratories and scheduled for deployment on the International Space Station (ISS) within ESA's Exobiology Facility (EXOBIO, Bartolomeo platform). Scheduled for launch in 2027, they represent the next generation of active space exposure experiments, combining the advantages of sample return with continuous, in-situ spectroscopic and microfluidic analytics- a capability that is new to exposure experiments outside the ISS.
OREOcube focuses on the photostability and chemical evolution of organic molecules under the combined effects of solar and cosmic radiation, using integrated UV–visible spectroscopy to monitor organic molecules in real time. Exocube extends this concept through two complementary modules: ExocubeChem, a Fourier-transform infrared (FTIR) spectrometer for infrared spectroscopic characterization of molecular assemblies, and ExocubeBio, a microfluidic system designed for biological samples with colorimetric and fluorescence measurements to study microbial survival and metabolic activity.

Together, these payloads address fundamental questions in astrochemistry, exobiology, radiation biology, planetary protection, and planetary exploration-probing the limits of molecular stability, biomarker persistence, and biological adaptation in space. By combining ISS exposure data with synchronized ground reference experiments, the missions will deliver unprecedented insight into photochemical pathways, organic and biological resilience, and radiation-driven evolution.
The integration of these complementary techniques allows direct investigation of the chemical–biological interface under true space conditions, providing the first quantitative datasets on coupled organic and microbial responses to the solar and cosmic radiation environment. The results from OREOcube and Exocube will inform the design of future life-detection missions, bioregenerative life-support systems, and contribute to the broader understanding of habitability and the persistence of life's chemical signatures beyond Earth.

*Speaker

Investigations of geochemical and prebiotic processes under hydrothermal conditions : a multiscale approach / Part II

Fatma Ercicek * [1], Valentin Moulay [1], Elisabeth Lapp [1], Vinogradoff Vassilissa [2], Arnaud Erriguible [3], Anaïs Cario [1], Samuel Marre [1]

[1] Institut de Chimie de la Matière Condensée de Bordeaux (ICMCB) – ICMCB, CNRS UMR 5026, University of Bordeaux, Bordeaux INP – France
[2] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université – France
[3] Institut de Chimie de la Matière Condensée de Bordeaux (ICMCB) – ICMCB, CNRS UMR 5026, University of Bordeaux, Bordeaux INP – France

Hydrothermal environments, such as deep-sea vents, are among the most plausible settings for the emergence of life, as they combine steep thermal and chemical gradients, high pressures, and reactive mineral matrices able to catalyze the formation of prebiotic molecules. Reproducing these conditions in the laboratory, however, remains a major challenge due to the complexity of the mineral reactions involved and the difficulty of observing them in real time at the pore scale.
To tackle this, we have developed two complementary experimental platforms. A few-milliliter sapphire reactor was designed to reproduce hydrothermal "white smoker" conditions (up to 150 ◦C and 100 bar). This system enables the study of mineral–fluid interactions using olivine as a catalyst and allows us to investigate the formose reaction, an autocatalytic process forming sugars under hydrothermal conditions.

At a smaller scale, a microfluidic reactor (μL range) made of silicon–Pyrex or sapphire reproduces the pore-scale confinement typical of hydrothermal rocks, where minerals, fluids, and gases interact in narrow, tortuous geometries. Within such confined microenvironments, steep local gradients of pH, temperature, and concentration can be generated and maintained over long periods, mimicking the dynamic interfaces that may have played a crucial role in prebiotic chemistry. The microreactor allows precise control over flow rates, temperature, and pressure, while offering optical transparency for *in situ* Raman, FTIR, and optical microscopy observations. By combining *in situ* monitoring with *ex situ* GC-MS analysis, we are able to identify a wide range of organic compounds formed during this reaction, offering a deeper understanding of the molecular diversity that could emerge from confined autocatalytic reactions in such environments.

Together, these complementary approaches enable a multiscale investigation of prebiotic processes: from bulk mineral reactivity to pore-scale catalytic mechanisms. This combined strategy offers new insights into how minerals, under hydrothermal gradients, could have driven key prebiotic reactions such as the formose reaction, leading to the formation of life's first organic building blocks.

*Speaker

Le grand jeu de l'exobiologie

Frédéric Foucher * [1]

[1] Conditions Extrêmes et Matériaux : Haute Température et Irradiation (CEMHTI) – Université d'Orléans, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France

Depuis 2016, le groupe Exobiologie du CNRS d'Orléans propose chaque année, en partenariat avec *La Maison pour la science* Centre - Val de Loire, une formation à l'exobiologie de 2 jours pour les enseignants du secondaire. Afin de proposer une activité ludique aux participants autour de cette thématique, un grand jeu de plateau a été créé en 2019, permettant de découvrir l'exobiologie. Ce jeu est également utilisé lors d'évènements grand public, telle que la fête de la science.
Lors de ce jeu, cinq équipes s'affrontent avec pour objectif d'être la première à découvrir la vie extraterrestre. Chaque équipe a une mission différente : l'équipe 1 recherche des traces de vie in situ sur Mars, l'équipe 2 recherche des traces de vie dans des échantillons rapportés de Mars, l'équipe 3 recherche de la vie dans l'océan d'Encelade, l'équipe 4 recherche des indices de vie en analysant les atmosphères d'exoplanètes et l'équipe 5 est à l'écoute d'un signal radio extraterrestre (*SETI*).

Le jeu se joue avec des cartes, des jetons et un grand plateau. Le jeu étant à but éducatif, des informations scientifiques en lien avec l'exobiologie, l'astronomie, l'histoire de la conquête spatiale, la planétologie, la géologie ou encore la culture populaire en lien avec l'exobiologie, figurent sur la majorité des cartes. Avec humour, le jeu met aussi en lumière les difficultés liées à l'exobiologie (par exemple le fait qu'habitable ne signifie pas habitée), à l'exploration spatiale (limitation de l'instrumentation spatiale par exemple) et à la recherche scientifique en générale (aléas financiers, pannes d'instrument, etc.). Le jeu est par ailleurs décliné en deux versions, une version 8-14 ans et une version plus de 14 ans, en fonction du niveau scientifique des informations présentes sur les cartes.
Le jeu sera présenté lors de la conférence.

*Speaker

Characterization of interstellar ice residues by GC-FT-Orbitrap-MS: A high-resolution approach

Adeline Garcia * [1], Vassilissa Vinogradoff [1], Grégoire Danger [1]

[1] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France

Since the Viking mission (1975), pyrolysis coupled with gas chromatography and mass spectrometry (Pyr-GC-MS) has become a commonly used technique in space exploration missions (1), (2). In this context, the analysis of organic residues from interstellar and cometary ice analogues by high-resolution pyrolysis-GC-MS (Orbitrap) follows the analytical protocols developed in astrochemistry. Previous studies on refractory organic residues derived from such ices have revealed a high molecular diversity, notably including hexamethylenetetramine (HMT, CHN) (3), (4). This stable polyheterocyclic molecule is of particular interest for understanding abiotic formation pathways of prebiotic organic compounds (5).
We explored various pyrolysis techniques, either coupled with gas chromatography followed then by MS, or pyrolysis directly coupled to high-resolution mass spectrometry (Orbitrap), including evolved gas analysis (EGA-MS) and thermal desorption (TD-GC-MS). In this study, a pre-cometary organic analogue was analyzed using a Pyrolyzer-GC-FT-Orbitrap-MS configuration. EGA-MS analysis revealed two major desorption profiles. The high mass resolution of the Orbitrap enabled the identification of hexamethylenetetramine (HMT) during the first thermal event, with a mass error of less than 2 ppm, as well as the detection of an HCN-type polymer in the second desorption profile (3). This method provides a first insight into the molecular composition and the desorption temperatures of these compounds. The TD-GC-MS analysis further confirmed the presence of HMT and identified several of its derivatives, in agreement with previous literature (6), (7).

This methodology was then applied to several carbonaceous chondrites (e.g., Paris, Murchison, Aguas Zarcas, Tarda, NWA), analyzed directly without any prior sample preparation, with the aim of evaluating the relevance of high-resolution pyrolyzer–GC–MS coupling for the analysis of complex extraterrestrial organic matter. Data were successfully acquired, but are still being processed due to the density and complexity of the information obtained. The presentation will focus on the results from the ice analogues, particularly the detection of HMT and its derivatives, as well as the application of the methodology to meteorites and the current challenges encountered, thereby paving the way for optimized data processing strategies in an astrochemical context.

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Investigation of a set of natural samples: preparing in situ research of organic matter at Mars' surface with the MOMA instrument onboard Rosalind Franklin

Théo Govekar * [1], Cyril Szopa [1], Caroline Freissinet [1], Arnaud Buch [2], Brieuc Bouhier [3], Maëva Millan [1], David Boulesteix [2], Clara Azémard [3], Fabien Stalport [3], Jorge Vago [4]

[1] Laboratoire Atmosphères, Milieux, Observations Spatiales – Laboratoire Atmosphères, Observations Spatiales (LATMOS), Université Versailles St-Quentin, UPMC Université Paris 06, CNRS, LATMOS, 11 Boulevard d'Alembert, 78280 Guyancourt, France – France

[2] Laboratoire de Génie des Procédés et Matériaux (LGPM) – CentraleSupélec, Université Paris-Saclay – France

[3] Laboratoire Interunversitaire des Systèmes Atmosphériques (LISA) – Univ Paris Est Créteil, Université de Paris – France

[4] ESA - ESTEC (Netherlands) – Netherlands

Mars is one of the Solar System targets of highest interest for research about prebiotic chemistry. This is because early Mars had similar conditions required for the emergence of life at the time it arose on Earth (1).
The ESA ExoMars mission landing site, Oxia Planum, northeast of Vallis Marineris, is characterized by wide plains rich in clays, mostly Fe/Mg phyllosilicate (2). Clay formation requires prolonged exposure to liquid water. The geochemical conditions necessary for the formation of such clays are known to facilitate prebiotic activity (3). Oxia Planum deposits may hold a record of formation and evolution of organic matter into molecules of biological interest.

One of the main objectives of the rover is to identify organic molecules in collected samples (4). To achieve this goal, a laser desorption plus gas chromatograph mass spectrometers (LD+GCMS) instrument named Mars Organic Molecule Analyzer (MOMA), is part of the Rosalind Franklin rover payload. In its GCMS mode, MOMA uses several complementary sample preparation technics. First, solid samples are heated through pyrolysis up to 850°C, which allows organic molecules to evolve (or be fragmented) into volatile species prior to their injection into the GCMS analyzer. In addition to this vaporization method, chemical reactants can be added to support molecule vaporization but limiting their fragmentation (TMAH (a)), or to target specific organic molecules of interest for prebiotic chemistry to make them analyzable by GCMS (MTBSTFA (b), DMF-DMA (c)), such as amino acids or fatty acids.

To prepare the interpretation of future data to be collected by the different instruments onboard the Rosalind Franklin rover, the Exomars science team organized a comparison campaign of analyses performed on a variety of terrestrial samples, possibly analogues of Oxia Planum soils and rocks, that were distributed among the laboratories participating to the ExoMars project. Our team's work focuses on the GCMS analyses. The goal of this study was to characterize organic molecules in the analogue samples using laboratory instrumentation similar to MOMA.

*Speaker

To achieve this, we tried to reproduce the different sample preparation processes used in MOMA: pyrolysis and derivatization. We tested the impact of different pyrolysis temperatures within the range of MOMA, and analyzed the samples with the three chemical reagents on board Rosalind Franklin (5), plus some other techniques out of the scope of MOMA but useful for the sample's characterization, such as evolved gas analysis.

As preliminary results, we were able to detect organic molecules in all samples though in various abundances. We also observed that the thermal treatment (temperature and duration of pyrolysis) had a significant impact on the organic molecules detected. The derivatization techniques used appeared to be complementary to each other's and to pyrolysis. They allow us to identify important biological molecules like amino acids. These results could prove useful when choosing the optimal operation mode of MOMA.

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(a) Tetramethylammonium hydroxide

(b) N-Methyl-N-(tert-butyldimethylsilyl)trifluoroacetamide

(c) Dimethylformamide dimethyl acetal

How Carbon Dioxide in Interstellar Ice Analogues Impacts Organic Matter Generated

Lawry Honold * [1], Jasmine Hertzog [2], Ruf Alexander [3,4], Fabrice Duvernay [1], Frédéric Aubriet [2], Vincent Carré [2], Philippe Schmitt-Kopplin [5,6], Alicja Domaracka [7], Grégoire Danger [1]

[1] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France
[2] Laboratoire de Chimie et Physique - Approche Multi-échelle des Milieux Complexes (LCP-A2MC) – Université de Lorraine – France
[3] Fakultät für Physik - Ludwig-Maximilians-Universität [München/Munich] (LMU) – Germany
[4] Excellence Cluster ORIGINS – Germany
[5] Helmholtz Zentrum München - Analytical BioGeoChemistry – Germany
[6] Technishe Universität München - Chair of analytical Food Chemistry – Germany
[7] Centre de recherche sur les Ions, les MAtériaux et la Photonique (CIMAP - UMR 6252) – Université de Caen Normandie, Institut Rayonnement Matière de Saclay (DRF), Ecole Nationale Supérieure d'Ingénieurs de Caen, Centre National de la Recherche Scientifique, Institut de Recherche sur les Matériaux Avancés – France

Understanding the formation and evolution of organic compounds present within hot molecular cores is crucial to determine the origins of a fraction of the chemical diversity observed in interplanetary objects. These environments are cold and dense regions of the interstellar medium (ISM), where physical and chemical conditions enable the growth of icy mantles around dust grains, hosting a rich organic chemistry (1). This results in a chemically complex matrix that is further processed by energetic radiation, leading to a high organic diversity that may later be incorporated into interplanetary object during the accretion phase (2).
In this context, laboratory astrophysics complements astronomical observations by simulating the evolution of interstellar ices. Using the MICMOC setup (3) at the PIIM laboratory, we simulate the pressure (10-7 - 10-8 mbar) and temperature (77 - 300 K) conditions of molecular cloud environments to study the photochemical evolution of ice analogues typically composed of H2O, CH3OH, NH3, CO, CO2, CH4, N2 and/or H2S. After VUV irradiation and warming up to room temperature, these ices yield in organic residues, in which high-resolution mass spectrometry (HRMS) analyses have revealed the presence of thousands of compounds, with molecular masses reaching up to 4000 Da (4) and a wide range of chemical functionalities. A key challenge remains to elucidate the impact of the most abundant ice constituents on the organic diversity observed (5).

In this study, we investigated the specific role of CO2 in shaping the organic diversity of interstellar ice analogues residues. We compared the soluble organic matter analogue produced in VUV-irradiated ices composed of H2O-CO2-CH3OH-NH3 with varying initial concentration of CO2 and CH3OH. The resulting molecular complexity was characterized by untargeted FT-ICR-MS (Fourier-Transform Ion Cyclotron Resonance Mass Spectrometry). A direct relationship could be established between the initial CO2/CH3OH ratio and both the oxidation degree and the length of the carbon chain of the detected molecules. Methanol-rich ices present

*Speaker

the highest molecular diversity, ion masses and DBE values, suggesting that methanol strongly influence the structure of the carbon backbone. In contrast, CO2-rich ices promotes a higher oxidation degree, by favouring the formation of specific oxygen-rich chemical families. These findings highlight the effect of the carbon oxidation state in initial ices on the pathway leading to the chemical complexity of organic residues.

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Favored Great Oxidation Event on exoplanets around M-Stars

Adam Yassin Jaziri * [1]

[1] Laboratoire Atmosphères, Milieux, Observations Spatiales – Université de Versailles Saint-Quentin-en-Yvelines, Institut National des Sciences de l'Univers, Sorbonne Universite, Centre National de la Recherche Scientifique – France

The Great Oxidation Event (GOE), which marked the transition from an anoxic to an oxygenated atmosphere, occurred 2.4 billion years ago on Earth, several hundreds of millions of years after the emergence of oxygenic photosynthesis. This long delay implies that specific conditions in terms of biomass productivity and burial were necessary to trigger the GOE. It could be a limiting factor for the development of oxygenated atmospheres on inhabited exoplanets. In this study, we explore the specificities of terrestrial planets in the habitable zone of M-dwarfs for a GOE. Using a 1D/3D coupled photochemical Global Climate Model, we simulate the atmospheric evolution of TRAPPIST-1e, an Earth-like exoplanet, exploring the effect of oxygen sources (biotic or abiotic). Our results show that the enhanced UV radiation from M-dwarfs promotes O3 production at lower O2 concentrations compared to Earth, and the ozone layer on TRAPPIST-1 e forms more efficiently. This lowers the threshold for atmospheric oxidation, suggesting that the GOE on TRAPPIST-1e would occur quickly after the rise of oxygenic photosynthesis, up to 1Gyrs earlier than on Earth, and would reach O2 enabling oxygenic respiration and thus the development of animals. Furthermore, we discuss how the overproduction of ozone could make O3 detection possible using the James Webb Space Telescope, providing a potential method to observe oxygenation signatures on exoplanets in the near future. Previous studies predicted that for an Earth-like atmosphere O3 would require over 150 transits for detection, but our results show that only 25 transits are needed. As there is no clear abiotic source that can trigger GOE, this detection would be a robust biosignature.

*Speaker

Laboratory experiments of sugar synthesis under prebiotic wet-dry cycling conditions

SalomÉ Lagasse * [1], Grégoire Danger [1], Vassilissa Vinogradoff [1], Sylvain Ravier [2]

[1] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France

[2] Laboratoire Chimie de l'environnement (LCE) – Aix Marseille Université, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France

On the early Earth, surface pools such as volcanic hot spring likely had access to multiple sources of organic precursors (e.g. via extraterrestrial delivery, atmospheric synthesis, or local geochemical synthesis). These pools were subjects to dynamic environmental conditions, particularly frequent wet-dry cycling driven by evaporation, precipitation, fluctuating water levels, and geyser activity (1). Such cycles have been proposed to facilitate the formation, stabilization, and evolution of polymers-potentially playing a crucial role in prebiotic chemistry (2-3).
Within this context, the formose reaction stands out as a prominent prebiotic pathway thought to have generated sugars relevant to early molecular systems (4-5). This complex network - involving the formation of sugars, polyols, and hydroxy acids from formaldehyde in a series of reactions - is inherently autocatalytic and sensitive to environmental parameters. Under specific conditions, selective product formation has been observed (6). However, due to its complex nature, the formose reaction remains a challenge to understand.

To investigate the feasibility of the formose reaction at the surface of early Earth, experiments were conducted under non-ideal conditions for this reaction (7), including moderate temperature and slightly acidic to neutral pH (bicarbonate buffer), in the absence of the typical Ca^2 catalyst. This mildly reactive environment was paired with repeated wet-dry cycles (up to 4), using gas flushing to mimic natural drying. Furthermore, we explored the influence of different drying gases (N2 and CO2), simulating varying atmospheric compositions. Reaction products have been analyzed using gas chromatography–mass spectrometry (GC-MS) and high resolution mass spectrometry (Orbitrap) equipped with an electrospray ionization source (ESI-MS). Initial tests were performed on glyceraldehyde, a C sugar and known initiator of the formose reaction, and already revealed reactivity and selective effects emerging through repeated wet-dry cycles. Furthermore, preliminary results indicate a significant difference in product distribution depending on the type of drying gas used. Indeed, flushing with N2 appears to promote basification of the bicarbonate-buffered solution during drying, thereby driving the formation of larger sugars. In contrast, CO2 flushing helps maintain a neutral pH and prevent the onset of alkalinity-driven reactions during the drying process. These findings suggest that, under early Earth surface conditions, drying alone could initiate sugar formation depending on the composition of the early atmosphere.

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Quantification of microbial contribution to calcite dissolution using vertical scanning interferometry: progress towards the identification of traces of life on mineral surfaces

Malaury Luzet * [1], Luca Stigliano [1,2,3,4], Karim Benzerara [3], Philippe Ackerer [4], Didier Jézéquel [5,6], Delphine Tisserand [1], Muriel Gugger [7], Damien Daval [1]

[1] Institut des Sciences de la Terre (ISTerre) – Institut de Recherche pour le Développement, Institut National des Sciences de l'Univers, Université Savoie Mont Blanc, Centre National de la Recherche Scientifique, Université Gustave Eiffel, observatoire des sciences de l'univers de Grenoble, Université Grenoble Alpes – France

[2] Oxford University, Department of Earth Sciences – United Kingdom

[3] Sorbonne Université, Museum National d'Histoire Naturelle, UMR CNRS 7590, Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie (IMPMC), 75005 Paris, France – Institut de Minéralogie, de Physique des Matériaux, et de Cosmochimie (IMPMC), Sorbonne Université, UMR CNRS 7590, Museum National d'Histoire Naturelle, IRD UMR 206, 4 place Jussieu, F-75005 Paris – France

[4] Institut Terre Environnement Strasbourg (ITES) – Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg, université de Strasbourg, Institut National des Sciences de l'Univers, Centre National de la Recherche Scientifique – France

[5] Institut de Physique du Globe de Paris (IPGP - UMR7154) –
−InstitutNationaldesSciencesdel′Univers, InstitutNationaldel′InformationGéographiqueetForestière[IGN], Univer
−France

[6] Centre Alpin de Recherche sur les Réseaux Trophiques et Ecosystèmes Limniques (CARRTEL) – Université Savoie Mont Blanc, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement, observatoire des sciences de l'univers de Grenoble – France

[7] Institut Pasteur, collection cyanobacteria – Université Paris Cité – France

Mineral surfaces have long been considered promising targets in the search of traces of life. Indeed, microorganisms participate in the alteration of these minerals and may therefore leave traces of their presence on surfaces. However, it remains challenging to attribute microscale surface features to microbial processes without ambiguity. With our study, we aim to quantify the contribution of microorganisms to calcite alteration as well as to identify biological traces on the mineral surface.
To achieve this, we use a series of microscopic techniques including vertical scanning interferometry, which allows us to investigate mineral surface topography at the nanometer scale. From these topography images, we infer mineral dissolution rates and quantitatively describe microtopography, using quantitative parameters (*e.g.*, surface roughness) and statistical approaches such as power spectral density and semi-variograms.

We conduct dissolution experiments on polished calcite chips at three different ecological scales: (a) the single-strain scale with three cyanobacteria strains selected for their interactions with

*Speaker

calcium carbonate (*Chroococcidiopsis thermalis* PCC 7203, *Synechocystis* sp. PCC 7511 and *Leptolyngbya* sp. PCC 9429); (b) the microcosm scale, using lake water samples under controlled conditions (temperature, light, pCO2); and (c) the macrocosm scale, involving *in-situ* incubation of the calcite chips in lacustrine environments.

Our first results reveal quantitative topographic parameters that can be used to recover the alteration conditions such as the saturation state and the presence of microorganisms, therefore contributing to the identification of new traces of life on mineral surfaces (1,2).

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Évolution photochimique des glaces stratosphériques de Titan : cas de l'acrylonitrile

Faustin Mathieu * [1]

[1] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France

Titan, la plus grande lune de Saturne, est le seul satellite du Système solaire à posséder une atmosphère dense (1,5 bar en surface) principalement composée de diazote (N2) et de quelques pourcents de méthane (CH4). Soumise à diverses sources d'irradiation, cette atmosphère constitue un milieu très réactif évoluant par croissance moléculaire et par production permanente d'aérosols. Parmi les molécules formées, les hydrocarbures (C6H6, C4H2, ...) et les nitriles (C2H3CN, HCN, ...) sont connus pour condenser dans la basse stratosphère et conduire à la formation de particules glacées et/ou de nuages (1, 2). Durant leur séjour au niveau de la basse atmosphère (stratosphère et troposphère), ces particules ou nuages sont soumis aux photons ultraviolets (UV) solaires de longueur d'onde supérieure à 230 nanomètres ($\lambda >$ 230 nm), à des électrons provenant de la magnétosphère de Saturne et vraisemblablement aux ions énergétiques GCR (Galactic Cosmic Rays) (2), et peuvent ainsi évoluer chimiquement.
De précédentes études ont permis de proposer plusieurs molécules pour prétendre expliquer l'origine des nuages observés au niveau des pôles par comparaison avec les expériences réalisées en laboratoire (1). Ainsi, le nuage HASP (High Altitude South Polar cloud) observé par la mission Cassini-Huygens résulterait de la condensation simultanée de benzène (C6H6), de cyanure d'hydrogène (HCN) et probablement d'acrylonitrile (C2H3CN) (1, 3).

Afin de mieux comprendre ces observations, la condensation et la photochimie du benzène et du cyanure d'hydrogène (isolés, puis condensés simultanément et ce à différents ratios (4-6)), ont été préalablement réalisées en se focalisant sur l'impact des photons UV ($\lambda >$ 230 nm). Aujourd'hui, l'objectif est d'intégrer l'acrylonitrile dans le modèle, en commençant par son étude sous forme de glace pure. Le dispositif expérimental (laboratoire PIIM) permet de suivre l'évolution de la phase solide des glaces lorsqu'elles sont soumises aux photons UV ($\lambda >$ 230 nm).

Ces résultats seront d'utilité dans l'interprétation des données de la mission Cassini-Huygens et à la préparation de l'analyse des futures données de la mission Dragonfly qui sera lancée en 2028 par la NASA.

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XCT Analyses of Carbonaceous Chondrites – Correlating Morphological Features

Malak Moghrabi * [1], Claude Geffroy [2], Arnaud Mazurier [3]

[1] UMR 7285 – Institut de Chimie des Milieux et Matériaux de Poitiers (IC2MP) – Institut de chimie des milieux et matériaux de Poitiers [UMR 7285], UMR 7285 (HydrASA) – France
[2] UMR 7285 – Institut de Chimie des Milieux et Matériaux de Poitiers (IC2MP) – Institut de chimie des milieux et matériaux de Poitiers [UMR 7285] – France
[3] UMR 7285 (HydrASA) – UMR 7285 (HydrASA) – France

Minerals are widely assumed to protect organic matter (OM) from degradation but also to catalyze reactions (1). The nature of preserved organic molecules, including aromatics, sugars, amino acids, nucleobases and carboxylic acids, from 4.5 billion years asteroids and meteorites, reveals information about early Solar System chemistry. A wide chemical diversity resulting from molecular evolution in each individual thermal history of the parent body is now ascertained. For example, analysis of meteorite extracts using ultra-high-resolution mass spectrometry revealed the presence of several tens of thousands of soluble organic species in the Murchison meteorite (2). These amazing results were possible thanks to chemical extraction steps which however erased the organics' spatial distribution.
Consequently, mineral phases involved in the formation / complexification of the organics are not yet clearly identified. Such samples contain micrometer-sized mineral particles that accreted to form parent asteroids. Thus, depending on the mineralogy, the organic compounds associated with the tiny particles may record distinct reactions that created the organic compounds in the early Solar System. Ryugu asteroid pristine samples, as many carbonaceous meteorites, contain hydrated minerals and organic compounds. Recent studies on Ryugu d-spacings of identified smectite exhibit a broad distribution of values, indicating significant heterogeneity. Such d-spacing variability could be the result of either the presence of organic matter trapped in the interlayers or the influence of various geochemical conditions at the sub-micrometer scale, suggestive of a range of organic compounds and/or changes in smectite crystal chemistry (3). In a view to comprehensive studies on the formation and preservation of these molecules, the understanding of interactions at the organics-minerals interface is mandatory. The development of new analytical strategies is still necessary to achieve the spatial distribution of the molecules. For those purposes, we propose to combine 3D imaging and chromatographic techniques.

X-ray microtomography, a non-destructive nor invasive 2-3D imaging technique, provides detailed information on the mineralogical and textural characteristics of materials. This technique allows to visualize and analyze quantitatively the internal structural organization of objects such as meteorites (3D cartography of mineralogical phases and their interfaces, pores morphology, defects, inclusions distribution,..) and thus assesses their heterogeneity without damage. Standardized protocols for the interpretation for astrobiological samples is however lacking contrary to other specimens (4). In this work, we present a workflow for a systematic analysis of morphological properties of Tagish Lake, Mukundpura, Murchison, and Aguas Zarcas meteorites.

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*Speaker

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Deciphering the origin of organo-sulphur hazes: an exploration of the actual limits of sulphur chemistry with potential implications for prebiotic chemistry and exoplanet characterization

Louis Maratrat * [1], Nathalie Carrasco [2], Maëva Millan [3], Ludovic Vettier [1], Arnaud Buch [4], Théo Govekar [5]

[1] SYSTEME SOLAIRE - LATMOS – Laboratoire Atmosphères, Observations Spatiales – France
[2] Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) – INSU, Université de Versailles-Saint Quentin en Yvelines, Université Pierre et Marie Curie - Paris VI, CNRS : UMR8190 – France
[3] PLANETO - LATMOS – Laboratoire Atmosphères, Milieux, Observations Spatiales – France
[4] Laboratoire de Génie des Procédés et Matériaux (LGPM) – CentraleSupélec, Université Paris-Saclay – France
[5] Laboratoire Atmosphères, Milieux, Observations Spatiales – LATMOS/IPSL, Sorbonne université, UVSQ Université Paris-Saclay, CNRS – France

Sulphur volatiles are components currently observed in the atmospheres of planetary bodies. This is true for the solar system with the examples of Venus and Io, but also for extrasolar systems as suggested by the recent findings of the James Webb Space Telescope (JWST). Infrared Transit spectroscopy performed with this instrument revealed SO2 signatures in several different types of exoplanets such as hot-Jupiter, warm-Neptunes, temperate Sub-Neptune or Super-Earth. This highlights the extended diversity of objects in term of atmospheric conditions which host sulphur species. In many of these very diversified contexts, photochemical processes implying sulphur volatiles are known to play a key role in the chemistry of the global atmosphere. However, despite the recurrence of sulphur in planetary/exoplanetary atmospheres and the importance of the photochemistry induced by such species, sulphur atmospheric reactivity remains in some aspects poorly understood. One of the most relevant examples to illustrate this lack of knowledge concerns sulphur aerosol formation processes. Several laboratory experiments revealed the existence of organo-sulphur hazes which are currently not predicted by atmospheric simulation models. To overcome this discrepancy between experimental observations and model, the chemical mechanisms leading to the formation of such aerosols need to be identified. The characterization of such hazes also has prebiotic impacts, as they incorporate up to five different elements, C,H,N,O,S, which are five of the six essential elements present in life building blocks, the famous C,H,N,O,P,S. The analysis of such hazes can highlight new atmospheric reaction pathways of sulfur organics which implies to extent the contribution of atmospheric chemistry to prebiotic chemistry. In this work we adopt an experimental approach to better constrain the mechanisms of formation of organo-sulphur aerosols. The objectives were more precisely to characterize the molecular signatures of the organo-sulphur molecules contained in such hazes with their chemical functions, and to constrain their formation mechanism. To do so, we synthetize organo-sulphur aerosols in a N2/CH4/S (where S represents either SO2 either H2S) plasma mixtures with sulfur abundances moving from 0.1 to 10%. This leads to the first molecular

*Speaker

characterization of organo-sulfur hazes, with the identification of several molecular signatures such as: organic thiocyanates and isothiocyanates, organic thiols and poly-sulfides, thioamides and sulfur aromatic rings thiazole and thiophene. This highlights new formation pathways of organo-sulfur molecules in the atmosphere. These results prompt to discuss the existence of such pathways in the primitive atmosphere, but also to consider the prebiotic impacts of new families of compounds mainly thiocyanates, isothiocyanates, and thioamides which appears to be efficiently produced in the conditions explored.

Interpreting the JWST observations of TRAPPIST-1 b and c

Alice Maurel * [1,2], Elsa Ducrot *

3,4

[1] Institut d'Astrophysique de Paris – Institut National des Sciences de l'Univers, Sorbonne Universite, Centre National de la Recherche Scientifique, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers – France

[2] Laboratoire de Météorologie Dynamique (UMR 8539) – Institut National des Sciences de l'Univers, Ecole Polytechnique, Ecole des Ponts ParisTech, Sorbonne Universite, Centre National de la Recherche Scientifique, Département des Géosciences - ENS Paris, Centre National de la Recherche Scientifique : UMR8539 – France

[3] Astrophysique Interprétation Modélisation (AIM (UMR$_7$158/UMR_{E9}005/$UM_1$12)) – –*Commissariatàl'énergieatomiqueetauxénergiesalternatives, InstitutNationaldesSciencesdel'Univers, UniversitéP* *Saclay, CentreNationaldelaRechercheScientifique, UniversitéParisCité – –France*

[4] Laboratoire d'Instrumentation et de Recherche en Astrophysique (LIRA) – Institut National des Sciences de l'Univers, Observatoire de Paris, Centre National de la Recherche Scientifique, Sorbonne Universite, CY Cergy Paris Université – France

Rocky temperate exoplanets are a choice target in astrobiology: harder to detect and characterize, they also possess the highest potential for harboring remotely detectable life forms. Because of the detection bias regarding palet-to-star size ratio, one must turn to the coolest and smallest stars, M-dwarfs, to detect temperate rocky exoplanets, that are thus often tidally locked. The TRAPPIST-1 system, with its seven temperate rocky planets, offers unique possibilities for the study of this kind of object.

So far, no atmosphere has been conclusively detected any rocky exoplanet, despite the numerous observations made possible by the James Webb Space Telescope. Indeed, the traditional method, transmission spectroscopy, is contaminated by the inhomogeneities of the star that can mimic planetary atmospheric features via the Transit light source effect and which, for now, strongly limit the conclusions that can be made from observations. Another possibility to detect an atmosphere is to look for planet's emission: during secondary eclipse, the drop of luminosity corresponds to the thermal emission contribution of the dayside of the planet. Secondary eclipses have been observed for several rocky exoplanets, including TRAPPIST-1 b and c. Emission can also be observed by a phase curve, during a full orbit of the planet, allowing access to the nightside emission. A phase curve of TRAPPIST-1 b and c have been observed, making them the coldest planets to be observed with this technique.

We used atmospheric models, both 1D and 3D Generic Circulation Models, to produce synthetic observables and compare them to the data available. After showing the results of emission observations of TRAPPIST-1 b and c, we will present you our modeling work, and which conclusions

*Speaker

it can bring on the presence or absence of atmospheres on these planets.

Investigation of geochemical and prebiotic processes under hydrothermal conditions: a multiscale approach. Part I.

Valentin Moulay * [1], Fatma Ercicek *

[1], Grégoire Boé , Thierry Tassaing , Ellie Harra [2], Vassilissa Vinogradoff [3], Anaïs Cario [4], Samuel Marre [5]

[1] Institut de Chimie de la Matière Condensée de Bordeaux (ICMCB) – Université de Bordeaux, Institut polytechnique de Bordeaux, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France

[2] Rensselaer Polytechnic Institute (RPI) – United States

[3] Aix Marseille Université (AMU) – CNRS, Aix Marseille Université – France

[4] Université Bordeaux, ICMCB, UMR 5026, Pessac, France – Centre National de la Recherche Scientifique - CNRS, Bordeaux-INP – France

[5] Université Bordeaux, ICMCB, UMR 5026, Pessac, France – ICMCB, CNRS UMR 5026, University of Bordeaux, Bordeaux INP – 87 Avenue du Dr Albert Schweitzer, 33600 Pessac, France, France

Hydrothermal systems, such as deep-sea hydrothermal vents, are considered as plausible complex geochemical environments for the abiotic formation of the building blocks of life and ultimately for the emergence of life (1). Hydrothermal vents are complex porous structures involving thermal, physical and chemical gradients and reactive minerals with available chemical-thermal energy. In order to reproduce these complex conditions of these systems at lab scale, we have developed two experimental setups. (i) The first one is a transparent high-pressure flow reactor that allows the controlled formation and study of self-organized mineral structures (2) under high pressure and controlled temperature conditions. This innovative device enables direct *in situ* observation (Fig 1) and precise control of experimental parameters (multiphasic conditions, drying / imbibition processes, simulation of chemical and temperature gradients and chemical characteristic of hydrothermal systems). This macro scale aims to study the impact of the artificial mineral and the geometry of a entire hydrothermal vent structure on prebiotic chemistry. (ii) The second experimental platform is based on millifluidic sapphire reactors that can be used as a closed system (batch mode) or as a serial multi-millifluidic reactors integrated in a multi-temperature flow through set-up (flow mode). In these two modes, mineral-catalyzed reactions can be investigated under realistic conditions with ocean-like solutions equilibrated with volatiles at pressure. As with the first experimental platform, these transparent sapphires tubes enable direct *in situ* observations by infrared and Raman spectroscopy. Based on this second experimental setup, a wide range of reactions are being studied; for instance, solubilization of phosphate from apatite mineral under CO_2 pressure, the polymerization of amino acids depending on the nature of minerals and gas pressure as well as the formose reaction under unexplored conditions. These hydrothermal flow reactors are versatile and modular platforms that makes it easy to modify pressure, temperature, gas and mineral conditions. As a result, it is quite conceivable to attempt to simulate other environmental contexts that could bring together the conditions necessary for the emergence of life.

*Speaker

Connectivity of microbial communities in the Lake Tenndammen catchment, Svalbard

Katrina Munns [1,2], Tommaso Musso * [1,3], Savannah Schklartschik [1,4], Amy Zamora [1,5], Lea A. B. Kneissle [1,6], Sara Rassner [1,7], Arwyn Edwards [1,7]

[1] The University Centre in Svalbard (UNIS) – Norway
[2] Norwegian University of Life Sciences (NMBU) – Norway
[3] University of Naples Federico II - Università degli studi di Napoli Federico II (UNINA) – Italy
[4] Department of biological and environmental Sciences, University of Gothenburg (UGOT) – Sweden
[5] Department of Biomedical Informatics, Harvard Medical School (HMS) – United States
[6] University of Stuttgart = Universität Stuttgart – Germany
[7] Aberystwyth University – United Kingdom

Extreme factors like low temperatures, UV exposure, and nutrient limitation have sculpted Arctic freshwater systems and contributed to distinct and abundant microbial communities. In this study, we use 16S rRNA sequencing and whole-genome analysis to investigate the connectivity of the microbial community in the Lake Tenndammen catchment (Svalbard). A previously mapped inflow, a recently observed inflow, outflow, and lake water were sampled in addition to the lake's sediments. Results show the lake, outflow, and new inflow communities exhibit strong similarities in relative abundance of certain microbial families, like *Comamonadaceae*, which dominate most sample locations. The mapped inflow, however, shows significantly different microbial compositions, exhibiting a notable percentage of unclassified taxa (also known as "others" and "uncultured bacteria"). This could be due to differences in location pH and temperature. Additionally, the two inflows show similarity to the lake's sediment microbial composition. Put together, this implies that while the more recent inflow is likely the main source of influence for the water column community, the mapped inflow might be a more historically dominant input. Microbial distributions may also be influenced by variations in pH and sediment transport. Our results show a high degree of microbial connectivity throughout the majority of the catchment, interrupted in limited places potentially due to differences in location features.

*Speaker

L'hypothèse djehoutyenne : la rotation rétrograde de Vénus et ses implications pour l'habitabilité planétaire et l'exobiologie

Cyrille Olou * [1]

[1] Muséum national d'Histoire naturelle, Paris-Université d'Abomey-Calavi, Bénin – Ecole des Hautes Etudes en Sciences Sociales (EHESS) – France

L'hypothèse djehoutyenne : la rotation rétrograde de Vénus et ses implications pour l'habitabilité planétaire et l'exobiologie
Session : " Exoplanètes, climats et zone habitable " et aussi en lien avec " Exploration du système solaire ").

Résumé

Dodji Djehouty OLOU
Docteur transdisciplinaire (Astrobiologie et philosophie)
Sous la direction de Florence Raulin-Cerceau (MNHN, Centre Alexandre Koyré) et de Gervais Kisserzounon (Université d'Abomey-Calavi, Bénin)
Email : cyrilolou86@yahoo.fr – Tél. : 06 50 10 89 08 – Saumur, France

La rotation rétrograde de Vénus demeure l'une des énigmes majeures de la planétologie. Alors que la plupart des modèles privilégient un impact géant ou des effets gravitationnels externes, je propose une explication alternative : **l'hypothèse djehoutyenne**. Selon ce modèle, l'inversion progressive de la rotation vénusienne serait le résultat de la dynamique interne de son noyau fluide, qui, désynchronisé du manteau et amplifié par les marées solaires, aurait conduit à un basculement complet au fil de centaines de millions d'années.

Cette hypothèse a des implications directes pour l'**exobiologie** :

Elle redéfinit la notion d'**habitabilité** en ajoutant la stabilité rotationnelle comme critère essentiel, au même titre que la distance à l'étoile ou la composition atmosphérique.

Elle suggère que certaines exoplanètes en zone habitable pourraient perdre ou acquérir leur habitabilité en fonction de l'évolution de leur noyau.

Elle invite à rechercher de nouvelles **biosignatures dynamiques**, liées aux rythmes planétaires (durée du jour, cycles climatiques).
L'exemple de Vénus, planète sœur de la Terre devenue inhospitalière, illustre la nécessité de repenser la diversité des trajectoires planétaires. Tester cette hypothèse nécessitera de futures missions vers Vénus, mais aussi l'application de modèles numériques aux exoplanètes rétrogrades

*Speaker

déjà détectées.
En replaçant le " cœur " des planètes au centre de leur destin, cette approche ouvre un **nouveau paradigme exobiologique** : la vie dépend non seulement de l'étoile et de l'orbite, mais aussi du rythme intime imposé par les profondeurs planétaires.

Photochemistry in the Solar System : VUV absorption cross sections of solid thin films of glycine, alanine and xanthine

Juliette Pastore * , Léna Belair , Hervé Cottin , Kafila SaÏagh , Jodie Bellila , Fabien Stalport [1], Nicolas Fray , Nathalie Carrasco [2,3]

[1] Laboratoire Interuniversitaire des Systèmes Atmosphériques (LISA) – CNRS UMR 7583, Université Paris Cité and Université Paris Est Créteil, 61 avenue du Général de Gaulle, Créteil, 94010, France – France

[2] SYSTEME SOLAIRE - LATMOS – Laboratoire Atmosphères, Observations Spatiales – France

[3] Ecole Normale Supérieure Paris-Saclay (ENS Paris Saclay) – ENS Paris Saclay, ENS Paris-Saclay – France

Organic matter on small bodies of the Solar System chemically evolves under UV and VUV photolysis before their delivery to Earth or other planets. It is important to characterize how these chemical mechanisms could contribute to the origin of life. Therefore, since the 90s, experiments studying the evolution of organic matter in astrophysical environments, and more specifically to solar photons in the vacuum ultraviolet range (120-200 nm), are regularly conducted in low Earth orbit and implemented on various space platforms. For their understanding, space experiments have also to be compared to UV and VUV photolysis ground experiments.
In the frame of the IR-COASTER space experiment, currently exposed outside the International Space Station for 12 months, this work presents a ground study on amino acids. The objective of this study is to measure their photoabsorption cross-section in the VUV/UV range (120-300 nm). For this, thin solid deposits (10 to 100 nm thickness) of pure amino acids were prepared on MgF2 windows using a sublimation/recondensation method. The thickness of these deposits was measured using interferometric microscopy. These samples were analyzed using VUV spectroscopy to measure their absorption cross-section.
Such data will be used for the interpretation of the incoming results of the IR-COASTER experiment. As measured in our study, the photoabsorption cross section of molecules is a prerequisite for a proper kinetic modelling of space or laboratory photolysis experiments to extrapolate results to astrophysical environments.

*Speaker

Strecker Pathways and Mineral-Organic Co-evolution under Aqueous Conditions Simulating Carbonaceous Asteroids

Alexandra Perron * [1], Vassilissa Vinogradoff [1], Olivier Grauby [2], Grégoire Danger [1]

[1] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France

[2] Centre Interdisciplinaire de Nanoscience de Marseille (CINaM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France

Organic matter (OM) is a key component of life on Earth, but its origin and transformation across the Solar System remain unresolved. Knowledge mainly stems from meteorite studies, remote sensing, and *in situ* lander analyses. Yet, these provide only fragments of OM history, as its original composition was profoundly altered over time. Carbonaceous chondrites (CCs), primitive meteorites from undifferentiated asteroids, contain diverse OM families (*e.g.*, amino acids, sugars) (1) and show evidence of aqueous alteration, revealed by secondary minerals like phyllosilicates (2). The mutual influence of OM and minerals in such contexts remains poorly understood (3),(4). This study investigates the co-evolution of organic and mineral phases under aqueous conditions through controlled experiments simulating asteroidal alteration.
For this purpose, chondritic analogues were altered under anoxic aqueous conditions (80 ◦C, water/rock ratio = 10, 1–42 days). We examined both (i) the mineralogical evolution of peridot micrograins (Mg-rich olivine, (Mg,Fe)SiO), which alter into phyllosilicates, using infrared spectroscopy, electron microscopy and X-ray diffraction analyses, and (ii) the chemical evolution of primary OM precursors (formaldehyde, ammonia, cyanide ions), known to form amino acids via the Strecker reaction, using high performance liquid chromatography coupled to mass spectrometry. To link both aspects, CHNS microanalysis was used to quantify carbon and nitrogen associated with phyllosilicates, providing insights into OM entrapment within mineral layers or its adsorption onto mineral surfaces.

(i) Solid-phase analyses revealed stepwise peridot transformation into serpentine- and talc-like phyllosilicates, with Fe enrichment after 1 day and then Mg after 3–7 days. CHNS analysis shows increasing carbon incorporation into phyllosilicates with decreasing NH input, while nitrogen trapping remains constant, pointing to selective organic entrapment. (ii) Liquid-phase analyses identified several amino acid and hexamethylenetetramine (HMT) compounds. In mineral-based experiments, the formation of most amino acids (*i.e.*, glycine, alanine, serine) was inhibited, with the exception of sarcosine (notably after 42 days). HMT formed in all mineral-based experiments within the first 7 days, even without added NH, whereas in mineral-free experiments, it was only obtained with CHO and NH as starting reactants. This likely reflects Fe^{2}-catalyzed KCN hydrolysis, which increases NH availability and favors HMT formation.

These findings demonstrate that minerals strongly influence organic evolution, altering amino acid and HMT yields, and are themselves affected by organic inputs, which modify the physicochemical properties (*e.g.*, composition, morphology) of phyllosilicates (5). This reciprocal

*Speaker

feedback underscores the dynamic co-evolution of organics/minerals during aqueous alteration on primitive bodies.

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Social Sciences and Exobiology

Perig Pitrou * [1,2]

[1] Maison Française d'Oxford, CNRS (MFO) – United Kingdom
[2] Equipe Anthropologie de la vie (Collège de France - Université PSL) – Collège de France, EHESS, CNRS – France

At a time when the search for life beyond Earth is opening up astonishing new perspectives, this round table invites us to explore how this quest challenges and enriches our reflections on humanity's place in the universe. To shed light on this contemporary question, the event will bring together perspectives from anthropology, history, philosophy, and exobiology.
The discovery of the first exoplanets in the 1990s marked a major breakthrough in the search for traces of life in the universe. This new way of looking at the cosmos has also transformed our perception of our own planet. Such a shift in perspective lies at the heart of exobiology, which studies both the conditions that enabled life to emerge on Earth and those that might exist on other planets. It also invites reflection on how humans conceive of their place in the universe and within the broader realm of living beings. In dialogue with the natural and cosmic sciences, the social sciences and the humanities examine the diversity of historical and cultural contexts through which the question of the origins of life can be approached.
Organized and chaired by: Périg Pitrou (CNRS – Maison Française d'Oxford, and Laboratoire d'anthropologie sociale, Collège de France, Université PSL),
in collaboration with Cécile Peltier (Revue *Sciences Humaines*). With: Florian Métral, CNRS, Centre André-Chastel, Sylvie Allouche, Université Catholique de Lyon, Adrienne Kish, Muséum National d'Histoire Naturelle

*Speaker

Exotic orbital architectures as planetary system-scale technosignatures

Sean Raymond * [1]

[1] Laboratoire d'Astrophysique de Bordeaux – CNRS : UMR5804, CNRS – France

A stable planetary system could be considered a technosignature, as long as it appears to be non-natural. Such systems could come in different flavors. Multi-resonant planetary systems naturally encode sequences of integers. We used N-body simulations to encode sequences of mathematical importance (e.g. the Fibonacci sequence) into planetary systems, and then showed that they remain dynamically stable for the age of the Universe, even surviving a Sun-like star's post-main sequence evolution. Some planetary systems could be even more exotic. Using celestial mechanics, I will show how up to 42 Earth-mass planets can stably share the same orbit around a Sun-like star. A ring of co-orbital planets is remarkably resilient – if it is perturbed, for example by a rogue planetary embryo, it can transition to a different dynamical state, in which each planet undergoes 'horseshoe oscillations' with its immediate neighbors. A single system can contain up to 400 Earth-mass planets on concentric rings of planets in orbit within the habitable zone of a Sun-like star, and remain stable for billions of years. Such unusual planetary systems are dynamically stable, but it is hard to imagine how they could form in nature. If carefully-placed, their orbital planes can be aligned with the Galactic plane, making them easy to detect from a distance and ideal technosignatures.

*Speaker

Simultaneous Analysis of Sugar and Amino Acid enantiomers in Ryugu and Orgueil Samples

Manuel Robert * [1], Vanessa Leyva , Jana Bokova [1], Cornelia Meinert [1]

[1] Institut de Chimie de Nice (ICN) – Université de Nice Sophia-Antipolis – France

The origin of life on Earth is intrinsically linked to the availability of essential biomolecules, such as amino acids and sugars. Understanding the processes that led to the emergence of these chiral molecules is crucial for elucidating the prebiotic chemistry that may have contributed to the development of life. In living organisms, sugars and amino acids exhibit homochirality, with the dominance of the d–form for sugars and the l–form for amino acids. One of the main hypotheses suggests that the exogenous delivery not only supplied prebiotic organic compounds but may have also influenced the selection of the life's handedness This idea is supported by the detection of small enantiomeric excesses of the l–form of amino acids in meteorites (1).
However, studying meteorites on Earth presents a major limitation: terrestrial contamination. To overcome this, samples from asteroids Ryugu and Bennu(2-3), collected and preserved under controlled conditions, offer an unprecedented opportunity to investigate extraterrestrial chiral molecules with minimal alteration. Since abiotic synthesis typically produces racemic mixtures, any slight deviation from this balance would provide a strong indication of an extraterrestrial origin.

To explore this question, we developed a methodology combining ultrasonic extraction, ion-exchange chromatography, and high-sensitivity enantioseparation using GC×GC–ToF–MS (4). This approach enabled the simultaneous characterization of amino acids and sugars in extraterrestrial material. Our analysis led to the first detection and enantiomeric separation of two C5 sugars-arabinose and xylose-in the combined aggregate samples A0478 and A0483 from asteroid Ryugu, as well as the identification of all four aldopentoses and ribulose, a ketopentose, in a sample from the Orgueil carbonaceous meteorite. In addition, nonproteinogenic amino acids were detected in both Orgueil and Ryugu, with enantiomeric excesses close to racemic, consistent with their extraterrestrial origin.

These findings expand the known extraterrestrial inventory of sugars and amino acids, strengthening the hypothesis that the exogenous delivery of organic compounds contributed to the emergence of life on Earth.

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*Speaker

Atmospheric chemistry of temperate exoplanets: a synergistic approach combining laboratory experiments, modeling, and observation to characterize habitability

Ori Sohier * [1], Yassin Jaziri [1], Ludovic Vettier [1], Audrey Chatain [1], Louis Maratrat [1], Nathalie Carrasco [1,2]

[1] SYSTEME SOLAIRE - LATMOS – Laboratoire Atmosphères, Observations Spatiales – France
[2] Ecole Normale Supérieure Paris-Saclay (ENS Paris Saclay) – ENS Paris Saclay, ENS Paris-Saclay – France

Characterizing the atmospheres of small, temperate exoplanets addresses a major scientific challenge. The James Webb Space Telescope offers us the opportunity to study the atmospheric composition of temperate exoplanets as small as mini-Neptunes. Recent observations of K2-18b and TOI-270d have revealed atmospheres rich in hydrogen and carbon compounds. Methane and carbon dioxide have been detected in significant amounts. Moreover, the presence of haze is suggested by these observations, indicating that complex chemistry may be taking place in these atmospheres.
However, our understanding of the chemistry governing these atmospheres remains largely unconstrained. This is why modelling and laboratory experiments are needed to better understand these observations. Developing our knowledge of these atmospheres will enable us to characterize their habitability. In this context, we have carried out parallel experimental, 0D and 1D numerical simulations of the out-of-equilibrium chemistry occurring in the upper layers of temperate exoplanets, in order to better understand the latest observational data.

Experimental simulations were carried out using two different and complementary devices, one a cold plasma reactor, the other a photochemical reactor. The cold plasma reactor features a Maxwellian distribution of electron energy, over a wide range of wavelengths and with relatively high intensity. The photochemical reactor uses a hydrogen flow lamp as an irradiation source, providing an almost monochromatic photon flux around Lyman-alpha, but less intense than plasma. These set-ups therefore complement each other in the energy distribution of the irradiation they provide, enabling us to take an energy-dependent approach to investigate the influence of the stars type on photochemistry, and the effect of the global spectra in relation to the Lyman-alpha contribution.

We used mass spectrometry and infrared spectroscopy to monitor the evolution of gas mixtures representative of sub-Neptune atmospheres across a range of C/O ratios (0.5 to ∞) and metallicities ($5\times$ to $50\times$ solar). The 0D photochemical model helps identify key chemical pathways leading to the formation of photochemical products. The 1D model evaluates their vertical distribution and detectability in atmospheric spectra.
Our results highlight the importance of metallicity and C/O ratio in determining the abundance

*Speaker

and observability of molecules such as hydrocarbons and oxygenated organic compounds. The oxidized compounds could be precursors of photochemical condensates of prebiotic interest. By integrating laboratory data and modeling, our approach improves the interpretation of current and future spectroscopic data from JWST and other missions.

Study of the degradation of biosignatures under simulated Martian irradiation

Berke Santos * [1,2], Frédéric Foucher [1], Aurélien Canizarès [1], Paul Sigot [1], Olivier Wendling [1], Aurelien Bellamy [1], William Hate [1], Assane Fall [2], Thierry Sauvage [1]

[1] CNRS, Conditions Extrêmes et Matériaux : Haute Température et Irradiation (CEMHTI) – Université d'Orléans, Institut de Chimie - CNRS Chimie, Centre National de la Recherche Scientifique – France
[2] Université d'Orléans (UO) – Université d'Orléans – France

Approximately 4 Ga, Mars was habitable due to the presence of liquid water on its surface. However, the planet's environmental conditions began to change throughout the Hesperian period, and, as a result, a decrease in atmospheric pressure occurred that ultimately led to the loss of surface liquid water. As such, the surface of Mars has become largely inhospitable to any form of life. Nonetheless, biogenic remains of a past life on the planet's surface (e.g., microbialites, kerogen-bearing carbonaceous microfossils, organic molecules, pigments) could potentially be found in ancient rocks (the absence of active plate tectonics on Mars would have guaranteed their preservation). The Perseverance rover (NASA Mars 2020 mission) is presently searching for these biosignatures in the Jezero crater, on Mars, and has recently discovered iron phosphate and sulfide minerals in organic carbon-bearing fine-grained sedimentary rocks within the Neretva Vallis.
As a direct consequence of Mars' low-pressure atmosphere and lack of a magnetosphere, the Martian surface is heavily irradiated by Solar Energetic Particles (SEPs) and Galactic Cosmic Rays (GCRs). These energetic particles are able to penetrate deep layers of the surface, which are significantly below the UV-exposed superficial layers (SEPs: several centimeters to _˜1.5 meters; GCRs: > 5 meters). Thus, these particles could have easily degraded potential biosignatures, found in the subsurface, over time (several Ga). With the objective of increasing the chances of detecting traces of life and/or prebiotic molecules, the Rosalind Franklin rover (ESA/NASA ExoMars mission) will be equipped with a drill capable of collecting samples from depths of up to two meters below the surface.

The objective of this project (PhD thesis) is to simulate and evaluate the combined effect of SEP and GCR irradiation (focusing on Proton irradiation) over several Ga on fossiliferous Mars analogue rocks, as well as to study the protective effect(s) of different minerals on the preservation and subsequent detection of molecular biosignatures. Therefore, the project's results could be highly relevant for the planning of the ExoMars mission, by providing estimates of the depths at which various biosignatures of interest may be preserved.

A substantial portion of the work will be devoted toward Monte Carlo (MC) simulations of the irradiation of the upper layers of the Martian surface, utilizing the Geant4 toolkit. These numerical simulations will help plan and validate the ensuing laboratory experiments. Analogue samples from the ISAR (International Space Analogue Rockstore) collection in Orléans (France), as well as artificial organo-mineral mixtures analogous to the Martian regolith, will be used. These samples will be exposed to proton irradiation at the CEMHTI Pelletron (CNRS-Orléans, France) - light ions electrostatic accelerator capable of accelerating protons to energies

*Speaker

up to 3 MeV. The flux of protons created by the accelerator will enable the exposure of samples to cumulative radiation doses equivalent to several Ga of Martian irradiation within a much shorter timeframe (hours/days).

Following the irradiation experiments, the samples will be characterized *in situ* and *ex situ*. For *in situ* characterization, a unique Raman spectrometer, developed by the CEMHTI team, will be employed – this novel device allows for sample analysis inside the irradiation chamber. Additionally, NRA (Nuclear Reaction Analysis), RBS (Rutherford Backscattering Spectrometry), ERDA (Elastic Recoil Detection Analysis), and PIXE (Particle Induced X-ray Emission) will be used to further characterize the samples (ion beam analysis techniques). High resolution Raman spectrometers, atomic force microscopes, electron microscopes, as well as numerical microscopes will aid in the *ex situ* characterization of the irradiated samples.
Overall, the project aims to provide critical insights regarding the effects of high-energy proton irradiation, from both SEPs and GCRs, on potential biosignatures embedded in the Martian regolith over several Ga. The comprehensive approach of this research – including MC simulations, methodical sample preparation, and proton exposure assays – should also provide accurate data regarding the depths at which certain biosignatures of interest could still be preserved. These results could help shape upcoming Mars missions, as is the case of ExoMars, and bring us one step closer to discovering unambiguous proof of (past or present) life on Mars.

Altération aqueuse d'analogues chondritiques : co-evolution SOM-IOM entre héritages interstellaires et nébulaires.

Coline Serra * [1,2], Vassilissa Vinogradoff [1], Grégoire Danger [1], Philippe Schmitt-Kopplin [2,3]

[1] Physique des interactions ioniques et moléculaires (PIIM) – Aix Marseille Université, Centre National de la Recherche Scientifique – France
[2] Helmholtz Zentrum München = German Research Center for Environmental Health (HMGU) – Germany
[3] Technische Universität München, Analytische Lebensmittel Chemie (TUM) – Germany

Les chondrites carbonées (CCs), fragments d'astéroïdes primitifs tombés sur Terre, constituent une archive précieuse de la matière organique (MO) ayant potentiellement contribué à l'enrichissement prébiotique de la Terre primitive. Cette MO, pouvant atteindre 4 % en masse, se divise en deux fraction après extraction aux solvants classiques : une fraction soluble (SOM), composée de petites molécules organiques, et une fraction insoluble (IOM), constituée de macromolécules riches en hétéroatomes. L'origine de cette MO est complexe et résulte de sources et de processus multiples comme par exemple un héritage de réactivité dans les glaces interstellaires froides, mais aussi une synthèse à haute température dans la nébuleuse protosolaire (Caselli and Ceccarelli, 2012), que nous avons considérés dans cette étude. Déterminer l'origine de cette MO et son évolution permet ainsi de mieux comprendre la diversité moléculaire présente dans les objets extraterrestres et sur les autres surfaces planétaires.
Des analogues expérimentaux reproduisant ces deux héritages ont été développés en laboratoire : d'une part, des résidus organiques issus de la photoréactivité de glaces interstellaires, chimiquement proches de la SOM des CCs (Danger et al., 2013) ; d'autre part, les analogues appelés *Nebulotron,* formés dans des plasmas ionisés et présentant des caractéristiques similaires à l'IOM des CCs (Bekaert et al., 2018). Ces matériaux sont susceptibles d'avoir été accrétés ensemble au sein des corps parents des météorites, où ils ont ensuite subi des processus secondaires, comme l'altération aqueuse. Ce phénomène d'altération aqueuse se définit par la circulation locale d'un fluide aqueux dans le corps parent induisant une réactivité avec l'eau qui affectent non seulement la minéralogie, mais également la composition chimique. Dans ce travail, nous avons soumis séparément et en mélange ces deux analogues organiques à des conditions hydrothermales simulant l'évolution au sein des corps parents. Les produits ont été caractérisés par spectrométrie de masse à haute résolution (fraction soluble) et spectroscopie infrarouge (fraction insoluble).

Nos résultats révèlent que l'altération aqueuse modifie profondément la composition élémentaire et structurale des organiques, avec des variations notables des rapports H/C et N/C. Dans le cas de l'altération du résidus interstellaire, les composés azotés sont rapidement transformés, tandis qu'une oxygénation accrue se poursuit sur des temps d'altération plus long comme cela avait déjà été démontré dans une précédente étude (Danger et al., 2021). Dans le cas du Nébulotron on observe la perte drastique de molécules de type CHNO à faible O/C, tandis que sa fraction insoluble reste globalement inchangée. Les expériences des mélanges mettent cependant en évidence une co-évolution synergique : les transformations observées ne se résument pas à

*Speaker

la somme des altérations individuelles avec plus de 10% de nouvelles compositions uniquement présentes dans le cas du mélange.

Ces résultats suggèrent un transfert de l'une fraction à l'autre et dans tous le cas des évolutions notables dû à un processus d'altération aqueux. Des processus d'évolution chimique comparables ont pu avoir lieu dans les corps parents des météorites, affectant donc différemment la SOM de l'IOM, et l'une pourrait en partie dériver de l'autre au cours des épisodes d'altération plus ou moins long et chaud. Nos expériences ouvrent ainsi la voie à de nouvelles investigations, afin de mieux contraindre le lien éventuel entre SOM et IOM dans les CCs, et d'explorer le rôle du degré d'altération aqueuse dans la transformation et/ou la perte de la matière organique.

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Peut-on, et doit-on, aller sur Mars ?

Michel Viso * [1], Lucie Poulet [2], Cyprien Verseux [3]

[1] Centre National d'Études Spatiales [Paris] (CNES) – Retired, Retired – France
[2] Université Clermont Auvergne (UCA) – Université Blaise Pascal, Clermont-Ferrand – France
[3] Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation (ZARM) – Germany

Lors de son discours d'investiture présidentielle du 20 janvier 2025, le président Donald Trump a affirmé qu'un drapeau américain serait bientôt planté sur Mars par un être humain. Cette annonce a initié de vifs débats sur la faisabilité et la pertinence des missions habitées vers la planète rouge.
De telles missions étaient depuis longtemps envisagées par les nations spatiales, bien que sans objectif clair ni calendrier précis. Elles sont en passe de devenir technologiquement faisables. Des choix pragmatiques doivent donc être faits quant aux types de mission à soutenir, et à ceux auxquels s'opposer. La polarisation des débats nuit malheureusement à la prise de décisions adéquates et à la sérénité des discussions.

Plus de soixante experts européens de renom se sont réunis pour examiner des scénarios de missions martiennes allant de l'exploration robotique à court terme aux projets de terraformation. Chacun de ces scénarios a été analysé à travers un large éventail de disciplines – telles que l'ingénierie, la biologie, la médecine, le droit ou l'éthique – pour circonscrire ce qui est envisageable et contribuer à évaluer ce qui est souhaitable.
Leurs principales conclusions seront présentées afin d'embrasser l'ensemble des données disponibles, des questions soulevées, les discuter et favoriser ainsi la formation d'opinions éclairées.

*Speaker

Interaction of water ions with Titan aerosol analogues

Véronique Vuitton * [1], Filip Matuszewski [2], Elsa Hénault [3], Richard Rácz [4], Laurène Flandinet [5], Thomas Gautier [6], Eric Quirico [7], Francois-Regis Orthous-Daunay [8], Rosario Brunetto [9], Alicja Domaracka [10], Hermann Rothard [10], Zoltán Juhász [11], Béla Sulik [11], Duncan V. Mifsud [4], Sandor Biri [4], Gergo Lakatos [4,12], Péter Herczku [4], Sandor Kovács [4], Nigel Mason [4,13], Fabien Stalport [14], Herve Cottin [15]

[1] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[2] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[3] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Centre National de la Recherche Scientifique, Université Grenoble Alpes – France
[4] Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI) – Hungary
[5] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[6] LATMOS – Université de Versailles Saint-Quentin-en-Yvelines (UVSQ) – France
[7] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[8] Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), France – Université Grenoble Alpes, Centre National de la Recherche Scientifique - CNRS – France
[9] Université Paris-Saclay, CNRS, Institut d'astrophysique spatiale (IAS), France – Université Paris-Saclay,Sorbonne Universités – France
[10] Centre de recherche sur les Ions, les MAtériaux et la Photonique – Normandie University, 14032 Caen, France ; UNICAEN, CIMAP, 14032 Caen, France ; ENSICAEN, 14050 Caen, France ; CEA, UMR6252, 14070 Caen, France ; and CNRS UMR6252, 14050 Caen, France – France
[11] Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI) – H-4001 Debrecen, PO Box 51, Hungary
[12] Institute of Chemistry, University of Debrecen, Debrecen – Hungary
[13] Centre for Astrophysics and Planetary Science, School of Physics and Astronomy, University of Kent, Canterbury – United Kingdom
[14] Univ Paris Est Créteil and Université Paris Cité, CNRS, LISA, Créteil, France – Univ Paris Est Créteil and Université Paris Cité, CNRS, LISA, Créteil, France – France
[15] Univ Paris Est Créteil and Université Paris Cité, CNRS, LISA, Créteil, France – Centre National de la Recherche Scientifique, Université Paris-Est Créteil Val-de-Marne - Paris 12, Université Paris Diderot - Paris 7 – France

The Cassini-Huygens mission detected macromolecules, attributed to polycyclic aromatic (nitrogen bearing) hydrocarbons (PANHs) in Titan's upper atmosphere and energetic water ions, originating from Enceladus' geysers, in the vicinity of Titan. When entering Titan's atmosphere, a fraction of the water ions must collide with the macromolecules but the impact on the atmospheric chemistry is unclear.
In this work, we have irradiated samples of adenine (C5H5N5), a simple heterocyclic aromatic molecule, with energetic water ions, at ion accelerators located in France and Hungary. During the irradiation, we monitored the infrared absorption spectra of the adenine samples and we

*Speaker

measured the material sputtered into the gas phase with mass spectrometry. We subsequently obtained the molecular content of the samples at the end of the irradiation with a very high-resolution mass spectrometer.
We show that the irradiation of the samples leads to their destruction, through both sputtering of light species into the gas phase and formation of new macromolecules in the solid phase. N2, small nitriles and hydrocarbons, are detected in the gas phase, throughout the irradiation, while intact adenine is only detected at the on-set of the irradiation. At the same time, thousands of molecules with m/z up to 500 are detected in the sample after irradiation and are attributed to PANHs. These experimental results suggest that ion deposition in Titan's atmosphere may play a role in both the replenishment of trace gas species and the rapid molecular growth occurring at high altitude. These processes will be implemented in a photochemical-microphysical model.