ACCADEMIA NAZIONALE DEI LINCEI E FONDAZIONE «GUIDO DONEGANI»

CONVEGNO

# ASTRONOMIA, ASTROFISICA, ASTROCHIMICA, ASTROBIOLOGIA

# *ASTRONOMY, ASTROPHYSICS, ASTROCHEMISTRY, ASTROBIOLOGY*

14-15 OTTOBRE 2024

*Comitato ordinatore*: Vincenzo AQUILANTI (Linceo, Università di Perugia, coordinatore), Vincenzo BARONE (Linceo, Scuola Normale Superiore Pisa), Francesco BERRILLI (Linceo, Università di Roma Tor Vergata), Paolo DE BERNARDIS (Linceo, Sapienza Università di Roma), Francesca MATTEUCCI (Lincea, Università di Trieste, coordinatrice), Marco TAVANI (Linceo, INAF), Adriano ZECCHINA (Linceo, Università di Torino)

## PROGRAMMA

L'interdisciplinarità di questo incontro si articola come ricognizione delle attività in corso su base nazionale e internazionale. Galileo, a partire dal 9 Gennaio 1610, punta il suo "cannocchiale" alle stelle, scopre che la Galassia non è fatta di latte e sperimenta in laboratorio, alla ricerca di leggi naturali valide in cielo e in terra; tra i primi membri dell'Accademia dei Lincei, costruisce per il fondatore, il principe Federico Cesi, un prototipo di microscopio, permettendogli di scoprire nelle piante aspetti invisibili a occhio nudo – pietra miliare a fondamento delle bioscienze. La fisica (classica, quantistica, relativistica) è a fondamento di astronomia e astrofisica; la nuova chimica, la scienza delle molecole e dei materiali, gioca un ruolo di ponte tra le varie discipline. Nel cosmo, le stelle sono i produttori degli elementi chimici a partire dal carbonio fino all'uranio e oltre, quindi anche degli elementi che sono alla base della vita. In esso si scopre una varietà ricchissima di inaspettati pianeti al di fuori del sistema solare, che promette di rivelare l'evoluzione delle molecole della vita; mentre ricerche sulle complesse molecole delle nanotecnologie e della biochimica condizionano economia e medicina e sono cruciali per la transizione ecologica e per la preparazione di nuovi farmaci, come è avvenuto per la tempestiva realizzazione dei vaccini anticovid. I temi sopra accennati sono stati affrontati in una serie di conferenze e in numeri speciali della rivista "Rendiconti Lincei, Scienze Fisiche e Naturali" da una dozzina di anni. Sono stati oggetto di una serie di filmati RAI tuttora regolarmente trasmessi, cui hanno partecipato alcuni dei soci qui proponenti. La collaborazione con l'Accademia Nazionale delle Scienze, detta dei XL, è stata proficua in molte occasioni, che nell'ambito di questo convegno si tradurrà in una giornata aggiuntiva dal titolo *Asimmetria molecolare e vita nella terra e nel cosmo* ispirato a quello di un famoso saggio di Primo Levi. Si tratta della chiralità e di altre proprietà molecolari cruciali per l'origine della vita e la sua evoluzione nell'universo e nel tempo.

## PROGRAMME

The main issue of this meeting is the interdisciplinarity of Astronomy and Astrophysics with aspects involving Chemistry and Biology. On the 9th of January 1610 Galileo Galilei, one of the first members of the Accademia dei Lincei, points his telescope to the stars discovering that the Milky Way is not made of milk, and searches for laws valid on earth and sky. He builds for the founder of the Lincei, Prince Federico Cesi, a prototype of a microscope, allowing him to discover invisible aspects of the plants, a milestone for the Biosciences. Physics (classic, quantistic, relativistic) is at the basis of Astronomy and Astrophysics. The new Chemistry, the science of molecules and materials, plays a bridge role among the various disciplines. In the cosmos, stars produce all the chemical elements starting from carbon to uranium and beyond, including the biogenetic elements. Moreover, we discover continuously a rich variety of unexpected extrasolar planets which promise to reveal the evolution of the molecules of life. While researches on the complex molecules in Nanotechnology and Biochemistry influence the Economy and Medicine and are crucial for the ecological transition and preparation of new drugs, as it has occurred for the realization of anticovid vaccines. For a dozen years, the previous arguments have been the subject of a series of conferences and appeared in special issues of the journal "Rendiconti Lincei, Scienze Fisiche e Naturali". They have been also the subject of a series of documentaries for the Italian National Television (RAI), which are currently broadcasted and where some of the organizers of this meeting have participated. The collaboration with the Accademia Nazionale delle Scienze, called of the Forty, has been very proficous on several occasions and now it will translate in a third day of meeting on *Molecular asimmetry and life on Heaven and Earth* inspired by a famous paper by Primo Levi. The focus will be on chirality and other molecular properties crucial for the origin of life and its evolution in universe and time.

**Monday, October 14**

14.00 *Welcome addresses from the Presidency of the Academy*

14.10 Vincenzo AQUILANTI (Linceo, Università di Perugia), Francesca MATTEUCCI (Lincea, Università di Trieste): *Introduction*

**Session I - Chair:** Francesca MATTEUCCI (Lincea, Università di Trieste)

14.30 Roberto RAGAZZONI (Linceo, Università di Padova, INAF Padova): *Astronomical technology*

15.00 Raffaele GRATTON (INAF Padova): *The discovery of exoplanets*

15.30 Alessandro MARCONI (Università di Firenze): *From biomarkers in exoplanet atmospheres to Universe expansion: the combined power of ANDES and the Extremely Large Telescope*

16.00 Break

**Session II - Chair:** Marco TAVANI (Linceo, INAF)

16.20 Francesca MATTEUCCI (Lincea, Università di Trieste): *The origin of chemical elements*

16.50 Massimo DELLA VALLE (Linceo, Osservatorio Astronomico di Capodimonte Napoli - INAF): *Supernova Dichotomy: Life's Ingredients and Hazards*

17.20 Emanuele SPITONI (INAF Trieste): *Galactic habitability*

**Tuesday, October 15**

**Session III - Chair:** Paolo DE BERNARDIS (Linceo, Sapienza Università di Roma)

9.15 Dario DE FAZIO (CNR, Montelibretti): *Reactions and early molecules in the primordial Universe*

9.45 Giovanna TINETTI (University College London): *How many flavours of exoplanets do exist?*

10.15 Piero UGLIENGO (Università di Torino): *Can computer modelling clarify the nature and adsorption properties of interstellar dust grains?*

10.45 Break

**Session IV - Chair:** Vincenzo BARONE (Linceo, Scuola Normale Superiore Pisa)

11.05 Andrea LOMBARDI (Università di Perugia): *Endohedral Fullerenes in the Chemistry of Space*

11.35 Eleanor CAMPBELL (University of Edinburgh): *Nanocarbon reactions in astrochemistry*

12.05 John BRUCATO (Università di Firenze): *Astrobiology strategy for the search of biosignatures in space*

12.35 Francesco PANICO (Università di Milano): *Alkaline hydrothermal vent and the emergence of life: an electrochemical perspective*

12.50 Break

**Session V - Chair:** Vincenzo AQUILANTI (Linceo, Università di Perugia)

14.00 Stefano BOVINO (Sapienza Università di Roma): *Astrochemistry, from star formation to the origin of life*

14.30 Savino LONGO (Università di Bari): *The spark of life: plasma chemistry as a key aspect of the Miller-Urey experiment*

15.00 Daniela BILLI (Università di Roma Tor Vergata): *Extremophiles and the search for life in the Solar system and beyond*

15.30 *Discussion and conclusions*

ROMA - PALAZZO CORSINI - VIA DELLA LUNGARA, 10
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La conferenza si svolge nell'ambito dei Giorni su Molecole e Vita nell'Universo e precede la giornata del 16 ottobre: *Asimmetria molecolare e vita nella terra e nel cosmo*, che si terrà a Roma nella Biblioteca dell'Accademia Nazionale delle Scienze detta dei XL, Villa Torlonia. Diretta streaming su https://www.accademiaxl.it/live

**The discovery of exoplanets**

Raffaele GRATTON (INAF Padova)

Extrasolar planets were first discovered in the mid '90s. Michel Mayor and Didier Queloz were awarded the Physics Nobel Prize in 2019 for this discovery. Thousands of planets were discovered since then. Investigations revealed a surprising diversity of planets; most of the planets discovered are quite different from those present in the Solar System. This unexpected variety required a revision of our understanding of how planets form. The formation of planets is a small detail of the general phenomenon of star formation, during which a disk around the star mediates the transfer of material from the interstellar medium and the forming star. Planets form in this disk. Two main mechanisms of planet formation gas been proposed: gravitational instabilities in the disk and core accretion. Further complications are due to the interaction of planets with disks and between different young planets, that causes migration of planets from the original birthplace and possible dynamical instabilities. Disk instability typically form massive objects and is one of the main mechanisms called for the formation of stellar companions, that are very common. It is a fast mechanism, and it is not well clear whether it can also form planets, that have less than one hundredth of the mass of the star. Core accretion is the favoured mechanism for the formation of the Solar System. It is a slow mechanism that requires the presence of dust in the disk. Core accretion is very complex, and it is not yet well understood from a theoretical perspective; the presence of pebbles may help solving the issues. The distribution of companions suggests that both mechanisms are active causing the formation of two families of companions separated by a low populated mass regime, the so-called brown-dwarf desert (brown dwarf being objects intermediate between stars and planets). Recent results also suggest that the environment where planets form plays a substantial role in the outcome of planet formation, with planets like Jupiter (that dominates the Solar System) being more common in small star forming regions. Since there is evidence that the Sun birthplace is rather a quite populous region of star formation, it makes the formation of the Solar System unusual.

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I pianeti extrasolari sono stati scoperti a metà degli anni '90 e il Premio Nobel per la Fisica del 2019 è stato assegnato a Michel Mayor e Didier Queloz per questa scoperta. Da allora, migliaia di pianeti sono stati scoperti rivelando una sorprendente varietà; gran parte dei pianeti scoperti sono abbastanza diversi da quelli presenti nel Sistema Solare. Questa varietà inaspettata richiede una revisione delle nostre idee su come si formano i pianeti. La formazione dei pianeti è in realtà un piccolo dettaglio nel fenomeno generale della formazione delle stelle, durante la quale un disco di gas e polvere media il trasferimento di materiale dal mezzo interstellare alla stella nascente. I pianeti si formano in questo disco. Sono stati proposti due meccanismi principali per la formazione dei pianeti:

instabilità gravitazionali nel disco e l'accrescimento su "cores". Ulteriori complicazioni sono dovuti alle interazioni tra disco e pianeta e tra diversi pianeti giovani, che causano migrazione dei pianeti lontano dal loro luogo di origine e possibili instabilità dinamiche. Le instabilità del disco formano tipicamente oggetti di grande massa e sono uno dei meccanismi con cui si pensa si formino compagni stellari, che sono molto comuni. È un meccanismo rapido e non è chiaro se possa formare anche pianeti, che hanno meno di un centesimo della massa della stella. L'accrescimento su "cores" è il meccanismo favorito per la formazione del Sistema Solare. È un meccanismo lento che richiede la presenza di polvere nel disco; è un meccanismo complesso e non ancora ben capito dal punto di vista teorico. Alcuni problemi presenti potrebbero forse essere risolti considerando anche l'accrescimento di grani di dimensioni intermedie. La distribuzione osservata dei compagni di stelle suggerisce che entrambi i meccanismi siano attivi causando la formazione di due famiglie di compagni separate da una regione in massa poco popolata, il cosiddetto deserto delle nane brune (le nane brune sono oggetti di massa intermedia tra stelle e pianeti). I risultati più recenti mostrano anche che l'ambiente in cui le stelle si formano gioca un ruolo importante e che pianeti simili a Giove (che domina il Sistema Solare) si formano più facilmente in piccole regioni di formazione stellare. Poiché c'è evidenza che il Sistema Solare si sia invece formato in una regione di formazione stellare abbastanza popolosa, sembra trattarsi di un evento abbastanza inusuale.

## Galactic habitability

Emanuele SPITONI (INAF Trieste)

The Galactic habitable zone is defined as the region with a metallicity that is high enough to form planetary systems in which Earth-like planets could be born and might be capable of sustaining life. Life in this zone needs to survive the destructive effects of nearby supernova explosion events. Our aim is to find the Galactic habitable zone using chemical evolution models for the Milky Way disk, adopting the most recent prescriptions for the evolution of dust and for the probability of finding planetary systems around M and FGK stars. Moreover, for the first time, we express these probabilities in terms of the dust-to-gas ratio of the interstellar medium in the solar neighborhood as computed by detailed chemical evolution models. At a fixed Galactic time and Galactocentric distance, we determined the number of M and FGK stars that host earths (but no gas giant planets) that survived supernova explosions. The probabilities of finding terrestrial planets but not gas giant planets around M stars deviate substantially from the probabilities around FGK stars for supersolar values of [Fe/H]. For both FGK and M stars, the maximum number of stars hosting habitable planets is at 8 kpc from the Galactic Center when destructive effects by supernova explosions are taken into account. Currently, M stars with habitable planets are roughly 10 times more frequent than FGK stars. Moreover, we provide a fit for the relation found with chemical evolution models in the solar neighborhood between the [Fe/H] abundances and the dust-to-gas ratio.

**Reactions and early molecules in the primordial Universe**

Dario DE FAZIO (CNR, Montelibretti)

Following the Big Bang theory, just after the primordial nucleosynthesis, the Universe was a dense hot plasma essentially composed by the lightest atomic nucleus (mainly alpha particles, protons and traces of Lithium) and photons. Since the primordial explosion the Universe start a rapid adiabatic expansion leading to make lower the gas temperature of about three orders of magnitude in few seconds. The formation of the first molecules plays a key role in this phase because of the additional degree of freedom available to store the atomic kinetic energy leading to further cooling of the primordial plasma and permitting the matter collapse required to form the first cosmological objects.

The interesting point from the chemical point of view, is that the chemistry driving the expansion is composed from the lightest particles so that, at least in principle, all the chemical processes can be calculated quantum-mechanically at the highest level of accuracy and the rates can be insert in the early Universe evolution models to determinate the abondance of the chemical species and their evolution during the expansion, testing cosmological theories. However, the huge range of temperature required (from tens of thousands at few Kelvin) make very hard to accomplish this project. In fact, most of the chemical quantum mechanical chemical rates are obtained in the ground reactants state, a poor approximation also at thermal temperatures. Moreover, the high energies involved, can open unusual reaction channels involving electronically non adiabatic and dissociations processes. Additionally, the range of temperatures required is adapt for classical mechanics in hot regimes, but quantum effects play a key role in the lowest temperature range, so that more dynamical methodologies should be applied to calculate reliable yields.

In the past years our group have attacked this problem trying to calculate in the most accurate way the most important reaction rates. In particular, the main effort has been spent to describe the Helium chemistry of the network known to be crucial for an accurate determination of molecular abundances at high red shift [1]. High accurate electronic potential energy surfaces have been obtained [2] as well as quantum reaction rates by 'exact' time independent studies of the reaction dynamics of the ground electronic state [3]:

He + H2+ à HeH+ + H

These calculations, feasible just below the three-bodies breakup threshold, has been extended by high accurate quasi classical trajectories studies [4] to achieve reaction rates from 1 K until 15000 K with accuracy within 1%. More recently, a wave packet time dependent code [5] has been implemented to study successfully [6] the conical intersection driven dynamics of the dissociative charge transfer process, namely:

He+ + H2 à He + H + H+

In the conference, the main results achieved in this long study of the Helium chemistry will be presented and further development planned will be discussed and analyzed.

References [1] R. Gusten et al; Nature 568, 357 (2019).
[2] C.N. Ramachandran, D. De Fazio, S. Cavalli, F. Tarantelli and V. Aquilanti; Chem. Phys. Lett. 473, 146 (2009).
[3] D. De Fazio; Phys. Chem. Chem. Phys. 16 (2014) 11662.
[4] F. Esposito, C.M. Coppola and D. De Fazio; J. Phys. Chem. A 119,12615 (2015).
[5] P. Defazio, B. Bussery-Honvault, P. Honvault, and C. Petrongolo; J. Chem. Phys. 135, 114308 (2011).
[6] D. De Fazio, A. Aguado and C. Petrongolo. Frontiers in Chemistry 7, 249 (2019)

## Can computer modelling clarify the nature and adsorption properties of interstellar dust grains?

Piero UGLIENGO (Università di Torino)

The mosaic of astrochemistry is comprised of three essential elements: astronomical observations, experiments conducted in terrestrial laboratories, and numerical models that illustrate the evolution of chemical species along the history of the Universe. The mosaic is incomplete without molecular modelling based on different degrees of approximation to the rigorous solution of the equations of molecular quantum mechanics. This allows us to gain an atomistic knowledge of the molecular species involved in the interstellar medium and beyond. This piece of the mosaic has become increasingly important in recent years thanks to the rapid development of sophisticated programs associated with powerful new computers capable of working in massively parallel mode. Dirac's paradigm is being realised. The fundamental laws are known, and it is only a question of solving the intrinsic mathematical complexity, now possible for systems limited to 30-40 atoms. While this limitation allows for highly accurate studies of gas-phase reactivity, it does not apply to the simulation of interstellar grains, whether core1 or mantle2. This is due to two factors. The first factor is the relatively large size of the grains (micrometric in scale), and the second is the amorphous, and therefore often unknown, nature of their molecular structure. Simulation is, therefore, a delicate balance between accuracy of calculation and adherence of the model to observational and terrestrial laboratory data. Experience and ingenuity are therefore required. A detailed knowledge of the chemical-physical properties of the grains and their interactions with molecules of astrochemical interest is essential to solving these problems. This knowledge must include binding energies and spectroscopic data. The outcome of these calculations is vital for feeding the numerical models of chemical evolution with refined data, such as kinetic constants and binding energy distribution. In the talk, I will present a summary of the recent results3-4 devoted to the molecular simulation of both structure and spectroscopic features of the core and adsorption of H2O, NH3, CH3OH, H2S and OCS at the mantle of the interstellar grains also relevant for interpreting the JWST observations.

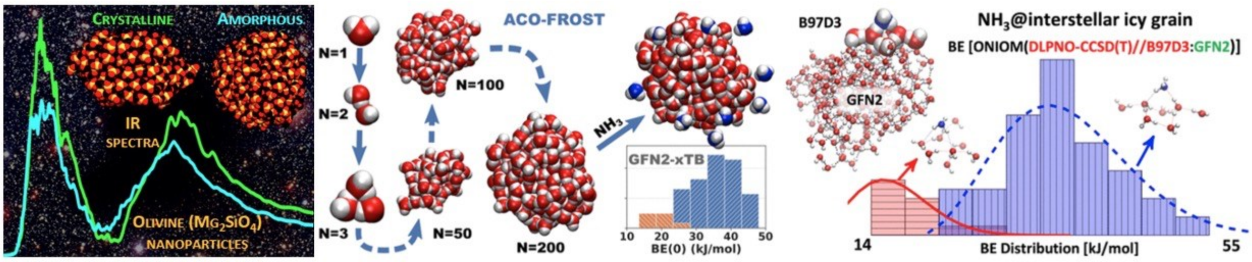



**Figure 1**: IR spectra of models of grain core and ACO-FROST procedure to compute icy mantle and $NH_3$ binding energy distribution


**References:**

[1] L. Zamirri, A. Macià Escatllar, J. Mariñoso Guiu , P. Ugliengo , S.T. Bromley, *ACS Earth Space Chem.* 2019, 3, 2323–2338.

[2] A. Germain, L. Tinacci, S. Pantaleone, C. Ceccarelli, P. Ugliengo, *ACS Earth Space Chem.* 2022, 6, 1286–1298.

[3] L. Tinacci, A. Germain, S. Pantaleone, C. Ceccarelli, N. Balucani, P. Ugliengo, *ApJ* 2023, 951, 32.

[4] V. Bariosco, S. Pantaleone, C. Ceccarelli, A. Rimola, N. Balucani, M. Corno, P. Ugliengo, *Mon. Not. R. Astron. Soc.* 2024, 531, 1371.

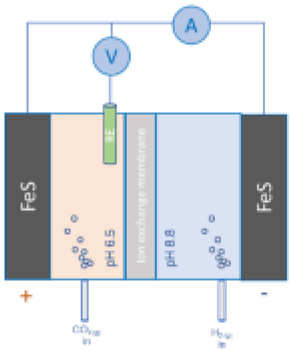

## Alkaline hydrothermal vent and the emergence of life: an electrochemical perspective


Francesco PANICO (Università di Milano)


More than a century has passed since the hypothesis was first proposed that primordial biological molecules could have formed from non-biological material with the input of some form of energy. Great efforts have been made to test possible energy sources in various environments and to determine whether the abiogenesis of biological molecules is possible. Among all the theories, the one involving hydrothermal vents has recently captured particular attention: it is based on the idea that the reduction of $CO_2$ and the initiation of a proto-metabolism could have occurred by exploiting a life-like thermodynamic disequilibrium on mineral structure that shows structural and compositional similarities with some catalytic centre of enzimes.[1-2]

Hydrothermal Vent are geological formation generated from the upwelling of geothermal fluids into the ocean, in the Archean era Alkaline HTV were generated by the reaction between alkaline (pH 10-11) and hydrogen rich fluids with the ocean rich in $CO_2$ (acidic 10-11) and metal ions such as Fe, Ni, Zn, Co, Mn; here at the mixing point a mineral barrier precipitate, composed mainly of iron hydroxide, green rust and iron sulphide. Across this mineral membrane an electrochemical potential difference is generated, because of the disparity in pH and redox species between the inner and outer sides of the vent, this thermodynamic disequilibrium can be dissipated by coupling two opposite reactions: $CO_2$ reduction and $H_2$ oxidation, the two semireaction take place on the opposite sides of the same mineral structure but in two different environments: the first acidic, the second alkaline. [3]

Electrochemistry applied to the study of the behaviour of mineral materials from hydrothermal vents is a valuable tool because it allows for a precise investigation of the reactivity of material surfaces and correlates it with their electronic structure.[4]




A hydrothermal vent system can be modelled as a short-circuited fuel cell (see figure hereabouts), with a continuous flow of reactants to the electrodes. These electrodes are made of the material that forms the barrier and are located in two different environments: the first electrode functions as a cathode for the reduction of $CO_2$ in an acidic environment, while the second functions as an anode for the oxidation of hydrogen (or other molecules) in an alkaline environment. An electric current is recorded between the two short-circuited electrodes. This coupling of reactions can be represented in an Evans diagram, analogous to a corrosion process. In our laboratory, we developed a technique for synthesizing Mackinawite ($FeS_m$) and Violarite ($FeNi_2S_4$). The samples have been characterized using spectroscopic, microscopic, and electrochemical methods. Using these materials, we have prepared electrodes for testing. A series of electrolysis experiments have demonstrated that these materials can electrochemically reduce $CO_2$, producing formic acid, methanol, and carbon monoxide. The behaviour of the electrodes was studied by recording Tafel plots (log(I) vs E) and creating an Evans diagram. This diagram illustrates the operational conditions of pH, catalytic material, and reaction environment under which it is possible to couple the $CO_2$ reduction and hydrogen oxidation reactions effectively. Subsequently, the short-circuited fuel cell was constructed, allowing for the measurement of the current flow (which is proportional to the reaction rate and indicates the cell's polarity) and the electric potential at which the coupled reactions occur.[5]

This approach to measurement and interpretation of Alkaline Hydrothermal Vent functioning represents, in our opinion, a groundbreaking development in the field of studies on this topic. The future challenge lies in identifying the optimal operational conditions that accurately simulate the real environment of an alkaline hydrothermal vent on the Archean ocean floor, capable of facilitating a spontaneous reduction reaction of $CO_2$.

(1) Russell M.J. Life 2018 (2) Branscomb E. & Russell M.J. BioEssays 2018 (3) Hudson R. et al. Proc Natl Acad Sci USA 2020 (4) Nitschke W., Panico F., et al. Electrochemical Science Advances 2023 (5) Panico F. at al. EPSC2024 2024

## Astrochemistry, from star formation to the origin of life

Stefano BOVINO (Sapienza Università di Roma)

Astrochemistry is a blend of different disciplines, from chemistry to astronomy, including computational sciences and biology. One of the fundamental questions in astrochemistry is related to the understanding of intricate physical processes like star- and planet-formation, and how these are connected to the emergence of chemical complexity. In this talk I will introduce the astrochemistry field, showing its different applications. I will present some recent exciting magneto-hydrodynamical simulations and introduce how the chemistry can help disentangling among the main processes which lead to the formation of stars. It will be a journey from the simple chemistry of diffuse gas to the complexity of the small and dense regions of the interstellar medium, where complex chemical processes play a fundamental role to unveil our astrochemical origins.

**The spark of life: plasma chemistry as a key aspect of the Miller-Urey experiment**

Savino LONGO (Università di Bari)

L'esperimento Miller-Urey ha dimostrato, più di 70 anni fa, la possibilità di produrre alcune delle molecole della vita dai componenti chimici dell'atmosfera primordiale della Terra, utilizzando una scarica elettrica.

L'esperimento è paradigmatico nel dibattito sull'origine della vita, e molte pubblicazioni gli sono state dedicate.

Pertanto, è sorprendente che solo di recente si sia prestata attenzione alla natura elettrica dell'esperimento, al fatto che i cambiamenti chimici nella miscela di gas sono avviati da una scarica elettrica. La miscela chimica nella scarica è un plasma elettrico, come viene chiamato dai fisici, e va compresa in quanto tale.

L'autore e i suoi collaboratori stanno cercando di capire meglio i fenomeni che trasformano l'energia elettrica in energia chimica attraverso gli elettroni liberi che si muovono nel gas.

Gli strumenti per questa comprensione sono disponibili da molti decenni nei campi della scienza della scarica elettrica, della fisica del plasma e della chimica del plasma.

In questo modo emergono alcuni aspetti, che non sono mai stati discussi in passato. Ad esempio: gli elettroni nell'esperimento devono avere una distribuzione di energia non banale, la cui conoscenza è il prerequisito per calcoli affidabili delle velocità delle reazioni chimiche iniziali.

Considerata l'enorme importanza di questo esperimento, queste considerazioni aprono un campo ampio e fertile a future indagini.

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The Miller–Urey experiment demonstrated, more than 70 years ago, the possibility of producing some of the molecules of life from the chemical components of Earth's primordial atmosphere, using an electric discharge [1].

The experiment is paradigmatic in the debate on the origin of life, and many publications have been dedicated to it [2].

Therefore, it is surprising that only recently attention was paid to the electrical nature of the experiment, to the fact that the chemical changes in the gas mixture are started by an electric discharge. The chemical mixture in the discharge is an electrical plasma, as physicists call it, and must be understood as such [3].

The author and his collaborators are trying to better understand the phenomena that transform electrical energy into chemical energy, through electrons moving in the gas.

The tools for this understanding have been available for many decades in the fields of electrical discharge science, plasma physics and plasma chemistry.

This way some aspects emerge, that have never been discussed in the past. For example: the electrons in the experiment must have a non-trivial energy distribution, whose knowledge is the prerequisite for reliable calculations of the rates of the initial chemical reactions.

Considering the enormous importance of this experiment, these considerations open a broad and fertile field for future investigations.

1. Miller SL, Urey HC. Organic compound synthesis on the primitive Earth. Science (1959) 130(3370):245–51. doi:10.1126/science.130.3370.245

2. McCollom, T. M. (2013). Miller-Urey and beyond: what have we learned about prebiotic organic synthesis reactions in the past 60 years?. Annual Review of Earth and Planetary Sciences, 41(1), 207-229.

3. Micca Longo, G., Vialetto, L., Diomede, P., Longo, S., & Laporta, V. (2021). Plasma modeling and prebiotic chemistry: A review of the state-of-the-art and perspectives. Molecules, 26(12), 3663.

## Extremophiles and the search for life in the Solar system and beyond

Daniela BILLI (Università di Roma Tor Vergata)

The search for life beyond Earth depends on our understanding of it: the key ingredients are liquid water, a set of biologically essential elements and an energy source. The surprising ability of extremophiles to thrive in hostile environments, the discovery of exoplanets in the habitable zone (HZ) of their stars, and the possibility of habitable niches underground in the icy moons of the Jovian and Saturnian systems outside of HZ space have paved the way to study possible habitable environments in our solar system and beyond. On Earth, extremophiles live in hostile environments such as hot and cold deserts (analogues of Mars) or Antarctic subglacial lakes (analogues of Europa and Enceladus). The existence of cyanobacteria capable of oxygenic photosynthesis in the infrared suggests the possibility of exotic photosynthesis in planets orbiting M dwarf stars. A selection of extremophiles has already been exposed to non-terrestrial conditions during Expose space missions outside the Space Station International. The goal is to investigate the limit of life as we know it and identify biosignatures to search for life on Mars. Astrobiology experiments so far have highlighted that extremophiles can cope with non-terrestrial conditions and support their use in laboratory planetary simulations and in future platforms beyond low Earth orbit.

### Gli estremofili e la ricerca della vita nel sistema solare ed oltre

La ricerca della vita oltre la Terra dipende dalla nostra comprensione di essa: gli ingredienti chiave sono l'acqua liquida, un insieme di elementi biologicamente essenziali e una fonte di energia. La sorprendente capacità degli estremofili di prosperare in ambienti ostili, la scoperta di esopianeti nella zona abitabile (HZ) delle loro stelle e la possibilità di nicchie abitabili nel sottosuolo nelle lune ghiacciate del sistema gioviano e saturniano al di fuori dello spazio HZ hanno aperto la strada a studiare possibili ambienti abitabili nel nostro sistema solare e oltre. Sulla Terra gli estremofili vivono in ambienti ostili come deserti caldi e freddi (analoghi di Marte) o laghi subglaciali antartici (analoghi di Europa ed Encelado). L'esistenza di cianobatteri capaci di fotosintesi ossigenata nell'infrarosso suggerisce la possibilità di fotosintesi esotica in pianeti orbitanti attorno a stelle nane M. Una selezione di estremofili è già stata esposta a condizioni non terrestri durante le missioni spaziali Expose al di fuori della Stazione Spaziale Internazionale. L'obiettivo è indagare il limite della vita come la conosciamo e identificare biofirme per cercare la vita su Marte. Finora gli esperimenti di astrobiologia hanno evidenziato che gli estremofili possono far fronte a condizioni non disparate condizioni non terrestri e supportano il loro uso in simulazioni planetarie in laboratorio e su future piattaforme oltre la bassa orbita terreste.