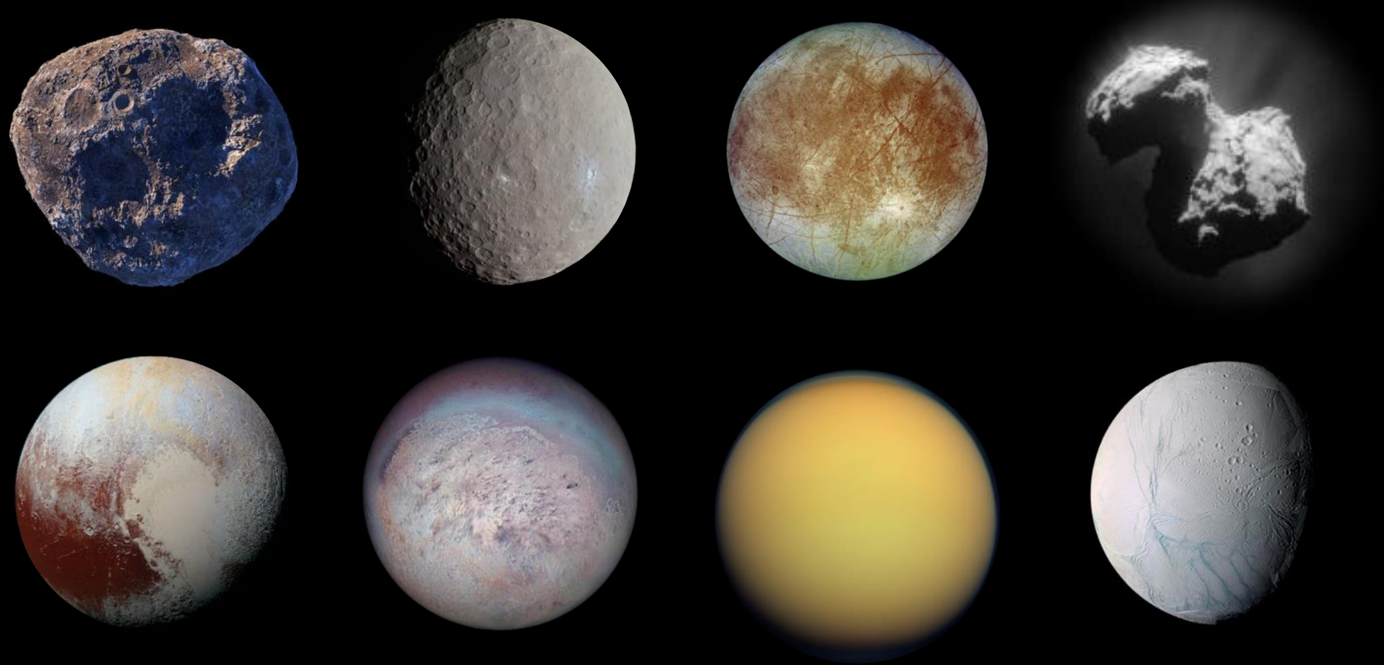
LABORATORY ASTROPHYSICS NEWSLETTER

SEPTEMBER 2025



COLD SOLAR SYSTEM OBJECTS

Interview with Farid Salama

Presentation of the Cold Solar System Objects (CSSO) ISFM Project Facilities

Recent publications (January–August 2025)

Upcoming conferences

Letter from the Editors

We are excited to present the Laboratory Astrophysics Newsletter, whose goal is to enhance communication and interactions between experimentalists, theoreticians, modelers, and observers in the fields of Astrophysics and Planetary Science around the world. This newsletter was initiated by the Cold Solar System Objects (CSSO) project led at NASA Ames Research Center (ARC) and in collaboration with NASA Goddard Space Flight Center (GSFC). The overarching goal of the CSSO project is to investigate and understand the composition, origin, evolution, and chemical processes occurring on the surfaces and in the atmospheres of cold Solar System objects using unique facilities and expertise at NASA ARC and GSFC.

This newsletter is intended to be released quarterly. Each issue will focus on a particular theme in the Laboratory Astrophysics field and include sections such as a cover image, a scientist interview, a description of facilities, recent publications in the field, and/or announcements for upcoming meetings.

The theme of the Laboratory Astrophysics Newsletter's first issue is **Cold Solar System Objects**. We present an interview of Dr. Farid Salama, a leader in Laboratory Astrophysics research at NASA ARC and who advocated for the field for decades. The laboratory facilities presented in this issue are the 5 facilities of the CSSO project team and include: the Ices, Ice Irradiation, and Organics Laboratory for Astrobiology (I^{3}OLAB), the COsmic SImulation Chamber (COSmIC), the Optical Constants Facility (OCF), and the Matrix Isolation/ Optical Constants of Ices (MIOCI), at NASA ARC, as well as the Cosmic Ice Laboratory at NASA GSFC. The long list of recent publications in this first issue covers work published since the beginning of 2025 and demonstrates the abundance and productivity of research conducted in the field of Laboratory Astrophysics within the Planetary Science community. Finally, several upcoming meetings relevant to the field of Planetary Science and Astrochemistry are listed in this issue.

Ella Sciamma-O'Brien

Michel Nuevo

Partha Bera

Lora Jovanovic

Joeseph Roser

Aaron McKinnon

In future issues, we look forward to featuring various Laboratory Astrophysics themes and include interviews of scientists and presentations of facilities around the world.

Visit our newsletter website for current and past issues here.

We welcome contributions to the newsletter. You can share announcements through our contribution form here.

We publish quarterly; keep an eye out for our next issue. Welcome to the Lab Astro newsletter!

The Editorial Team

Interview with Farid Salama

Farid Salama is an Astrophysicist in the Space Science and Astrobiology Division at NASA Ames Research Center. His current research is centered around the study of interstellar, planetary and exoplanetary molecules and ions in the laboratory and the formation of grains and aerosols from molecular precursors in astrophysically relevant environments.

How did you get into Lab Astro research? Can you tell us about your career path?

I got into lab astro research by coincidence. I had not been involved in astronomy and astrophysics before. My background was in Molecular Physics and Physical Chemistry working on molecules and molecular ions. After I graduated from my PhD, I applied for a postdoc and received two offers for positions in Northern California.

One offer was in UC Berkeley, at the Lawrence Berkeley Lab (LBL) in the laboratory of Prof. Pimentel who had developed the technique of Matrix Isolation Spectroscopy (MIS) to work with Heinz Frei on the use of laser reaction excitation spectroscopy as a tool to locate extremely weak vibronic transitions that can be activated by near-infrared photons. The goal of the research project was to identify molecules that can offer a way to accomplish new chemical synthesis with long-wavelength near-infrared solar photons.

The second offer was a National Research Council (NRC) fellowship to work at NASA Ames with Lou Allamandola who was just setting up a new IR Lab Astro Laboratory in the Space Science Division to support the NASA Kuiper Airborne Observatory (KAO). This is where I got exposed to Laboratory Astrophysics for the first time with the opportunity to work on Jupiter’s moon, Io. My core project, however, was to set up a Lab Astro Laboratory in the UV-visible range using my experience with MIS and VUV spectroscopy. I found this multidisciplinary work fascinating, and I decided to continue working in this field. In addition, having built and set up a new experimental system I was keen to work and perform research with this new tool close to my heart.

Briefly, my career path is as follows: graduate student and PhD in molecular physics at the University of Paris-Orsay and the Pierre & Marie Curie Institute in Paris, followed as postdoc at the LBL, UC Berkeley, and, since then, worked in the Astrophysics branch of the Space Science Division at NASA Ames first as a NRC fellow, then as a UC Berkeley Astronomy research assistant, SETI PI and finally as a NASA civil servant. I’m currently the Director of the COSmIC Facility where I have had the pleasure to work with a fantastic team of young and seasoned scientists and engineering technicians over the past years who helped make it possible to build this truly unique laboratory facility.

What inspired you to become a scientist? Which scientist had the largest impact on your research or inspired you?

I was initially not considering going into research and becoming a scientist. I was advised and encouraged by my university Professors to go beyond the Master and try a one-year postgraduate degree for advanced studies (DEA in France). I ended up selecting a project, among the many I had been presented with, that was based on molecular spectroscopy using the MIS technique. This was the first time I was confronted with research, and I found that I was actually very interested in continuing in this direction.

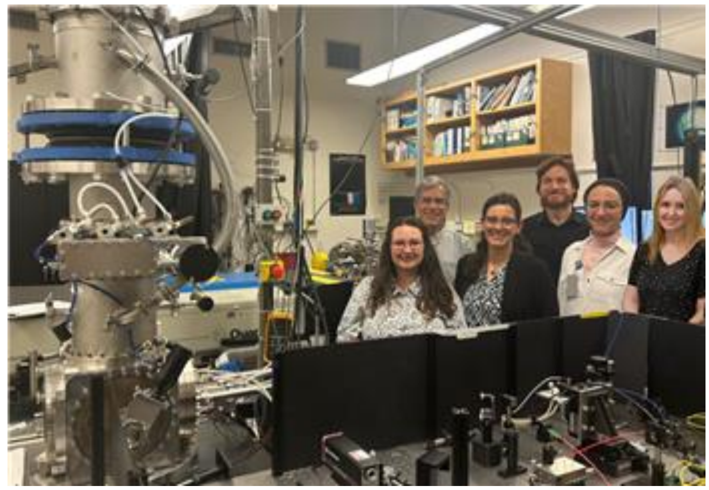
Many scientists I met during my career had a large impact on my research and inspired me. In science, we build ourselves on the knowledge and experience of the scientists who preceded us. As the saying goes: “We stand on the shoulders of the giants that preceded us”. To cite a few, these include my thesis adviser, Janine Fournier, who guided me in my first exposure to a research lab, Antoine Fournier, the Director of the Lab, who was an unconventional scientist who taught me a lot too. The discussions I had with Sidney Leach who was leading the Molecular Photophysics Laboratory in Orsay had also a strong impact on my career choices. When I moved to the US and started my career as a researcher, the late George Pimentel in UC Berkeley, Lou Allamandola and Xander Tielens at NASA Ames are among the researchers who inspired me a lot.

I was also quite inspired by the late Giacinto Scoles, a Professor in Princeton and a pioneer in the study of intermolecular forces whom I met as a PhD student visiting the University of Waterloo in Canada in 1985 during my postgraduate studies. I happened to attend a seminar he gave at the university where he encouraged young students and early career scientists to choose a topic that attracted them regardless of its current popularity or conceived importance and to work hard until becoming a world expert in the subject topic. His advice was that this approach helped science. His advice struck me as worth following and my career and experience showed me how correct his advice was.

What is your current research about? What motivates you in your research? What do you enjoy the most about your research?

My research centers on molecular spectroscopy and mass spectrometry in the areas of laboratory astrophysics and astrochemistry in conjunction with ground-based and space-based ultraviolet, optical and infrared astronomy (Diffuse Interstellar Bands (DIBs) and Aromatic Infrared Bands (AIBs) in galactic and extragalactic environments; planetary ices; planetary and exoplanetary atmospheres, ...).

What motivates me in my research is to increase our knowledge and strengthen our understanding of the composition of the materials that surround us (interstellar clouds, circumstellar environments, planets, planetary atmospheres, exoplanets, comets, etc.). I’m also driven by the curiosity of identifying elements that are ubiquitous in space such as the hundreds of absorption bands in the visible and the emission bands in the IR.



The COSmIC Team: *Farid Salama, with, from left to right, Lora Jovanovic, Ella Sciamma-O’Brien, David Dubois, Salma Bejaoui, and Claire Ricketts.*

What do you consider to be your greatest achievement in your research? What impact has your research had in the field?

I consider the design and development of the Cosmic Simulation Chamber (COSmIC) to generate laboratory analogs of interstellar, circumstellar, planetary and exoplanetary molecules, ions and grains as my greatest achievement. This unique facility has had a strong impact in interstellar and circumstellar astrophysics, planetary and exo-planetary studies and has allowed breakthroughs such as the first survey of DIBs in translucent clouds for PAH signatures, the formation of circumstellar grain analogs in the laboratory, and the measure-ments of planetary and exoplanetary haze molecules and aerosols.

The COSmIC Facility impact was recognized with a NASA Award for “recognition of the unique and exceptional contribution to astrophysics and planetary advances (image below).

Top: *In 2003, G. Scott Hubbard, NASA Ames Research Center's director awarded Farid Salama the NASA Exceptional Achievement Medal for developing a unique experimental facility in laboratory astrophysics and for innovative research on diffuse interstellar bands.* ***Bottom:*** *A picture of the plasma produced in the COSmIC chamber to simulate astrophysical environments.*

How has the field evolved since you started your career in Lab Astro? What role did you play in it?

The field of Lab Astro has largely evolved since I started my career and continues to evolve at an impressive pace. Because of its multidisciplinary aspect and the requirement to address problems and issues that are beyond the current level of knowledge in fundamental science (physics, chemistry, etc.), Laboratory Astrophysics is continuously challenged to push the limits of science. The discovery of a new form of carbon (fullerene C_{60}) that resulted from a laboratory study of potential carriers of the Diffuse Interstellar Bands led to a Nobel prize for the researchers and is a testimony to the strong impact of Laboratory Astrophysics on basic sciences.

The role I have been playing in Lab Astro has had various components: direct contribution to science results, leadership and mentorship as laboratory director and advocacy for the field.

In 2022, Farid Salama was named a fellow of the AAS in recognition of his significant advances in astrophysics and astrochemistry, and for his service to the community through the creation of the Lab Astro Division of the AAS.

Regarding the science aspect, I contributed to a better knowledge of the spectra of PAH ions by providing the first spectroscopic data on the electronic spectra of isolated PAHs molecules and ions measured with COSmIC under astrophysically relevant conditions that led to the first survey of PAHs in the search of Diffuse Interstellar Bands in galactic and extragalactic environments. I also contributed to the formation of laboratory analogs of circumstellar carbon grain with COSmIC. I also contributed to the first results on planetary ices on Io (Jupiter's moon) for comparison with infrared airborne data as well as the formation of laboratory analogs of planetary aerosols with COSmIC for a better understanding of Titan's (Saturn/s moon) and other planetary hazes. I also participated to the ORGANIC experiments on the multi-user facility EXPOSE-R on the International Space Station where I investigated the chemical evolution, survival, destruction, and chemical modification of PAHs and fullerenes in space.

Regarding the science advocacy aspect, I played a key role in the establishment of laboratory astrophysics as a recognized and vital field of science. I am a co-founder of the Laboratory Astrophysics Division of the American Astronomical Society (AAS) launched in 2012, and I helped found the Astrochemistry sub-commission of the American Chemical Society subsequently launched. I also founded the International Astronomical Union (IAU) Laboratory Astrophysics Commission. In both cases, I played a leading role, as Chair of the AAS LAD Division and first President of the IAU Commission.

Which open question in Lab Astro would you like to see answered in the near future?

I would like to see a full identification and characterization of the species (molecules, ions, grains) responsible for the DIBs seen all over the universe, in galactic and extragalactic environments. Identifying the DIBs is a key open question for astrophysics and astronomy. Identifying the carriers of the DIBs has various implications from probing the Galactic structure and evolution to unraveling interstellar chemistry and answering fundamental questions in astrobiology.

What was the most important advice somebody gave you?

Most important advice: choose a topic that attracts you (see Giacinto Scoles above) and believe in and advocate your research.

Do you have some advice for early career scientists?

My advice: choose a science field that you like/enjoy, make sure to work in a friendly environment with a friendly team (teamwork is essential), although research is competitive, try to always work with an open team spirit. Stay motivated, curious and, most of all, modest. Learn to open up to other fields and activities and look to each for the values they provide to our global knowledge. Most importantly, work hard, do not get discouraged and stay patient; remember that research is more than often a long and hard endeavor that always brings results if you believe in your work. Always keep in mind the high ethical requirements in research: honesty and fairness.

What are the top books that you recommend reading to get started in the field of Lab Astro?

There are a large number of publications that have been published in the past two or three decades that have witnessed the evolution of the field of Laboratory Astrophysics. Some examples include proceedings from Laboratory Astrophysics workshops and conferences.

A non-exhaustive list of books is provided below:

- Proceedings of Laboratory Astrophysics workshops and conferences:
- NASA LAW books (1990, 1998, 2002, 2006, etc.);
- ECLA 2020;
- IAU Proceedings (IAU 371, IAU 350, IAU 280);
- Molecular Spectroscopy in Astrophysics, Spectrochimica Acta, Part A: Molecular and Biomolecular Spectroscopy, Elsevier, Vol. **57**, 613–958 (2001).

How do you balance your professional and personal life?

I have always tried to balance my professional and personal life as well as I could. It is not always an easy thing to do but I strongly believe that it is essential to have a balanced life. Outside of work I spend most, if not all, my time with my family (and my dog). I very much enjoy walking or hiking with my family and my friends. I also spend time reading and/or watching movies or listening to music. I also enjoy traveling and discovering and exploring new places for the first time.

Farid's family: Amira, Farid, Josie, Maissa, and Milou.

Laboratory Astrophysics Facilities:

The Cold Featured Solar System Objects ISFM Project Facilities

In this first issue of the Laboratory Astrophysics Newsletter, we will present the 5 laboratory facilities that are used to carry out the experimental work of the Cold Solar System Objects (CSSO) Internal Scientist Funding Model (ISFM) project. These 5 laboratory facilities are: the Ices, Ice Irradiation, and Organics Laboratory for Astrobiology (I^{3}OLAB), the COsmic SImulation Chamber (COSmIC), the Optical Constants Facility (OCF), and the Matrix Isolation/Optical Constants of Ices (MIOCI) at NASA Ames Research Center, as well as the Cosmic Ice Laboratory at NASA Goddard Space Flight Center.

I^{3}OLAB Facility at NASA Ames

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https://www.nasa.gov/ices-ice-irradiation-and-organics-laboratory-for-astrobiology/
https://www.astrochem.org/fac/ice_lab.php

Cosmic Ice Laboratory at NASA Goddard

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https://science.gsfc.nasa.gov/691/cosmicice/

COSmIC at NASA Ames

Farid Salama (farid.salama@nasa.gov), Ella Sciamma-O'Brien
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Optical Constants Facility at NASA Ames

Ella Sciamma-O'Brien (ella.m.sciammaobrien@nasa.gov), Farid Salama
https://www.nasa.gov/space-science-and-astrobiology-at-ames/research-teams/all-research-teams/optical-constant-facility/

Matrix Isolation/Optical Constants of Ices at NASA Ames

Joseph Roser (joseph.e.roser@nasa.gov)
https://www.nasa.gov/space-science-and-astrobiology-at-ames/research-teams/all-research-teams/matrix-isolation-optical-constants-of-ices-laboratory/

I^3OLAB Facility at NASA Ames

Michel Nuevo (michel.nuevo@nasa.gov), Scott Sandford
https://www.nasa.gov/ices-ice-irradiation-and-organics-laboratory-for-astrobiology/
https://www.astrochem.org/fac/ice_lab.php

Identify, characterize, and study the evolution of ices in astrophysical environments

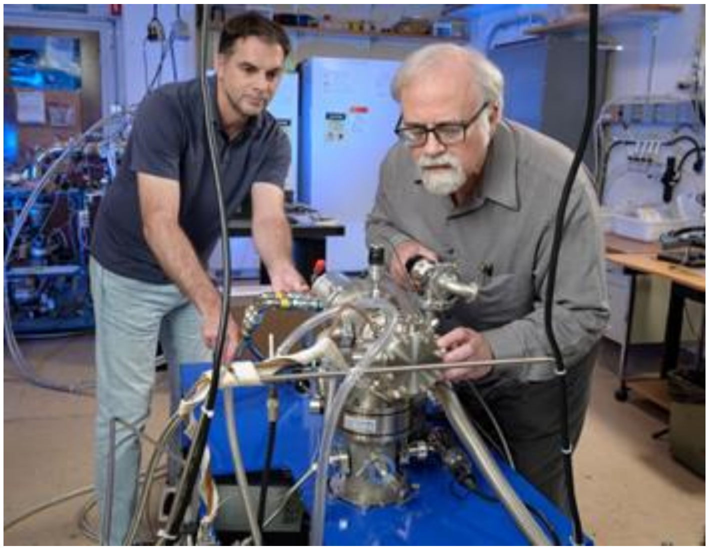
Various astrophysically relevant ice analogs simulating interstellar dense molecular clouds, protostellar disks (PPDs), and outer Solar System objects are simulated in cryo-vacuum systems, charactered with infrared (IR) spectroscopy, and compared to mission data for the detection of specific compounds and families of compounds, e.g., astronomical data obtained by NASA, ESA, and JAXA missions and IR observatories (*Spitzer*, *JWST*, *ISO*, *SOFIA*, *IRTF*).

Study chemical processes occurring when ices and organics are exposed to ionizing radiation and subsequent formation of complex organic materials

Astrophysically relevant ices are irradiated with ultraviolet (UV) photons or energetic electrons and monitored with IR spectroscopy to study their chemical evolution and the formation of new species upon irradiation, with an emphasis on investigation of astro-biologically relevant compounds, such as amino acids, sugar derivatives, nucleobases, and amphiphiles. The organics residues resulting from the warm-up of the ices to room temperature are also analyzed to determine their molecular and elemental compositions using IR spectroscopy, gas chromatography coupled to mass spectrometry (GC-MS), and X-ray absorption near-edge structure (XANES) spectroscopy.

Study chemical processes when organic residues are exposed to further ionizing radiation, and subsequent formation of insoluble materials that resemble insoluble organic matter in extraterrestrial materials

Ice-covered dust grains and more complex organics are believed to experience high doses of ionizing radiation in PPDs, resulting in the formation of a very refractory, insoluble material whose composition resembles that of insoluble organic matter (IOM) in meteorites, interplanetary dust particles (IDPs), and asteroid materials from Ryugu (*Hayabusa2*) and Bennu (*OSIRIS-REx*).



Exposing organic residues to additional high-energy radiation results in changes in their chemical and elemental compositions, which can be studied as a function of the radiation dose.

Study extraterrestrial materials from comets and asteroids and support sample return missions

I^3OLAB also characterizes organics in extraterrestrial samples (meteorites, IDPs, asteroids) for their chemical and elemental compositions to understand the processes and conditions in which those materials formed and evolved.

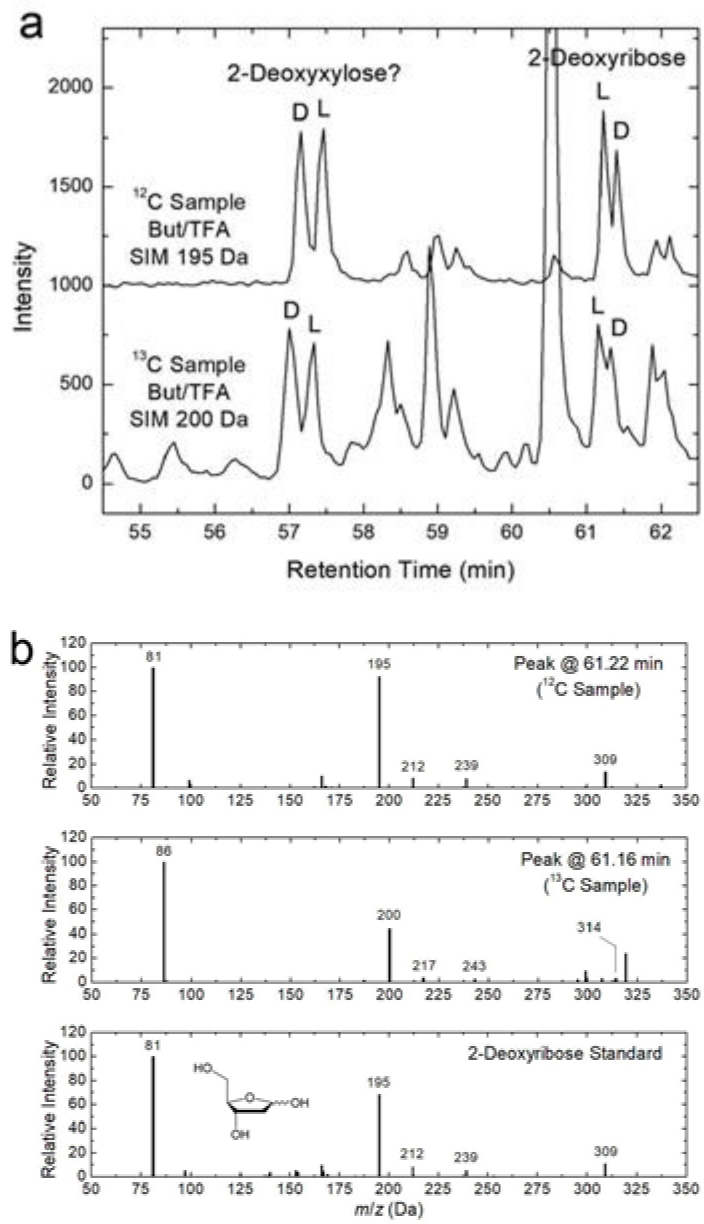
Laboratory equipment

Cryovacuum systems. The I^3OLAB facility has cryo-vacuum systems (see photo above) that typically operate in the 10^{-8} torr range and are equipped with closed-cycle He cryocoolers to perform experiments below 20 K. Ices are made by depositing pre-mixed gases onto a cold substrate (aluminum foil or IR-transparent window) and are simultaneously irradiated with UV photons from a microwave-powered H_2 lamp or 1.2-keV electrons from an electron gun. UV lamps emit primarily Lyman-α photons (121.6 nm) in addition to a continuum centered at 160 nm, with a total flux of about 10^{14} photons cm^{-2} s^{-1}. Photon doses in those experiments are equivalent to about 10^5 years in the diffuse interstellar medium (ISM) and 10^8 years in the dense ISM.

FTIR spectroscopy. One of the cryovacuum systems is equipped with a Thermo Fisher iS50 Fourier-transform infrared (FTIR) spectrometer. Samples are deposited on an IR-transparent window, allowing for real-time collection of transmission IR spectra during ice deposition, irradiation, and thermal cycling. The spectrometer can measure spectra in the near-IR (NIR) (10000– 4000 cm^{-1} range) and mid-IR (MIR) (5000–600 cm^{-1} range, 1 cm^{-1} resolution) ranges using different beamsplitters and a liquid nitrogen (LN_2)- cooled mercury–cadmium–telluride (MCT) detector.

FTIR microscopy. A Thermo Fisher Nicolet iN10 MX FTIR microscope is used to analyze a wide variety of samples, including organic residues produced from the UV irradiation of astrophysical ice analogs and extraterrestrial samples including meteorites (e.g., Sutter's Mill) and samples from asteroids Ryugu and Bennu, with a ≥5-µm spatial resolution down to and a ≥4-cm^{-1} spectral resolution by collecting transmission or reflection spectra in the MIR (4000–675 cm^{-1}) and NIR (7000–4000 cm^{-1}) ranges, thanks to an LN_2-cooled MCT detector and a KBr beamsplitter.

GC-MS. The gas chromatography coupled to mass spectrometry (GC-MS) device at I^{3}OLAB combines a Thermo Trace gas chromatograph with a Thermo DSQ II mass spectrometer, which can record mass spectra in the 50–650 Da mass range. Using a variety of GC columns (e.g., Rxi-5ms, Rtx-200MS, DB-17HT), derivatization techniques (BSTFA, MTBSTFA, etc.), and temperature gradients, GC-MS separates organic components of complex mixtures from samples produced in the laboratory or extraterrestrial materials. Compound identification is made by comparison of retention times and mass spectra of GC peaks in samples with commercial standards prepared in the same manner as the samples. In the absence of relevant standards, mass fragmentation spectra can provide constraints on the structure of unidentified compounds. GC-MS analysis of residues produced from the UV irradiation of ices of astrophysical interest have shown that astrobiologically relevant molecules such as amino acids, nucleobases, and sugar derivatives (see figure) can be made under abiotic conditions.



GC-MS data showing the detection of 2-deoxyribose in a residue produced from the UV irradiation of an H_2O:CH_3OH ice mixture (from Nuevo et al. 2018).

Gas handling system. Ice samples are condensed from pre-mixed gas mixtures whose compositions simulate various environments (e.g., ISM clouds, PPDs, comets, icy satellites). Mixtures are made from gases (lecture bottles) and vapors (from liquids) of simple molecules (e.g., H_2O, CH_3OH, CO, CO_2, NH_3, CH_4, N_2) which are prepared in a gas handling system that operates with a background pressure of about 10^{-6} mbar. The composition of each mixture is determined by the partial pressures of individual components. The resulting mixtures are transferred to glass bulbs that are then interfaced with the cryovacuum systems, and from which ices can be deposited on cold substrates.

Cosmic Ice Laboratory at NASA Goddard

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Overview

For over 40 years, the Cosmic Ice Laboratory at NASA Goddard Space Flight Center has researched icy Solar System and interstellar environments. Our laboratory specializes in molecular spectroscopy, obtaining fundamental physical properties of ices, low temperature chemistry, radiation chemistry, and reaction kinetics. Our work has a wide range of applications from astronomy to astrobiology. This includes identifying and quantifying infrared bands in observational data, making predictions about the chemical composition of Solar System and interstellar ices, interpreting the origins of molecules detected in extraterrestrial samples, and determining the lifetimes of molecules in an extraterrestrial environment. Our data benefit all phases of NASA missions from planning to final analysis by providing fundamental data about what might be detected, how long it might last, how much of it there is, and what its presence could imply about the environment.

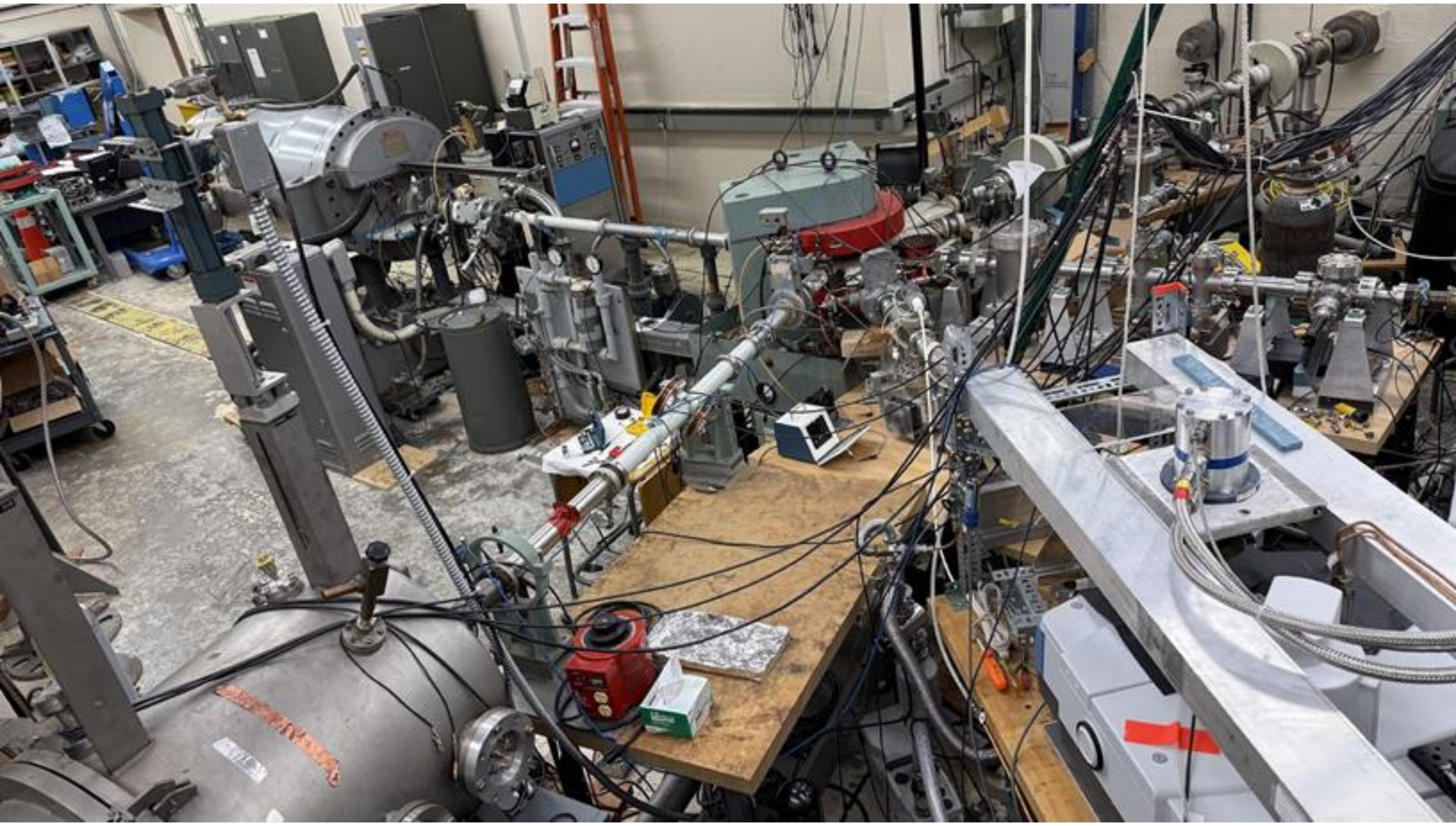
Research topics

Molecular spectroscopy: We use laboratory experiments to measure the infrared spectra of compounds that are known or predicted to exist in icy Solar System and interstellar environments. These measurements can then be used to identify specific molecules or classes of molecules in spectra obtained from samples, missions, and ground and space telescopes. Our laboratory spectral data also provide information about the structure of the ices (e.g., amorphous or crystalline). We also specialize in obtaining optical constants of ices which can be used to quantify the abundance of specific compounds in target objects of interest. The data we generate are critical for the interpretation of observations.

Fundamental physical properties of ices: We use experiments to measure the fundamental physical properties of ices including their densities, indices of refraction, vapor pressures, and enthalpies of vaporization, among other things. These important fundamental properties are important to predict the behavior of molecules in icy environments and are often essential to fully quantify their abundance and chemical reactivities.

Radiation Chemistry: We use a combination of infrared spectroscopy and p^+ radiolysis to simulate a range of Solar System and interstellar radiation environments and monitor chemical changes in sample ices *in situ*. These experiments allow us to track the radiolytic destruction of reactant compounds and the formation of new products as a function of radiation dose. These measurements are quantitative and can be applied to the interpretation of different space environments. The destruction and formation kinetics of reactants and products allow us to make predictions about the the presence of molecules, their relative abundances, and expected lifetimes in different icy environments. These experiments also help interpret the origins of compounds detected in extraterrestrial samples.

Low temperature chemistry: We perform low temperature thermochemistry experiments to observe the reactivities of compounds in the solid phase. These experiments involve reactive species that can be collected together or form within an ice at low temperatures and become able to react as the ice is warmed. Such experiments include solid phase acid-base reactions and oxidation-reduction reactions. These reactions are especially relevant to icy objects that undergo seasonal or periodic temperature changes. Additionally, these reactions are of significant importance to sample return missions where the sample undergoes significant temperature changes between collection and analysis.



Laboratory Equipment

Van de Graaff Accelerator (above): This accelerator is located at NASA Goddard's Radiation Facility. It has been used by our lab since the 1980s and has played a role in ~75% of our papers. It delivers ~0.9-MeV protons with an incident flux sufficient to provide a 200 MGy (20000 Mrad) dose to ice samples over 1–2 days, with pauses to record IR spectra. To determine doses, we measure the beam current on the ice's underlying metal substrate, biased at +50 V to prevent the emission of secondary electrons. We can vary the incident flux by an order of magnitude or more to check for non-linear effects. The doses available are sufficient to replicate radiation chemistry for many astronomical environments.

Cryovacuum systems coupled with integrated FTIR spectrometers: Four cryovacuum systems (~10 to 300 K temperature range, ~10^{-8} torr operating pressure) are dedicated to the IR spectroscopy of ices. Each system has a dedicated manifold with calibrated leak valves allowing us to control the deposition rate and create ice mixtures without premixing gases. Two of the chambers are interfaced with the Van de Graaff accelerator for our ice radiolysis studies.

The cold end of each cryostat is interfaced with a multi-port sample chamber so that IR measurements can be made *in situ* during thermal annealing, and before and after irradiations of ices. Infrared spectra can be collected either in transmission (KBr, ZnSe windows as a substrate) or reflection (polished aluminum mirror substrate) and diode lasers (670 nm) are used for interferometry to measure sample thicknesses. If desired, samples can be collected after warming for *ex situ* analyses such as GC-MS or LC-MS or for use in aqueous chemistry experiments.

Ultra-high vacuum system: This cryovacuum system (~10 to 300 K temperature range, ~10^{-10} torr operating pressure) is equipped with a quartz-crystal micro- balance, a two-laser interferometer, a quadru-pole mass spectrometer and is interfaced to an IR spectrometer. This system is primarily used to measure physical properties of ices including indices of refraction and densities.

Recent Sources of Funding: NASA's Solar System Workings Program, NASA's Emerging Worlds Program, NASA's Astrophysics Research and Analysis Program, FLaRe ISFM, NASA Astrobiology Institute.

COSmIC at NASA Ames

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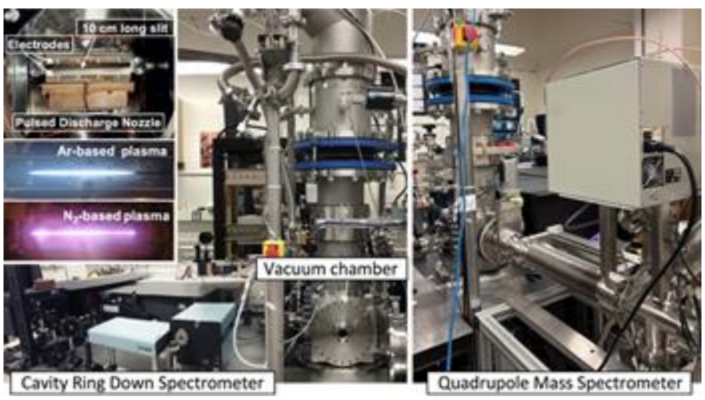
https://www.nasa.gov/cosmic-facility/

Overview

COSmIC stands for "Cosmic Simulation Chamber" and was developed to generate, process and analyze interstellar, circumstellar, and (exo)planetary analogs in the laboratory. COSmIC is used to study neutral and ionized molecules and nanoparticles and grains under temperature and vacuum conditions that are representative of space environments.

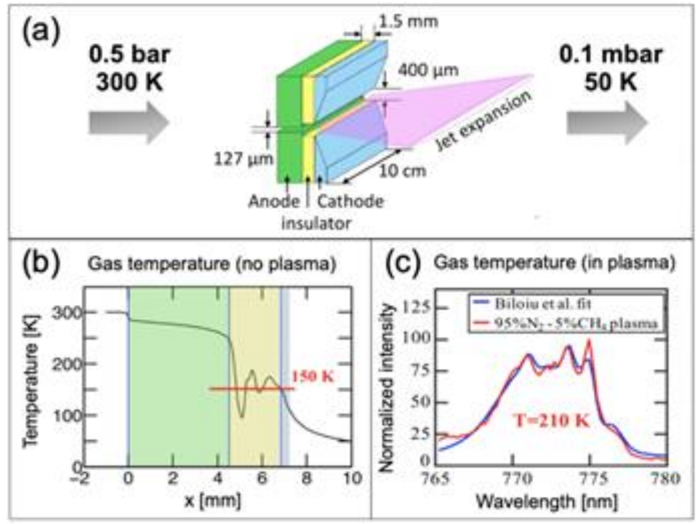
Laboratory equipment

COSmIC, depicted below, consists of a *pulsed discharge nozzle (PDN)* mounted on a vacuum chamber and coupled to a *cavity ringdown spectrometer (CRDS)* and a *quadrupole mass spectrometer (QMS)*. An *RF/DC Plasma Static Langmuir Probe* can also be connected to the chamber.



Pictures of the COSmIC facility. ***Left inserts:*** *the PDN slit and images of an argon-based (blue) and a nitrogen- based (pink) plasma.* ***Left:*** *the CRDS system coupled to the COSmIC chamber.* ***Right:*** *The QMS coupled to COSmIC.*

The *PDN* is used to generate a free supersonic expansion by injecting a gas mixture into the vacuum chamber through a very thin slit (127 µm x 10 cm). A reservoir with heating plates (up to 300°C) allows to mix precursors into a carrier gas before expansion through the slit. The expansion lowers the gas temperature (50-150 K) and the pressure (0.1–30 mbar). A cold plasma discharge (1–2 eV energy) can be generated in the stream of the expansion by applying a high voltage (600–1000 V) onto electrodes placed along the slit (see schematic). This plasma discharge then generates cold isolated neutral, ions, radicals in the gas phase, as well as solid particles in a setting that realistically simulates astrophysical and (exo)planetary environments.



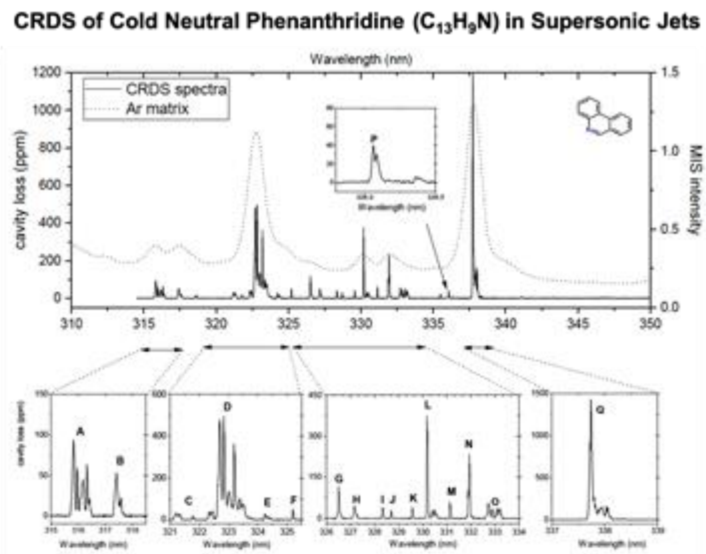
(a) *Schematic of the pulse discharge nozzle (PDN).* ***(b)*** *Gas temperature before the plasma is turned on.* ***(c)*** *Gas temperature after the plasma is turned on.*

Cavity Ringdown Spectroscopy (CRDS) is an ultra-sensitive direct absorption technique based on the measurement of the lifetime of probe photons trapped into an optical cavity formed by two high reflectivity (>99.99%) mirrors facing each other. On COSmIC, a laser and several sets of mirrors allow measuring the absorption spectra of neutral and ionized molecules (with and without plasma) in the ultraviolet to near infrared spectral range from 300 to 900 nm. An IR CRDS system (2.7–4.0 µm) is also under development. These measured absorption spectra can then be directly compared to observational data for their interpretation.

Mass spectrometry is another *in situ*, non-intrusive technique that allows monitoring the neutral and ionized species produced in the plasma expansion on COSmIC. The first mass spectrometer installed on COSmIC was a time-of-flight mass spectrometer that enabled studying the chemical pathways leading to the formation of heavier molecular species precursors of solid particles analogs of cosmic dust grains and planetary aerosols. Recently a new quadrupole mass spectrometer was installed on COSmIC that will enable not only the detection of positive ions and neutrals in the plasma expansion but also negative ions. *A Langmuir probe* can also be coupled to the COSmIC chamber to characterize the plasma parameters (e.g., pressure, temperature).

Simulating Interstellar Environments (gas phase):

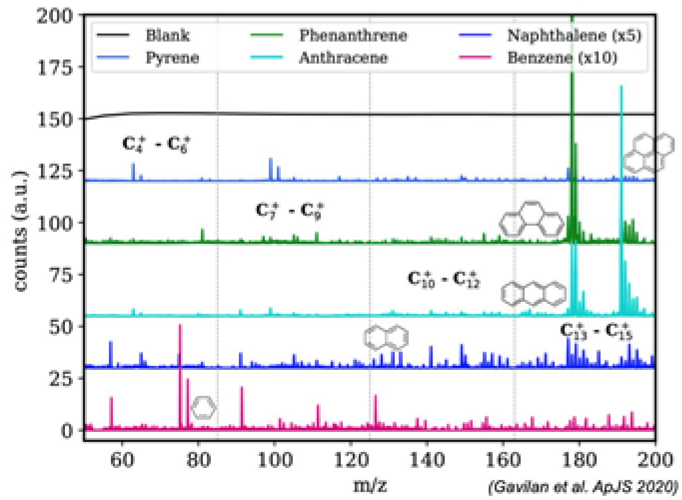
CRDS can be used on COSmIC to measure the absorption spectra in the NUV-NIR range of ionized PAHs and nitrogen-contained PAH molecules (PANHs) isolated in a cold free jet expansion of argon (Ar) carrier gas. These high-resolution experimental spectra can then be compared to the observations and the upper limits for the column densities of the PAHs and PANHs molecular carrier can be derived. A first quantitative survey of neutral and ionized PAHs in the optical range, and in particular a comparison of CRDS experimental absorption spectra of pentacene to ISO interstellar observations opened the way for unambiguous quantitative searches of PAHs in a variety of interstellar and circumstellar environments.



Experimental gas-phase CRDS absorption spec- trum of phenanthrene compared to solid matrix isolation spectroscopy spectrum demonstrating the high-resolution capability of the CRDS technique.

Simulating Circumstellar Environments (gas and solid phases):

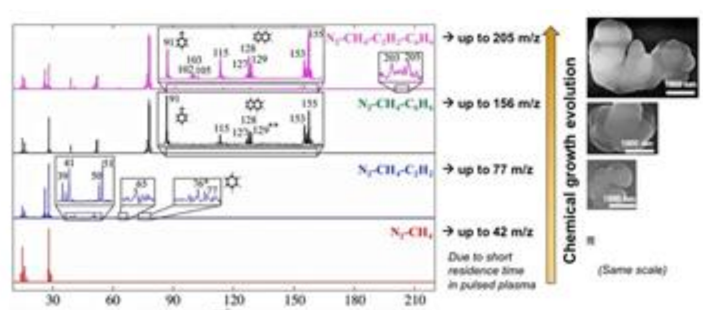
In COSmIC, simple hydrocarbons (e.g., CH_4, C_2H_2) and PAHs seeded in Ar gas can be used as precursors to study grain formation in the gas phase. The plasma chemistry induced in the PDN produces more complex molecular species, that can then be directly detected *in situ* by mass spectrometry, and solid phase materials, that can be collected on substrates and analyzed *ex situ*, with high-resolution mass spectrometry, scanning electron microscopy, and spectrally with the Optical Constants Facility (OCF).



High-resolution laser desorption mass spectra of grains formed by plasma chemistry from aromatic precursors seeded in Ar gas.

Simulating (Exo)Planetary Environments (gas and solid phases):

The COSmIC facility can also be used to simulate the chemistry occurring in the upper layers of planetary (e.g., Titan, Pluto, Triton, Jupiter) and exoplanetary atmospheres. Different gas mixtures (e.g., N_2:CH_4, N_2:CH_4:C_2H_2, N_2:CH_4:C_6H_6, N_2:CH_4:CO, Ar:NH_3:CH_4, Ar:NH_3:C_2H_2, Ar:CH_4:CO, Ar:CH_4:CO_2) can be injected in the plasma, in order to investigate the chemical pathways leading to the formation of aerosols, via in-situ mass spectrometry, and produce aerosol analogs for further ex-situ analysis (Scanning electron microscopy, x-ray absorption spectroscopy, high resolution mass spectrometry, optical properties with OCF.



Left: Time-of-flight mass spectra of Titan-simulated N_2:CH_4-based atmosphere with and without the addition of heavier gas-phase precursors (C_2H_2, C_6H_6). Right: Scanning electron microscope images of the resulting solid grains.

Optical Constants Facility at NASA Ames

Ella Sciamma-O'Brien (ella.m.sciammaobrien@nasa.gov), Farid Salama

https://www.nasa.gov/space-science-and-astrobiology-at-ames/research-teams/all-research-teams/optical-constant-facility/

Overview:

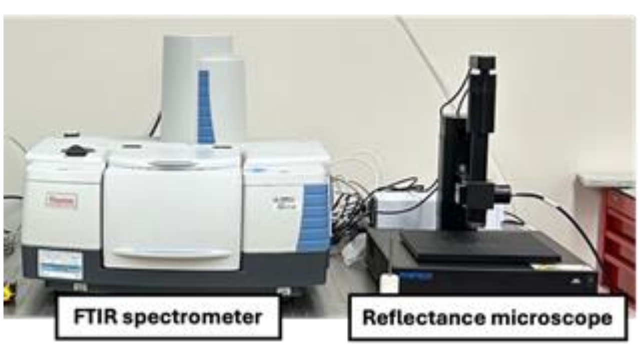
The NASA Ames Optical Constants Facility (OCF) was recently developed to characterize the spectral properties of non-homogeneous refractory solid samples, using transmission and reflection measurements, and determine their optical constants, from the near ultraviolet (NUV) to far infrared (FIR).

Optical constants are the real and imaginary parts of the complex refractive index, respectively *n* and *k*, of a material: $N = n + ik$. They describe how a material interacts with incident light, including transmission, reflection, refraction, absorption, and scattering. Both real and imaginary indices vary with wavelength.

Optical constants are fundamental input parameters for models (e.g., radiative transfer, atmospheric, and reflectance spectral models) used to interpret observational data returned from space missions and ground-based observatories. They thus support strategic research activities recommended by the "Origins, Worlds and Life" Planetary Science and Astrobiology Decadal Survey 2023–2032.

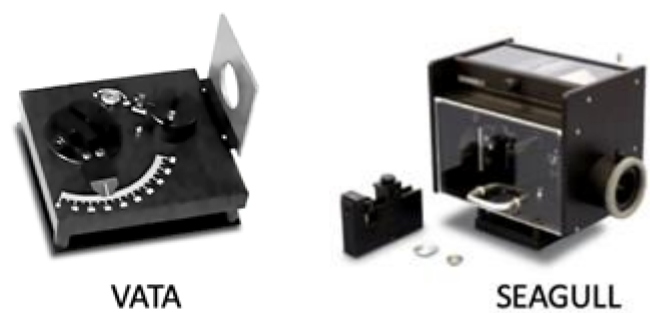
Laboratory equipment:

The OCF is composed of a Filmetrics-KLA F40-UVX reflectance microscope, a Thermo Fisher iS50 Fourier-transform Infrared (FTIR) spectrometer, and two Harrick Scientific variable angle transmission (VATA) and reflection (SEAGULL) accessories.



The reflectance microscope allows characterization of the optical properties of samples deposited on single-polished silicon (Si) substrates from 200 nm to 1.7 µm. This instrument is equipped with a x10 objective, and different apertures (50, 100, 250, and 500 µm) that allow conducting measurements on spots as small as 5 µm diameter, hence enabling the characterization of spectral properties of both homogeneous and inhomogeneous samples.

The Fourier-Transform InfraRed (FTIR) spectrometer allows characterization of the spectral properties of samples deposited on different types of substrates (*e.g.*, magnesium fluoride MgF_2, cesium iodide CsI, potassium bromide KBr, double-polished silicon, Si) from 0.6 to 200 µm (17,000–50 cm^{-1}). This wide wavelength range is made possible by the availability of four different detectors [Si (visible, Vis), TEC-InGaAs (near infrared, NIR), DLaTGS-KBr (mid-infrared, MIR), DLaTGS-Polyethylene (far infrared, FIR)] and four different beamsplitters [Quartz (Vis), CaF_2 (NIR), KBr (MIR), Solid Substrate (FIR)]. An automated exchanger allows full spectral coverage without breaking purge. The spectra can be measured with a resolution as low as 0.5 cm^{-1} .

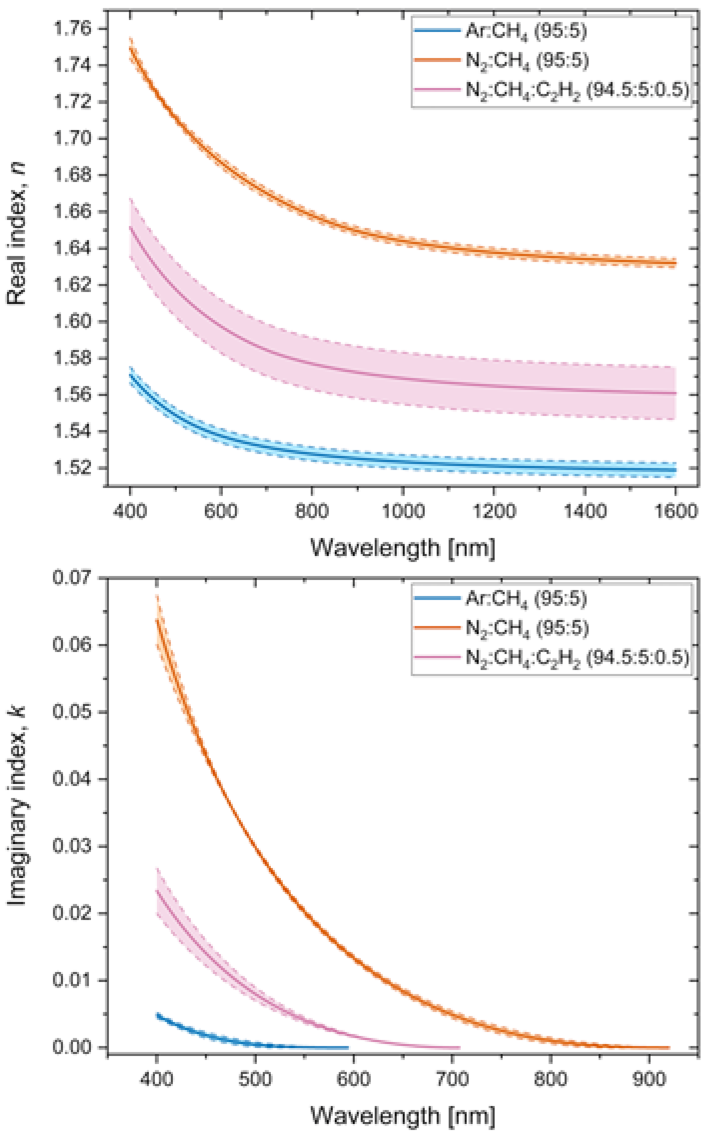


The Variable Angle Transmission Accessory (VATA) and *the SEAGULL variable angle reflectance accessory* can be coupled to the FTIR spectrometer. They allow the characterization of the optical properties of solid samples, over a broad range of incidence and emittance angles, from 0° to 90° for the VATA accessory, and from 5° to 85° for the SEAGULL accessory. The VATA and SEAGULL accessories enable the characterization of the angular light distribution in both transmission and reflection measurements.

Optical constant determination:

Inversion codes using the Cauchy equation, Swanepoel method, and subtractive Kramers–Kronig relations have been developed to determine the thickness and both *n* and *k* indices by fitting interference fringes observed in spectral measurements.

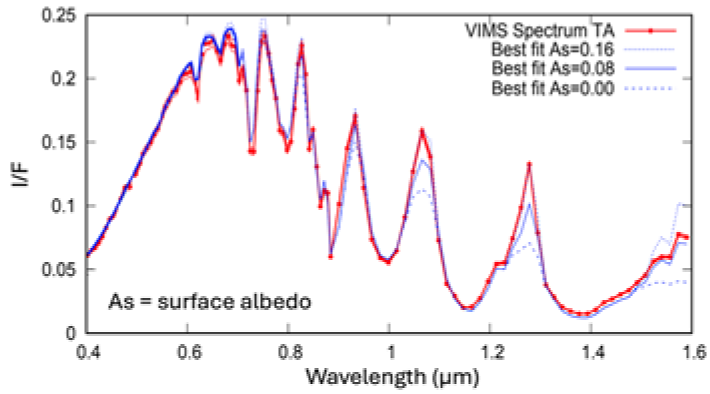
By combining optical constants determined from reflection measurements in the NUV-NIR range and from transmission measurements in the Vis-FIR range, the OCF provides refractive indices of refractory solid samples over a wide wavelength range. Below are examples of optical constants of analogs produced with the COSmIC and deter- mined with OCF:



Optical constants n and k determined for aerosol analogs produced by plasma chemistry in Ar:CH_4, N_2:CH_4 and N_2:CH_4:C_2H_2 gas mixtures (adapted from Sciamma-O'Brien et al. 2023). This comparison shows that higher nitrogen content in the solid samples (from elemental composition determined by Nuevo et al. 2022) results in higher n and k.

Example of Planetary Application – Titan:

The optical constants of COSmIC N_2:CH_4 aerosol analogs shown above were used in a radiative transfer model to interpret *Cassini* VIMS (Visible and Infrared Mapping Spectrometer) observations of Titan (T-79 flyby).



Radiance factor observed with VIMS between 0.4 and 1.6 µm during the T-79 flyby (in red) compared to best fits calculated with optical constants determined for Titan aerosol analogs produced with the COSmIC facility, considering different surface albedos A_s (adapted from Sciamma-O'Brien et al. 2023).

The analysis of *Cassini* VIMS observations showed that aerosol analogs, which contain more nitrogen and are more absorbing, have a spectral behavior that is more representative of Titan's aerosols.

Optical Constants database (OCdb):

The NASA Ames Optical Constants database (OCdb) was launched in January 2023. It is a data repository developed to provide published, peer- reviewed optical constants of organic refractory materials and ices relevant to (exo)planetary and astrophysical environments.

Optical Constants db

The goal of OCdb is to centralize published optical constants data to facilitate both their access by the scientific community and the analysis and inter- pretation of observational data returned by ground- and space-based telescopes and space missions. Laboratories generating optical constants are encouraged to contribute their data in order to increase their visibility and availability.

For now, the Optical Constants database provides data sets for ice samples (pure and mixtures), and organic refractory materials produced from irra- diation of ice samples (also called "ice tholins" or "ice residues") or gas precursors (also called "gas tholins"). We plan to expand the types of materials in the future.

Matrix Isolation/Optical Constants of Ices at NASA Ames

Joseph Roser (joseph.e.roser@nasa.gov)

https://www.nasa.gov/space-science-and-astrobiology-at-ames/research-teams/all-research-teams/matrix-isolation-optical-constants-of-ices-laboratory/

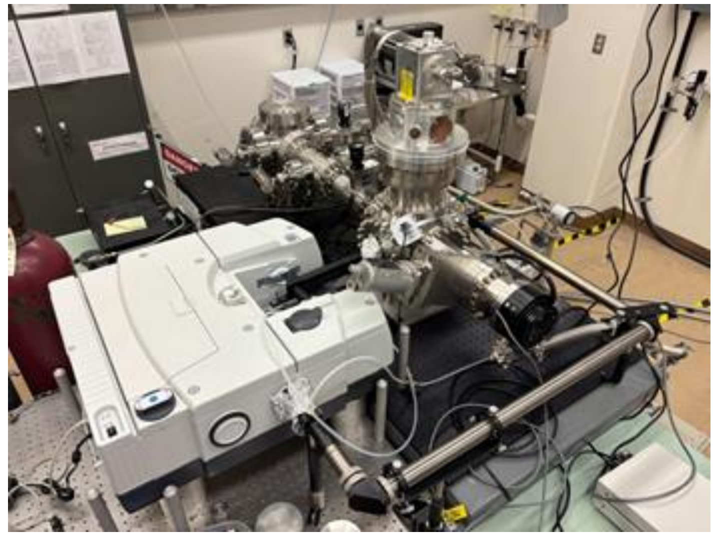
The Matrix Isolation/Optical Constants of Ices (MIOCI) vacuum system supports the infrared transmittance spectroscopy of ices with vacuum deposition in a high vacuum (1e-8 torr) environment and at deposition temperatures as low as 5 Kelvin.

The original MIOCI vacuum system was designed to investigate carbonaceous molecules that may be present in the interstellar medium, and in particular, the class of molecules known as polycyclic aromatic hydrocarbons or PAHs. These molecules have long been theorized to be present in the interstellar medium as the emitters of well-known infrared emission bands seen in numerous interstellar environments. With the MIOCI system, the infrared absorption spectra of isolated PAH molecules can be measured by co-depositing the PAH species of interest with argon ice. The argon matrix (thus “matrix isolation spectroscopy”) serves as a relatively non-perturbing medium for producing a solid-state infrared transmittance measurement that resembles a gas-phase measurement.

If the PAH molecules are not completely isolated from one another within the argon matrix, their mutual interactions could appear in the transmission spectra. This observation led to a series of publications investigating small molecular aggregates of PAH molecules (or “clusters”) in the infrared by repeating the matrix isolation experiments and identifying changes in the spectra as the PAH/argon ratio increases.

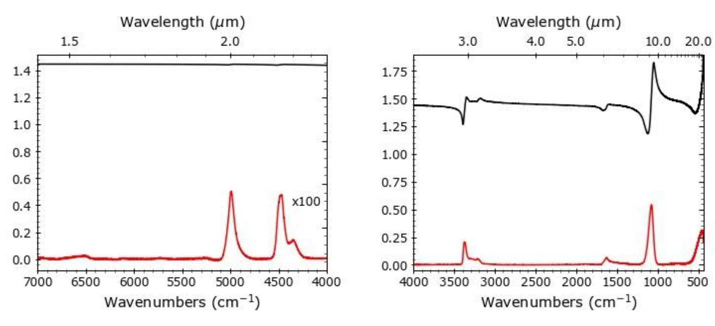
The transmission spectra measured by MIOCI can also be used to calculate the complex index of refraction (also known as “optical constants”) of cryogenic ices in the mid-infrared. The Kramers-Kronig relation provides a relation linking the real and imaginary parts of the complex index of refraction. This allows both quantities to be determined using a single transmission measurement. This led to a publication describing the complex index of refraction of ammonia ice deposited at 40 K, a temperature representative of the temperatures of icy outer Solar System bodies such as Pluto.

Surface ammonia ice detections on these bodies are particularly interesting since the ammonia ice could be rapidly destroyed by radiation exposure.



Surface ammonia ice can therefore be indicative of cryovolcanism occurring within these outer Solar System bodies.

The MIOCI system is nearing completion of a system redesign that added a new capability for molecular beam deposition to the experiments that can be performed. In this new system, a microwave discharge source will produce a beam of molecular fragments that can be co-deposited along with other ices onto the cryogenic substrate window. This will allow low-energy chemical reactions of the deposited ices to be studied without the need for energetic processing to drive the experiments.



The mid-infrared real index of refraction (black) and complex index of refraction (red) of ammonia ice vacuum deposited at 40 K. Data used to create this graph is available under the Creative Commons Attribution 4.0 license from Roser, J., Ricca, A., Cartwright, R. J., Dalle Ore, C. & Cruikshank, D. P. 2021, “The Infrared imaginary Refractive Index of Amorphous Ammonia Ice at 40 K (1.43–22.73 μm) and Its Relevance to Outer Solar System Bodies,” Planet. Sci. Journal, 2, 240, DOI 10.3847/PSJ/ac3336. (https://creativecommons.org/licenses/by/4.0)

Recent Publications

January–August 2025

Formation of hydrogen trioxide (HOOOH) in extraterrestrial ice analogs and its role as an oxidizer in prebiotic chemistry
Bai, X., Li, C., Luo, Y., et al.
Science Advances, **11**, eadw5720 (2025)
https://doi.org/10.1126/sciadv.adw5720

X-ray induced photochemistry of hydrocarbons: Implications for the formation of organic haze in (exo)planetary atmospheres
Bejaoui, S., Dubois, D., Nemsak, S., Salama, F.
The Planetary Science Journal, **6**, 203 (2025)
https://doi.org/10.3847/PSJ/adf4d3

Gas and aqueous phase computations on the keto-enol tautomerization of pyruvic and zymonic acids: Implications for prebiotic enol phosphates
Bera, P. P., Wilson, M., Pohorille, A., et al.
The Journal of Physical Chemistry A, **129**, 7287 (2025)
https://doi.org/10.1021/acs.jpca.5c01351

Oxygen isotopic heterogeneities in refractory inclusions in the ungrouped carbonaceous chondrite Acfer 094
Fagan, T. J., Kobayashi, S., Krot, A. N., Yurimoto, H.
Meteoritics & Planetary Science, **60**, 1734 (2025)
https://doi.org/10.1111/maps.70003

Na,Ca carbonates in OSIRIS-REx samples: Evidence for low-temperature, Na-bearing brines on Bennu's parent body
Singerling, S.A., Brenker, F.E., Tkalcec, B., et al.
Geochimica et Cosmochimica Acta, **404**, 86 (2025)
https://doi.org/10.1016/j.gca.2025.06.028

Laboratory infrared spectra and band strengths of carbonyl sulfide (OCS) in CH_3OH- and CO-rich ice mixtures for analyzing interstellar ice observations
Slavicinska, K., Coone, C., Benz, B., et al.
ACS Earth and Space Chemistry, **9**, 2148 (2025)
https://doi.org/10.1021/acsearthspacechem.5c00134

Physicochemical properties of α-pinene in water ice analogs under energetic heavy-ion irradiation
de Barros, A. L. F., Doreste, D. V., Ricca, A., et al.
ACS Earth and Space Chemistry, **9**, 2180 (2025)
https://doi.org/10.1021/acsearthspacechem.5c00152

Formation of lactic acid ($CH_3CH(OH)COOH$), a metabolic keystone for the molecular origins of life, in interstellar ice analogues
Wang, J., Zhang, C., Bergantini, A., et al.
Journal of the American Chemical Society, **147**, 29088 (2025)
https://doi.org/10.1021/jacs.5c07637

Photochemical haze formation on Titan and Uranus: A comparative review
David Dubois
International Journal of Molecular Sciences, **26**, 7531 (2025)
https://doi.org/10.3390/ijms26157531

Vacuum ultraviolet photoabsorption spectroscopy of space-related ices: Formation of (cyano)polyynes in 1 keV electron irradiated hydrocarbon-rich ices
Kaňuchová, Z., Borchert, L. E., Mifsud, D. V., et al.
Astronomy & Astrophysics, **700**, A115 (2025)
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Richards, G., Richárd Rácz, R., Kovács, S. T. S., et al.
Planetary and Space Science, **266**, 106179 (2025)
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Muñoz Caro, G. M., Carrascosa de Lucas, H., Martín-Doménech, R.
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Experimental constraints on the shock history of CI chondrites and Ryugu grains
Nakahashi, T., Miyahara, M., Yamaguchi, A., et al.
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Solar System’s earliest solids as tracers of the accretion region of Ryugu and Ivuna-type carbonaceous chondrites
Kawasaki, N., Arakawa, S., Miyamoto, Y., et al.
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Cryogenic differential calorimetry: Exothermicity of amorphous-to-crystalline phase transitions (ACPT) in astrophysical and cometary ice analogs
Kushwaha, R. K., Gudipati, M. S., Henderson, B. L.
The Astrophysical Journal, **987**, 190 (2025)
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Experimental and theoretical porosity determination for ices of astrophysical interest: CH_4, C_2H_4, C_2H_6, CH_3OH, N_2, NH_3, CO, and CO_2
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Quirico, E., Yabuta, H., Beck, P., et al.
Geochimica et Cosmochimica Acta, **402**, 316 (2025).
https://doi.org/10.1016/j.gca.2025.05.046

Interstellar water ice analogue properties as a function of temperature: Updated density, porosity, and infrared band strength
Escribano, B., del Burgo Olivares, C., Carrascosa, H., et al.
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Missing interstellar sulfur in inventories of polysulfanes and molecular octasulfur crowns
Herath, A., McAnally, M., Turner, A. M., et al.
Nature Communications, **16**, 5571 (2025)
https://doi.org/10.1038/s41467-025-61259-2

Synthesis of new hexamethylenetetramine-based products (HMT-R) in UV-irradiated pre-cometary ice analogues
del Burgo Olivares, C., Carrascosa, H., Muñoz Caro, G. M., et al.
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H_2S ice sublimation dynamics: Experimentally constrained binding energies, entrapment efficiencies, and snowlines
Santos, J.C., Piacentino, E. L., Bergner, J. B., et al.
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Wilkins, O. H., Yocum, K. M., Esposito, V. J., et al.
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Exploring the formation and alteration of organics in ice: experimental insights for astrochemistry and space missions
Hofmann, F., Asanova, N., Urso, R. G., Elsaesser, A.
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Taillard, A., Martín-Doménech, R., Carrascosa, H., et al.
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Gonçalves, D., Hofmann, F., Drauschke, J., et al.
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VIS-to-MIR reflectance and Raman spectroscopy of the CM2 NWA 12184 carbonaceous chondrite
Galiano, A., Dirri, F., Ferrari, M., et al.
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Characterization of H_2O:N_2 ice under bombardment by cosmic rays – I. Reaction rates and chemical equilibrium
Queiroz, L. M. S. V., Silva, J. R. C., Ferrão, L. F. A., Pilling, S.
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Rojas, J., Duprat, J., Dartois, E., et al.
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Jiménez-Escobar, A., Ciaravella, A., Mangione, A., et al.
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Photochemistry of benzene (C_6H_6) hydrogen cyanide (HCN) co-condensed ices part 2: Formation of aerosols analogues of Titan's atmosphere
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Icarus, **438**, 116626 (2025)
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Mid-infrared detection and characterization of refractory inclusions in CM and CO chondrites: A non-destructive approach for returned space samples
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Le Pivert-Jolivet, T., Brunetto, R., Pilorget, C., et al.
Astronomy & Astrophysics, **695**, A168 (2025)
https://doi.org/10.1051/0004-6361/202453270

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Dionnet, Z., Djouadi, Z., Delaye, L., et al.
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Irradiation origin and stability of CO on trans-Neptunian objects: Laboratory constraints and observational evidence from JWST/DiSCo-TNOs
Hénault, E., Brunetto, R., Pinilla-Alonso, N., et al.
Astronomy & Astrophysics, **694**, A126 (2025)
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Molecular evolution of H_2O:O_2 ices at different temperatures in simulated space environments. I. Chemical kinetics and equilibrium
Silva, J. R. C., Queiroz, L. M. S. V., Ferrão, L. F. A., Pilling, S.
The Astrophysical Journal, **985 (2)**, 254 (2025)
https://doi.org/10.3847/1538-4357/adc924

Tholin formation and accumulation due to hypersonic high-temperature flows in methane-containing atmospheres
Lappa, M., Esposito, A., Russo, C., Apicella, B.
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Community Announcements

List of Upcoming Conferences:

European Planetary Science Congress (EPSC)/Division of Planetary Science (DPS) Joint Meeting
7–12 September 2025,
Helsinki, Finland
https://www.epsc-dps2025.eu/
Abstract submission deadline: Closed
Registration deadline: 7 September 2025

Titan Cassini-Huygens workshop
16–18 September 2025
Paris, France
https://huygens20.sciencesconf.org/resource/page/id/3

IR spectroscopy from Space
6–8 October 2025,
Pasadena, CA, USA
https://www.ipac.caltech.edu/event/infrared-spectroscopy-from-space
Abstract submission deadline: 1 July 2025
Registration deadline: 1 August 2025

Planetary Science Conference 2025
October 23–25, 2025
Krakow, Poland
https://mars.uj.edu.pl/index.php/planetary-science-conference/planetary-science-conference-2025/
Registration deadline: 6 October 2025 (no fee, but registration is required)

COSPAR Symposium
3–7 November 2025,
Nicosia, Cyprus
https://cosparhq.cnes.fr/next-cospar-symposium/

American Geophysical Union (AGU) Fall meeting
15–19 December 2025,
New Orleans, LA, USA
https://www.agu.org/annual-meeting
Abstract submission deadline: 30 July 2025
Registration deadline: (early bird) Early November 2025, (regular) 15 December 2025

Astrochemistry: From Quantum to Cosmos
21–24 October 2025,
Radboud University, The Netherlands.
https://indico.imapp.ru.nl/event/330/overview
Abstract submission deadline: 31 August 2025
Registration deadline: 15 August 2025

Pacifichem
15–20 December 2025,
Honolulu, HI, USA
https://pacifichem.org/
Abstract submission deadline: Closed
Registration deadline: (early bird) 12 October 2025, (regular) 20 December 2025

Astrochemistry in the Broadband Era: ngVLA & ALMA WSU
20–24 October, 2025
Portland, ME, USA
https://aas.org/events/2025-03/astrochemistry-broadband-era-ngvla-alma-wsu-2025
Abstract submission deadline: Closed
Registration deadline: (early bird) 12 October 2025, (regular) 20 December 2025

American Physical Society (APS) Global Physics Summit
Symposium: Chemical Physics in Astrophysical Environments
15–20 March 2026
Denver, CO, USA
https://www.aps.org/about/partner/global-physics-summit-2026

American Chemical Society (ACS) Spring Meeting
Astrochemistry Subdivision Symposium: “The Icy Universe Revealed by JWST”
22–26 March 2026
Atlanta, GA, USA
http://astro.phys-acs.org/symposia/Spring2026.html

Astrobiobiology Science Conference (AbSciCon)
17–22 May 2026
Madison, WI, USA

COSPAR General Assembly
1–9 August 2026
Florence, Italy
https://cosparhq.cnes.fr/next-cospar-scientific-assembly/