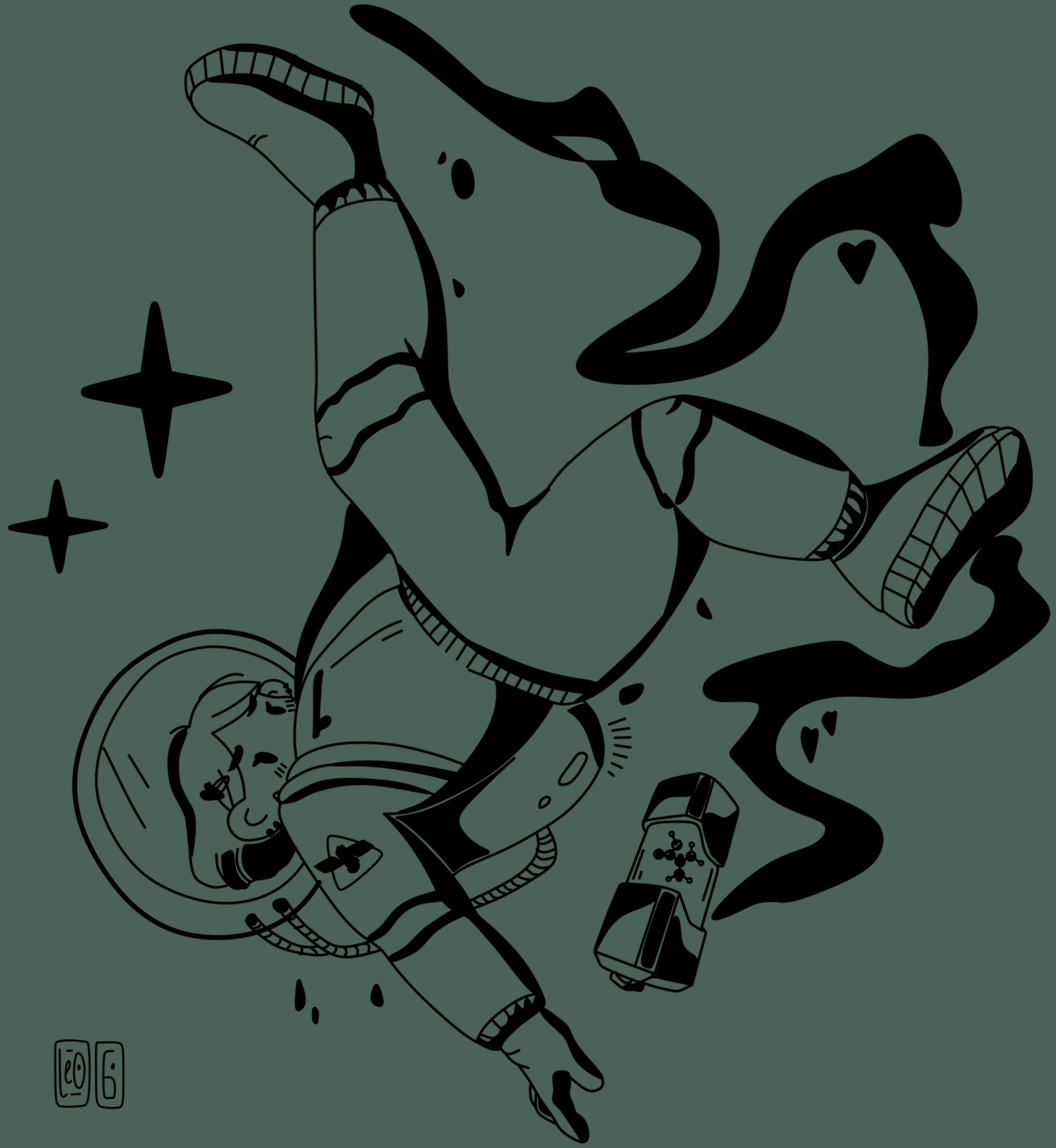


LIVRET DE CONFÉRENCE*

EXOBIOLOGIE JEUNES CHERCHEURS

EXOBIOLOGIE JEUNES CHERCHEURS

17-19 OCTOBRE 2022
SALLE DE L'ESPACE - CNES, PARIS

*Faites un geste pour la planète, n'imprimez pas ce document

La conférence Exobiologie Jeunes Chercheurs (EJC) est dédiée aux jeunes chercheurs impliqués dans les domaines et thématiques de recherche s'interrogeant sur les origines et évolutions de la vie dans l'Univers. Quatre éditions en 2013, 2015, 2017 et 2019 se sont déroulées avec succès et ont permis une meilleure visibilité de cette communauté exobiologiste ainsi qu'une meilleure intégration des jeunes chercheurs. Cette année nous proposons l'édition 2022 de ces rencontres articulée autour de thèmes balayant la formation du système solaire jusqu'à la vie primitive. Cet événement aura lieu du 17 au 19 Octobre 2022, à la Salle de l'Espace du CNES à Paris. La tenue d'une telle conférence permet aux jeunes chercheurs de présenter leurs travaux de recherches devant un public averti et donc de contribuer au rayonnement de cette communauté interdisciplinaire.

Les thèmes abordés lors de ces journées seront, de façon générale, ceux des origines de l'Univers, du Système Solaire et de la Terre, de leur devenir, de l'apparition de la vie sur Terre et de son existence ailleurs dans l'Univers.

Nous tenons à remercier sincèrement tous nos partenaires pour leur contribution. Sans eux, l'édition 2022 de la conférence Exobiologie Jeunes Chercheur n'aurait pas pu voir le jour. Un grand merci à Léa Pader-Lucon pour les visuels de cette conférence.

Un remerciement tout particulier à Hervé Cottin, Vassilissa Vinogradoff, Muriel Gargaud pour leur soutien et un grand merci Fabien Stalport pour son aide dans la gestion des finances.

Heure	Lundi	Mardi	Mercredi
9h		Des galaxies au Système Solaire	Mars et petits corps du Système Solaire
10h			
11h		Pause	Pause
		Des galaxies au Système Solaire	Extraction de la Matière Organique
12h		Astrobiologie & Philosophie	
13h		Déjeuner	Déjeuner
	Accueil		
14h	Les mondes glacés	Extrêmophiles & Paléosignatures	La recherche d'une vie extraterrestre : un problème anthropologique
15h			Pause
16h	Pause	Pause	Table ronde vulgarisation
17h	Matière Organique dans le Système Solaire	Briques élémentaires du vivant	Remise des prix & clôture
18h	Session poster & apéritif		
19h			Soirée Astro Péniche

Lundi 17 octobre 2022: Après-midi

13h30-14h	**Arrivée et Accueil**
14h-14h20	Gabriel Tobie (*invité*), Habitability of ice-covered ocean worlds in the Solar system
14h20-14h40	Valentin Moulay, Preparation of in-situ analyses of icy moons: characterization of analog samples from Lake Tirez, La Mancha, Spain
14h40-15h	Maryse Napoleoni, Analog experiments for the detection of bacterial biosignatures in ice grains from ocean worlds
15h-15h20	Arnaud Sanderink, OLYMPIA-LILBID: A new Laboratory Setup to Calibrate Spaceborne Hypervelocity Ice Grain Detectors using High-Resolution Mass Spectrometry
15h20-15h40	Louis Maratrat, Interactions between Titan aerosols and surface liquid phases
15h40-16h10	**Pause**
16h10-16h30	Tania Le Pivert-Jolivet, Grain scale heterogeneities in Ryugu samples: a key to understand aqueous alteration and space weathering
16h30-16h50	Boris Laurent, Tarda and Tagish Lake: Possible vestiges of a common, distant asteroid
16h50-17h10	Laure Bejach, Multi-analysis comparison between asteroid Ryugu samples returned by the Hayabusa2 space mission and Antarctic Micrometeorites (AMMs)
17h10-17h30	Adriana Clouet, Characterization of Insoluble Organic Matter (IOM) analogues prior to high pressure experiments, and comparison with meteoritic IOM
17h30-17h50	Marceau Lecasble, Hydrogen isotope exchange between polycyclic aromatic hydrocarbons and water during aqueous alteration events on carbonaceous asteroids
18h-19h	**Session poster et apéritif**

Mardi 18 octobre 2022: Matin

9h-9h20	Nadège Lagarde (*invité*), De Apollo à Gaia : Comprendre l'évolution chimique des étoiles et de notre Galaxie
9h20-9h40	Gabriel Meletti, Amplitude Modulations in Strato-Rotational Instabilities (SRI) with applications to star formation in accretion disks
9h40-10h	Audrey Andreu, Water deuteration in solar-type star forming regions
10h-10h20	Yohann Layssac, Interstellar ices: the first chemistry reactor of star forming regions
10h20-10h40	Sarah Joiret, Constraints on the timing of cometary bombardment relative to Earth's growth
10h40-11h10	**Pause**
11h10-11h30	Yassin Jaziri, Dynamics of the Great Oxidation Event from a 3D photochemical-climate model
11h30-11h50	Mathilde Poveda, High temperature VUV cross section measurements of CO and application for the study of hot exoplanets
11h50-12h10	Zoé Perrin, Heterogeneous chemistry on Titan : Evolution of Titan's tholins through time with gas phase chemistry
12h10-12h30	Cyrille Jeancolas, Breakthrough results in Astrobiology: is 'high risk' research needed?
12h30-14h	**Déjeuner**

Mardi 18 octobre 2022 : Après-midi

14h-14h20	Anaïs Cario (*invité*)
14h20-14h40	Chloé Truong, Biosignatures of hyperthermophilic archaea in sulfur-rich hydrothermal vents
14h40-15h	Alexandra Perron, Thermal analyses of biocarbonates as part of the search for traces of life in planetary environments
15h-15h20	Laurane Fogret, Stromatolites: 3.5 billion years of exceptional paleoenvironmental archives
15h20-15h40	Mathilde Bon, Molecular characterization of G. Prisca microfossils by secondary-ion and laser desorption-ionization mass spectrometry techniques
15h40-16h10	**Pause**
16h10-16h30	Louis Ter-Ovanessian, Pyrimidines in kit: How to assemble the uracil skeleton at the origins of life?
16h30-16h50	Yuanyuan He, Influence of aqueous alteration on the evolution of amino acids
16h50-17h10	Timothée Devergne, Combining machine learning and ab initio enhanced sampling methods for prebiotic chemical reactions
17h10-17h30	Adeline Garcia, Orbitrap and GC-Orbitrap for in situ analyses: clues from laboratory experiments
17h30-17h50	Vanessa Leyva, On the origin of life homochirality: development of an integrative workflow for the reliable enantioselective analysis of amino acids and sugars in astrophysical samples

Mercredi 19 octobre 2022 : Matin

9h-9h20	Sylvain Bouley (*invité*)
9h20-9h40	Léna Jossé, Laboratory analysis of Ryugu and Bennu samples: a multi-scale look at primitive samples
9h40-10h	Virgile Malarewicz, Revisiting Zircons in the Martian Regolith Breccia Northwest Africa 7533
10h-10h20	Giovanni Poggiali, Astrobiology on Phobos and Deimos: preparatory studies and future investigation from MIRS instrument on board the JAXA Martian Moon eXploration sample return mission
10h20-10h40	Antonin Wargnier, Synthesis of a spectral Phobos regolith analog in preparation of the Martian Moon eXploration mission
10h40-11h10	**Pause**
11h10-11h30	Maxime Pineau, Opaline silica: a mineralogical best friend for studying paleoclimates and exobiological purposes beyond Earth?
11h30-11h50	Rachel Gonthier, Extraction method optimisation of organic molecules from complex samples under MOMA instrument analytical conditions of the Exomars mission (ESA)
11h50-12h10	Ramzi Timoumi, New strategies for extracting biomarkers in 'astrobiological' environments: towards in-situ analysis
12h10-12h30	David Boulesteix, Influence of pH and salts on the DMF-DMA derivatization for GC-MS analysis of potential bioindicators on extraterrestrial surfaces (Mars, Titan, Europe, Enceladus,…)
12h30-14h	**Déjeuner & Vote de la meilleure présentation et du meilleur poster**

Mercredi 19 octobre 2022: Après-midi

14h-15h	Perig Pitrou (invité), The search for extraterrestrial life: an anthropological problem
15h-15h30	**Pause**
15h30-17h	Anna Niemiec, Robin Isnard, Anthony Guimpier, Table ronde "Vulgarisation scientifique"
17h-18h	Remise des prix & Clôture
19h	**Soirée de Gala : Astro Péniche**

La soirée de Gala se situe à la péniche "Le Marcounet", Port des Célestins, Quai de l'hôtel de ville, 75004 Paris. L'endroit est accessible à pied depuis le CNES en 20 minutes. Descendez la rue du Pont Neuf jusqu'à la Seine (ne traversez pas) et longez les Quais à votre Gauche. La péniche se situe en contrebas au niveau de l'arrêt de Métro 7 Pont Marie.

En métro :

Centre national d'études spatiales (CNES)
2 Pl. Maurice Quentin, 75001 Paris

À pied : 6min - 450m

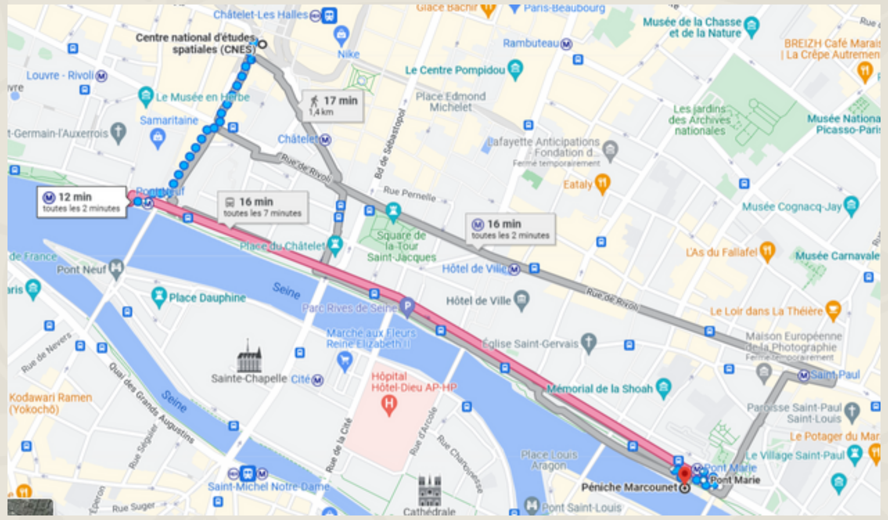
Pont Neuf

Métro : 7 Mairie D'ivry

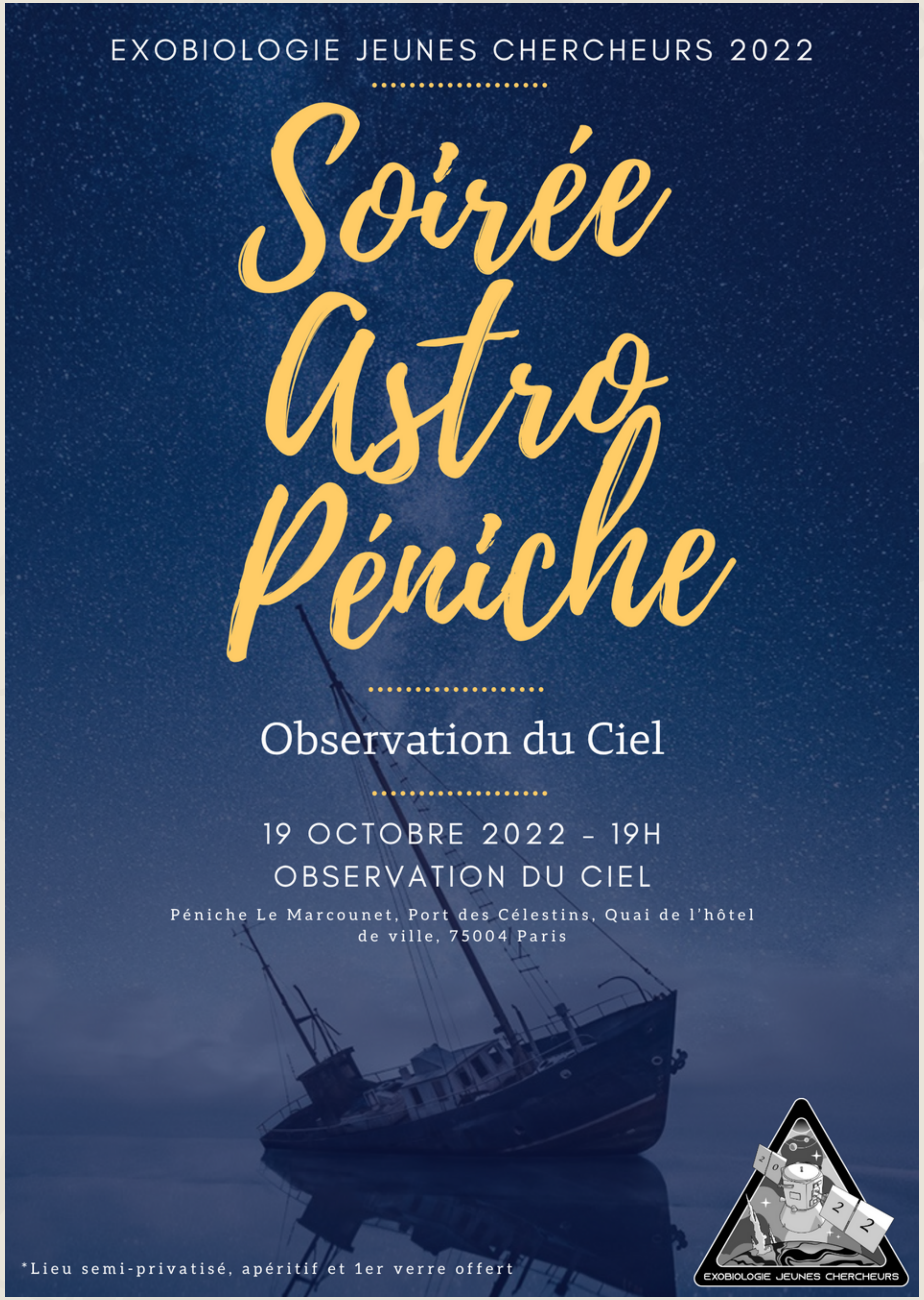
Pont Marie

À pied : 3min - 220m

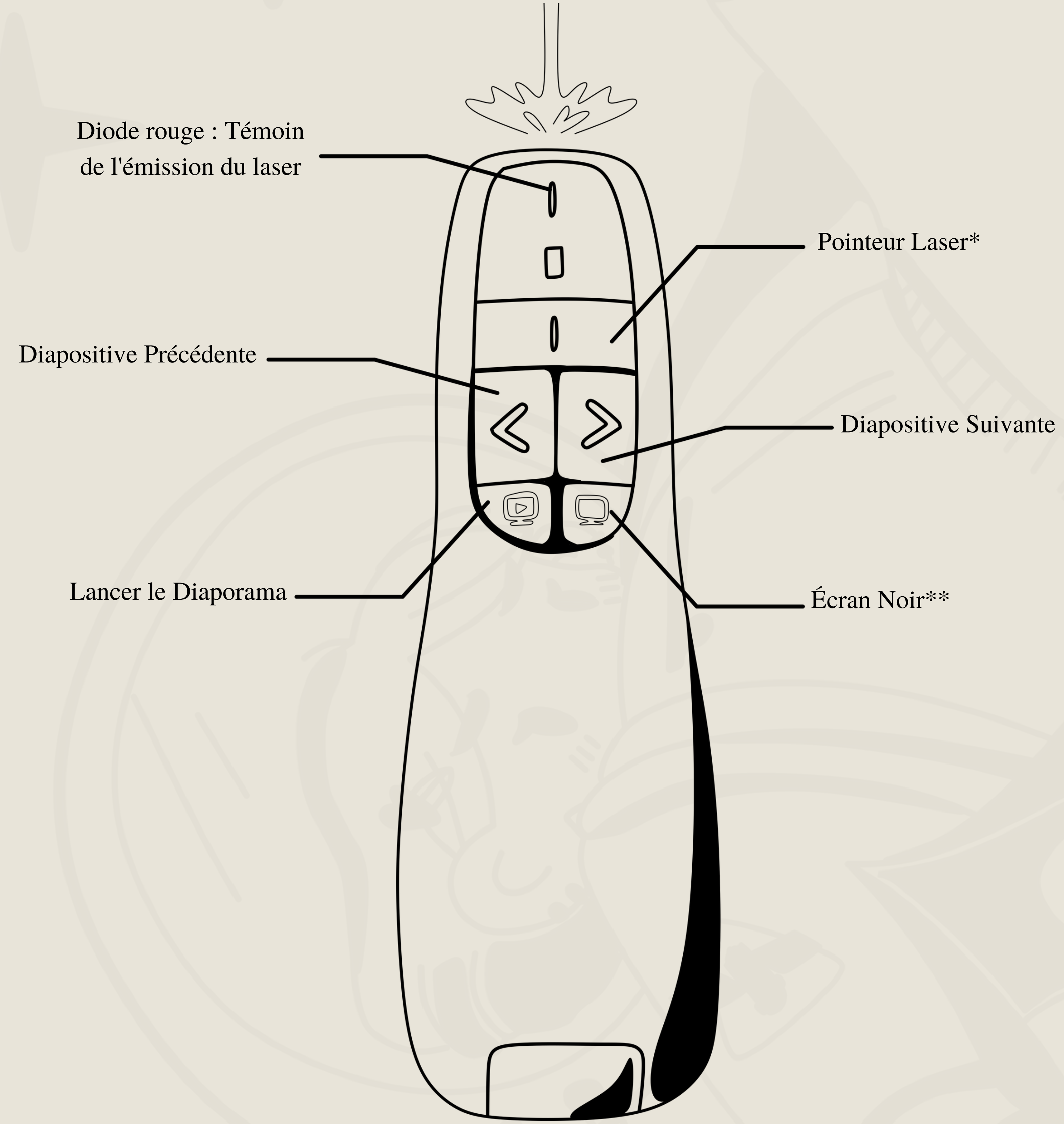
Péniche Marcounet
Port des Célestins, Quai de l'hotel de ville, 75004 Paris



Programme



Guide d'utilisation du pointeur laser



* Laisser le bouton enfoncé pour émettre le laser, relâcher pour stopper l'émission
** Appuyer de nouveau pour restaurer l'affichage

Consigne pour les présentations

Les présentations sont à remettre au niveau du pupitre de présentation en début de chaque demi-journée précédant votre passage (matin ou midi). Seuls les formats .pdf et .pptx seront pris en compte. Dans le cas ou le format de votre présentation ne correspond pas aux formats pris en charge, merci de vous rapprocher de l'un des membres de l'organisation lors de la conférence.

Votre présentation doit comporter le nom suivant : PRENOM_NOM .pdf/.pptx

Dans le cas où vous souhaiteriez déposer votre présentation mais aucun organisateur n'est présent pour vous assister, veuillez suivre ces étapes :

- Munissez-vous de votre périphérique de stockage à connectique USB Type A et insérez-le dans le port prévu à cet effet
- Ouvrez le dossier EJC 2022
- Sélectionnez le dossier correspondant à votre demi-journée de passage (Lundi après-midi, Mardi Matin, Mardi après-midi, Mercredi matin et mercredi après-midi)
- Déposez votre présentation (PRENOM_NOM.pdf)
- Dirigez vous dans le coin inférieur droit de l'écran et cliquez sur la flèche qui pointe vers le haut
- Cliquez sur l'icône de clef USB pour éjecter en toute sécurité votre périphérique
- Retirez votre périphérique
- Allez profiter des présentations de nos participants accompagné d'une boisson à la température de votre convenance

Water deuteration in solar-type star forming regions

Audrey Andreu 1 , Audrey Coutens 1
1Institut de Recherche en Astrophysique et Planétologie (IRAP), Université de Toulouse, UT3-PS, CNRS, CNES, 9 av. du Colonel Roche, 31028 Toulouse Cedex 4, France

The origin of life on Earth has been recurrently studied by scientists. Nowadays, it is well known that water is fundamental to the emergence of life. Water molecules are efficiently produced in molecular clouds and play a key role in star forming regions as they cool down the warm regions and boost the gravitational collapse leading to star formation. Water is detected at different stages of the star formation process from cold prestellar cores to protoplanetary disks [e.g., van Dishoeck et al. 2021 and Hogerheijde et al. 2011] as well as in comets and asteroids [e.g., Davies et al. 1997 and Rivkin et al. 2010].

Deuterium fractionation measurements (i.e. the abundance ratios of deuterated molecules with respect to their non-deuterated versions) are very useful to determine the physical conditions involved in the formation of molecules and their evolution during the star formation process. Indeed, deuteration efficiency is very sensitive to the physical conditions in which molecules form [Ceccarelli et al. 2014]. By characterizing the HDO/H2O abundance ratios in objects at different evolutionary stages and in primitive objects of our Solar System, it is then possible to understand the history of water during the star formation process and connect it to the origin of water on Earth [Cleeves et al. 2014].

Several measurements of HDO/H2O ratios were obtained for young Class 0 solar-type protostars [e.g., Jørgensen et al. 2010 and Jensen et al. 2019] but such information is missing for more evolved protostars. To better understand how the chemistry of water evolves at later stages of the star formation process, we recently carried out HDO and H218O observations towards a Class I solar-type protostar with the NOEMA interferometer. Both isotopologues are detected. We determined the HDO/H2O ratios in the two components of this protostar. We will present these results and discuss the evolution of water during the star formation process by comparing these ratios to the values found in younger protostars as well as comets.

Ceccarelli et al. 2014, Protostars and Planets VI
Cleeves et al. 2014, Science, vol 345, 6204
Davies et al 1997, Icarus, vol 127
Hogerheijde et al. 2011, Science, vol 334, 6054
Jørgensen et al. 2010, ApJ, vol 725
Jensen et al. 2019, A&A 631, A25
Rivkin et al. 2010, Nature, vol 464, 7293
van Dishoeck et al. 2021, A&A 648, A24

X-ray irradiation of protoplanetary ices: a new laboratory experiment *

C. Assadourian1,2, F. Borget2, C. Laffon1, Ph. Parent1
1 Aix Marseille Univ, CNRS, CINaM, Marseille, France
2 Aix Marseille Univ, CNRS, PIIM, Marseille, France

Around young stars of solar type T Tauri, disks of dust and cold gas are in rotation, extending over a few tens of astronomical units. The protoplanetary disks are regions where the physico-chemical conditions (density, temperature, radiations) are particular. The temperature gradients are very high (10 K-1000 K, depending on the distance to the star), and they present a very specific radiation inventory. The UV radiation from the central star is stopped by the high density of rotating matter in its vicinity (< 1 au), and the strong stellar winds protect them from cosmic rays. The main radiations are the 1 keV X-rays emitted in abundance by the star, which penetrate very deeply into the disk and significantly affect the chemistry of ices located in the midplan [1]. In this context, we have developed at the CINaM a new and unique laboratory X-ray astrochemistry experiment, equipped with a 1.4 keV X-ray source, to provide quantitative data on the X-ray irradiation of protoplanetary ices. Our analytical methods are X-ray photoelectron spectroscopy (XPS), FTIR spectroscopy (FT-RAIRS), and mass spectroscopy (QMS). A microwave-discharged hydrogen flow lamp is also available, allowing to compare UV and X-ray irradiation. Our laboratory studies will complement and enrich the X-ray studies conducted with synchrotron radiation by us and others [2–4]. So far, we have successfully developed the experimental method to produce reliable X-ray and UV photolysis rates, and we will present our first results on simple ices such as pure H2O, pure CH3OH, and CO2 and CH3OH mixed with H2O.

[1] C. Walsh, H. Nomura, T.J. Millar, Y. Aikawa, Chemical processes in protoplanetary disks. II. on the importance of photochemistry and X-ray ionization, Astrophys. J. 747 (2012).
[2] C. Laffon, S. Lacombe, F. Bournel, P. Parent, Radiation effects in water ice: A near-edge x-ray absorption fine structure study, J. Chem. Phys. 125 (2006).
[3] R. Dupuy, M. Bertin, G. Féraud, M. Hassenfratz, X. Michaut, T. Putaud, L. Philippe, P. Jeseck, M. Angelucci, R. Cimino, V. Baglin, C. Romanzin, J.H. Fillion, X-ray photodesorption from water

*Poster

Multi-analysis comparison between asteroid Ryugu samples returned by the Hayabusa2 space mission and Antarctic Micrometeorites (AMMs)

L. Bejach1, C. Engrand1, J. Duprat1, E. Dartois,2 J. Mathurin3, A. Dazzi3, A. Deniset-Besseau3, N. Rividi4, C. Sandt5, F. Borondics5, D. Troadec6, T. Nakamura7, H. Yabuta8, T. Morita7, M. Kikuiri7 , K. Amano7, E. Kagawa7, T. Noguchi9, H. Yurimoto10, R. Okazaki11, H. Naraoka11, K. Sakamoto12, S. Tachibana12,13, S. Watanabe14, Y. Tsuda12 and the Hayabusa2-initial-analysis Stone and IOM teams, 1Univ. Paris-Saclay, CNRS, IJCLab, France (laure.bejach@ijclab.in2p3.fr), 2Univ. Paris-Saclay, CNRS, ISMO, France, 3Univ. Paris-Saclay, CNRS, ICP, France, 4CAMPARIS, Univ. Paris Sorbonne, Jussieu, France, 5Synchrotron SOLEIL, CNRS, CEA, Paris-Saclay, France, 6Institut d'électronique de microélectronique et de nanotechnologie (IEMN) UMR CNRS 8520, 7Tohoku University, Sendai 980-8578, Japan, 8Hiroshima University; Higashi-Hiroshima, Hiroshima, 739-8526, Japan. 9Kyoto University, Kyoto 606-8502, Japan, 10Hokkaido University, Sapporo 060-0810, Japan, 11Kyushu University, Fukuoka 819-0395, Japan, 12Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Sagamihara 252-5210, Japan, 13The University of Tokyo; Bunkyo-ku, Tokyo,113-0033, Japan, 14Nagoya University; Chikusa-ku, Nagoya, 464-8601, Japan.

Micrometeorites, pristine material that shed light on primitive conditions of the Solar System and degree of parent body aqueous alteration, are the dominant extraterrestrial infalling on Earth today. Ryugu is a primitive Cb-type, organic matter rich asteroid sampled by the Japanese mission Hayabusa2, both at the surface and potential sub-surface of the asteroid [1]. The comparison between the two sets of samples of Ryugu, and Antarctic micrometeorites (AMMs) allows to investigate possible differences between both Ryugu sampling sites on one hand, and with micrometeorites on the other hand. Samples have been analyzed by SEM/EDX, synchrotron based µ-FTIR, AFM-IR and STXM-XANES. Ryugu samples are composed mostly of phyllosilicates' matrix with structural OH and interlayer water, carbonates and magnetite with different textures, including framboidal magnetite [2, 3, 4]. Organic matter in Ryugu samples is finely mixed within the phyllosilicates. These mineralogical and organic components show similarities with C1 meteorites, such as Orgueil, Ivuna, which are extremely aqueously altered. In the Cap Prudhomme and Concordia AMM collections [5, 6], around 5% of the particles (called "C1-like AMMs") show those features. Preliminary results of ongoing analyses on AMMs show fine-scale intercalation of organic matter within phyllosilicates. We investigate the possibility that C1-like AMMs could originate from a parent body similar to Ryugu. Since AMMs represent the major extraterrestrial material infalling on Earth, analyzing organic matter embedded in these primitive materials and comparing them with Ryugu also gives insight on possible input of prebiotic matieral on Earth and potentially elsewhere in the Solar System.

Acknowledgments: This work was supported by CNES (MIAMI-HY2), the French ANR (COMETOR, ANR-18-CE31-0011) as well as INSU (PNP, PCMI), IN2P3, DIM-ACAV+ (Région Île de France), CNRS. We are grateful to the French and Italian polar institutes IPEV and PNRA, for their financial and logistic support to the micrometeorites collection at the vicinity of the CONCORDIA station (Dome C).

[1]Tsuda, Y. et al. (2020) Acta Astronautica 171, 42-54
[2] Yada, T., Nat Astron 6, 214–220 (2022)
[3] Yabuta, H., et al. LPSC meeting (2022)
[4] Nakamura, T., et al. LPSC meeting (2022)
[5] Maurette M. et al. (1991) Nature 351, 44-47
[6] Duprat J. et al. (2007) Adv. Space Res. 39, 605–611.

Résumés

Development of an experimental high pressure - high/low temperature milli fluidic assembly for the simulation of the chemistry of the alkaline hydrothermal vents *

Grégoire BOE1, Thierry TASSAING1
1Institut des Sciences Moléculaires, UMR 5255 CNRS-Université de Bordeaux
351, cours de la Libération
33405 Talence Cedex

Hydrothermal vents located at the oceans floor are suspected to be the environment that allowed the formation of the first prebiotic molecules on earth, four billion years ago. Some research groups have applied themselves to describe the particular chemistry proposed by these mineral structures1,2. Allowed by strong temperature and acidity gradients, the formation of pre-biotic molecules such as the first amino acids would be possible, especially in this porous environment extremely rich in minerals3. As part of this project, the objective is to study the catalytic role of the different minerals found on these structures whose activity depends on their chemical composition and their morphology, thanks to an experimental assembly developed in the laboratory. This completely closed assembly makes it possible to accurately represent the extreme physical conditions of these marine environments, in particular by supporting pressures of up to 400 bars and a temperature of 400°C. This assembly also allows in-situ analyzes (IR, Raman) and sampling for ex-situ analyses (HPLC, GC, RMN, DRX…). This unique experimental model stands out from the rare setups that have been proposed by other research teams4–6, by allowing the entire hydrothermal vent to be simulated: the hydrothermal fluid (400°C, super-critical), the chimney (solid minerals), and the ocean (15°C, liquid). Preliminary results have been obtained with olivine to test the functionality of the assembly in real conditions.

(1) Macleod, G.; McKeown, C.; Hall, A. J.; Russell, M. J. Hydrothermal and Oceanic PH Conditions of Possible Relevance to the Origin of Life. Orig. Life Evol. Biosph. 1994, 24 (1), 19–41. https://doi.org/10.1007/BF01582037.
(2) Barge, L. M.; Flores, E.; VanderVelde, D. G.; Weber, J. M.; Baum, M. M.; Castonguay, A. Effects of Geochemical and Environmental Parameters on Abiotic Organic Chemistry Driven by Iron Hydroxide Minerals. J. Geophys. Res. Planets 2020, 125 (11). https://doi.org/10.1029/2020JE006423.
(3) Russell, M. J.; Ponce, A. Six 'Must-Have' Minerals for Life's Emergence: Olivine, Pyrrhotite, Bridgmanite, Serpentine, Fougerite and Mackinawite. Life 2020, 10 (11), 291. https://doi.org/10.3390/life10110291.
(4) Seyfried, W. E.; Janecky, D.; Berndt, M. E. Rocking Autoclaves for Hydrothermal Experiments: II. The Flexible Reaction-Cell System. In Hydrotherm. Exp. Tech.; 1987; pp 216–239.
(5) Herschy, B.; Whicher, A.; Camprubi, E.; Watson, C.; Dartnell, L.; Ward, J.; Evans, J. R. G.; Lane, N. An Origin-of-Life Reactor to Simulate Alkaline Hydrothermal Vents. J. Mol. Evol. 2014, 79 (5), 213–227. https://doi.org/10.1007/s00239-014-9658-4.
(6) Mielke, R. E.; Russell, M. J.; Wilson, P. R.; McGlynn, S. E.; Coleman, M.; Kidd, R.; Kanik, I. Design, Fabrication, and Test of a Hydrothermal Reactor for Origin-of-Life Experiments. Astrobiology 2010, 10 (8), 799–810. https://doi.org/10.1089/ast.2009.0456.

*Poster

Molecular characterization of *G. Prisca* microfossils by secondary-ion and laser desorption-ionization mass spectrometry techniques

Bon Mathilde 1,2,3, Lepot Kevin 1,4, Carpentier Yvain 2, Bray Fabrice 5, Riboulleau Armelle 1, Baudin François 6, Nuns Nicolas 7, Rolando Christian 5, Steemans Philippe 8 and Vandenbroucke Thijs R.A. 3

1Univ. Lille, CNRS, Univ. Littoral Côte d'Opale, UMR 8187 – LOG – Laboratoire d'Océanologie et de Géosciences, F-59000 Lille, France, 2Univ. Lille, CNRS, UMR 8523 – PhLAM – Physique des Lasers Atomes et Molécules, F-59000 Lille, France, 3Department of Geology (WE13), Ghent University, Krijgslaan 281/S8, Ghent, 9000, Belgium, 4Institut Universitaire de France (IUF), 5Univ. Lille, CNRS, USR 3290 – MSAP – Miniaturisation pour la Synthèse, l'Analyse et la Protéomique, F-59000 Lille, France, 6SU CNRS, ISTeP UMR 7193, 4 Place Jussieu, 75005 Paris, France, 7Univ. Lille, CNRS, Centrale Lille, Univ. Artois, UMR 8181 - UCCS - Unité de Catalyse et Chimie du Solide, F-59000 Lille, France, 8EDDy Lab/Palaeobotany and Palaeopalynology, Univ. Liège, 4000 Liège, Belgium

The microfossil species "*Gloeocapsomorpha prisca*" forms the bulk of the organic matter in organo-sedimentary rocks called "kukersite" (here from a 460 million year-old deposit of northwestern Russia7). This microfossil is probably a cyanobacterium1,2,4,6. We analyze the macromolecular, insoluble organic matter (kerogen) extracted from this kukersite with HCl, HF and organic solvents, with the goal of deciphering its molecular composition in terms of biomacromolecule derivatives (algenan, cellulose, etc.) and potentially linked biomarker signatures. We use molecular characterization methods that can perform analyses down to the single-microfossil scale. We analyze the kerogen and evaluate the preparation protocols by secondary-ion time-of-flight mass spectrometry (ToF-SIMS), which combines extreme surface sensitivity with micrometric spatial resolution. This analysis shows a majority of (poly)aromatic hydrocarbons, along with small aliphatic fragments and carbonaceous aggregates (C_nH_{0-3}) generated by fragmentation, as well as a minor contribution of oxygen, nitrogen and sulfur compounds. The kerogen is further analyzed by Fourier-transform ion cyclotron resonance mass spectrometry allowing very-high mass resolution, using laser desorption/ionization (LDI-FT-ICR-MS) on aggregates of *G. prisca*. The obtained spectra indicate that the organic matter is mainly composed of aromatic hydrocarbons, oxygenated and nitrogenous compounds. The predominance of oxygenated functions in LDI-FT-ICR-MS is in agreement with the composition of *G. prisca* set in light by chemolysis- and pyrolysis-assisted gas-chromatography mass spectrometry1,2,3,4. Using two-step laser desorption-ionization (L2MS), (poly)aromatic hydrocarbons dominate the signal over oxygenated and nitrogenated molecules. The apparent aromaticity observed could be related to fragmentation of aliphatic chains in SIMS, to pyrolysis in LDI, and/or to the selectivity of UV ionization, in particular for post-desorption ionization at 266 nm in L2MS. This approach will be applied to the search for possible chemotaxonomic parameters on different morphospecies from other samples with a more diverse microfossil assemblage. Our protocols have potential to become benchmarks in the search for molecular signatures for exobiology, as, for example, a LDI-MS instrument has been developed for the ExoMars rover5.

1Blokker P, van Bergen P, Pancost R, et al (2001) The chemical structure of Gloeocapsomorpha prisca microfossils: implications for their origin. Geochimica et Cosmochimica Acta 65:885–900. https://doi.org/10.1016/S0016-7037(00)00582-2

2da Silva TF , Mendonça Filho JG, da Silva MC, et al (2016) Botryococcus braunii versus Gloecapsomorpha prisca : Chemical composition correlation using laser micropyrolysis-gas chromatography/mass spectrometer (LmPy-GCMSMS). International Journal of Coal Geology 168:71–79. https://doi.org/10.1016/j.coal.2016.08.010

3Derenne S, Largeau C, Casadevall E, et al (1990) Characterization of Estonian Kukersite by spectroscopy and pyrolysis: Evidence for abundant alkyl phenolic moieties in an Ordovician, marine, type II/I kerogen. Organic Geochemistry 16:873–888. https://doi.org/10.1016/0146-6380(90)90124-I

4Derenne S, Metzger P, Largeau C, et al (1992) Similar morphological and chemical variations of Gloeocapsomorpha prisca in Ordovician sediments and cultured Botryococcus braunii as a response to changes in salinity. Organic Geochemistry 19:299–313. https://doi.org/10.1016/0146-6380(92)90001-E

5Goesmann F, Brinckerhoff WB, Raulin F, et al (2017) The Mars Organic Molecule Analyzer (MOMA) Instrument: Characterization of Organic Material in Martian Sediments. Astrobiology 17:655–685. https://doi.org/10.1089/ast.2016.1551

6Kiipli E, Kiipli T (2013) Nitrogen isotopes in Kukersite and black shale implying Ordovician-Silurian seawater redox conditions. Oil Shale 30:60. https://doi.org/10.3176/oil.2013.1.06

7Raevskaya, E., le Herisse, A., & Steemans, P. (2004). Quantitative distribution and evolution of palynomorphs associated with kukersite deposits in the Middle-Upper Ordovician of the East European Platform. Paper presented at International Symposium on Early Palaeozoic Palaeogeography and Palaeoclimate, Erlangen, Germany.

Influence of pH and salts on the DMF-DMA derivatization for GC-MS analysis of potential bioindicators on extraterrestrial surfaces (Mars, Titan, Europe, Enceladus,…).

D. Boulesteix1,, A. Buch1, J. Samson1, M. Millan2, J. Jomaa3, D. Coscia2, V. Moulay2, O. McIntosh2, C. Freissinet2, C. Szopa2.*

1 Laboratoire Génie des Procédés et Matériaux, CentraleSupélec, University Paris-Saclay, 8-10 rue Joliot-Curie, 91190, Gif-sur-Yvette, France.

2 LATMOS/IPSL, UVSQ University Paris-Saclay, Sorbonne University, CNRS, 11 Bd d'Alembert, 78280, Guyancourt, France.

* Corresponding author. E-mail address: david.boulesteix@centralesupelec.fr (David Boulesteix)

For *in situ* Gas Chromatography - Mass Spectrometry space analyzes, pH and salts (*e.g.,* chlorides, sulfates) can enhance or inhibit the detection of targeted astrobiological molecules. We observed on Mars recombination of organic molecules with salts (mainly perchlorates) during Sample Analysis at Mars experiments onboard the Curiosity rover (*Mars Science Laboratory* mission) (Freissinet et al., 2015; Millan et al., 2020, 2022; Szopa et al., 2020). Indeed, salts and pH may generate side reactions, but salts also influence the ionic force, may create salt complex or mask basic ions in the sample (hydroxide ion, ammonia, etc…) (Bretti et al., 2020; Ming et al., 2009; Permyakov, 2021). In future space missions, one of the GC-MS pre-treatment is based on an organic reagent used to volatilize polar or refractory organic molecules, called dimethylformamide dimethyl acetal (DMF-DMA), which has the capability to derivatize acidic groups in organics, such as amine and carboxylic functions in amino and carboxylic acids, or nucleobases, without modifying their chiral conformation (Freissinet et al., 2010). The influence of pH and a diversity of salts present in extraterrestrial surface samples on the DMF-DMA derivatization is still understudied. In this presentation, we observe the influence of different salts, or different pH on the DMF-DMA derivatization for various potential bioindicators (amino acids, fatty acids, and nucleobases). First, salts influence differently the derivatization yield, according to the organic and the salt studied. Second, monovalent salts regardless of pH allow a higher or equal recovery of organics compared to divalent salts, and basic pH solutions. Considering the overall negative effect of the salts on the detection of organics using DMF-DMA derivatization, future space missions may have to consider a desalting step prior to derivatization and GC-MS analyzes.

Bretti, C., Cardiano, P., Irto, A., Lando, G., Milea, D., Sammartano, S., 2020. Interaction of N-acetyl-l-cysteine with Na+, Ca2+, Mg2+ and Zn2+. Thermodynamic aspects, chemical speciation and sequestering ability in natural fluids. J. Mol. Liq. 319, 114164. https://doi.org/10.1016/j.molliq.2020.114164

Freissinet, C., Buch, A., Sternberg, R., Szopa, C., Geffroy-Rodier, C., Jelinek, C., Stambouli, M., 2010. Search for evidence of life in space: Analysis of enantiomeric organic molecules by N,N-dimethylformamide dimethylacetal derivative dependant Gas Chromatography–Mass Spectrometry. J. Chromatogr. A 1217, 731–740. https://doi.org/10.1016/j.chroma.2009.11.009

Freissinet, C., Glavin, D.P., Mahaffy, P.R., Miller, K.E., Eigenbrode, J.L., Summons, R.E., Brunner, A.E., Buch, A., Szopa, C., Archer, P.D., Franz, H.B., Atreya, S.K., Brinckerhoff, W.B., Cabane, M., Coll, P., Conrad, P.G., Des Marais, D.J., Dworkin, J.P., Fairén, A.G., François, P., Grotzinger, J.P., Kashyap, S., ten Kate, I.L., Leshin, L.A., Malespin, C.A., Martin, M.G., Martin-Torres, F.J., McAdam, A.C., Ming, D.W., Navarro-González, R., Pavlov, A.A., Prats, B.D., Squyres, S.W., Steele, A., Stern, J.C., Sumner, D.Y., Sutter, B., Zorzano, M.-P., the MSL Science Team, 2015. Organic molecules in the Sheepbed Mudstone, Gale Crater, Mars: Detection of organics in martian sample. J. Geophys. Res. Planets 120, 495–514. http://www.exobiologie.fr/EJC2022/ Millan, M., Szopa, C., Buch, A., Summons, R.E., Navarro-Gonzalez, R., Mahaffy, P.R., Johnson, S.S., 2020. Influence of Calcium Perchlorate on Organics Under SAM-Like Pyrolysis Conditions: Constraints on the Nature of Martian Organics. J. Geophys. Res. Planets 125, e2019JE006359. https://doi.org/10.1029/2019JE006359

Millan, M., Teinturier, S., Malespin, C.A., Bonnet, J.Y., Buch, A., Dworkin, J.P., Eigenbrode, J.L., Freissinet, C., Glavin, D.P., Navarro-González, R., Srivastava, A., Stern, J.C., Sutter, B., Szopa, C., Williams, A.J., Williams, R.H., Wong, G.M., Johnson, S.S., Mahaffy, P.R., 2022. Organic molecules revealed in Mars's Bagnold Dunes by Curiosity's derivatization experiment. Nat. Astron. 6, 129–140. https://doi.org/10.1038/s41550-021-01507-9 Ming, D.W., Lauer, H.V., Archer, P.D., Sutter, B., Golden, D.C., Morris, R.V., Niles, P.B., Boynton, W.V., 2009. Combustion of Organic Molecules by the Thermal Decomposition of Perchlorate Salts: Implications for Organics at the Mars Phoenix Scout Landing Site 2241. Permyakov, E.A., 2021. Metal Binding Proteins. Encyclopedia 1, 261–292. https://doi.org/10.3390/encyclopedia1010024 Szopa, C., Freissinet, C., Glavin, D.P., Millan, M., Buch, A., Franz, H.B., Summons, R.E., Sumner, D.Y., Sutter, B., Eigenbrode, J.L., Williams, R.H., Navarro González, R., Guzman, M., Malespin, C., Teinturier, S., Mahaffy, P.R., Cabane, M., 2020. First Detections of Dichlorobenzene Isomers and Trichloromethylpropane from Organic Matter Indigenous to Mars Mudstone in Gale Crater, Mars: Results from the Sample Analysis at Mars Instrument Onboard the Curiosity Rover. Astrobiology 20, 292–306. https://doi.org/10.1089/ast.2018.1908

Characterization of Insoluble Organic Matter (IOM) analogues prior to high pressure experiments, and comparison with meteoritic IOM

Adriana Clouet1, Clémence Queffélec1, Christophe Sotin2, Olivier Bollengier2,Bruno Bujoli1, Erwan Le Menn2, Pauline Lévêque1,2, Gabriel Tobie2
1CEISAM, UMR 6230, Nantes Université, CNRS, F-44000 Nantes, France.
2Nantes Université, Univ Angers, Le Mans Université, CNRS, UMR 6112, Laboratoire de Planétologie et Géosciences, F-44000 Nantes, France.

The ubiquitous presence of organic matter in primitive bodies of the Solar system, together with the necessity to add a low-density component to icy moons' interior models suggest the presence of insoluble organic matter (IOM) in icy satellites. Using diamond anvil cell experiments, we simulate the pressure (HP) and temperature conditions found in the interiors of Titan and Ganymede, and the degradation of different IOM analogues will be described. This work corresponds to the characterization of the initial state of these analogues. Raman spectra typical of disordered carbonaceous matter, as observed in meteoritic IOM, were obtained for almost all samples, with an increase in disorder correlated with the nitrogen content. Surprisingly, samples thought to be highly aromatic displayed mass spectra with fragmentation patterns suggesting a possible strong contribution of aliphatic (CH2)2n groups. Infrared spectroscopy and elemental analysis showed that the nitrogen poor Nebulotron samples are the best analogues for the aromatic and rich in oxygen-bearing functions chondritic IOM, but the use of a diversity of analogues (nitrogen-rich Nebulotron samples, PAMPRE tholins, asphaltenes and microalgae residues) will allow the evaluation of the influence of nitrogen, oxygen, sulfur and aliphatic percentages on the degradation of the IOM. Interestingly, the carbon isotopic fractionation and/or the nitrogen content of some of our analogues resemble some UCAMMs and cluster IDPs more than chondritic IOM. Finally, preliminary synchrotron results showing an apparent graphitization of the IOM under HP conditions (P. Lévêque) encouraged XRD analyses to confirm that the analogues are initially amorphous.

Résumés

Combining machine learning and ab initio enhanced sampling methods for prebiotic chemical reactions

Timothée Devergne1, Theo Magrino1, Fabio Pietrucci1 , A. Marco Saitta1
1Institut de minéralogie et de physique des matériaux et de cosmochimie (IMPMC) – Sorbonne Université, CNRS : UMR7590, Muséum National d'Histoire Naturelle – 4,place Jussieu - Tour 23 - Barre 22-23, 4e´etage - 75252 Paris Cedex 5, France

The study of the thermodynamics, kinetics, and microscopic mechanisms of chemical reactions in solution requires the use of advanced free-energy methods for predictions to be quantitative1,2. This task is however a formidable one for atomistic simulation methods, as the cost of quantum- based ab initio approaches, to obtain statistically meaningful samplings of the relevant chemical spaces and networks, becomes exceedingly heavy. In this work, we critically assess the optimal structure and minimal size of an ab initio training set able to lead to accurate free energy profiles sampled with neural network potentials. The results allow to propose an ab initio protocol where the ad hoc inclusion of a machine-learning (ML)-based task can significantly increase the computational efficiency, while keeping the ab initio accuracy and, at the same time, avoiding some of the notorious extrapolation risks in typical atomistic ML approaches. We focus on two representative, and computationally challenging, reaction steps of the classic Strecker-cyanohydrin mechanism for glycine synthesis in water solution3, where the main precursors are formaldehyde and hydrogen cyanide. We demonstrate that indistinguishable ab initio-quality results are obtained, thanks to the ML-subprotocol, at about one order of magnitude less of computational load

(1) Pietrucci, F.; Aponte, J. C.; Starr, R.; Pérez-Villa, A.; Elsila, J. E.; Dworkin, J. P.; Saitta, A. M. Hydrothermal Decomposition of Amino Acids and Origins of Prebiotic Meteoritic Organic Compounds. ACS Earth Space Chem. 2018, 2, 588–598

(2) Pietrucci, F.; Saitta, A. M. Formamide reaction network in gas phase and solution via a unified theoretical approach: Toward a reconciliation of different prebiotic scenarios. Proc. Natl. Acad. Sci. U. S. A. 2015, 112, 15030–15035

(3) Magrino, T.; Pietrucci, F.; Saitta, A. M. Step by Step Strecker Amino Acid Synthesis from Ab Initio Prebiotic Chemistry. J. Phys. Chem. Lett. 2021, 12, 2630–2637.

Stromatolites: 3.5 billion years of exceptional paleoenvironmental archives

L. Fogret1,*, P. Sansjofre1, S.V. Lalonde2
1 Laboratoire IMPMC, Muséum National d'Histoire Naturelle, 41 rue Buffon 75005, Paris, France 2 Laboratoire Géosciences Océan, Institut Universitaire Européen de la Mer, Technopôle Brest-Iroise, 29280 Plouzané, France
* laurane.fogret@mnhn.fr

Stromatolites are laminated microbial sedimentary structures which represent the oldest traces of life in Earth history. By their presence through geological time and deposition in a wide range of aqueous environments, they are exceptional geochemical archives and potential tracers of various environmental deposition settings.

This work was performed on the MNHN Microbialites Collection which currently contains more than 1120 specimens spanning more than 3.5 Ga of life history on all continents. With microscopic observation we evaluate the lithology, biogenicity, and depositional environments of the specimens. Using stable carbon and oxygen isotope analyses by IRMS, as well as major, trace, and rare earth element analyses by HR-ICPMS, we describe geochemical trends.

Bulk δ13Ccarb in the collection varies between -9.17 and +15.57 ‰ (VPDB) and δ18Ocarb between -19.12 and +6.63 ‰ (VPDB). This large variability is related to the different local phenomena that can influence stromatolite depositional environments (i.e., evaporation, biomass production, diagenesis). In this study we explore the potential of different geochemical proxies to be related to specific environments or metabolisms. We placed our datasets in a more carbonate global compilation that allow distinguishing local effect on the geochemical signal to global perturbations.

Building models describing these habitable environments of deep time and tracing the adaptation of microbial communities in response to major geochemical disruptions provides important perspectives for geobiology and exobiology, notably for the search for evidence of life on Mars.

Orbitrap and GC-Orbitrap for in situ analyses: clues from laboratory experiments

A.Garcia1, G.Danger1
1 Aix Marseille Univ, CNRS, PIIM, Marseille, France

In the context of future space missions, the orbitrap, a high-resolution mass spectrometer, is being spatialized. Here, we investigate the interest of a coupling between a gas chromatograph and an Orbitrap mass spectrometer. A first approach focuses on the use of this system for a targeted analysis of amino acids in soluble organic matter analogues of meteorites. In a second step, we studied the interest of a high-resolution mass spectrometry for the direct analysis or via gas chromatograph of these same analogues using pyrolysis or thermodesorption as sampling techniques. The interest of such analogues is that they present a molecular diversity similar to that observed in the SOM of meteorites, which allows to demonstrate the relevance of such a technology for the analysis of natural samples. All analyses carried out demonstrate the interest of the orbitrap coupled or not with GC for the analysis of such samples, in particular because of the high mass resolution which makes it possible to obtain the raw formulae of the ions formed and thus to reinforce the identification of the compounds, as well as to obtain first information on the molecular content of a sample before considering a targeted analysis.

Extraction method optimisation of organic molecules from complex samples under MOMA instrument analytical conditions of the Exomars mission (ESA).

R. Gonthier1, C. Azémard1, F. Stalport2, N. Chaouche1, K. Lepot3,4, H. Cottin1
1Univ Paris Est Creteil and Université Paris Cité, CNRS, LISA, F-94010 Créteil, France, 2Université Paris Cité and Univ Paris Est Creteil, CNRS, LISA, F-75013 Paris, France, 3Univ. Lille, CNRS, Univ. Littoral Côte d'Opale, UMR 8187 - LOG, F-59000 Lille, France, 4Institut Universitaire de France (IUF)

Mars is a target for astrobiology research because of its similarity with Earth in the past. Several probes and rovers have been sent for more than 50 years to Mars, to search for records of past and/or extant life on this planet. One of the next martian missions is Exomars from the European Space Agency (ESA). This mission will launch a rover named Rosalind Franklin carrying a drill capable of sampling up to 2 meters below the surface and an analytical laboratory drawer with various instruments to characterize the samples. The LISA and LATMOS laboratories participated in the development and delivery of the MOMA (Mars Organic Molecule Analyzer) instrument. Part of this instrument couples a gas chromatograph to a mass spectrometer for gazeous compounds separation and identification. Before the mission, the instrument needs a specific database. For this purpose, Mars-like samples (standards, synthetic or natural) must be analyzed and characterized with laboratory setups close to the MOMA instrument to support the in situ analysis. In order to optimize the MOMA analytical procedure, we studied the time required to extract targeted compounds during the mission such as carboxylic acids (CA) by thermodesorption at 200°C. The natural samples are terrestrial rocks (Jurassic deposits from Orbagnoux, late Archean rocks, etc.) and extraterrestrial material (Murchison) that contain complex organic matter. First results for the Orbagnoux samples indicate the detection after extraction of hexanoic acid ($C_5H_{11}COOH$), glycolic acid ($C_2H_4O_3$) and oxalic acid (C2H2O4). Extraction of CAs is incomplete if the thermodesorption step is less than 5 min, while a time greater than 7.5 min appears to degrade them. The optimization of CAs extraction is still needed for the different matrices available for this study. The choice of thermodesorption time needs to be optimized taking into account both the optimization for CAs and amino acids, and the other target molecules for the mission. Additional Mars analog samples will be analyzed with this method.

Influence of aqueous alteration on the evolution of amino acids

Yuanyuan HE 1, L. HUET 1, L. REMUSAT 1, S. BERNARD 1, A. M. SAITTA 1, Arnaud BUCH 2, F. PIETRUCCI 1
1 Muséum National d'Histoire Naturelle, UMR CNRS 7590, Sorbonne Université, Institut de Minéralogie, Physique des Matériaux et Cosmochimie, IMPMC, Paris, France.
2 Laboratoire Génie des Procédés et Matériaux, CentraleSupélec, University Paris-Saclay, 8-10 rue Joliot-Curie, 91190, Gif-sur-Yvette, France.

Asteroids, comets, and their fragments including meteorites, micrometeorites, and interplanetary dust particles (IDPs) could serve as delivery vehicles for organic matter to Earth [1]. Therefore, the organic compounds of chondrites, carbonaceous meteorites, and comets are essential for the decoding of the evolution of organic materials in the early solar system. Among the organic compounds detected in chondrites, amino acids are of particular interest because they are the monomers of proteins and enzymes in all life on Earth. Hence, extraterrestrial amino acids could have contributed to the origin of life on the early Earth [2]. The aqueous alteration that affected chondrite the parent bodies could have influenced the formation and degradation of amino acids. For instance, while the relative abundance of β-alanine increases with the increasing aqueous alteration, α-alanine shows a different trend. Moreover, there have been few studies that reported the influence of aqueous alteration on the evolution of stable isotope ratios of amino acids under hydrothermal conditions. Therefore, the influence of aqueous alteration on the evolution of amino acids and the role of minerals during hydrothermal processes remains to be addressed.

A laboratory investigation of the evolution of a few emblematic amino acids was performed in this study. Amino acids including b-alanine, α-alanine, 2-aminoisobutyric acid and r-aminobutyric acids were dissolved in pure degassed water and heated at 150 oC for several different days under an oxygen free atmosphere in titanium Parr© reactors. The released gas, soluble organic molecules, and the residual solids were characterized. New organic products have been detected during the experiment with β-alanine (Figure 1). However, no new product was detected from α-alanine and 2-aminoisobutyric acid and r-aminobutyric acids. The formation of new products likely results from the decarboxylation and deamination of β-alanine and recombination to form the new product. To further understand the mechanisms of amino acids evolution, ab initio simulations will be performed in the future to compare with the data from experimental results.

[1] D. Glavin, C. Alexander, J. C. Aponte, et al., in Primitive Meteorites and Asteroids, Elsevier Inc., 2018, pp. 205–271.
[2] J. Elsila, S. Charnley, and A. Burton, et al., Meteoritics & Planetary Science, 47(2012).

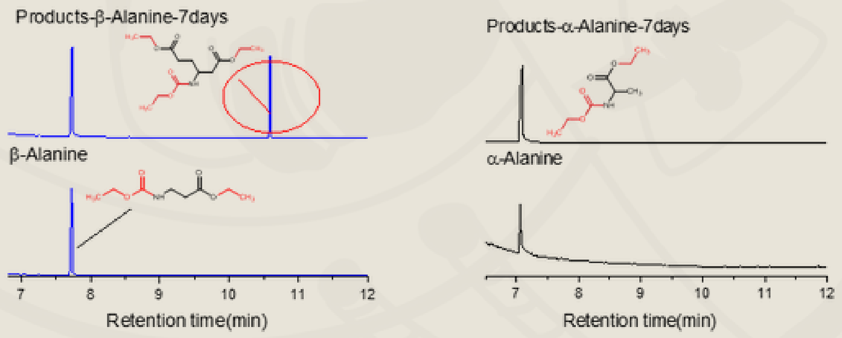


Figure 1. The products of experiments on a- and b- alanine in pure H2O at 150°C

Prebiotic chemistry pathway discovering by a fully agnostic ab initio molecular dynamics method *

Léon HUET1, Fabio Pietrucci1, A. Marco Saitta1
1Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie,
Sorbonne Université, Muséum National d'Histoire Naturelle, CNRS UMR 7590

The use of advanced modelization is nowadays an essential research tool in prebiotic chemistry. It supports experimental advances but also helps to explore new compounds and new mechanisms, even in extreme conditions that are difficult to reproduce. One of the major research flow in the domain is about the synthesis of the first amino acids. The Strecker mechanism, as relying only on small inorganic compounds and supported by the first laboratory experiments, has long been the only accepted pathway for this. However, studies of meteorites contradict its uniqueness, has is does not explain the presence of β and γ amino acids. Within our team, we are developing an ab initio method to study a reaction, depending only on its reactants and products. This method has the possibility to critically assess the feasibility of this well known synthesis pathways and to guess new ones. Moreover it determines the essential properties of the studied path: major intermediates, limiting reactants, etc.

We used that method on the glycine synthesis assessing the Strecker mechanism and finding out alternative pathways.

*Poster

Dynamics of the Great Oxidation Event from a 3D photochemical-climate model

A. Y. Jaziri1,4, B. Charnay3, F. Selsis1, J. Leconte1, F. Lefèvre2
1Laboratoire d'astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, alle Geoffroy Saint-Hilaire, 33615 Pessac, France.
2LATMOS/IPSL, Sorbonne Universit, UVSQ, CNRS, Paris, France
3LESIA, Observatoire de Paris, Universit PSL, CNRS, Sorbonne Universit, Universit de Paris, 5 place Jules Janssen, 92195 Meudon, France
4Observatoire de Genève, Chemin Pegasi 51, 1290 Versoix, Suisse

From the Archean toward the Proterozoic, the Earth's atmosphere underwent a major shift from anoxic to oxic conditions, around 2.4 to 2.1 Gyr, known as the Great Oxidation Event (GOE). This rapid transition may be related to an atmospheric instability caused by the formation of the ozone layer. Previous works were all based on 1D photochemical models. Here, we revisit the GOE with a 3D photochemical-climate model to investigate the possible impact of the atmospheric circulation and the coupling between the climate and the dynamics of the oxidation. We show that the diurnal, seasonal and transport variations do not bring significant changes compared to 1D models. Nevertheless, we highlight a temperature dependence for atmospheric photochemical losses. A cooling during the late Archean could then have favored the triggering of the oxygenation. In addition, we show that the Huronian glaciations, which took place during the GOE, could have introduced a fluctuation in the evolution of the oxygen level. Finally, we show that the oxygen overshoot which is expected to have occurred just after the GOE, was likely accompanied by a methane overshoot. Such high methane concentrations could have had climatic consequences and could have played a role in the dynamics of the Huronian glaciations.

Breakthrough results in Astrobiology: is 'high risk' research needed?

Cyrille Jeancolas[1]
[1]Department of Philosophy, Durham University, UK

Astrobiology is inherently overwhelmed with uncertainties. The historical origin of life on Earth may remain a complete mystery and extraterrestrial life forms, if they exist, might have nothing to do with what has been imagined so far. Given this context, it is hard to draw a solid paradigm in this still nascent discipline and it might be warranted to engage with projects that significantly deviate from the actual scientific mainstreams. However, Astrobiology seems to be risk averse (Vickers, 2020), like contemporary scientific research in general where projects following the mainstream are favoured in order to secure results (Stanford, 2019). On the other hand, unconventional research led by mavericks is more intellectually risky, in the sense of being prone to not getting interesting results, but can be an efficient way to explore new ideas and catalyze the chance of a breakthrough. In order not to miss critical discoveries, an appropriately balanced portfolio of low-, medium- and high-risk projects could therefore foster major breakthroughs (Avin, 2019; Weisberg & Muldoon, 2009). Here, we look at the recent history of Astrobiology and seek to draw lessons that could be applied to future practices in the field. Did the major advances in Astrobiology of the past 20 years come from risky research? To answer this question, we show to what extent the most high-impact scientific papers reporting Astrobiology-related results come from low-, medium- or high-risk research, according to contacted corresponding authors. Then, based on semi-directive interviews with several of them, we gather a diversity of stories about the projects that led to the respective breakthrough. Finally, we report their opinions on the balance of risk and reward of contemporary Astrobiology and their views on the evolution of the field.

Avin, S. (2019). Centralized Funding and Epistemic Exploration. The British Journal for the Philosophy of Science, 70(3), 629–656. https://doi.org/10.1093/bjps/axx059
Stanford, P. K. (2019). Unconceived alternatives and conservatism in science: The impact of professionalization, peer-review, and Big Science. Synthese, 196(10), 3915–3932. https://doi.org/10.1007/s11229-015-0856-4
Vickers, P. (2020). Expecting the unexpected in the search for extraterrestrial life. International Journal of Astrobiology, 19(6), 482–491. https://doi.org/10.1017/S1473550420000269
Weisberg, M., & Muldoon, R. (2009). Epistemic Landscapes and the Division of Cognitive Labor. Philosophy of Science, 76(2), 225–252. https://doi.org/10.1086/644786

Résumés

Constraints on the timing of cometary bombardment relative to Earth’s growth

Sarah Joiret[1], Sean Raymond[1], Guillaume Avice[2], Eric Gilabert ´ [3], and Denis Horlait[4]
[1]Laboratoire d’Astrophysique de Bordeaux – CNRS : UMR5804 – France
[2]Institut de Physique du Globe de Paris – CNRS : UMR7154 – France
[3]Laboratoire de Physique des 2 Infinis Bordeaux – CNRS : UMR5797 – France [4]Laboratoire de Physique des 2 Infinis Bordeaux – CNRS : UMR5797 – France

Isotopic signatures of Xe are different in the mantle and in the atmosphere of the Earth. While mantle Xe is chondritic (Peron & Moreira, 2018; Broadley et al., 2020), atmospheric Xe would have evolved from the so-called primordial U-Xe, which is a mixture of ˜80% chondritic Xe and ˜20% cometary Xe (Marty et al., 2017). This naively suggests that the cometary bombardment only happened after the Earth was fully formed. The bombardment of comets is thought to have been triggered by the giant planet instability (Gomes et al., 2005) early in the history of the solar system. The timing of this instability is still uncer tain (Morbidelli et al., 2018), but recent simulations seem to favour a very early instability (Clement et al., 2018). We present our ongoing project to constrain the timing of cometary bombardment relative to Earth’s growth, using numerical simulations on one hand, and laboratory isotopic measurements of meteorites on the other hand.

Laboratory analysis for Ryugu and Bennu samples: a multi-scale overlook on primitive asteroids

Léna Jossé[1]
[1]Institut d’Astrophysique Spatiale

The returning samples from both missions Hayabusa II (JAXA) and Osiris-rex (NASA) offers the possibility to analyse unique samples of primitive asteroids, Ryugu and Bennu. Those small asteroids, less than 1km of diameter are C-type bodies and are, thus, composed of carbonaceous and hydrated materials. They are not differentiated, and are composed of clasts of different composition from hydrated to anhydrous minerals. During this PhD we will analyse and observe those clasts using different technics such as X-ray tomography, visible and infra-red spectroscopy, transmission and scanning microscopy and we will determine the mineralogy, petrology and processes underwent by those clasts. From nano to micrometer-scale observations of the returned samples, we will better understand orbital or ground-based Earth observations. Therefore, the main objectives are to establish a scenario of formation and evolution for these two asteroids and to constrain the link between asteroids and meteorites.

Tarda and Tagish Lake: Possible vestiges of a common, distant asteroid.

Laurent B.1, Lescable M.1, Bernard S.1, Brunetto R.2 and Remusat L.1
1Muséum National d'Histoire Naturelle, Sorbonne Université, UMR CNRS 7590, Institut de minéralogie, de physique des matériaux et de cosmochimie, Paris, France (boris.laurent@mnhn.fr). 2Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, 91405, Orsay, France.

Tagish Lake has been one of the most puzzling carbonaceous meteorites, since its fall on a frozen lake in Canada, in 2000. Different fragments of this C2-ungrouped (Grady et al. 2002) were recovered, some deemed as "pristine", and other as "degraded" after subsequent terrestrial alteration (Brown et al. 2000). Uniquely, Tagish lake presents at least 5 different lithologies associated with different degrees of alteration by fluids (Herd et al. 2011), possibly during the asteroidal stage. The insoluble fraction (IOM) of Tagish lake organic matter has shown very high D/H and 15N/14N bulk signatures (Herd et al. 2011), contrasting with primitive CIs or CMs chondrites. Based on spectroscopic evidences (Hiroi et al. 2011), Tagish-Lake has been deemed as related to D-type asteroids, present in the outer belt and beyond. This link between D-type asteroid and Tagish lake has been recused lately, the VNIR resemblance being posed as insufficient (Vernazza et al., 2017), with a better but yet partial match with Ceres (Vernazza et al., 2017). This has left a persistent mist surrounding the origins of Tagish Lake. In 2021, the fall of Tarda in the Moroccan desert (C2-ungrouped, Chennaoui Aoudjehane et al., 2021), has reopened the debate, with mineralogical and isotopic evidences linking Tarda and Tagish Lake (Marrocchi et al., 2021). We will be presenting new data regarding the molecular and isotopic compositions of Tarda's IOM. The data show a great similarity with the least altered lithologies of Tagish Lake, and partially with CIs chondrites, accounting for a possible common origin from a distant asteroid, beyond the snowline.

Résumés

Interstellar ices: the first chemistry reactor of star forming regions

Layssac, Y.1, Gutiérrez-Quintanilla, A.1, Duvernay, F.1
1Aix Marseille Univ, CNRS, PIIM, Marseille, France

The interstellar medium (ISM) consists of 99% gas and 1% dust, by mass. In dense molecular clouds, where stars and planetary systems can form, the combination of low temperatures (~10 K) and pressures (< 10-14 mbar) leads to the accretion of atoms (H, C, N, O, …) and small molecules (CO) onto dust grains to form what is called "interstellar ices" [1]. These astrophysical objects are composed of simple molecules such as H2O, CO, CO2, CH4, NH3 and CH3OH [2]. Eventually, a star appears from the gravitational collapse of the cloud and begins to emit energetic radiation that can process interstellar ices, forming radical intermediary species. These reactive molecules are thought to be at the basis of a rich and complex chemistry generating prebiotic material such as sugars or amino acids [3,4]. Newly formed molecules can be ejected in the gas phase of the ISM or remain in grains to ultimately be part of asteroids and comets [1].
With this presentation, I want to give some insights about the chemical solid reactivity in interstellar ices by focusing on how these objects are simulated in the laboratory and what are the main results obtained by the experimental astrochemistry community so far.

[1] Öberg, K. I. « Photochemistry and astrochemistry: Photochemical pathways to interstellar complex organic molecules ». Chemical Reviews. 2016, 116, 9631-9663.
[2] Boogert, A. C. A.; Gerakines, P. A.; Whittet, D. C. B. « Observations of the icy universe ». Annual Review of Astronomy and Astrophysics. 2015, 53, 541-581.
[3] Meinert C., Myrgorodska, I., De Marcellus, P., Buhse, T., Nahon, L., Hoffmann, S. V., Le Sergeant d'Hendecourt, L., Meierhenrich, U. J. « Ribose and related sugars from ultraviolet irradiation of interstellar ice analogs ». Science. 2016, 352, 208-212.
[4] Munoz Caro, G. M., Meierhenrich, U. J., Schutte, W. A., Barbier, B., Arcones Segovia, A. Rosenbauer, H., Thiemann, W. H.-P., Brack, A., Greenberg, J. M. « Amino acids from ultraviolet irradiation of interstellar ice analogues ». Nature. 2002, 416, 403-406.

Hydrogen isotope exchange between polycyclic aromatic hydrocarbons and water during aqueous alteration events on carbonaceous asteroids

Marceau Lecasble, Laurent Remusat, Nadia Khodorova, Isis Criouet and Sylvain Bernard
Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, Sorbonne Universités, CNRS UMR 7590, Muséum National d'Histoire Naturelle, Paris.

Polycyclic aromatic hydrocarbons (PAHs) are widely distributed in the interstellar medium (ISM) where deuterium enrichment likely occurs due to low-temperature astrochemical processes. PAHs are commonly detected in carbonaceous chondrites (CC) and their hydrogen isotope ratio has been found depleted in deuterium. The loss of their hydrogen isotope signature may be due to secondary processes on parent bodies such as aqueous alteration. Here, we investigate the hydrogen isotope evolution of phenanthrene and pyrene under aqueous alteration at temperatures comprised between 50 and 370°C. We also investigate the impact of a phyllosilicate (saponite) on this process. PAHs efficiently exchange their hydrogen isotopes with water at temperatures above 300°C, PAH values reaching a plateau within a week at 350 °C, with a half-life of two days. In the experiments with saponite, exchange rate is increased and saponite also efficiently exchange with water. Also, the isotope fractionation between PAHs and water is reduced, suggesting that equilibrium is shifted. This experimental work confirms that PAHs in CCs may have easily lost their pre-accretion hydrogen isotope signatures, hence losing the memory of their synthesis environment.

Grain scale heterogeneities in Ryugu samples: a key to understand aqueous alteration and space weathering

Tania Le Pivert-Jolivet1, Rosario Brunetto1, Cedric Pilorget1, Jean-Pierre Bibring1, Aiko Nakato2, Damien Loizeau1, Lucie Riu1, Vincent Hamm1, Cateline Lantz1, Kentaro Hatakeda2,3, Kasumi Yogata2, Donia Baklouti1, Toru Yada2 Tatsuaki Okada2, Tomohiro Usui2, and the Micromega IAS/ISAS Curation Team.
1IAS, Université Paris-Saclay, CNRS, France, 2Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3Marine Works Japan, Ltd

Hayabusa2 is the first space mission to study and collect samples from a C-type asteroid. In December 2020, the spacecraft brought back to Earth ~5.4g of materials from the surface of asteroid (162173) Ryugu. The samples were collected from two different sites TD1 and TD2 [1] at the surface of the asteroid. The second touchdown was performed near the artificial crater created by the small carry-on impactor [2] to collect both surface and subsurface materials. The samples were delivered to JAXA (Japan Aerospace eXploration Agency) Extraterrestrial Curation Center for preliminary analyses. The samples were extracted from chambers A and C, corresponding to TD1 and TD2 respectively, and analyzed in a controlled N_2 environment by an optical microscope, a FTIR, and MicrOmega, a near-infrared (0.99-3.65 µm) hyperspectral microscope. MicrOmega acquires images of 256x250 pixels with a spatial resolution of 22.5 µm [3]. The first spectral characterization of the bulk samples within the Curation Facility [4,5] showed that the grains are extremely dark and exhibit absorption features at 2.72 µm, 3.1 µm and 3.4 µm due to phyllosilicates, NH-rich compounds, and organics and/or carbonates respectively. The 2.72 µm feature was also observed on the asteroid's surface by the NIRS3 spectrometer [6]. In addition to the bulk samples, observations of millimeter sized grains, extracted from the bulks, were performed with MicrOmega. We investigate here the variations of the position and the depth of the 2.72µm feature at the individual grain scale, on 177 grains from chambers A and C.
The position of the 2.72 µm OH feature is consistent with the position found in CI chondrites and highly aqueously altered CM chondrites [7]. Contrary to the bulk spectra where the 2.72µm OH feature was very similar between chambers A and C [5], the position of the OH varies within an interval of 10 nm at individual grain scale. Importantly, our results show differences in the distribution of the 2.72 µm band position and depth between the two chambers. The OH feature position can change with the Mg/Fe ratio in phyllosilicates [8]. Moreover, space weathering experiments on carbonaceous chondrites have shown that irradiation tends to shift the band position towards longer wavelength after [9] and decrease the band depth [10]. We will discuss the spectral differences between the collected grains, in particular between chambers A and C, and what information they carry about the composition of the phyllosilicates and the space weathering processes affecting Ryugu's surface materials.

References: [1] Tachibana et al. (2020) LPS XXXXXI Abstract #2027. [2] Arakawa et al. (2017) Space Sci. Rev. 208, 187-212. [3] Bibring et al. (2017) Space Sci. Rev. 208, 401-412. [4] Yada et al. (2022) Nat Astron, 6, 214-220. [5] Pilorget et al. (2022) Nat Astron, 6, 221-225. [6] Kitazato et al. (2019) Science, 364, 272-275. [7] Takir et al. (2013) M & PS 48, 1618-1637. [8] Besson and Drits (1997), CCM, 45, 158. [9] Lantz et al. (2017) Icarus 285, 43-57. [10] Matsuoka et al. (2020) ApJL 890, L23.

On the origin of life homochirality: development of an integrative workflow for the reliable enantioselective analysis of amino acids and sugars in astrophysical samples

Vanessa Leyva1, Raphaël Pepino1, Jana Bocková1, Cornelia Meinert1
1Institut de Chimie de Nice, Université Côte d'Azur, CNRS, UMR 7272, 06108 Nice, France

When, where and how did life begin on Earth remains not only one of the most intriguing questions, but also a decisive one in guiding the search for convincing signs of life beyond our planet. Strong evidence supports the hypothesis that the emergence of life on Earth is inherently linked to symmetry breaking events that led to enantiomeric excesses (ees) of L-amino acids and D-sugars that enabled the evolution of functional homochiral biopolymers – DNA/RNA and proteins [1,2]. Given that a major source of these enantiomer-enriched molecules may have been the continuous bombardment of early Earth by interstellar bodies [1,2], our ability to accurately detect and quantify chiral compounds in simulated and authentic extraterrestrial matter is crucial to elucidating the events that led to biological homochirality [1,4,5]. Although significant progress has been made in the development of efficient analytical protocols for the enantioseparation of chiral molecules, effective methods combining high sensitivity, resolution, and reliable determination of ees are still lacking [1-4]. This work proposes therefore the development of an integrated protocol combining extraction, purification, derivatization, and analysis of astrophysical samples, such as those from the Hayabusa2 and Osiris-Rex missions, for the reliable enantioselective analyses of chiral amino acids and sugars employing multidimensional gas chromatography. The results of this research will also help to build a unified view of the potential role of circularly polarized light, the most promising source to trigger molecular asymmetry under astrophysical conditions [2,5], in the origin of biological homochirality

This work is supported by the European Research Council under the EU's HORIZON 2020 research & innovation programme [grant agreement 804144].

[1] D. Glavin, et al., Chem. Rev. (2020) 120, 4460-4689.
[2] A. Garcia, et al., Life (2019) 9, 1-21.
[3] I. Myrgorodska, et al., J. Chrom. A (2016) 1433, 131-136.
[4] Y. Furukawa, et al., PNAS (2019) 116, 24440-24445.
[5] C. Meinert et al. Angew. Chem. Int. Ed. (2014) 53, 214-2018.

Revisiting Zirconsin the Martian Regolith Breccia Northwest Africa 7533

V. Malarewicz a,b, O. Beyssacb, B. Zandab,c, R. Hewinsb, D. Rubattod, J. Marin-Carbonnee, H.Lerouxf, S. Pontb, S. Bernardb,S. Bouleya,c
aGEOPS – Géosciences Paris Sud, CNRS, Univ. Paris Saclay, 91400 Orsay, France. bIMPMC- Sorbonne Univ., MNHN, UPMC Paris 06, UMR CNRS 7590, 75005 Paris, France, cIMCCE – Observatoire de Paris, CNRS-UMR 8028, Paris, France, dInstitute of Geological Sciences, Uni. of Bern, Switzerland, eInstitute of Earth Sciences, Uni. of Lausanne, 1015 Switzerland, fUniv. Lille, CNRS, INRAE, Centrale Lille, UMR 8207 - UMET, F-59000, Lille, France

NWA7533 is an exceptional martian meteorite as it is a regolith breccia giving unique access to the early history of the martian crust [1]. NWA7533 exhibits a complex diversity of lithic clasts providing evidence for magma differentiation processes leading to a primitive felsic crust starting around 4.2-4.4 Gy [2,3]. Here, we combine Raman and luminescence spectroscopy, SEM, EDX mapping, TEM on FIB sections and new SIMS data to explore in detail the structure and chemistry of zircons in the matrix and in the various lithic clasts, as they are critically important minerals for the determination of the thermal and geochronological history of the sample.

The zircon crystals display impressive textural and structural variability at the grain scale, due to local metamictization and/or alteration processes. Clear growth zonation of preserved crystal are observed next to partially amorphous or degraded domains containing number of micro-inclusions and/or pores. The nanoscale texture of the zircon crystals has been investigated using TEM on FIB sections and inclusions of Si- or Fe-S- rich phases and magnetite were identified. The textural variations of grains are related to their petrological settings: well crystallized grains are found in microbasaltic clasts and yield U-Pb ages around 4.4-4.2 Ga, while degraded zircons are mostly found in the matrix with younger ages clustered around 1.5 Ga, paired with high U-content, consistent with some metamictization processes. Finally, fragmented and heterogenous zircons in feldspathic clasts suggest that their formation and modification happened before their injection in the clasts, leaving the different textures as witness from their early life.

These new observations bring several new questions regarding the interpretation of geochronological data and the origin of alteration mechanism (aqueous or magmatic) early in the martian history.

[1] Hewins R. et al. (2017) Meteoritics & Planetary Science52, 89-124.
[2] Humayun M. eal. (2013) Nature 503, 513-516.
[3] Hu S. et al (2019) Meteoritics & Planetary Science 54, 850-87

Interactions entre les aérosols de Titan et les phases liquides de surface

Louis Maratrat1, Valentin Moulay1, Ludovic Vettier1, Daniel Cordier2, Nathalie Carrasco1, Caroline Freissinet1, Zoé Perrin1, Thomas Gauthier1
1 LATMOS, UMR CNRS 8190, Université Versailles St Quentin, Guyancourt, France
2 Groupe de Spectrométrie Moléculaire et Atmosphérique, UMR CNRS 7331, Université de Reims Champagne-Ardenne, Reims, France.

Titan, le principal satellite de Saturne, dispose d’une atmosphère dense composée principalement d’azote N2 et de méthane CH41. Dans les hautes couches atmosphériques, ces composés sont photo dissociés amorçant ainsi un réseau de réactions chimiques conduisant à la formation de molécules organiques complexes. Il en résulte l’obtention de particules organiques solides2 (ou aérosols), qui, une fois formées, sédimentent jusqu’à la surface du satellite.

Or Titan comporte en surface des étendues liquides : des lacs de méthane liquide3, stables dans les conditions locales de pression et température (1.5bar, 90K) et on y suspecte aussi l’existence de cryovolcans4, geysers d’eau ammoniaquée en provenance des couches internes du satellite5. Qu’en est-il donc des interactions existantes entre ces aérosols solides se déposant en surface et ces phases liquides ?

Le but de ce travail a été d’envisager deux types d’interactions : des interactions chimiques ayant attrait à la solubilité de ces particules dans les liquides, et des interactions physiques liées à la flottabilité et l’évolution morphologique des aérosols. Ces interactions ont été étudiées au laboratoire avec des analogues d’aérosols Titan, synthétisés dans le réacteur PAMPRE du LATMOS. Les interactions avec les étendues liquides de Titan, méthane et eau, ont été étudiées à température ambiante et le méthane a ainsi été simulé par le pentane, hydrocarbure liquide dans les conditions du laboratoire.

Sur le plan physique, une flottabilité des Tholins a pu être mise en évidence dans ces phases liquides : celle-ci est spontanée en phase aqueuse tandis qu’elle apparaît uniquement sous agitation dans le cas du pentane. Cette flottabilité dans le pentane pourrait d’ailleurs expliquer l’observation de certaines bandes d’évaporites en surface de Titan6.

Enfin, chimiquement, des produits d’hydrolyse des Tholins à pH neutre ont été caractérisés par GC MS.

(1) Waite, J. H.; Niemann, H.; Yelle, R. V.; Kasprzak, W. T.; Cravens, T. E.; Luhmann, J. G.; McNutt, R. L.; Ip, W.-H.; Gell, D.; De La Haye, V.; Müller-Wordag, I.; Magee, B.; Borggren, N.; Ledvina, S.; Fletcher, G.; Walter, E.; Miller, R.; Scherer, S.; Thorpe, R.; Xu, J.; Block, B.; Arnett, K. Ion Neutral Mass Spectrometer Results from the First Flyby of Titan. Science 2005, 308 (5724), 982–986. https://doi.org/10.1126/science.1110652.
(2) Israël, G.; Szopa, C.; Raulin, F.; Cabane, M.; Niemann, H. B.; Atreya, S. K.; Bauer, S. J.; Brun, J.-F.; Chassefière, E.; Coll, P.; Condé, E.; Coscia, D.; Hauchecorne, A.; Millian, P.; Nguyen, M.-J.; Owen, T.; Riedler, W.; Samuelson, R. E.; Siguier, J.-M.; Steller, M.; Sternberg, R.; Vidal-Madjar, C. Complex Organic Matter in Titan’s Atmospheric Aerosols from in Situ Pyrolysis and Analysis. Nature 2005, 438 (7069), 796–799. https://doi.org/10.1038/nature04349.
(3) Mastrogiuseppe, M.; Poggiali, V.; Hayes, A. G.; Lunine, J. I.; Seu, R.; Mitri, G.; Lorenz, R. D. Deep and Methane-Rich Lakes on Titan. Nat. Astron. 2019, 3 (6), 535–542. https://doi.org/10.1038/s41550-019-0714-2.
(4) Lopes, R. M. C.; Mitchell, K. L.; Stofan, E. R.; Lunine, J. I.; Lorenz, R.; Paganelli, F.; Kirk, R. L.; Wood, C. A.; Wall, S. D.; Robshaw, L. E.; Fortes, A. D.; Neish, C. D.; Radebaugh, J.; Reffet, E.; Ostro, S. J.; Elachi, C.; Allison, M. D.; Anderson, Y.; Boehmer, R.; Boubin, G.; Callahan, P.; Encrenaz, P.; Flamini, E.; Francescetti, G.; Gim, Y.; Hamilton, G.; Hensley, S.; Janssen, M. A.; Johnson, W. T. K.; Kelleher, K.; Muhleman, D. O.; Ori, G.; Orosei, R.; Picardi, G.; Posa, F.; Roth, L. E.; Seu, R.; Shaffer, S.; Soderblom, L. A.; Stiles, B.; Vetrella, S.; West, R. D.; Wye, L.; Zebker, H. A. Cryovolcanic Features on Titan’s Surface as Revealed by the Cassini Titan Radar Mapper. Icarus 2007, 186 (2), 395–412. https://doi.org/10.1016/j.icarus.2006.09.006.
(5) Mitri, G.; Showman, A. P.; Lunine, J. I.; Lopes, R. M. C. Resurfacing of Titan by Ammonia-Water Cryomagma. Icarus 2008, 196 (1), 216– 224. https://doi.org/10.1016/j.icarus.2008.02.024.
(6) MacKenzie, S. M.; Barnes, J. W.; Sotin, C.; Soderblom, J. M.; Mouélic, S. L.; Rodriguez, S.; Baines, K. H.; Buratti, B. J.; Clark, R. N.; Nicholson, P. D.; McCord, T. B. Evidence of Titan’s Climate History from Evaporite Distribution. Icarus 2014, 243, 191–207. https://doi.org/10.1016/j.icarus.2014.08.022.

Amplitude Modulations in Strato-Rotational Instabilities (SRI) with applications to star formation in accretion disks.

Gabriel Meletti"†1,2, Stéphane Abide2, Stéphane Viazzo3, Uwe Harlander4
1Lyon Institute of Origins LabEx LIO, Université Claude Bernard Lyon1, Lyon
2Laboratoire de Mathématiques et Physique, University of Perpignan Via Domitia, Perpignan 3Laboratoire de Mécanique, Modélisation et Procédés Propre, Aix-Marseille University, CNRS, Centrale Marseille
4Department of Aerodynamics and Fluid Mechanics, Brandenburg University of Technology (BTU) Cottbus-Senftenberg, Cottbus, Germany.

In geophysical and astrophysical flows, stratified vortices can be found from small to large scales, and they are relevant in the distribution of heat and momentum in stably stratified systems such as the atmosphere or oceans. In the astrophysical context, accretion disks (from which solar systems are formed) can be seen as stratified vortices.
In such systems, understanding the mechanisms that can result in an outward transport of angular momentum is a central problem.

For a planet or star to be formed in a disk, angular momentum has to be carried away from its center to allow matter aggregation by gravity; otherwise, its rotation speed would be far too large, avoiding this matter aggregation (and the consequent star formation) to happen.

In such gas systems, turbulence is the most likely mechanism to achieve such a large angular momentum transport. However, it was shown that the flow profile of accretion disks is stable with respect to purely shear instabilities, and the question arises about how the turbulence can be generated.

Among other candidates, the strato-rotational instability (SRI) has attracted attention in recent years. The SRI is a purely hydrodynamic instability that manifests itself as non-axisymmetric spirals and can be modeled by a classical Taylor-Couette (TC) system with stable density stratification. The density stratification causes a change in the marginal instability transition when compared to classical non-stratified TC systems, making the flow unstable in regions where, without stratification, it would be stable. This characteristic makes the SRI a relevant phenomenon in planetary and astrophysical applications, particularly in accretion disk theory. In this work, it will be presented confrontations of experimental data with non-linear High-performance numerical simulations of strato-rotational flows that reveal non-linear interactions of SRI modes leading to periodic changes in the SRI spirals axial direction of propagation. These spiral patter changes lead to low-frequency velocity amplitude modulations related to two competing spiral wave modes.

We will then show how two different spirals linearly interacting could lead to these pattern changes, but related to the non-linear transfer of energy from the base flow to these secondary instabilities. We will also show how the presence of amplitude modulations impact the momentum transfer regime and the net momentum flux driven by the SRI, that might represent strong influences on star formation regimes in accretion disks.

Keywords: Astrophysical fluid dynamics; stratified Taylor-Couette flow; stratorotational instability, Particle Image Velocimetry (PIV), non-Linear Numerical Simulations, Direct Numerical Simulations (DNS)

Experiments on penetrative convection *

Gabriel Meletti"†1,2, Thierry Alboussiere1, Sylvain Joubaud2, Philippe odier2, and Stephane Labrosse1
1Laboratory of Geology of Lyon : Earth, Planets and Environments (LGLTPE) - Université Lyon 1
2Laboratoire de Physique - École normale Supérieure (ENS) de Lyon

Penetrative convection regards the interaction between a convective and a stable density stratified layer and is relevant in various astrophysical and geophysical applications, such as the excitation of waves in the stably stratified upper atmosphere by the convective lower troposphere. In the context of Earth's interior dynamics, the core is known to be in a convective state that sustains the Earth's magnetic field by dynamo action. Although seismology does not yet bring a definite answer, a stably stratified layer on the top of the core may exist since the Earth’s origin, as current estimations of the core thermal conductivity would lead to an excessive heat flux coming out of the core to sustain a fully convective region. Against this background, it is important to understand what kind of motion can exist in a potentially stable layer excited by a convective region. To help answer key questions relative to penetrative convection, an experimental setup was built to investigate the interaction of a stably stratified layer with a convective region. Salty stratification was used with concentration increasing in the direction of gravity. Lighter fresh water is then slowly introduced from the bottom of the cavity, creating the convective region. The velocity of the convective interface advancing in the stable regions was investigated. The presence of gravity waves in the stable region was also observed using Schlieren technique, and will also be presented. These investigations are the first step before looking at these phenomena on a rotating experimental setup, that is now in its final phase of construction. The experimental task is made more difficult in a rotating frame but is important to be performed in a planet's interior context due to Coriolis forces in the core, that become strong when compared to the ocean or atmosphere applications, for example. These future investigations on a rotating frame will also create a rich environment in terms of physical processes, such as rotating convection, and the presence of Inertial-gravity waves due to the stratification and rotation.

Keywords: Penetrative convection; Buoyancy-driven instability; Internal waves; Stratified flows

"Speaker
†Corresponding author: gabriel.meletti@univ-lyon1.fr.

*Poster

Preparation of in-situ analyses of icy moons : characterization of analog samples from Lake Tirez, La Mancha, Spain

V. Moulay1, C. Freissinet1, D. Boulesteix2, A. Buch2, N. Ruscassier2, Y. Marcangeli3, F. Gomez4, C. Szopa5.
1LATMOS/IPSL, UVSQ Université Paris-Saclay, Sorbonne Université, CNRS, 11bd d'Alembert, 78280 Guyancourt, France
2Laboratoire Génie des Procédés et Matériaux, CentraleSupelec, Université Paris-Saclay, 8-10 rue Joliot Curie, 91190, Gif-sur-Yvette, France
3Responsable Plateau d'EcoGéoChimie, iEES-Paris, Sorbonne Université
4Centro de Astrobiología (INTA-CSIC), Madrid, Spain

Europa and Enceladus, two ocean worlds in our solar system, are targets of high interest for astrobiology in the decades to come. Past space missions (Cassini-Huygens and Galileo) and recent observations with the Hubble Space telescope have revealed the presence of salts and of small organic molecules (sulfate and/or chloride) in the plumes of Enceladus and in the components of Europa'ssurface (1-4). In order to prepare the future in-situ analysis of these moons, analog samples were studied to evaluate the ability of payload to detect organic molecules from potential life. Samples from the Tirez Lake, La Mancha Spain were consideredas analogous to the ocean and the crust of Europa and potentially Enceladus. These samples and their intrinsic characterization (their intrinsic characterization is understudied (organic content, chemistry of salts, etc). Only an exhaustive study focusing on the characterization of the microbial communities was done (5). Therefore, in this work, we report several physicochemical results from different analytical techniques, allowing a beginning of a whole characterization of these analogs. Morphology, salts content, salts quantification and the organic content were investigated. In the near future, we plan to use more instruments to better characterize the inventory of organic molecules in these samples.

1. T. B. McCord, Hydrated salt minerals on Europa's surface from the Galileo near-infrared mapping spectrometer investigation. Journal of Geophysical Research 104, (1999).
2. Waite, Cassini Ion and Neutral Mass Spectrometer Enceladus Plume composition and Structure. Science 311, (2006).
3. S. K. Trumbo, M. E. Brown, K. P. Hand, Sodium chloride on the surface of Europa. Science Advances 5, eaaw7123 (2019).
4. S. K. Trumbo, et al., A New UV Spectral Feature on Europa: Confirmation of NaCl in Leading hemisphere Chaos Terrain. (2022).
5. L. Montoya et al., Microbial community composition of Tirez lagoon (Spain), a highly sulfated athalassohaline environment. Aquatic Biosystems 9, 19 (2013).

Analog experiments for the detection of bacterial biosignatures in ice grains from ocean worlds

Maryse Napoleoni1, Fabian Klenner1, Miriam Pavlista1, Janine Bönigk1, Marie Dannenmann1,2, Nozair Khawaja1, Jon K. Hillier1, Karen Olsson-Francis3, Bernd Abel4 and Frank Postberg1
1Freie Universität Berlin, Germany 2University of Zurich, Switzerland 3The Open University, United Kingdom 4Leipzig University, Germany

Active ocean worlds, such as Enceladus and potentially Europa, eject plumes containing ice grains formed from subsurface water into space. The emitted ice grains can be analyzed by impact ionization mass spectrometers such as the Cosmic Dust Analyzer (CDA) onboard the Cassini spacecraft or the Surface Dust Analyzer (SUDA) onboard NASA's Europa Clipper, providing insight into the oceans' compositions by flybys. Salts [1] and various organic molecules [2,3] were detected in ice grains from Enceladus.

The Laser Induced Liquid Beam Ion Desorption (LILBID) experiment reproduces the impact ionization mass spectra of ice grains recorded in space [4], and can be used to calibrate spaceborne mass spectrometers to identify biosignatures that are potentially incorporated in ice grains [5].

We conducted high-resolution LILBID experiments with cell material isolated from Escherichia coli and Sphingopyxis alaskensis bacteria to predict their spectral appearances in cationic and anionic impact ionization mass spectra. The extracted biosignatures include genomic DNA, membrane lipids and the aqueous phase of the lipid extraction, which potentially contains polar molecules. These extracts were also investigated in NaCl-rich matrices to account for salty Enceladean or Europan oceans.

We identified characteristic microbial mass spectral signals, such as fatty acids, DNA nucleobases, and compounds deriving from the phosphate deoxyribose backbone of DNA, at ppm-level concentrations. Mass spectra of all substances exhibit unambiguous biogenic patterns, which in some cases show significant differences between the two bacterial species. The spectral sensitivity of the extracts decreases with increasing salt concentration of the matrix.

[1] Postberg et al.(2009) Nature 459:1098–1101
[2] Postberg et al.(2018) Nature 558:564–568
[3] Khawaja et al.(2019) Mon.Not.R.Astron.Soc 489:5231-5243
[4] Klenner et al.(2019) Rapid Commun Mass Spectrom 33:1751-1760
[5] Klenner et al.(2020) Astrobiology 20:179-189.

Heterogeneous chemistry on Titan : Evolution of Titan's tholins through time with gas phase chemistry

Zoé Perrin1; Nathalie Carrasco1; Nathalie Ruscassier2; Julien Maillard3; Thomas Drant1, Ludovic Vettier1; Guy Cernogora1
LATMOS, Guyancourt, 1
LGPM – Centrale-supélec, Gif-sur-Yvette 2
COBRA – Université de Rouen, Mont St Aignan 3

In the surprising atmosphere of the satellite Titan, the photochemistry of its two major components N_2 and CH_4 leads to the formation of complex organic molecules, until the formation of solid aerosols, in the form of an orange haze.
Models [1] and laboratory [2] experiments in agreement with observations from the Cassini-Huygens mission [3], strongly suspect that this haze is formed and evolves by polymerization of several nitrogenous photochemical products (precursors) such as HCN, as well as hydrocarbons like C_2H_2. Our aim is to investigate experimentally the interaction of the haze particles with their atmospheric chemical environment, focusing on possible reactive molecules produced by gas phase photochemistry such as HCN and C_2H_2.
In this work, a dusty plasma reactor [4] is used to simulate the chemistry of Titan's upper atmosphere, as well as the synthesis of analogous aerosols (tholins). Gaseous precursors formed by electron dissociation were monitored in-situ by mass spectrometry, simultaneously with the formation and growth of haze particles. The haze particles ex situ are analyzed by electron microscopy and high resolution mass spectrometry (FTICR-LDI). Our results show that the precursors are consumed while the particles appear and grow. The harvested particles show a changing nitrogen chemical signature through time. Based on our kinetic experimental data, we investigate various interactions between the particles and the reactive gas (absorption, adsorption, desorption, diffusion).

[1] : Lavvas P. et al., The Astrophysical Journal (2011).
[2] : Gautier T. et al., Earth and Planetary Science Letters 404 : 33-42 (2014).
[3] : Israël G. et al., Nature 438 : 796-99 (2005).
[4] : Szopa C. et al., Planetary and Space Science 54 (2006).

Thermal analyses of biocarbonates as part of the search for traces of life in planetary environments

A. Perron1,2, F. Stalport2, F. Baudin3, R. Gonthier2, C. Azemard2, A. Chevillot-Biraud4, S. Borensztajn1, S. Nowak5, L. Lecourt1, B. Ménez1

1Université de Paris, Institut de physique du globe de Paris, CNRS, Paris, perron@ipgp.fr,
2Université de Paris, Laboratoire Interuniversitaire des Systèmes Atmosphériques, CNRS, Créteil, France,
3Sorbonne Universités, UPMC Univ. Paris 06, CNRS, ISTeP, Paris, France,
4Université de Paris, Laboratoire Interfaces Traitements Organisation et DYnamique des Systèmes, CNRS, Paris, France,
5Université de Paris, Plateforme RX, UFR Chimie, Paris, France.

The search for organics in extraterrestrial environments is the primary strategy to highlight a potential extinct or extant life. One alternative method is to search for the presence of biologically-formed minerals, probably more resistant in such environments and capable of preserving remnants of biological organic matter. The goal is then to distinguish bio- and organo-minerals from their abiotic counterparts by using instruments as close as possible to in situ space ones such as pyrolysis coupled with gas chromatography (GC) and mass spectrometry (MS).
Carbonates are abundant minerals in the Earth's rock record that are formed mostly by biological activity. Pyrolysis performed by differential thermal analysis (DTA) show differences of at least 20°C in phase transition temperatures between abiotic Mg- and Ca-carbonates and their natural (modern and fossil) or laboratory biogenic counterparts (Perron et al., submitted to Astrobiology). DTA-MS analysis as well as Rock-Eval pyrolysis also reveal that the biological organic matter trapped in bio-related minerals can be thermally dissociated from organic compounds adsorbed on the mineral surface. Additional single and dual injection pyrolysis-GC-MS can identify these organic compounds released at different temperatures. Overall, each pyrolysis technique provides complementary information on the organic matter trapped in bio-related carbonates' crystalline structure. Thermal analysis would then have the potential to distinguish bio-related carbonates from abiotic carbonates and to highlight their ability to preserve associated organic molecules of biological origin. Those approaches could be used for the search for possible records of life in extraterrestrial environments such as Mars, Enceladus, Europa and Titan by current and future space exploration missions.

Opaline silica: a mineralogical best friend for studying paleoclimates and exobiological purposes beyond Earth?

Maxime PINEAU1, Simon GOUZY2,3, Boris CHAUVIRÉ2,4, Benjamin RONDEAU2, John CARTER1,5, Vassilissa VINOGRADOFF3, Lu PAN6, Laetitia LE DEIT2, Nicolas MANGOLD2

1 Lab. Astrophys. de Marseille, Aix-Marseille Univ., CNRS-CNES, Marseille, France.
2 Lab. Planét. et Géos., Nantes Univ., Univ. d'Angers, Le Mans Univ., CNRS, Nantes, France.
3 Phys. Intérac. Ioniques et Mol., Aix-Marseille Univ., CNRS, Marseille, France.
4 Inst. Sciences de la Terre., Univ. Grenoble-Alpes, CNRS, Grenoble, France.
5 Inst. Astrophys. Spatiale, Univ. Paris-Saclay, CNRS, Orsay, France.
6 Globe Institue, Univ. Copenhagen, Copenhagen, Denmark.

Everyone has seen necklaces, rings, bracelets or other jewelry products set with agate, onyx, obsidian, and/or precious opal displaying play-of-color patterns. All these species or mineral varieties belong to the same mineral family: that of opaline silica ($SiO_2.nH_2O$; hydrated amorphous to cryptocrystalline silica). Beyond its obvious aesthetic and economic interests, opaline silica has much more to offer from a scientific point of view. First, it is readily accessible to scientific scrutiny, being a very common phase found in most water-rich geological settings on Earth: mid-oceanic ridges, volcanic activity, subsurface or aerial hydrothermal activity, diagenetic and sedimentary contexts, soil weathering profiles, among others [1,2]. Opaline silica is therefore a useful proxy for tracing diverse geological processes at the Earth's surface. Notably, recent studies have shown that it is possible to determine the geological origin (hydrothermal activity versus continental weathering) of terrestrial opals by studying their spectral signature in the near-infrared range, which allows to make paleoclimatic reconstructions [1]. Opaline silica has been detected at the surface of Mars, both by in-situ rover observations and orbital remote-sensors in various geological contexts, some of which may be specific to the red planet [see refs in 2,3,4]. Application of specific spectral criteria to determine the geological origin of opaline silica from Mars data has demonstrated that both hydrothermal silica and low-temperature weathering silica have formed on the planet, sometimes quite recently in the aqueous history of Mars [2,3]. But silica's greatest potential came back to the science forefront. It is well known that silica minerals interact with the carbon cycle and allow a more durable fossilization against time than other compounds like amber or carbonates, while allowing a very good preservation of organic tissues [5]. Thus, it is not surprising to see that the oldest traces of life observed so far on Earth are found in siliceous rocks (cherts, possibly derived from opaline silica), dated at a period older than 3.5 Gyr [6,7]; period during which liquid water likely flowed and even accumulated on Mars [8]. These ancient traces of life have been observed in fossil geyser systems and it is well known that terrestrial siliceous geysers develop favorable conditions to support rich and dynamic ecosystems. Such fossil environments have also been observed on Mars and are therefore prime targets for exobiological studies [see refs in 2,9]. Thus, silica represents one of the most promising materials for exobiological studies in the Solar System even beyond the asteroidal belt as other planetary bodies such Enceladus or Europa exhibit internal oceans that are thought to harbor hydrothermal seamount systems [10].

[**1**] Chauviré et al. (2017) *Eur. J. Min.*, doi: 10.1127/ejm/2017/0029-2614
[**2**] Pineau et al. (2020) *Icarus*, doi: 10.1016/j.icarus.2020.113706
[**3**] Pan et al. (2021) *Planet. Sci. J.*, doi: 10.3847/PSJ/abe541
[**4**] Carter al. (2022) *Icarus*, doi: 10.1016/j.icarus.2022.115164
[**5**] Chauviré et al. (2020) *Sci. Reports*, doi: 10.1038/s41598-020-67412-9
[**6**] Djokic et al. (2017) *Nature Comm.*, doi: 10.1038/ncomms15263
[**7**] Nutman et al. (2019) *Precamb. Research*, doi: 10.1016/j.precamres.2019.105347
[**8**] Ehlmann et al. (2011) *Nature*, doi: 10.1038/nature10582
[9] Ruff et al. (2011) Astrobiology, doi: 10.1089/ast.2019.2044
[10] Damer & Deamer (2020) Astrobiology, doi: 10.1089/ast.2019.2045

Astrobiology on Phobos and Deimos: preparatory studies and future investigation from MIRS instrument on board the JAXA Martian Moon eXploration sample return mission

Giovanni Poggiali1, Antonella Barucci1
1LESIA-Observatoire de Paris,
Université PSL, CNRS, Sorbonne Université, Université de Paris,
5 place Jules Janssen, 92190 Meudon, France (giovanni.poggiali@obspm.fr)

The debate over the origin of Mars' moons, Phobos and Deimos, presents a unique opportunity for astrobiology studies. Two possible scenarios have been proposed to explain their formation: a giant impact on Mars and subsequent re-accumulation of debris (Rosenblatt et al 2016, Hyodo et al 2018) or the capture of primitive asteroids (Hartmann 1990, Higuchi & Ida 2017). As known, both Mars and early asteroids are interesting astrobiological targets. The former represents one of the celestial bodies where the probability of finding life (extant or extinct) is higher. The latter represent the most effective vehicles for the transport and delivery of organic material from the protoplanetary disk onto rocky planets, including Earth.

To investigate the origin of Martian moons, JAXA will launch in 2024 a new sample return mission, Martian Moons eXploration (MMX, Kuramoto et al 2022), with the ambitious objective to study in detail the two little moons of Mars and bring back on Earth a sample (>10 g) from Phobos, the bigger one, in 2029. This mission will aim to determine the most probable formation process for Phobos and Deimos but also to investigate the early Solar System evolution in terms of volatile delivery across the snow line to the terrestrial planets having habitable surface environments. To perform such interesting objectives, the spacecraft payload will include a suite of scientific instruments to study in detail the surface of the moons. Among them, the MMX InfraRed Spectrometer (MIRS, Barucci et al 2021) will acquire infrared data in the range between 0.9 and 3.6 µm with spectral resolution better than 20 nm. This wavelength range is critical for the study of volatile and other fundamental components for the origin of life such as water, organics and carbonates. When MMX will arrive in the Martian system and MIRS will begin to observe the moons, a huge amount of data will be available. In this presentation we will show the preparatory studies and the future astrobiological investigations that will be carried out using the capabilities of the infrared spectrometer on board MMX spacecraft.

Barucci M. A., et al., 2021, Earth, Planets and Space, 73, 211
Hartmann W. K., 1990, Icarus, 87, 236
Higuchi A., Ida S., 2017, AJ, 153, 155
Hyodo R. et al. 2018, ApJ, 860, 150
Kuramoto K., et al., 2022, Earth, Planets and Space, 74, 12
Rosenblatt P. et al. 2016, Nature Geoscience, 9, 581

High temperature VUV cross section measurements of CO and application for the study of hot exoplanets

M.Poveda1,2, Y.Bénilan1, B.Fleury1, A.Jolly1, P.Tremblin2, O.Venot3
1Univ Paris Est Creteil and Université de Paris, CNRS, LISA, 94010 Créteil, France 2Université Paris-Saclay, UVSQ, CNRS, CEA, Maison de la Simulation, 91191, Gif-sur-Yvette, France
3Université de Paris and Univ Paris Est Creteil, CNRS, LISA, 75013 Paris, France

For the study of warm and hot exoplanets atmospheres, some physicochemical data are lacking at high temperature, such as VUV absorption cross-sections. In this context, we developed a new UV spectroscopic platform, which has just been installed at LISA to perform measurements at high temperatures on molecules of interest for exoplanets atmospheres. The first studied molecule was carbon monoxide (CO). We carried out this study in the $A^1\Pi$-$X^1\Sigma^+$ electronic transition between 68 000 and 78 000 cm-1 (128 to 147 nm), at different temperatures to reduce uncertainties on the determination of the temperature of the gas inside the cell. This study shows that CO can be used as a direct temperature probe of the gas inside our oven, and led us derive a new line list of CO in the VUV field. At the end, we will be able to determine a parametrization on the variation of absorption cross-sections with temperature. In 1D kinetic models, this parametrization will allow to calculate photodissociation rates that are essential to determine the chemical composition on the top of hot exoplanets atmospheres. The accurate VUV cross-sections at high temperature will be introduced in photochemical models to prepare and analyse future observations of exoplanetary atmospheres made by JWST and ARIEL.

Improving tidal models to better constrain the habitability of close-in planets *

A. Revol1, E. Bolmont1, G. Tobie2, C. Dumoulin2, Y. Musseau2, S. M.Athis3, A. Strugarek3, A.S. Brun3
1Observatoire de Genève, 51 Chemin Pegasis, 1290 Sauverny, Suisse.
2Laboratoire de planétologie et géodynamique, Université de Nantes, 2 rue de la Houssinière, 44322 Nantes.
3AIM, CEA, CNRS, Université Paris-Saclay, Université Paris Diderot, Sorbonne Paris Cité, 91191 Gif-sur-Yvette.

Half of the 5000 exoplanets discovered up to now have an orbital period less than 10 days and should experience some form of strong tidal evolution.The rotational state and the orbital evolution of exo planets are impacted by tidal interactions from the exchange of angular momentum.It influences the habitability through the rotation of the planet, both in terms of spin rate, which drives the heat re distribution (Turbet et al. 2020) and can prevent atmospheric collapse (Wordsworth, R. 2015), and the spin obliquity which drives seasonal variations.

If a planet has an atmosphere, another tidal mechanism should be taken into account: the thermal tide, which is caused by the differential heating between day and night sides (Auclair-Desrotour 2017a).In the case of thick atmospheres such as that of Venus, the thermal tides acting on the atmosphere can be

as strong as the gravitational tides acting on the solid core (Auclair-Desrotour et al. 2017b) and can both de-synchronize the planet and increase the spin inclination. Thermal tides are a possible explanation for the rotation state of Venus (e.g. Correia & Laskar, 2001).

We are here revisiting this work using an improved tidal model for the solid tide along with a prescription of atmospheric tides.In particular, recent developments have shown that more realistic rheological responses (e.g. the Andrade rheology) better reproduce the behaviour of a rocky body under external forcing, together with the atmospheric tides formalisms for thick atmospheres of Leconte et al. (2015). Our developments were added to code ESPEM (Benbakoura et al. 2019) to compute the orbital and rotational evolution of a Venus-like planet around a Sun-like star.

The evolutions we obtain are complex, with spin-orbit resonances, coming from either the eccentricity or the inclination of the orbit, and an obliquity of the planet which can vary dramatically with the presence or not of a thick atmosphere.

• Auclair-Desrotour, P. Laskar, J. Mathis, S. 2017a, A&A, 603, A107
• Auclair-Desrotour, P. Laskar, J. Mathis, S. Correia, A. C. M. 2017b, A&A,603, A108
• Benbakoura, M. Réville, V. Brun, A. S. Le Poncin-Lafitte, C. Mathis, S. 2019,A&A, 621, A124 • Correia A. C. M., Laskar J., 2001, Nature, 411, 767
• Leconte J., Wu H., Menou K., Murray N., 2015, Science, 347, 632

*Poster

OLYMPIA-LILBID: A new Laboratory Setup to Calibrate Spaceborne Hypervelocity Ice Grain Detectors using High-Resolution Mass Spectrometry

Arnaud Sanderink1,2, Fabian Klenner2, Illia Zymak3, Jan Zabka3, Frank Postberg2, Christelle Briois1.

1. Laboratoire de Physique et Chimie de l'environnement et de l'Espace, UMR-CNRS 7328, Orléans, France. 2. Institute of Geological Sciences, Freie Universität Berlin, Berlin, Germany. 3. J.H. Institute of Physical Chemistry, Prague, Czech Republic.

In the search for life as we know it, ocean worlds such as Europa and Enceladus, moons of Jupiter and Saturn respectively, are prime targets in our solar system. Numerous studies are modelling the inner oceans and their possible chemical properties to assess the habitability of those moons1–3. In addition, Cassini's Cosmic Dust Analyser (CDA)4 could measure the composition of ice grains emitted from the subsurface ocean of Enceladus, detecting a complex organic chemistry5,6. As the definition of life itself is still subject to discussions, the instruments for the detection of extra-terrestrial life will have to be state of the art to agnostically discriminate whether a sample is abiotic, prebiotic or even biotic. In this context we built a new analytical method that combines an ultra-high-resolution mass analyser, the OrbitrapTM 7 and an ionisation technique able to reproduce mass spectra of hypervelocity ice grain impacts in laboratory, the Laser Induced Liquid Beam Ion Desorption (LILBID)8. This new instrument, named OLYMPIA, will be used to create a high-resolution mass spectral data library for NASA's future mission Europa Clipper and its hypervelocity time of flight mass spectrometer, the SUrface Dust Analyser (SUDA)9. OLYMPIA is also used as a testbench for future Orbitrap-based hypervelocity detectors that will support spaceborne high resolution mass spectrometry.

1. Hand et al. Energy, Chemical Disequilibrium, and Geological Constraints on Europa. Astrobiology. 2007;7(6):1006-1022.
2. Parkinson et al. Habitability of Enceladus: Planetary Conditions for Life. Orig Life Evol Biospheres. 2008;38(4):355-369.
3. Hand et al. On the Habitability and Future Exploration of Ocean Worlds. Space Sci Rev. 2020;216(5):95.
4. Srama et al. The Cassini cosmic dust analyser. Space Sci Rev. 2004;Volume 114(Issue 1-4):465-518.
5. Postberg et al. The E-ring in the vicinity of Enceladus. Icarus. 2008;193(2):438-454.
6. Postberg et al. Macromolecular organic compounds from the depths of Enceladus. Nature. 2018;558(7711):564-568.
7. Makarov A. Electrostatic Axially Harmonic Orbital Trapping: A High-Performance Technique of Mass Analysis. Anal Chem. 2000;72(6):1156-1162.
8. Klenner et al. Analogue spectra for impact ionization mass spectra of water ice grains obtained at different impact speeds in space. Rapid Commun Mass Spectrom. 2019;33(22):1751-1760.
9. Kempf et al. SUDA: A Dust Mass Spectrometer for Compositional Surface Mapping for a Mission to Europa. Paper presented at: September 9, 2014.

Résumés

Pyrimidines in kit: How to assemble the uracil skeleton at the origins of life?

Louis Ter-Ovanessian1,2, Jean-François Lambert1, Marie-Christine Maurel2
1Laboratoire de Réactivité de Surface (LRS, UMR 7197 CNRS), Case courrier 178, Sorbonne Université, 4, Place Jussieu, 75005, Paris, France
2Institut de Systématique, Evolution, Biodiversité (ISYEB), Muséum National d'Histoire Naturelle, Sorbonne Université, Ecole Pratique des Hautes Etudes, Université des Antilles, CNRS, CP 50, 57 rue Cuvier, 75005, Paris, France

A large set of amino acids and nucleotide precursors is found in meteorites, implying that several chemical reservoirs are present in the solar system.

To build a bridge between these primitive bricks and protometabolism1, at an early stage of evolution, it is crucial to explore how protometabolic paths developed from simple precursors in an enzyme-free prebiotic world2. This implies to study how the geochemical context affected the first reactions between "biomolecules". Here we focus on the pyrimidine part in RNA monomer synthesis. In the living cell, the second step of synthesizing uridine and cytidine RNA monomers is formally a carbamoyl transfer from a carbamoyl donor to aspartic acid. This carbamoyl transfer coins the nucleobase moiety on which a phosphorylated ribose is later added.

In this presentation, we will show two enzyme-free scenarios: aqueous and dried/wetted mineral, compared to their biosynthetic version. Rock-assisted abiotic synthesis of the pyrimidine linear skeleton (in the form of N-carbamoyl aspartic acid) was performed over a thermal range up to 250 °C. In addition to aqueous synthesis of pyrimidine nucleobases, which readily occurred at 25 °C within 16 h, the catalytic properties of silica and hydromagnesite minerals were explored. Finally, this communication will emphasize how kinetics plays a determining role in selecting possible paths for the carbamoylation of aspartic acid, although various carbamoyl donors (urea, cyanate, etc.) could be efficient according to thermodynamics.

1. Lazcano, A. & Miller, S. L. On the origin of metabolic pathways. J. Mol. Evol. 49, 424–431 (1999).
2. Ter-Ovanessian, L. M. P., Rigaud, B., Mezzetti, A., Lambert, J.-F. & Maurel, M.-C. Carbamoyl phosphate and its substitutes for the uracil synthesis in origins of life scenarios. Sci. Rep. 11, 19356 (2021).

New strategies for extracting biomarkers in 'astrobiological' environments: towards in-situ analysis

Ramzi TIMOUMI1, Aurélie LE POSTOLLEC2, Michel DOBRIJEVIC2, Brian GREGOIRE1, Pauline POINOT1, Guillaume RIOLAND3, Claude GEFFROY-RODIER1

1 - Université de Poitiers, UMR CNRS 7285, Institut de Chimie des Milieux et Matériaux de Poitiers (IC2MP), France.
2 - Université de Bordeaux, UMR CNRS 5804, Laboratoire d'Astrophysique de Bordeaux (LAB), Observatoire Aquitain des Sciences de l'Univers (OASU), France.
3 - Centre National d'Etudes Spatiales (CNES), Toulouse, France.

The development of new instruments and associated analytical strategies, such as high-resolution mass spectrometry coupled with ultra-high performance liquid chromatography or gas chromatography, is essential to search for bio-signatures in the universe (planets, satellites, asteroids, comets). Their sensitivity would enable us to emphasize, in laboratory or for in-situ experiments, the presence of organic compounds that could have been engaged in prebiotic synthesis pathways.

While the extraction step is commonly recognized as a key point in most analytical studies, this step has rarely been considered in astrobiological research. For instance, no solid/liquid extraction protocol has been selected for future Martian missions so far even though some pre-selected analyzers require liquid samples. Besides in-situ applications, the extraction protocols currently used for laboratory research, which do not take into account the nature of the mineral matrix nor the properties of the molecules, rarely enable quantitative extraction and can even induce biases by modifying the original nature of the detected molecules.

Therefore, the development of new extraction strategies is necessary to obtain representative extracts, compatible with analytical techniques.

In this context, the objective of this project is to develop innovative strategies allowing the extraction of different families of organic molecules (amino acids, nucleobases and peptides) present at ultra-traces in extraterrestrial bodies according to the mineralogy of the samples. For that, carbonaceous chondrites meteorites have been used since they are the closest representation of the extraterrestrial mineral surfaces that has both complex mineral composition and diverse organic constituents. The strategy focuses on ultrasonic assisted extraction (UAE) [1] for a quantitative extraction of the target compounds. Multiple parameters were studied then tested and optimized on mineral model matrices that included silica, clays, phyllosilicates and metal oxides which were doped with organic molecules mixtures prior to extraction. Afterwards, real meteorite samples were extracted using the new protocol and compared to the reference method for carbonaceous chondrites: hot water extraction [2] through GC-MS/MS and LC-MS/MS analysis and quantification. Analyzing the results with specialized data treatment software could give new insight on extracted molecules and potentially unlock new pathways for the study of molecular networks evolution towards complexity.

[1] A. BUCH, D. P. GLAVIN, R. STERNBERG, C. SZOPA, C. RODIER, et al, Planetary and Space Science, 54 (2006)
[2] A. S. BURTON, H. McLAIN, D. P.GLAVIN, J. E. ELSILA, et al, Meteoritics & Planetary Science, 50 (2015)

Biosignatures of hyperthermophilic archaea in sulfur-rich hydrothermal vents

C. Truong1, A. Gorlas2, S. Bernard1, G. Morin1, P. Le Pape1 and F. Guyot1, 3
1 Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, Sorbonne Université, UMR 7590 CNRS, Museum National d'Histoire Naturelle
2 Université Paris-Saclay, CEA, CNRS, Institute for Integrative Biology of the Cell (I2BC)
3 Institut Universitaire de France (IUF)

The metabolism of hyperthermophilic archaea, such as sulfur-reducers Thermococcales which live around black smokers at temperatures higher than 80°C, have often been described as similar to the metabolism of very ancient forms of life [1]. Despite their potentially central role in early life, the evolution of hyperthermophilic microorganisms over ther Earth's history remains poorly constrained, as does their exact contribution to the geochemistry of modern black smokers. Better constraining the evolution and the contribution of hyperthermophilic microorganisms requires to identify their fossilized traces in the ancient and modern geological record, i.e. determining what biosignature(s) these microbes may produce during their life.

In this project, we study the mineral phases formed in presence of those microorganisms by X-ray diffraction, synchrotron-based X-ray absorption and scanning and transmission electron microscopies, coupled to gas content measurements and growth monitoring (cell couting and ATP measurements).

The presence of Thermococcales leads to an oxidation sequence of FeS initially produced, coupled to a progressive reduction of zero-valent sulfur S0 [2]. This oxidation event occuring in a strictly anaerobic system induces abundant quantities of pyrite FeS2 which precipitates as characteristic spherules made of nanometer-sized pyrite crystals. The FeS2 spherules contain complex organic matter with a strong absorption in the amides group, as detected by STXM, which is consistent with a biological signature. The spherules seem to act as organic matter traps with a promising biopreservation potential.

[1] Atomi H., Fukui T., Kanai T., Morikawa M., Imanaka T. Archaea, Vol 1, (2004)
[2] A. Gorlas, E. Marguet, S. Gill, C. Geslin, J.-M. Guigner, F. Guyot, P. Forterre. Biochimie, Vol 118, (2015)

Synthesis of a spectral Phobos regolith analogue in preparation of the Martian Moon eXploration mission

A. Wargnier1,2 , T. Gautier2,1, O. Poch3, P. Beck3, E. Quirico3, A. Buch4, T. Drant2, Z. Perrin2 and A. Doressoundiram1
1 LESIA-Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, Université de Paris, 5 place Jules Janssen, 92195 Meudon, France
2 Université Versailles St-Quentin, UPMC Univ. Paris 06, CNRS, LATMOS, 11 Blvd. d'Alembert, 78280 Guyancourt, France 3 Université Grenoble Alpes, CNRS, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), Saint-Martin d'Heres, France 4 Laboratoire Génie des Procédés et Matériaux, CentraleSupélec, Université Paris-Saclay, Gif-sur-Yvette, France

The origins of Phobos and Deimos – the two Martian moons are still unknown. The Martian Moon eXploration (MMX) mission of the Japanese Space Agency (JAXA) which will leave the Earth towards Phobos in 2024 will answer this question of the origins by a sampling of the Phobos' surface (return of the sample on Earth schedule in 2029), but also by in-situ observations especially with the near-infrared spectrometer MIRS (0.9-3.6 µm), currently under construction in LESIA (Barucci, 2021). There are two mains proposed hypothesis to explain the formation of Phobos and Deimos. First, they could have been formed by a giant impact between Mars and a protoplanet (Craddock et al, 2011) and the accretion of the orotoplanet and Martian material. However, in this case, one would expect to find these materials (notably basalt) on the surface of Phobos but that has never been observed by the different space missions and ground-based observations. On the other hand, Phobos and Deimos could also be main belt captured asteroids. In fact, spectral features of Phobos are consistent with a D-type asteroid (Murchie 1999, Rivkin 2002, Fraeman 2014), which are carbonaceous, highly processed, mainly found in the outer main belt or in the Jupiter Trojans swarm and possibly linked to comets (Vernazza and Beck 2017). Hence, if Phobos is indeed from a captured asteroid, it could be expected that organic matter represent a significant volume fraction of the surface material (Bardyn 2017). MIRS should be able to detect minerals and organics features and then give clues for the Phobos' origins.

In the preparation of the MMX mission and to study the feasibility of organic compounds detection at the surface of Phobos by the MIRS spectrometer, we developed a spectral laboratory analogue to reproduce the Phobos spectral features between 1.5 and 2.5 µm: a very low albedo, a red spectral slope, and no absorption bands. With our first experiments, we reproduced a spectral analogue for which the reflectance VIS/NIR measurements – at IPAG, on the SHADOWS spectrogonio-radiometer – show a red spectral slope in the near-infrared (1.5-2.4 µm) and a reflectance similar to that of CRISM (Fraeman 2012). This spectral analogue is a mixture of olivine (grain size 50-100 µm), hyperfine anthracite (< 1µm) and Titan tholins (400 nm) in volume fraction respectively of 77, 20 and 3 %. We then added different amounts of organics (Titan tholins) and studied the 3 µm band depth due to the N-H stretching modes of the organic compounds. We determined that organics are detectable for less than 5% in volume in the analogue. We also study the effect of observation geometry on some spectral parameters such as reflectance, spectral slope, and 3 µm band depth. Spectra with different geometry were measured for a mixture and for phase angles ranging from 10° to 130°. No phase effect on the organic matter's absorption band was detected for phase angles smaller than 80°, showing that small phase angles should be favored when looking for organics. A phase reddening and a strong forward and back-scattering were also observed for our mixture, which is consistent with the same spectral parameters for Phobos or other small bodies such as 67P or Bennu.

Présentation Orales

Andreu Audrey	audrey.andreu@irap.omp.eu
Bejach Laure	laure.bejach@ijclab.in2p3.fr
Bon Mathilde	mathilde.bon07@gmail.com
Boulesteix David	david.boulesteix@centralesupelec.fr
Clouet Adriana	adriana.clouet@hotmail.fr
Devergne Timothée	timothee.devergne@sorbonne-universite.fr
Fogret Laurane	laurane.fogret@mnhn.fr
Garcia Adeline	adeline.garcia@etu.univ-amu.fr
Gonthier Rachel	rachel.gonthier@lisa.ipsl.fr
He YuanYuan	yuanyuan.he@mnhn.fr
Jaziri Yassin	adam.jaziri@unige.ch
Jeancolas Cyrille	cyrille.jeancolas@durham.ac.uk
Joiret Sarah	sarah.joiret@u-bordeaux.fr
Josse Léna	lena.josse@free.fr
Laurent Boris	boris.laurent@mnhn.fr
Layssac Yohann	yohann.layssac@univ-amu.fr
Lecasble Marceau	marceau.lecasble@mnhn.fr
Le Pivert-Jolivet Tania	tania.le-pivert-jolivet1@universite-paris-saclay.fr
Leyva Vanessa	vanessa.leyva@univ-cotedazur.fr
Malarewicz Virgile	virgile.malarewicz@universite-paris-saclay.fr
Maratrat Louis	louis.maratrat@latmos.ipsl.fr
Meletti Gabriel	gabriel.meletti@univ-lyon1.fr
Moulais Valentin	valentin.moulay@latmos.ipsl.fr
Napoleoni Maryse	m.napoleoni@fu-berlin.de
Perrin Zoé	zoe.perrin@latmos.ipsl.fr
Perron Alexandra	perron@ipgp.fr
Pineau Maxime	maxime.pineau@lam.fr
Poggiali Giovanni	giovanni.poggiali@obspm.fr
Poveda Mathilde	mpoveda@lisa.ipsl.fr
Sanderink Arnaud	arnaud.sanderink@cnrs-orleans.fr
Ter-Ovanessian Louis	louis.ter-ovanessian@mnhn.fr
Timoumi Ramzi	ramzi.timoumi@univ-poitiers.fr
Truong Chloé	chloemary.truong@gmail.com
Wargnier Antonin	antonin.wargnier@obspm.fr

Posters

Assadourian Céline	celine.assadourian@univ-amu.fr
Revol Alexandre	alexandre.revol@unige.ch
Huet Léon	leon.huet@sorbonne-universite.fr
Meletti Gabriel	gabriel.meletti@univ-lyon1.fr
Boe Grégoire	boe.gregoire@laposte.net

Invités

Tobie Gabriel	gabriel.tobie@univ-nantes.fr
Cario Anais	anais.cario@icmcb.cnrs.fr
Lagarde Nadège	nadege.lagarde@u-bordeaux.fr
Bouley Sylvain	sylvain.bouley@universite-paris-saclay.fr
Pitrou Perig	perig.pitrou@college-de-france.fr

Table Ronde

Niemiec Anna	anna.niemiec@hotmail.fr
Loteguy Xavier	xavier@allfourprod.com
Isnard Robin	robin-isnard@hotmail.fr
Guimpier Anthony	anthony.guim@hotmail.fr