frontiers | Frontiers in Astronomy and Space Sciences

TYPE Editorial
PUBLISHED 11 August 2022
DOI 10.3389/fspas.2022.989509

OPEN ACCESS

EDITED BY
Cristina Puzzarini,
University of Bologna, Italy

REVIEWED BY
Eric Herbst,
University of Virginia, United States
Malgorzata Biczysko,
Shanghai University, China

*CORRESPONDENCE
Ashraf Ali,
aali1234@umd.edu

SPECIALTY SECTION
This article was submitted to Astrochemistry,
a section of the journal Frontiers in Astronomy and Space Sciences

RECEIVED 08 July 2022
ACCEPTED 15 July 2022
PUBLISHED 11 August 2022

CITATION
Ali A, Canosa A and Leisawitz D (2022), Editorial: RNA world hypothesis and the origin of life:
Astrochemistry perspective.
Front. Astron. Space Sci. 9:989509.
doi: 10.3389/fspas.2022.989509

Editorial: RNA world hypothesis and the origin of life: Astrochemistry perspective

Ashraf Ali[1]*, André Canosa[2] and David Leisawitz[3]

[1]Department of Physics, University of Maryland, College Park, MD, United States, [2]CNRS, IPR (Institut de Physique de Rennes)–UMR 6251, Université de Rennes, Rennes, France, [3]Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD, United States

KEYWORDS

RNA-world, laboratory astrochemistry, radio-astronomy, sub-millimeter astronomy, ground-based observations, space-based observations, interstellar chemistry, reaction kinetics

Editorial on the Research Topic
RNA World Hypothesis and the Origin of Life: Astrochemistry Perspective

The primary goal of this Research Topic is to address the chemistry occurring in space: from interstellar prebiotic molecules to the origin of life. In the RNA-World Hypothesis, RNA is the predecessor to the first life form on Earth. This view has been largely accepted by chemists, and a general consensus has been reached that we indeed live in an RNA Universe, where self-replicating RNA plays a central role (Altman and Cech, 1989; Turk-MacLeod et al., 2013).

To study the RNA-World hypothesis and the origin of life, the first step is to understand how and where small prebiotic molecules could form and how far the molecular complexity could proceed, as interstellar clouds evolve toward star formation (see Figure 1). To try to achieve this goal, efforts are required in different directions from integrated experimental and theoretical studies of elementary reactions at low temperatures, to high-resolution molecular-spectroscopy laboratory studies supported by quantum-chemical calculations, to astronomical observations.

Then, twelve articles, summarized below, contributed to this Research Topic. Interstellar chemistry is reviewed and laboratory rotational spectroscopy is addressed as one bridge between laboratory astrochemistry and astronomical observations. Millimeter and sub-millimeter telescope features are also briefly introduced. Afterwards, several contributions focus on recent observational discoveries, projects (FAUST) or instrumental tools, among others, SKA or OASIS. Some laboratory contributions illustrating the activity in millimeter spectroscopy, gas-phase reactivity and quantum theoretical calculations conclude the present Research Topic. We expect that this research topic provides the readers with the current state of knowledge on the chemistry at different evolutionary stages of star and planet formation. This is the

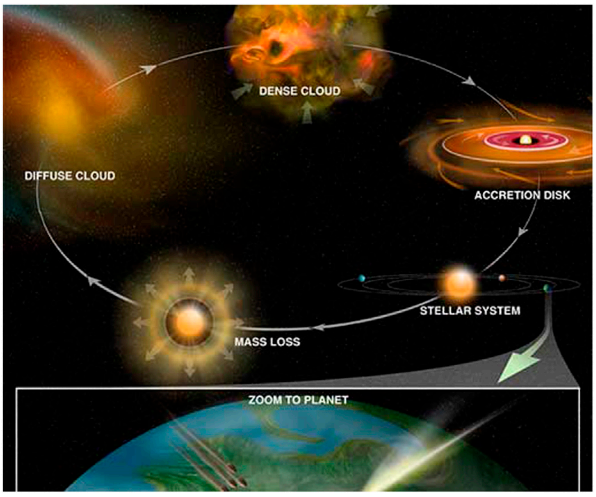

FIGURE 1
Life cycle of matter in space: from diffuse clouds to stellar and planetary formation. Credit Bill Saxton, NRAO.

chemistry at the basis of astrobiology and, in particular, of the RNA-world hypothesis for the origin of life.

In "Unusual Chemical Processes in Interstellar Chemistry: Past and Present", Herbst reviewed the historical development of the interpretation of interstellar chemistry. Both gas-phase processes and reactions on the surfaces of dust grains, the latter particularly on and in water-dominated ice mantles, in cold clouds are described. First, after an introduction on the interstellar medium (ISM), the author addresses in detail the gas-phase chemistry, with particular emphasis on radiative association. Both theoretical models and laboratory experiments are detailed. Some emphasis is put on reactions with a U-shaped rate dependence on temperature. The second part of the review, which focuses on granular chemistry, starts with a detailed review of rate equations and then introduces stochastic approaches. These are thoroughly described together with the modifications of rate equations to bring their results closer to stochastic treatments. Significant examples are provided such as the formation of methanol (CH_3OH): by revising the older literature, the mechanism currently accepted is addressed, which is CO sequential hydrogenation on grains followed by desorption of CH_3OH.

"*Gas-phase Chemistry in the Interstellar Medium: the Role of Laboratory Astrochemistry*" is the perspective contribution by Puzzarini. Here, the author provides an overview of the general problem of how molecules are formed and can further react. The role of rotational spectroscopy in guiding astronomical detections is also addressed, with emphasis placed on the interplay of quantum chemistry and experiment. The recent detection of propargylimine in the quiescent G+0.693–0.027 molecular cloud is taken as an example to outline the importance of such interplay. The author emphasizes the importance of carrying out computational studies at the state of the art in thermochemical characterization of reactive potential energy surfaces. This is illustrated by taking the reaction of methylamine (CH_3NH_2) with cyano (CN) radical as an example. A generalized system for the reaction of methanimine (CH_2NH) with a generic small radical X (e.g., OH, CN, CP, and CCH) is also presented.

Mifsud et al. contributed with a review article entitled "*The Role of Terahertz and Far-IR Spectroscopy in Understanding the Formation and Evolution of Interstellar Prebiotic Molecules*". This paper mainly consists of two sections. Section 1 describes the gas-phase ion chemistry of diffuse clouds and pre-stellar dense (dark) clouds. An overview of ongoing observational projects which include radio/sub-millimeter/Far-IR frequencies in their operational ranges is also presented there. Section 2 first addresses the spectrometer and detector technology, with particular emphasis on the THz/FIR region. In the second part of section 2, telescope facilities are summarized, while in the third part the interest is on laboratory astrochemistry using THz/FIR spectroscopy.

"*Organic Molecules in Interstellar Space: Latest Advances*" is a critical review by Guélin and Cernicharo. The authors highlight the latest astronomical observations in three different sources in interstellar space, using large sub-millimeter and radio observatories equipped with a new generation of quantum-limited and highly sensitive receivers that allowed the detection of vanishingly weak rotational transitions in molecules. The three sources are: 1) TMC-1 (a cold pre-stellar core located in the Taurus constellation); 2) an arm of a spiral galaxy at redshift z = 0.89; and 3) a young Quasar at redshift z = 2.6. TMC-1 turned out to be an amazingly rich chemical laboratory. The authors address the most exciting on-going line surveys of TMC-1 between 20 and 50 GHz: GOTHAM (GBT Observations of TMC-1: Hunting Aromatic Molecules) which uses the Green Bank Telescope facility and QUIJOTE (Q-band Ultra-sensitive Inspection Journey in the Obscure TMC-1 Environment), which takes advantage of the Yebes 40-m ground-based telescope. Both GOTHAM and QUIJOTE surveys recently reported the detection of several cyclic molecules. While GOTHAM relied on a spectral stacking technique, QUIJOTE was able to detect individual rotational lines in their surveys, owing to the sub milli-Kelvin sensitivity of the receiver. The QUIJOTE detection of indene is the first one for a double-ring species.

The authors in this review also present the detection of ten new molecules in the arm of a spiral galaxy, 6 billion light-yr distant, and twelve molecular species in a quasar at 11 billion light-yr. The chemical composition of the gas in distant galaxies seems not much different from that in the nearby interstellar clouds in the Milky Way. A profound sense of regularity in molecular composition throughout the Universe is implicated in this review article. The authors conclude that similarly to TMC-1, distant galaxies may comprise aromatic rings and complex prebiotic molecules, putative precursors of the RNA nucleobases. However, the lines of such complex species lie below the detection limits of current investigations.

In their paper entitled "*Molecular Precursors of the RNA-world in Space: New Nitriles in the G+0.693–0.027 Molecular Cloud,*" Rivilla et al. used both the IRAM 30-m and Yebes 40-m ground-based telescopes to obtain high sensitivity spectra of the G+0.693–0.027 cloud in the 71.8–116.7 GHz, 124.8–175.5 GHz and 199.8–238.3 GHz windows. This molecular cloud, located in the Galactic Centre, raised a lot of attention quite recently with the discovery of the propargylimine molecule, which is thought to play a fundamental role in the formation of amino acids (see also Puzzarini's contribution). In the present paper, the authors focus on several nitriles including four oxygen-bearing species: namely cyanic acid (detected and quantified), cyanoformaldehyde, glycolonitrile (both only tentatively detected) and cyanoacetaldehyde (abundance upper limit provided only); and three C_4H_3N isomers: cyanoallene, propargyl cyanide and cyanopropyne. The chemistry of these molecules is also discussed and the authors point out that formation of the C_4H_3N isomers can result from gas-phase chemistry involving the CN radical and unsaturated hydrocarbons like methylacetylene or allene. Impact of the studied nitriles to prebiotic chemistry and further to the formation of building blocks of RNA is also noted with an abundant bibliography.

Codella et al. contributed a perspective article entitled "*Enlightening the Chemistry of Infalling Envelopes and Accretion Disks around Sun-like Protostars: the ALMA FAUST Project*". The primary goal of the FAUST (Fifty AU STudy) Large Program (LP) is to reveal and quantify the variety of chemical compositions found in the envelopes and disks in a sample of class 0 and I protostars at scales of 50 au, which can be considered as representative of the chemical diversity observed at larger scales. For each source, FAUST proposes a list of specific molecules that will be able to: 1) disentangle the zones of the 50–2000 au envelope/disk system; 2) characterize the organic complexity in each of them; 3) probe their ionization structure; and 4) measure their molecular deuteration. With an unprecedented sensitivity as well as spatial and spectral resolution, the FAUST project will provide a legacy dataset that will be a milestone for astrochemistry and star formation studies.

Jimenez-Serra et al. contributed with a perspective article: "*The SKA as a Prebiotic Molecule Detector*" in which they addressed the issue of possibly detecting sugars with three and four carbon atoms, such as glyceraldehyde $CHOCHOHCH_2OH$, dihydroxyacetone $CH_2OHCOCH_2OH$, and erythrulose $C_4H_8O_4$, in the ISM using the Square Kilometer Array (SKA) working in the centimeter-wave region. The SKA will be the largest radio interferometer telescope in the world operating at centimeter and meter wavelengths. The authors illustrate the possibility of detecting these large sugars and other prebiotic complex organic molecules (COMs) at rather low excitation temperatures (T_{ex}). Indeed, sources where COMs show low T_{ex} represent better targets for the search and discovery of new large prebiotic species in the ISM. It is also suggested that carrying out observations in absorption against a bright continuum background source may allow the detection of low-abundance COMs. Furthermore, it was pointed out that Giant Molecular Clouds (GMCs) located in the Galactic Center such as G+0.693–0.027 are well suited targets. Finally, the paper discusses future expansion of the SKA: The BAND 6 Receivers will increase the frequency coverage up to 50 GHz.

"*Astrochemistry with the Orbiting Astronomical Satellite for Investigating Stellar Systems*" by Bergner et al. is a research article addressing OASIS (Orbiting Astronomical Satellite for Investigating Stellar Systems): a proposed NASA mission for a space-based observatory (at THz frequencies) that will study astrochemistry of prebiotic molecules involving the CHNOPS elements. OASIS will utilize an inflatable 14-m reflector along with a heterodyne receiver to observe prestellar cores, class 0 and I protostars and their envelopes, protostellar outflows, and protoplanetary disks (evolved class II) with unprecedented sensitivity and angular resolution. OASIS covers a wide frequency range in four bands: Band-1 (455–575 GHz), Band-2 (1,100–2,200 GHz), Band-3 (2,475–2,875 GHz), and Band-4 (3,682–3,692 GHz). OASIS is expected to take the next giant step in the far-infrared spectral range, following the Herschel Space Observatory and the Stratospheric Observatory for Infrared Astronomy (SOFIA). OASIS will place constraints on abundances of light hydrides in protoplanetary disks, high-excitation organics in hot corinos and the envelopes of low-mass protostellar systems. This mission will enable the survey of line transitions of NH_3 and H_2S in protoplanetary disks specifically. It will thus provide the excitation conditions, ortho-to-para ratios, and isotopic fractionation levels of these molecules in disks. The OASIS survey of high-excitation lines in the far-infrared of organics such as acetaldehyde (CH_3CHO), dimethyl ether (CH_3OCH_3), ethanol (C_2H_5OH), and methyl formate (CH_3OCHO) in protostellar hot corinos and envelopes will play a critical role in understanding the formation and evolution of prebiotic molecules.

In "*Rotational Rest Frequencies and First Astronomical Search of Protonated Methylamine*," a research article by Schmid et al., the laboratory rest frequencies for rotational transitions of protonated methylamine, $CH_3NH_3^+$, measured in a cryogenic 22-pole ion trap machine and employing an action spectroscopy scheme, are reported for the first time. Thirteen transitions, between 80 and 240 GHz, were measured in the ground vibrational state. Since methylamine (CH_3NH_2) already has been identified in space, its protonated species is surely an interesting candidate for detection. The authors carried out a high-resolution rotational spectroscopic experiment, which was able to point out a substructure in the spectrum that was attributed to internal rotation splitting. An unsuccessful astronomical search in the star-forming objects SgrB2(N) and

SgrB2(M) using the ALMA (Atacama Large Millimeter/sub-millimeter Array) facility was also performed.

In "*Gas-Phase Reactivity of OH Radicals with Ammonia (NH_3) and Methylamine (CH_3NH_2) at around 22 K*," Gonzalez et al. report on the hydrogen abstraction reaction using the CRESU technique (Rowe et al., 2022). In their experimental studies, the authors observe the quantum tunneling effect, which was theoretically predicted for the hydrogen abstraction reaction by the OH radical attacking NH_3. Despite the fact that the OH + NH_3 reaction has a significant energy barrier, a non-Arrhenius behavior was experimentally confirmed. For the OH + CH_3NH_2 reaction, there are two possible exothermic channels: H-abstraction from the methyl group or from the amino group. The investigation pointed out that the reaction is much faster at 22-K than at 300-K. To conclude, the authors discuss the implication of the measured rate coefficients in modeling the abundance of interstellar NH_3 and CH_3NH_2.

A theoretical original research paper on "*Electronically Excited States of Potential Interstellar, Anionic Building Blocks for Astrobiological Nucleic Acids*" is reported by Santaloci et al. In their work, the closed-shell excited states of deprotonated anionic derivatives of benzene, naphthalene, and anthracene functionalized with either a hydroxyl or ethynyl group are quantum chemically characterized. The main focus is on the dipole-bound excited states (DBXSs) of these anion derivatives, and whether the anions are involved in the formation of nucleic acids in gas-phase astrophysical environments. The authors also discuss the possible role of functionalized polycyclic aromatic hydrocarbon (PAH) anions in the formation of nucleobases in the gas-phase.

Finally, Mathew et al., contributed with the perspective article entitled "*Methanol in the RNA world: Astrochemistry Perspective*". In this perspective article the authors anticipate that extraterrestrial methanol played a central role in the evolution of prebiotic-molecule precursors in the origin and structure of RNA world, with an extended bibliography.

Concluding remarks

The articles comprising this Research Topic provide a sample of research activities in the field of Astrochemistry, with the aim of understanding the formation of prebiotic molecules at different stages of star formation and their potential role in the origin of life. It is our opinion that synergies among observation, experiment, theory and modeling as well as among chemistry, physics and astronomy, which is peculiar to the research activities in the field of Astrochemistry are well represented in this compendium.

Author contributions

AA, AC, and DL contributed to the writing, and evaluation of the document.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Altman, S., and Cech, T. R. (1989). *Nobel lectures*.

Rowe, B. R., Canosa, A., and Heard, D. E. (2022). *Uniform supersonic flows in chemical physics: Chemistry close to absolute zero studied using the CRESU method*. World Scientific. doi:10.1142/q0324

Turk-MacLeod, R., Gerland, U., and Chen, I. (2013). "Life: the physical underpinnings of replication," in *Astrochemistry and Astrobiology*. Editors I. W. M. Smith, C. S. Cockell, and S. Leach (Springer), 271–306.