Czech Academy of Sciences

J. Heyrovský Institute of Physical Chemistry

ZÁMEK DĚČÍN

The Booklet

J. Heyrovský Institute Opens the Gateway to the Universe

Děčín Castle - May 21, 2024

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Welcome to the "J. Heyrovský Institute Opens..."— the leading motto for a series of events organized by our institute. These events are designed to showcase the applications of our research, facilitate meetings with our industrial and academic partners, and foster new partnerships and collaborations. Within “J. Heyrovský Institute Opens...,” we have previously shared exciting research outcomes in areas such as energy deposition, renewable resources, and novel technologies for chemical catalysis.

Founded in 1952 as part of the Czechoslovak Academy of Sciences (ČSAV), our institute boasts a longstanding tradition in physical chemistry. Today, we stand as a modern institution with 72 years of tradition and are recognized as a flagship research center within the Czech Academy of Sciences. Our research has expanded into new scientific areas, including the development of nanomaterials, electrochemical and spectrometric detection technologies, biophysical research, and an increasingly prominent segment of space research. We are actively involved in both European and national space projects, serving as collaborators or even principal leaders, while closely integrating fundamental science with engineering development.

We eagerly anticipate launching and receiving data from the Ariel space telescope, which will explore thousands of exoplanets; the EnVision mission to Venus; and the upcoming VZLUSAT3 and Space Rider missions. These ventures into space technology have inspired us to organize this year’s conference on Space Technologies at the J. Heyrovský Institute, demonstrating how chemists are opening the gateway to the Universe.

Martin Hof, the director of the institute

We are living at the dawn of an era featuring unprecedented opportunities for science and technology to collaborate in space exploration, investigating almost any target in the universe with a broad range of in situ and ex situ tools. Our institute proudly continues the exceptional legacy of Czech Nobel Prize laureate Jaroslav Heyrovský, who developed the unique method of polarography, one of cornerstones of chemical analysis in the 20th century. Today, space science and technology are one of leading scientific fields, much like advanced instrumental analysis was in Heyrovský's time. The expanding base of knowledge about the chemistry and physics of celestial bodies, as well as interplanetary and interstellar space, demands multidisciplinary engagement from specialists across all the fields of science and technology. Among them, physical chemistry and chemical physics hold a firm position. Contemporary space exploration must be supported by laboratory science, experiments under well-controlled conditions, theoretical computations, and the development of advanced instruments and technologies. Our institute actively contributes across all these areas, with the application of physical chemistry serving as the common denominator. The main strategy of our institute is not focused on quantity but on the development of unique instruments, technologies, scientific approaches, and concepts, as well as fostering broad and open collaboration within the field of space engineering and sciences.

It is precisely our collaboration, networking, and expression of gratitude to our partners that have brought us to this historic location — the Děčín Castle. Perched atop a cliff-like rock and rising above the Elbe River in countryside bordering the Central Bohemia Uplands and Bohemian-Saxon Switzerland, it offers breathtaking views of the Elbe Sandstone Valley.

Enjoy today's event. The people you will meet here are not only great personalities but also our closest collaborators. Perhaps a discussion over coffee, a glass of wine, or a beer will spark new ideas and further collaborations. If this gathering turns out to be more than just a social event and fosters deeper connections and ideas, then it has truly served a greater purpose. And if not, simply...

...enjoy the experience!

Martin Ferus, Ján Žabka, Klára Kozlíková, Miroslava Poskočilová and Miroslava Macháčková
on behalf of the organizers

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Editor: Martin Ferus

Contributors: Michal Fárník, Juraj Fedor, Martin Ferus, Kateřina Němečková, Michaela Malečková, Anatolii Spesyvyi, Ján Žabka.

Graphics: David Černý, Marcela Mozolová, J. Heyrovský Institute of Physical Chemistry.

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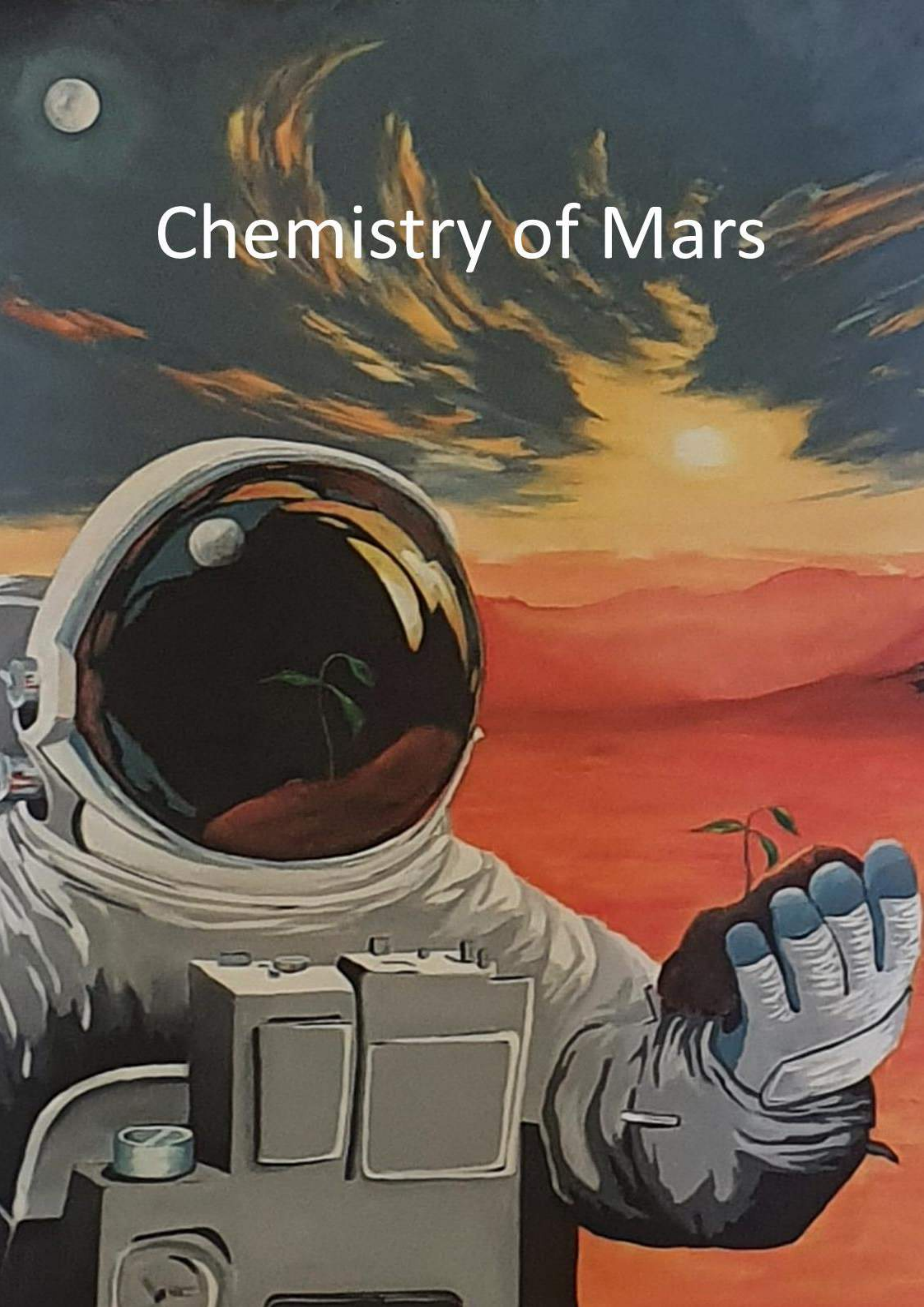
Chemistry of Mars



Chemistry of Mars

...a story about ions, lasers, and artificial photosynthesis.

Exploration of Martian atmosphere and surface chemistry contributes significantly to our broader understanding of planetary sciences, including the mineralogical and rock compositions, chemical evolution, and the potential for ancient origins of life on the Red Planet. These topics drive scientific research at our institute.

Recent investigations have demonstrated that novel surface reactions involving acidic minerals and rocks can produce methane through the photochemical reduction of carbon dioxide, the primary atmospheric constituent, to methane — a trace gas discovered in the Martian atmosphere and discussed as a potential biosignature. Does this abiotic "photosynthesis" mean that there is no life on Mars? Nobody knows, but caution is warranted when interpreting simple molecules as signs of life on other worlds. This chemistry also leads to the synthesis of perchlorates, chlorates, and methyl chlorides, providing a comprehensive chemical network that explains the presence of these compounds on Mars and suggests that the salty, chemically aggressive surface could be very hostile to life.

Another research focus is the exploration of ion-molecule reactions in the Martian ionosphere. Our experimental studies have provided critical density and kinetic data on the principal chemical processes and constituents in the Martian ionosphere, such as the reaction of oxygen anions with carbon dioxide to form carbonate anions. Understanding these reactions at various temperatures helps refine our models of the Martian atmosphere and predict ion behavior under different Martian conditions.

Future research and development at our institute also focuses on the construction of analytical devices for Mars rovers and landers. Here, the critical step involves constructing a miniaturized Orbitrap system coupled with Laser-Induced Breakdown Spectroscopy (LIBS). Such a rover would provide detailed data on Martian rocks, minerals, trace elements, isotopic compositions, as well as the molecular and organic milieu.

Relevant project:
CZ.02.1.01/0.0/0.0/16_019/0000778 Center of Advanced Applied Sciences, in multilateral collaboration, the prime was Faculty of Nuclear Research and Engineering of the Czech Technical University in Prague (MEYS - ESF).

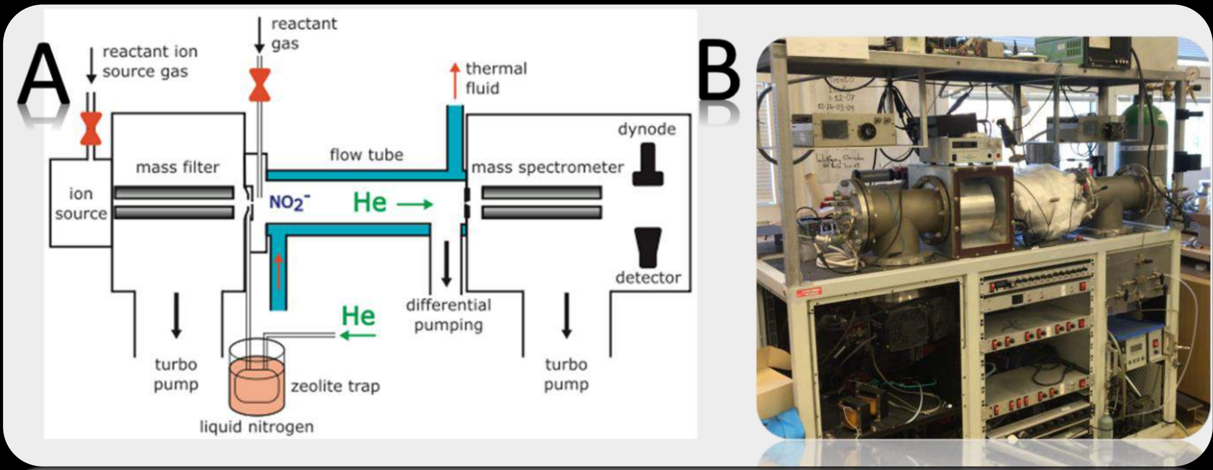
Selected papers for further reading:

The origin of methane and biomolecules from a CO_2 cycle on terrestrial planets: S. Civiš, A. Knížek, O. Ivanek, P. Kubelík, M. Zukalová, L. Kavan, M. Ferus, Nature Astronomy, 1, 721-726, 2017.

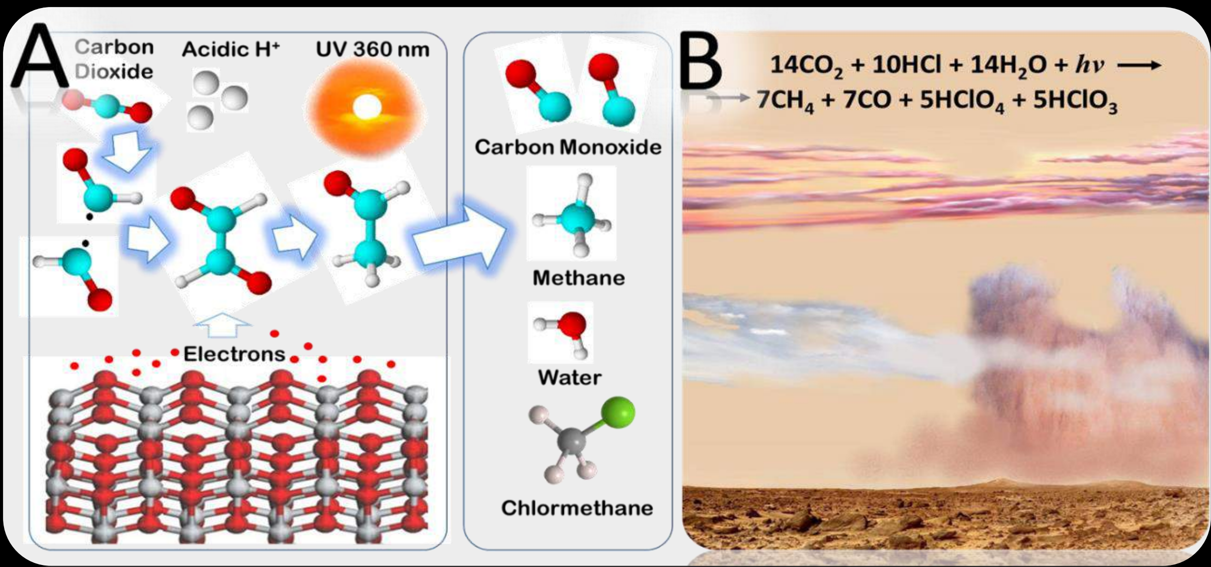
Formation of Methane and (Per)Chlorates on Mars: S. Civiš, A. Knížek, P. B. Rimmer, M. Ferus, P. Kubelík, M. Zukalová, L. Kavan, E. Chatzitheodoridis, ACS Earth Space Chem., 3, 2, 221-232, 2019.

Prediction of a CO_2^{++} layer in the atmosphere of Mars: O. Witasse, O. Dutuit, J. Lilensten, R. Thissen, J. Zabka, C. Alcaraz, P. L. Blelly, S. W. Bougher, S. Engel, L. H. Andersen, K. Seiersen, Geophysical Research Letters, 29, 104-1-104-4, 2002.

Experimental study of the reaction of NO_2^- ions with CO_2 molecules at temperatures and energies relevant to the Martian atmosphere: I. Zymak, J. Žabka, M. Polášek, P. Španěl, D. Smith, Icarus, 335, 113416, 2020.

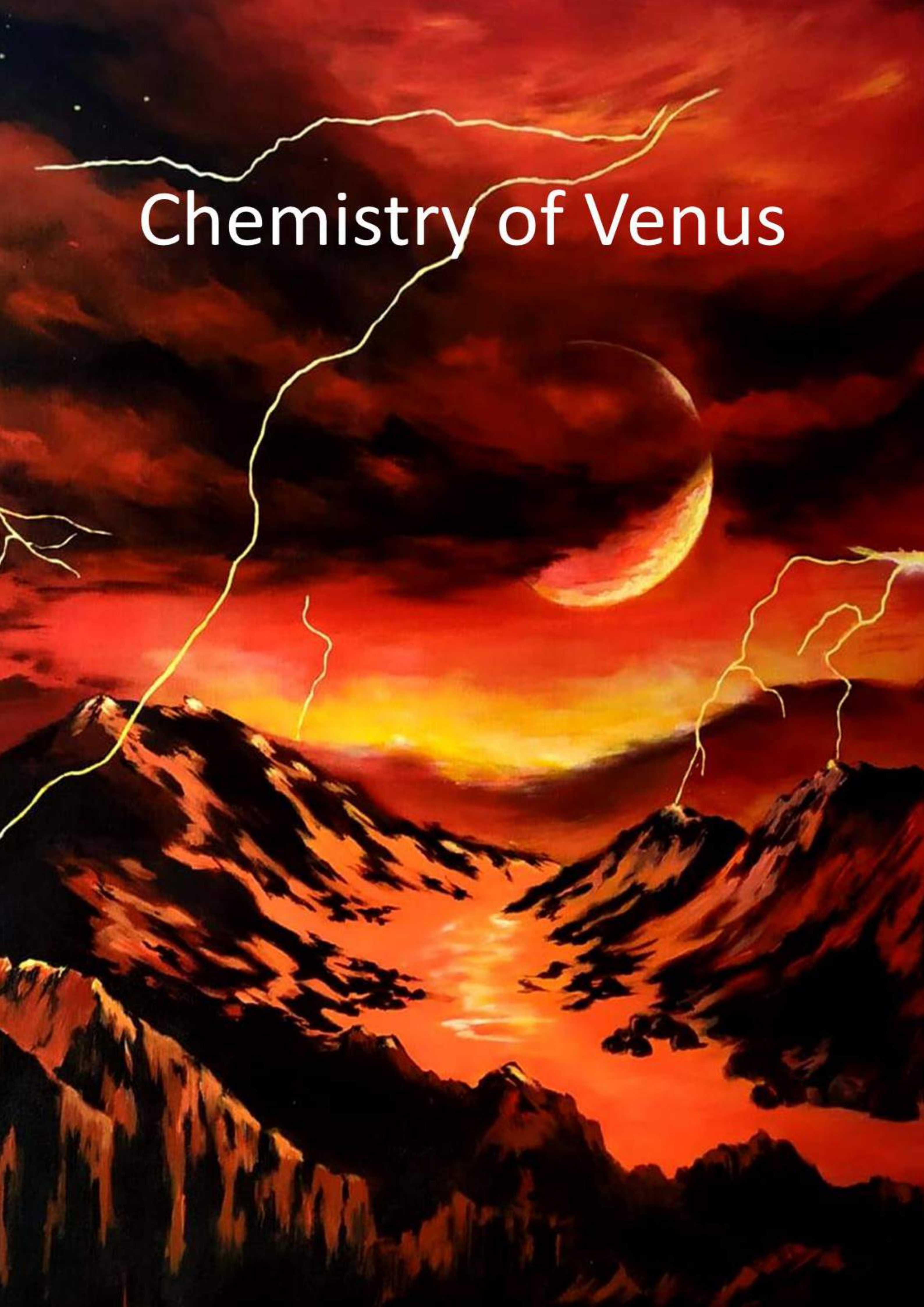


Ionosphere of Mars in a Steel Chamber: Laboratory astrochemistry focuses on constructing precise instruments capable of simulating selected processes under well-controlled laboratory conditions. The experience of physical chemists is crucial in this field. Panel A depicts the system that directs ions into a flow tube, where they undergo reactions. The reactants and products are precisely detected by a mass spectrometer. Panel B illustrates how scientists at the J. Heyrovský Institute recreate the ionosphere of Mars in a steel "test tube."



Artificial 'Photosynthesis' on a Hostile World? The synthesis of methane using materials with semiconductor or photocatalytic properties has been studied since the 1980s as a promising industrial process for a Closed Carbon Cycle Economy. Panel A schematically depicts the spontaneous process discovered and explored in our laboratories. It occurs on the acidic surfaces of titania, clays, and even Martian meteorites. Panel B presents a landscape of Mars and a summary equation that illustrates the production of methane along with the perchlorate salts confirmed on the Martian surface.

Chemistry of Venus



Chemistry of Venus

…Czechia returns to the hellish planet.

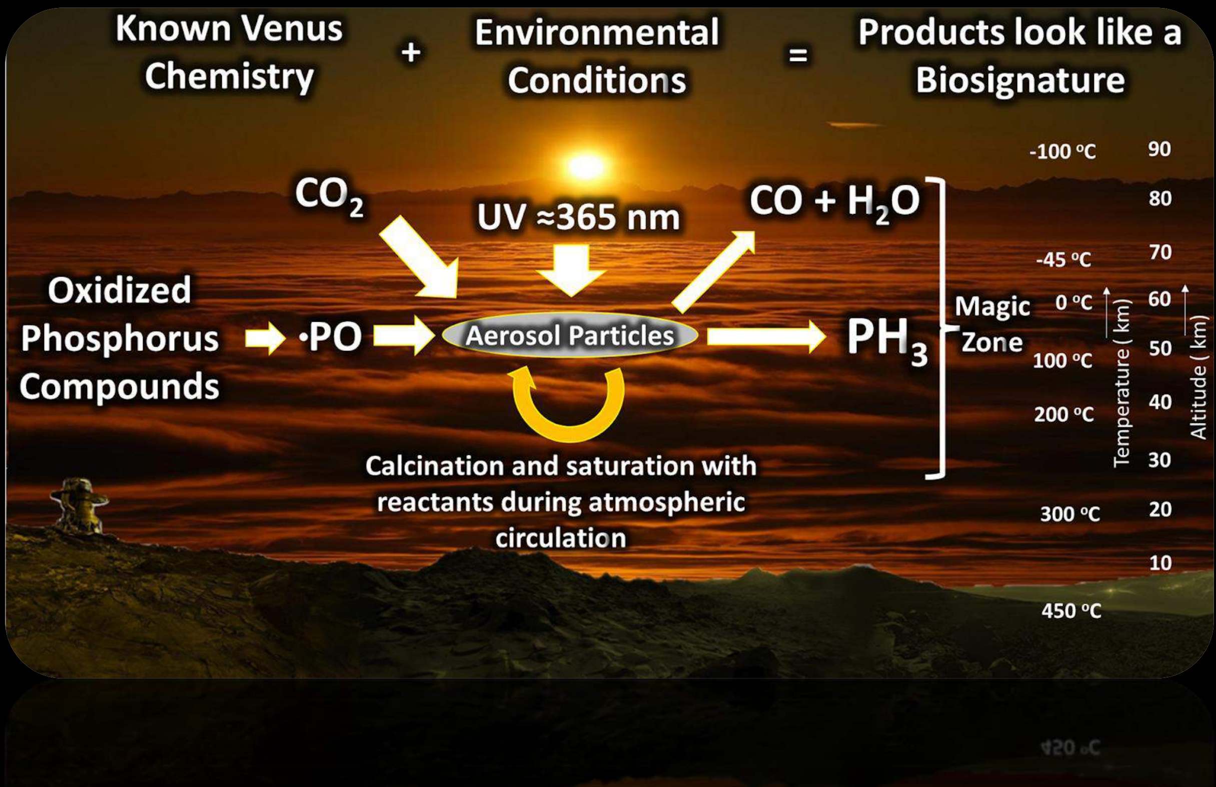
In the 1980s, Czechoslovakia developed a stabilized instrument platform for Soviet Vega probes, enabling the exploration of the so-called hellish planet through balloon flights. Today, scientists and technicians from our institute are actively involved in preparing the European EnVision probe, equipped with optical, spectral, and radar instruments to map the surface and atmosphere of Venus. Czech scientists will play a significant role in this endeavor, particularly in testing and assembling the electronic "heart" of the instrument – the complete control electronics for the trio of spectrometers, especially for the VenSpec-H instrument aboard the EnVision probe. This encompasses the complete development of various electronic boards and interconnecting harnesses, essential for the mission's operation. Our responsibilities extend to creating and managing datasets for testing these components, ensuring they meet the required specifications for data quality and flow. The development phases involve rigorous testing and validation processes, where both experimental and simulated spectral libraries play a vital role in calibrating the instrument's accuracy and efficiency.

A recent study from our team has uncovered a new fully abiotic mechanism of phosphine (PH_3) synthesis over acidic dust in the Venusian atmosphere. This discovery holds significance as phosphine has been considered a potential biosignature on rocky planets with oxidized atmospheres, such as Venus. The novel photochemical pathway involves radical reactions initiated by ultraviolet radiation illuminating the upper atmosphere. This groundbreaking work not only advances our understanding of Venus's atmospheric chemistry but also contributes to broader astrobiological studies by proposing mechanisms for biosignatures like phosphine, ammonia, or methane formation in the atmospheres of alien planets.

Relevant project:
24-12656K Redox Disequilibrium in the Clouds of Venus: A Sign of Life? in collaboration with IWF Graz (GAČR, FWF); Prodex PEA 4000143801 - EnVision VenSpec-H Electronics, in collaboration with Geophysical Institute CAS and Czech Geological Survey (MEYS, MTCR, ESA).

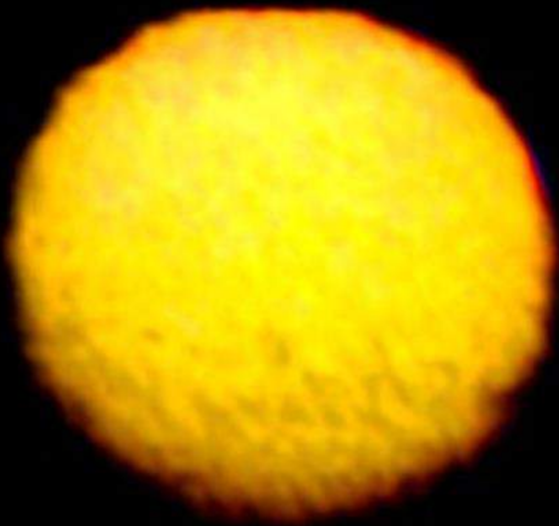
Selected paper for further reading:

A Novel Abiotic Pathway for Phosphine Synthesis over Acidic Dust in Venus' Atmosphere: K. Mráziková, A. Knížek, H. Saeidfirozeh, L. Petera, S. Civiš, F. Saija, G. Cassone, P. B. Rimmer, M. Ferus, Astrobiology, 24(4), 407-422, 2024.



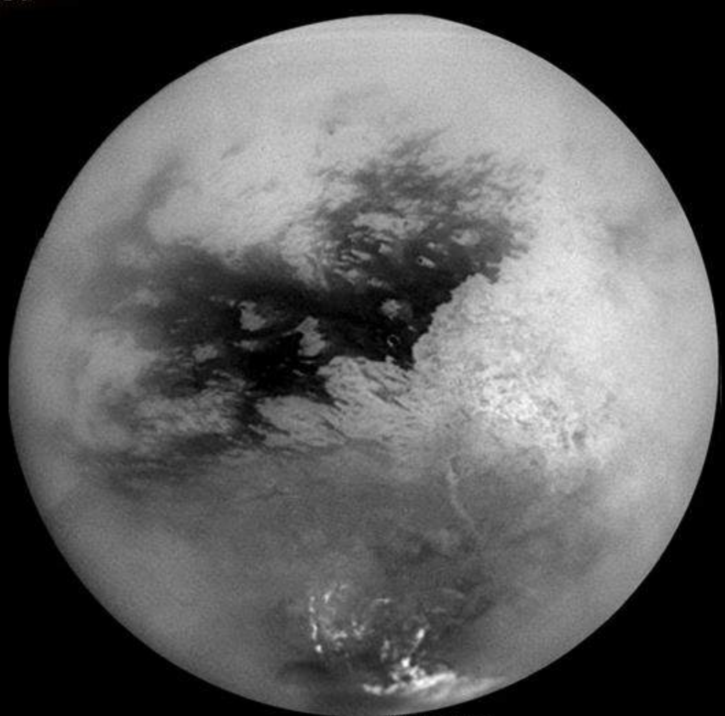
Does an Aerial Biosphere Exist in Venus's Clouds? Tentative evidence for the occurrence of hydrides such as phosphine, as well as indications of ammonia and methane in Venus's atmosphere, are considered potential signatures of life or unknown chemical processes in the atmosphere. Despite much controversy surrounding the detection itself, the unknown chemistry, or even the existence of life "as we don't know it" at altitudes of 50 - 60 km—where Earth-like physical conditions exist (ambient temperature and pressure), many scientists have focused their efforts on solving this enigma from various perspectives. Our team recently published a theoretical study, supported by previous experimental evidence, on the photochemical synthesis of methane from CO_2 over acidic minerals. We predict that phosphine can be synthesized from PO· radicals over acidic dust under conditions common in Venus's atmosphere. This chemical step was previously identified as the bottleneck reaction, explaining the fully abiotic origin of phosphine in Venus's atmosphere. Our study has offered a solution, although final experimental evidence and detailed investigation of the problem are now being explored in a joint project with IWF Graz, in collaboration with the University of Cambridge and IPCF Messina.

Titan



Pioneer 11, 1979

Voyager, 1981



Cassini, 2004

Chemistry of Titan

...towards understanding the chemistry of primordial Earth.

Our investigation into the chemistry of Titan has illuminated profound insights into the intricate processes within the atmospheres and ionospheres of Saturn's largest moon. Often dubbed the "Earth-like" moon due to its presumed resemblance to the complex organic chemistry of primordial Earth before the emergence of life, Titan serves as a compelling analog for understanding our planet's early chemical evolution.

Employing both theoretical models and experimental analyses, we have delved into diverse reaction pathways and mechanisms underlying the formation of large anions in Titan's ionosphere. Despite the formidable challenges posed by frigid environments, our investigations have furnished invaluable data on reactions involving molecules such as acetylene and cyanide, illuminating the enigmatic chemistry of these celestial bodies.

Moreover, our endeavors have extended to crafting robust theoretical frameworks for forecasting chemical kinetics in Titan's ionosphere. Leveraging innovative methodologies like the Variable Temperature Selected Ions Flow Tube, we've scrutinized ion-molecule reactions at temperatures pertinent to Titan's atmosphere. These endeavors have not only corroborated prior findings but have also unearthed fresh insights into reaction rates and product formation, enriching our comprehension of the chemical dynamics in Titan's intricate milieu.

Our comprehensive review of production processes and reactions relevant to Titan's atmosphere has furnished a panoramic vista of active nitrogen species and their interactions with diverse molecules. By scrutinizing reactions involving nitrogen species and hydrocarbons, we've pinpointed pivotal pathways contributing to the genesis of N-bearing hydrocarbons, further elucidating the chemistry of Titan's atmosphere.

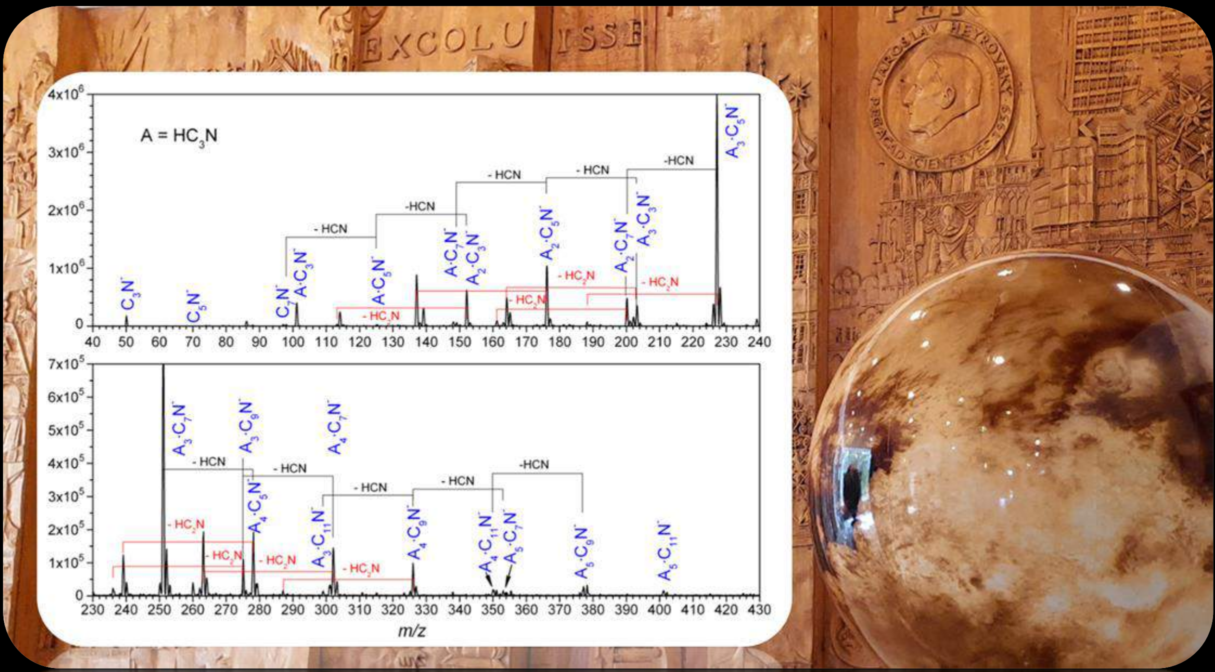
In sum, our research epitomizes a concerted endeavor to unravel the enigmas of Titan by probing their distinctive chemistry. Through interdisciplinary collaboration and innovative methodologies, we persist in forging substantial advancements in our understanding of these captivating celestial bodies and their potential for nurturing life.

Relevant project:
17-14200S Experimental and theoretical study of the chemical processes in the planetary atmospheres (GAČR)

Selected papers for further reading:

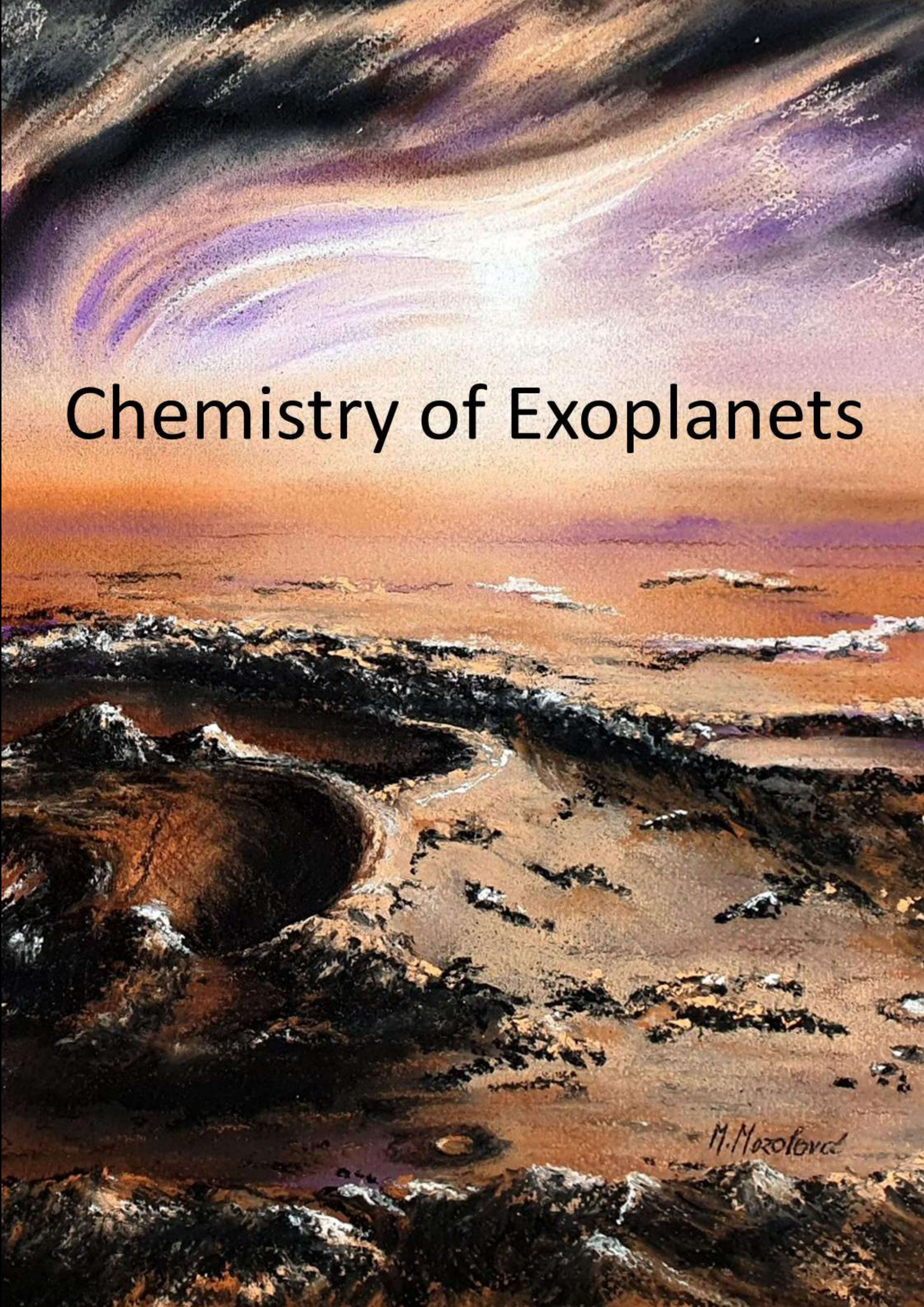
Anion chemistry on Titan: A possible route to large N-bearing hydrocarbons: J. Žabka, C. Romanzin, C. Alcaraz, M. Polášek, Icarus, 219(1), 161-167, 2012

A Pilot Study of Ion - Molecule Reactions at Temperatures Relevant to the Atmosphere of Titan: I. Zymak, J. Žabka, M. Polášek, P. Španěl, D. Smith, Orig Life Evol Biosph, 46(4), 533-538, 2016



I know your weight; is that enough? Physical chemists from our institute have focused their efforts on data returned by the Huygens descent probe during its landing on Titan. In fact, it is not so easy to associate a series of masses detected by the onboard mass spectrometer with particular molecules due to the low resolution of the instrument. The results will therefore remain a mystery until a new mission equipped with better analyzers is launched.

Chemistry of Exoplanets



Chemistry of Exoplanets

...are we like frogs in a pond?

Our research endeavors in the field of exoplanets represent a pioneering effort to unravel the mysteries of worlds beyond our solar system. By leveraging advanced technological tools and innovative methodologies, we are at the forefront of exploring the existence of planets orbiting distant stars and characterizing their diverse environments. Through initiatives such as the Ariel mission, we are poised to make groundbreaking strides in systematically measuring the chemical composition and thermal properties of exoplanet atmospheres, offering invaluable insights into their atmospheric dynamics and potential habitability.

Currently, representatives from our institute serve as Co-Principal Investigators of the Ariel space telescope mission and coordinate the manufacturing of secondary mirrors for the telescope taking place in Toptec center of the Institute of Plasma Physics.

Additionally, our investigations into the chemical consequences of impacts on young planets provide crucial insights into the formation and evolution of planetary atmospheres, shedding light on the conditions conducive to the emergence of life. This research is performed utilizing high-power laser facilities such as PALS and HiLASE, which are among the most powerful laser sources in the world.

Our focus on experimental laboratory measurement, analysis, and assignment of infrared emission spectra of astrophysically relevant molecular radicals also equips us with essential tools for deciphering the composition of exoplanetary atmospheres and advancing our understanding of their complex chemistry.

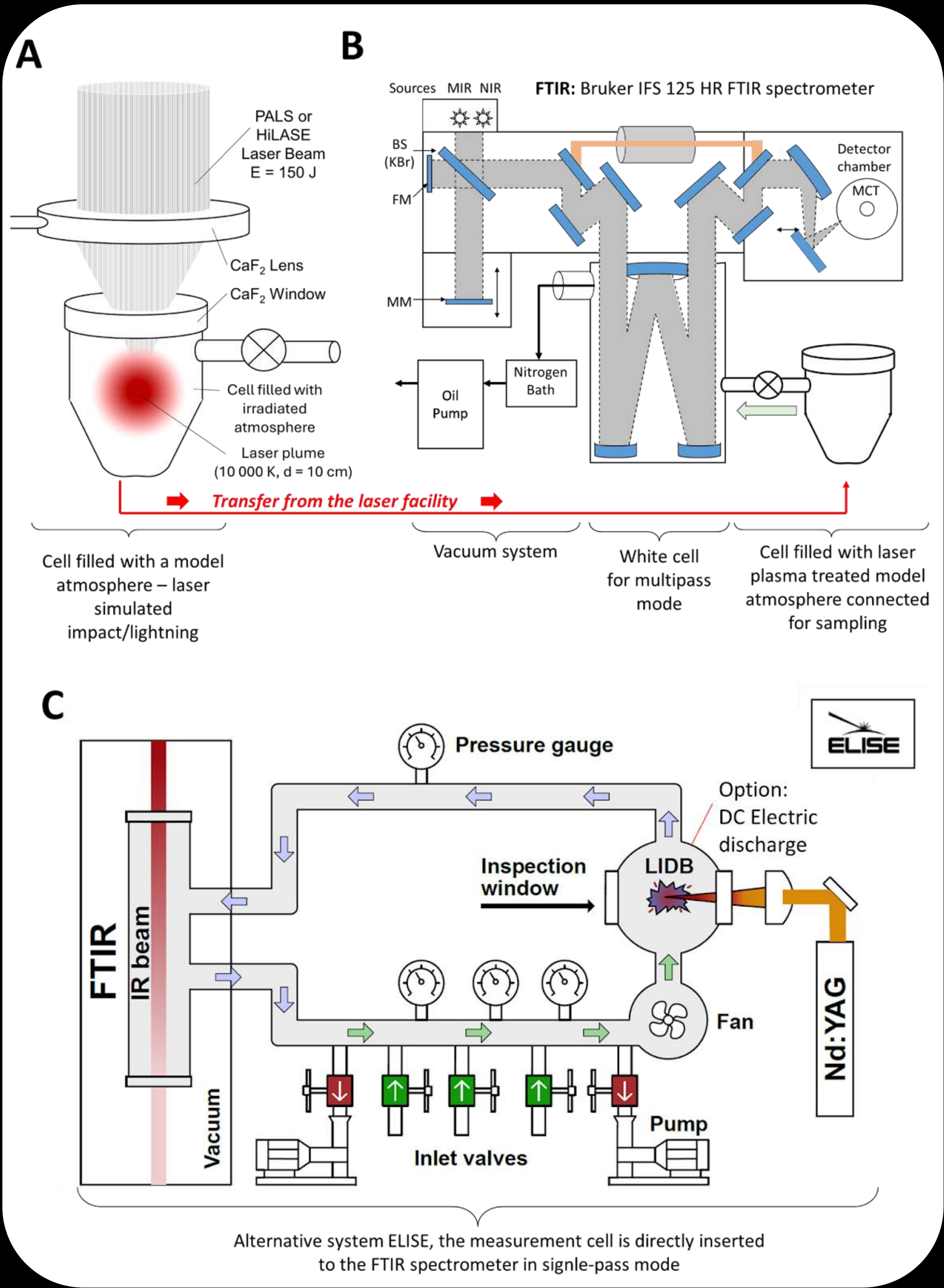
Overall, our collective efforts serve as a gateway to unlocking the secrets of exoplanetary systems, paving the way for a deeper understanding of our place in the cosmos and the potential for life beyond Earth.

Relevant projects:
FW01010038 Advanced solutions of light sources, in collaboration with Crytur (TAČR); 19-03314S Plasma and UV/XUV/X-Ray Reprocessing of planetary atmospheres: What can we expect on young exoplanets? in collaboration with PALS Center of the Institute of Plasma Physics and the Institute of Physics of the Czech Academy of Sciences (GAČR); R200402401 Stellar Observational and Laboratory Spectroscopy - Support for the Ariel Space Telescope, in collaboration with the Valašské Meziříčí Observatory (CAS); R200402401 Stellar Observational and Laboratory Spectroscopy - Support for the Ariel Space Telescope (CAS).

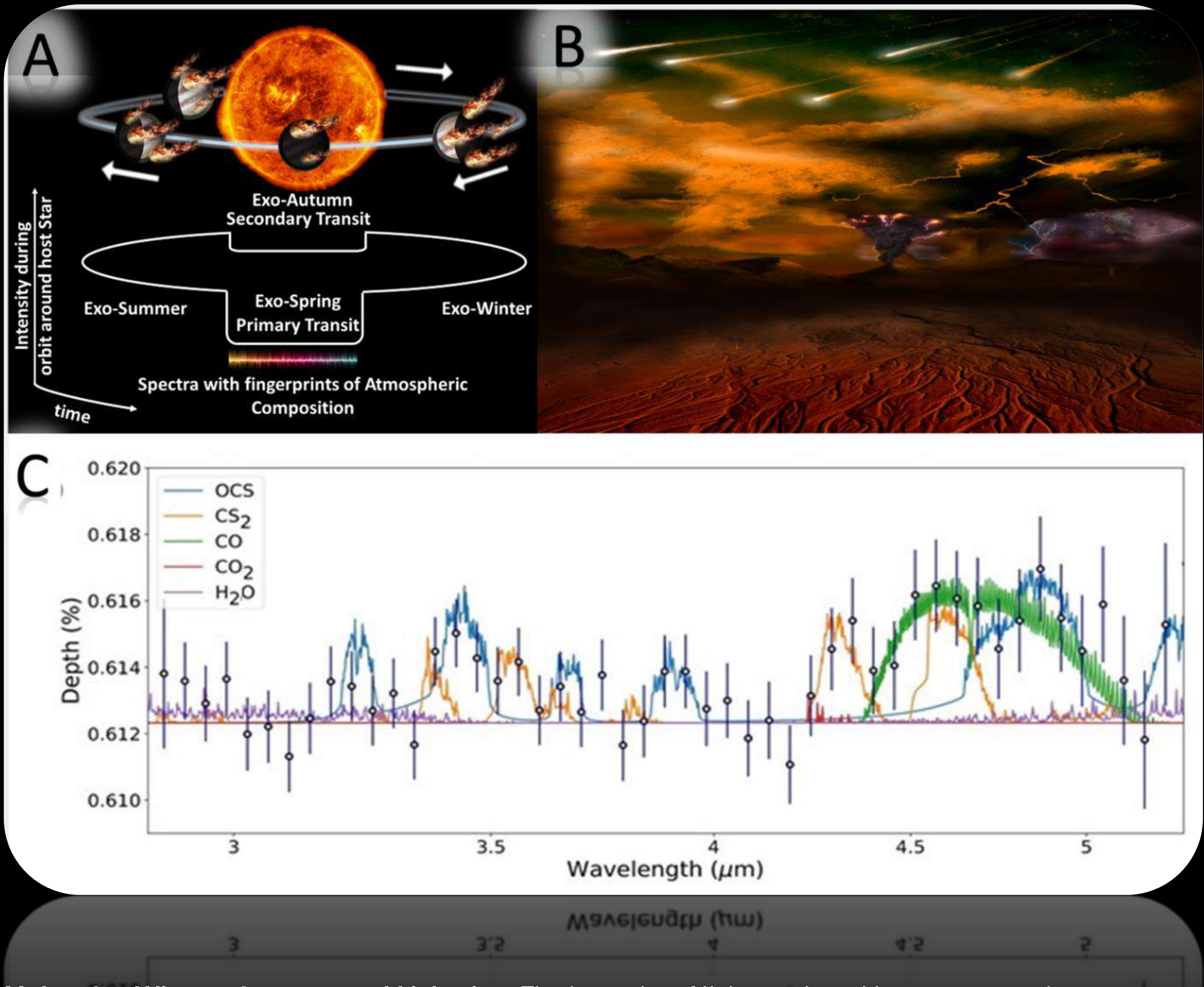
Selected papers for further reading:

Identifiable Acetylene Features Predicted for Young Earth-like Exoplanets with Reducing Atmospheres Undergoing Heavy Bombardment: P. B. Rimmer, M. Ferus, I. P. Waldmann et al. The Astrophysical Journal, 888(1), Article id. 21, 12 pp., 2020.

Ariel - a window to the origin of life on early earth? M. Ferus, V. Adam, G. Cassone et al. Experimental Astronomy, 53(2), 679-728, 2022.

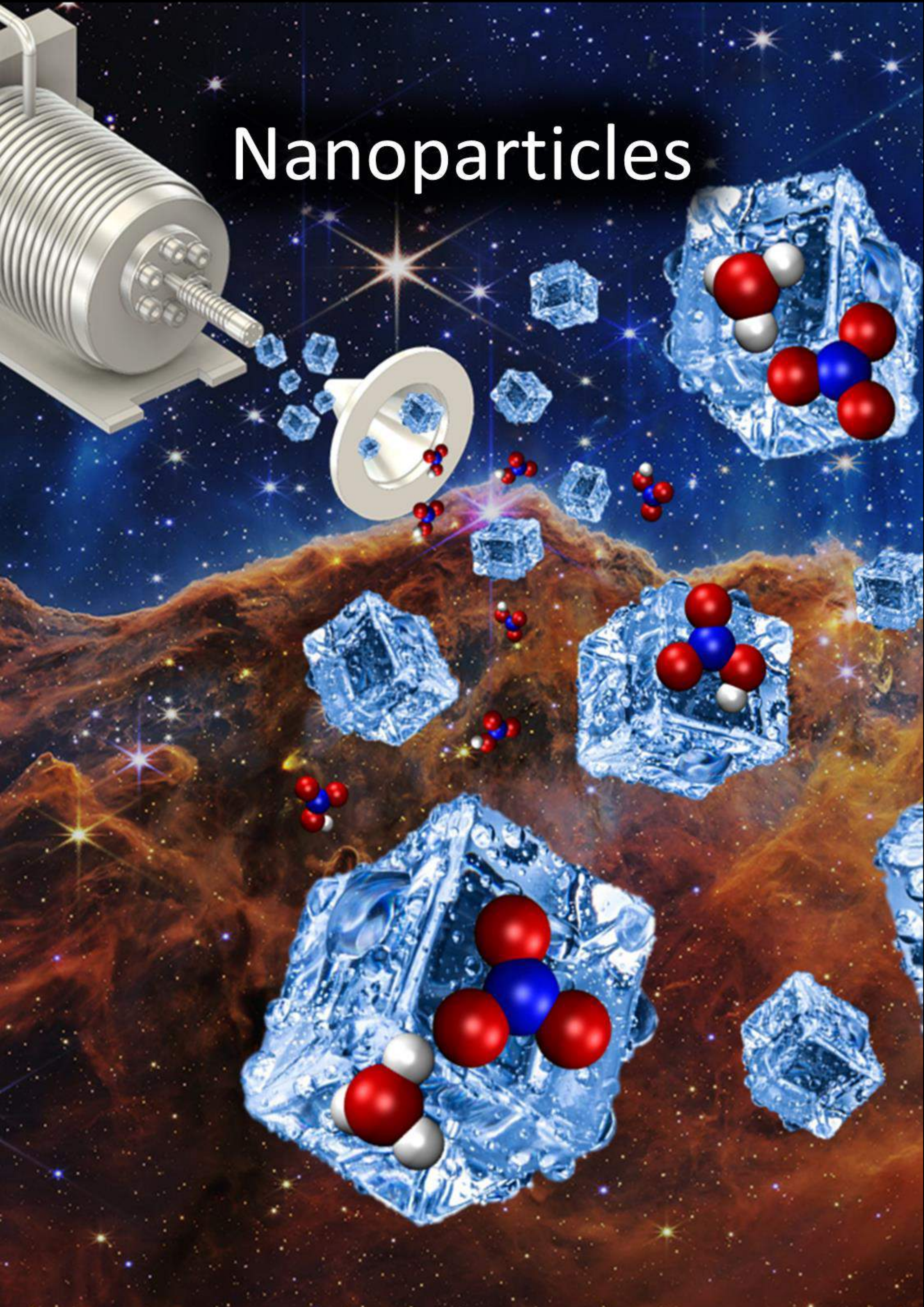


Laser Experiments for Plasma Event Simulations: Panel A depicts a static experiments performed using High-Power Lasers PALS and HiLASE. The gas phase is then analyzed by FTIR IFS 125 HR, shown in Panel B, equipped with optics that can be configured for either multipass or single-pass measurement modes, or GC-MS and other techniques. Panel C depicts the Experimental Laboratory Impact Simulator for Exoplanets (ELISE). Plasma generated in these experiments can be analyzed using various diagnostic methods, including Optical Emission Spectroscopy (OES).



Molecules Witness Impacts and Lightning: The intensity of light produced by a meteor or impact event, coupled with the brief duration typically measured in seconds, makes direct observation highly unlikely. Instead, high impact rates or significant single events can induce plasmochemical transformations in atmospheric constituents, altering their equilibrium ratios. This disequilibrium in atmospheric composition, or even the presence of molecules unlikely to be found in an atmosphere not subjected to heavy impacts, can act as signatures of such events. Precise laboratory experiments and computational models of atmospheric chemistry, along with calculations of spectral intensities of molecular bands associated with impacts, can provide indirect evidence and clues about impact activity on distant worlds. Through this approach, we aim to determine if impacts represent a common evolutionary scenario for all early planets post-formation and if such impacts are prevalent in evolved planetary systems, where large debris clouds have recently been recognized. The collaboration on the exploration of exoplanet chemistry is one of our broadest joint efforts. It begins with experiments using high-power lasers (PALS and HiLASE at the Institute of Plasma Physics and Physical Institute CAS), includes atmospheric models developed in collaboration with the University of Cambridge, and involves transition spectra computed at University College London. Quantum calculations are performed in partnership with the Institute of Physical and Chemical Processes in Messina, and newly, the astronomical observations are conducted in cooperation with the Observatory Valašské Meziříčí. Furthermore, there is close collaboration with the PLATO mission coordinated by the Astronomical Institute CAS, among many other networking efforts.

Nanoparticles



Chemistry of ice-, dust-, and aerosol-nanoparticles

…"just" dust?

Our research into the chemistry of ice-, dust-, and aerosol-nanoparticles in the interstellar medium (ISM) and planetary atmospheres, including Earth's, is driven by a quest to understand the synthesis of complex organic molecules in the environments seemingly hostile to any sort of chemical synthesis. Despite the sparse collisions and low temperatures characteristic of the ISM, over 200 molecules have been identified, including amino acids and polyaromatic hydrocarbons (PAHs), hinting at intriguing astrochemical pathways explored in our laboratories. By investigating surface catalysis on dust/ice grains through laboratory studies and molecular-beam cluster experiments, we've gained insights into the formation of complex organic molecules.

Our exploration of PAHs, both in the ISM and Earth's atmosphere, sheds light on their role in astrochemical evolution and atmospheric chemistry, offering a bridge between fundamental astrochemistry and environmental science. Our endeavors underscore the interdisciplinary nature of the work, culminating in advancements that enhance our understanding of chemical processes in diverse environments, from planetary atmospheres to the depths of interstellar space.

Moreover, our development is also focused on more applied topics, such as construction of innovative mass spectrometry techniques, exemplified by instruments like OLYMPIA and OLYMPIA-LILBID, further propels our ability to explore and characterize the chemical compositions of planetary environments, paving the way for future spaceborne missions and enhancing our grasp of celestial phenomena.

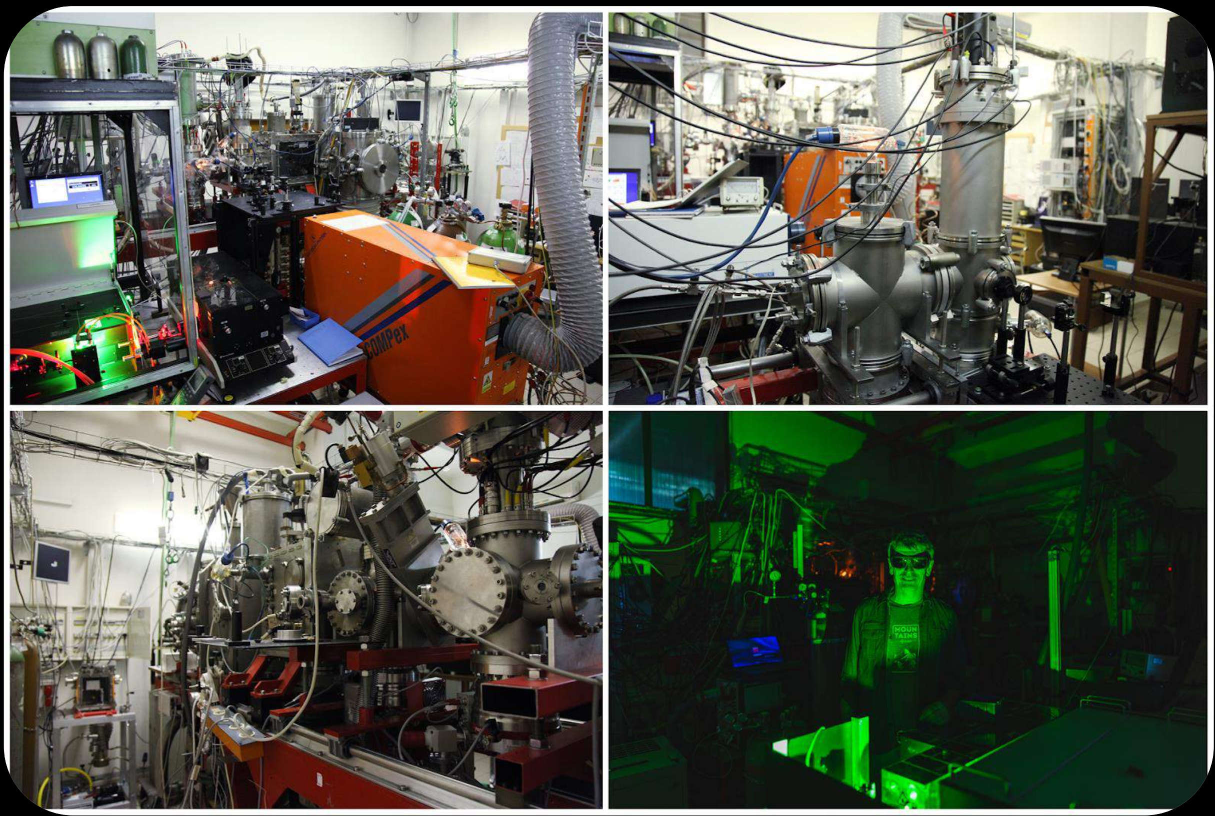
Relevant projectss: CA21126 European network COST NanoSpace - Processing, reactivity and relaxation pathways of nanocarbon (MEYS); 21-07062S Clusters of PAHs in Laboratory Research of Astrochemical and Atmospherical Processes (GAČR); 24-11390S Atmospheric Aerosol Nanoclusters in Molecular Beam Experiments and Computer Simulations (GAČR); Praemium Academiae: Investigation of elementary chemical processes at the molecular level using molecular beam techniques (CAS).

Selected papers for further reading:

Pickup and reactions of molecules on clusters relevant for atmospheric and interstellar processes: M. Fárník, J. Fedor, J. Kočišek, J. Lengyel, E. Pluhařová, V. Poterya, A. Pysanenko, Physical Chemistry Chemical Physics, 31, 3195-3213, 2021.

Uptake of Molecules by Polyaromatic Hydrocarbon Nanoparticles: V. Poterya, I. S. Vinklárek, A. Pysanenko, E. Pluhařová, and M. Fárník, ACS Earth Space Chemistry 8, 369–380, 2024.

OLYMPIA-LILBID: A New Laboratory Setup to Calibrate Spaceborne Hypervelocity Ice Grain Detectors Using High-Resolution Mass Spectrometry: A. Sanderink, F. Klenner, I. Zymak, J. Žabka et al.: Anal. Chem., 95(7), 3621-3628, 2023.



Simulating Interstellar Space Conditions - CLUB (CLUster Beam) Apparatus: This apparatus utilizes cold molecular beams in a vacuum to simulate the harsh conditions of interstellar space within our laboratory. It includes clusters or nanoparticles ranging from 10^2 - 10^3 molecules (H_2O to ice nanoparticles approximately 1-5 nm in size). Using various laser beams and electrons of different energies, it can induce photochemical reactions and electron-induced processes, capturing reactions with molecules, electrons, and UV/IR radiation, thus mimicking astrochemistry under controlled conditions.

Space Dust

Space dust composition analysis

…accelerated icy dust in lab for novel space probes development.

Nanometer to micrometer-sized icy and mineral particles, which constitute cosmic dust, can originate from comets, plumes on icy satellites, and hypervelocity meteoroid impacts on various icy surfaces. Mass spectrometric measurements of the molecular composition of such ice grains from Enceladus, performed with the Cosmic Dust Analyzer on the Cassini spacecraft, revealed the presence of organic molecules with masses exceeding 200 amu. Therefore, for future missions, it is essential to have a laboratory source of hypervelocity ice particles, which facilitates the testing of new generations of high-resolution space mass spectrometric detectors.

In cooperation with Leipzig University and IOM Leipzig, we have developed and built a unique apparatus named SELINA (Selected Ice Nanoparticle Accelerator) with a miniature footprint capable of producing beams of size-selected ice and solid dust analogues up to 1000 nm in size.

Recently, we obtained the first mass spectrometric data from the hypervelocity impact (3-4 km/s) of 100 nm water ice particles on a golden target, measured by time-of-flight MS. The ability to accelerate analog dust particles provides means to test novel high-resolution mass spectrometers like the Orbitrap-based HANKA, and calibrate data from existing and future impact ionization space probes.

We have also explored a unique sample returned from the Hayabusa mission from asteroid Ryugu. Investigation of the organic and mineral inventory of such pristine interplanetary matter opens the gate for understanding the composition of dust released from these bodies through various processes.

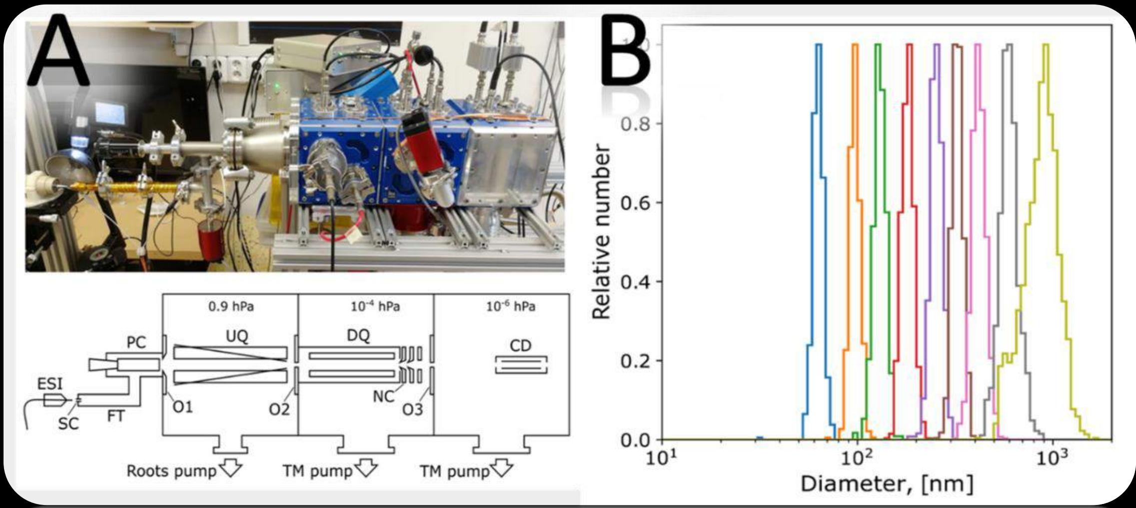
Relevant projects:
21-11931J High resolution mass spectrometry laboratory experiments for the analysis of past and future space data (GAČR); 17-14200 Experimental and Theoretical Study of Chemical Processes in Planetary Atmospheres (GAČR); Investigating the Evolution of Macromolecular Organic Material from Asteroid 162173 Ryugu (JAXA).

Selected papers for further reading:

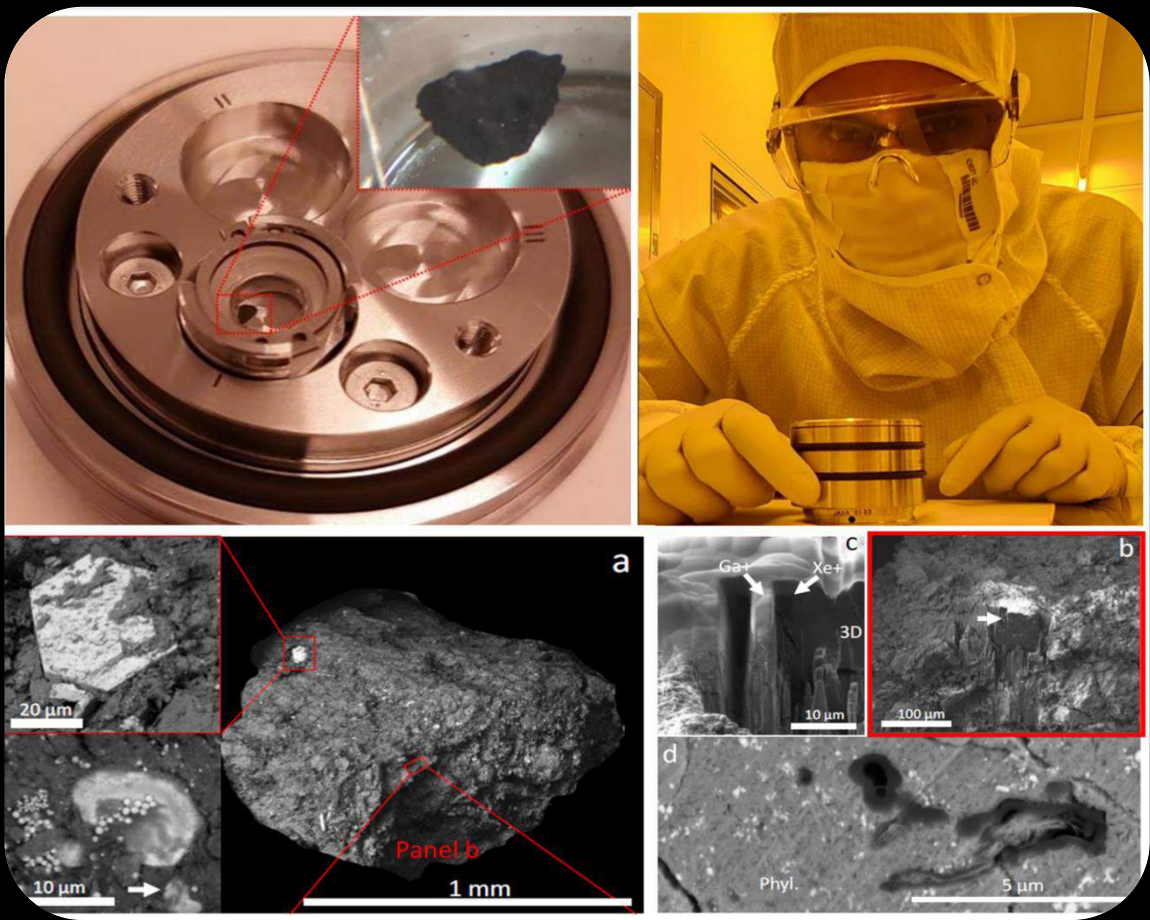
Charged Ice Particle Beams with Selected Narrow Mass and Kinetic Energy Distributions: A. Spesyvyi, J. Žabka, M. Polášek, A. Charvat, J. Schmidt, F. Postberg, B. Abel: Journal of the American Society for Mass Spectrometry, 34 (5), 878-892, 2023.

Selected Ice Nanoparticle Accelerator Hypervelocity Impact Mass Spectrometer (SELINA-HIMS): Features and Impacts of Charged Particles: A. Spesyvyi, J. Žabka, M. Polášek, M. Malečková, N. Khawaja, J. Schmidt, S. Kempf, F. Postberg, A. Charvat, B. Abel, Phil. Trans. R. Soc. A, 382: 20230208, 2024.

The evolution of organic material on Asteroid 162173 Ryugu and its delivery to Earth: H. G. Changela, Y. Kebukawa, L. Petera, M. Ferus, E. Chatzitheodoridis, L. Nejdl, R. Nebel, V. Protiva, P. Krepelka, J. Moravcova, R. Holbova, Z. HLavenkova, T. Samoril, J. C. Bridges, S. Yamashita, Y. Takahashi, T. Yada, A. Nakato, K. Sobotková, H. Tesařová, D. Zapotok, Nature Communications, accepted, 2024.



Our space dust generator and accelerator SELINA: The specialized apparatus and its schematic are depicted in Panel A. Panel B displays the size distributions of selected beams of ice nanoparticles produced by SELINA (Selected Ice Nanoparticle Accelerator).



Ryugu Asteroid at J. Heyrovský Institute: Among only a few institutions worldwide, we have acquired a sample of the Ryugu asteroid from the JAXA Hayabusa mission. It is now under examination in our laboratories.

Chemistry of Earth's Evolution

Chemistry of Earth 's Evolution

...lasers address the question of the origin of life on the hellish early Earth.

Our pioneering research in prebiotic chemistry and the origin of life is shedding light on the profound mysteries of our planet's history. Leveraging high-performance laser technology, our investigations delve into the chemical pathways that could have catalyzed the emergence of life on Earth. By simulating extraterrestrial impacts and other high-energy events using lasers, we recreate the conditions prevailing during the Late Heavy Bombardment period, uncovering how these cataclysmic events generated crucial prebiotic molecules like nucleobases, amino acids, and sugars.

Through meticulous spectroscopic analysis and quantum chemical calculations, we elucidate the intricate reaction pathways leading from simple precursors to biologically relevant molecules. Our research also explores the catalytic effects of minerals and impact processes, showcasing how geological materials could have facilitated the synthesis and preservation of organic compounds.

By integrating our findings into comprehensive models of early Earth's chemistry, we offer a holistic understanding of the dynamic interplay between energy sources and synthetic pathways crucial for life's origin. Moreover, our insights extend beyond Earth, contributing to astrobiology by providing a chemical blueprint for life's potential on other planets. From elucidating the role of hydrogen cyanide and formamide to exploring the impact of ionizing radiation and the significance of quantum dots, our multifaceted approach uncovers the universal principles underlying life's emergence.

In summary, our research bridges prebiotic chemistry with astrobiological potential, offering profound insights into life's universal origins and evolution across the cosmos.

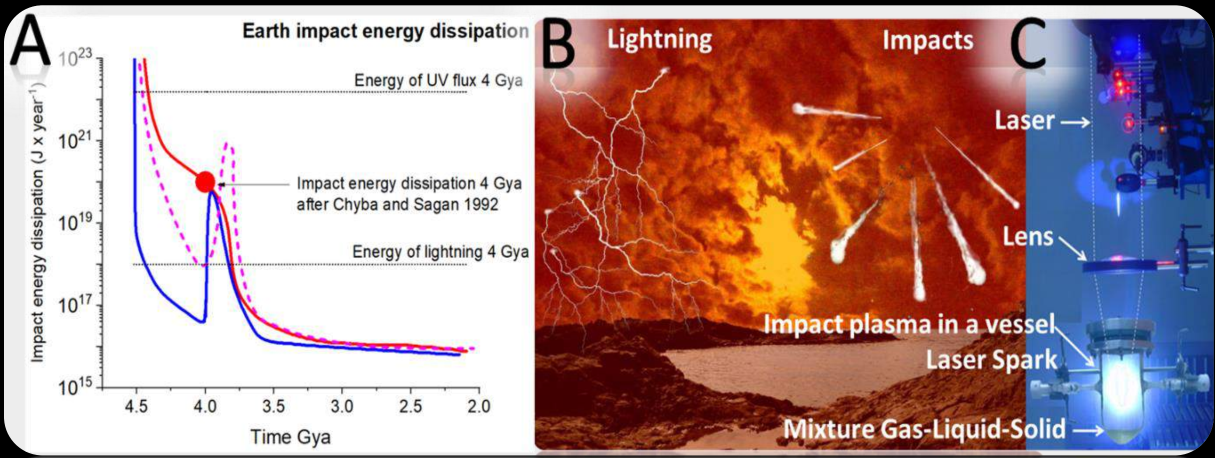
Relevant projects:
17-05076S Origin of life on Earth and in the space - experiment and theory, in collaboration with the Biophysical Institute of the Czech Academy of Sciences (GAČR); CZ.02.1.01/0.0/0.0/16_019/0000778 Center of Advanced Applied Sciences, in multilateral collaboration, the prime was Faculty of Nuclear Research and Engineering of the Czech Technical University in Prague (MEYS - ESF).

Selected papers for further reading:

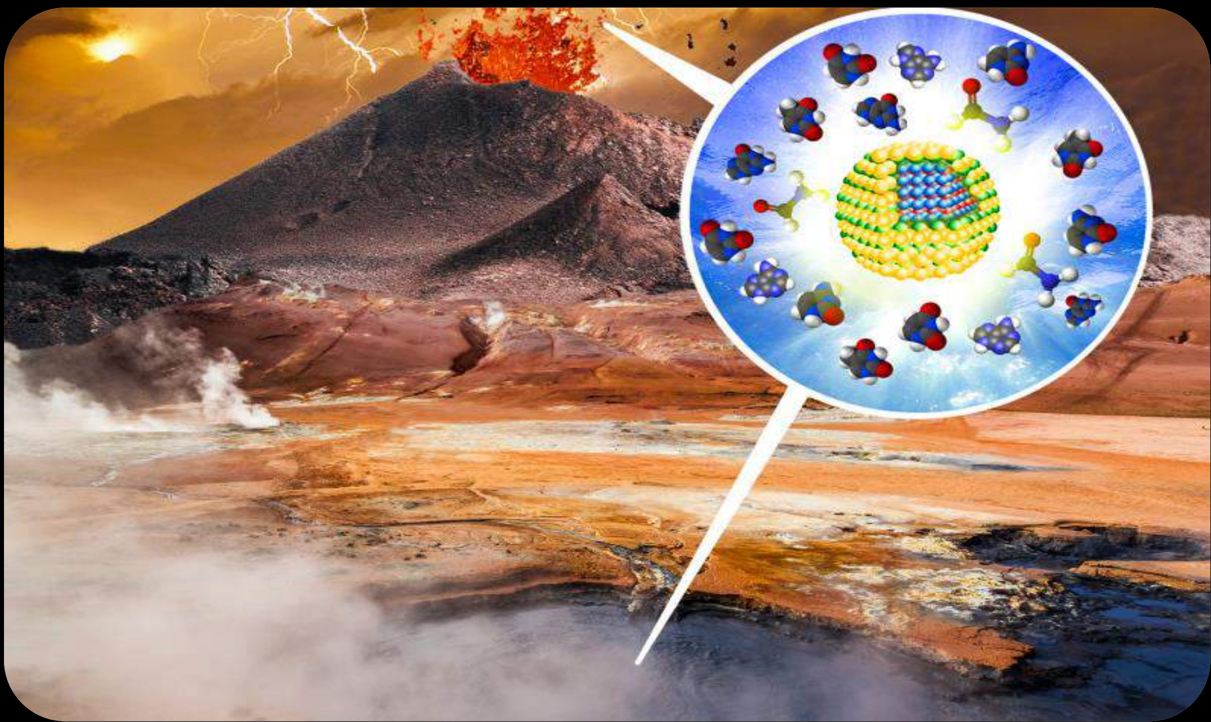
High-energy chemistry of formamide: A unified mechanism of nucleobase formation: M. Ferus, D. Nesvorný, J. Šponer, P. Kubelík, R. Michalčíková, V. Shestivská, J. E. Šponer, S. Civiš, Proceedings of the National Academy of Sciences, 112(3), 657-662, 2015.

Formation of nucleobases in a Miller-Urey reducing atmosphere: M. Ferus, F. Pietrucci, A. M. Saitta, A. Knížek, P. Kubelík, O. Ivanek, V. Shestivská, S. Civiš, Proceedings of the National Academy of Sciences, 114(17), 4306-4311, 2017.

Formamide-Based Post-impact Thermal Prebiotic Synthesis in Simulated Craters: Intermediates, Products and Mechanism: M. Ferus, A. Knížek, L. Petera, A. Pastorek, J. Hrnčířová, L. Jankovič, O. Ivanek, J. Šponer, A. Křivková, H. Saeidfirozeh, S. Civiš, E. Chatzitheodoridis, K. Mráziková, L. Nejdl, F. Saija, J.E. Šponer, G. Cassone, Frontiers in Astronomy, 9, Article 882145, 1-11, 2022.

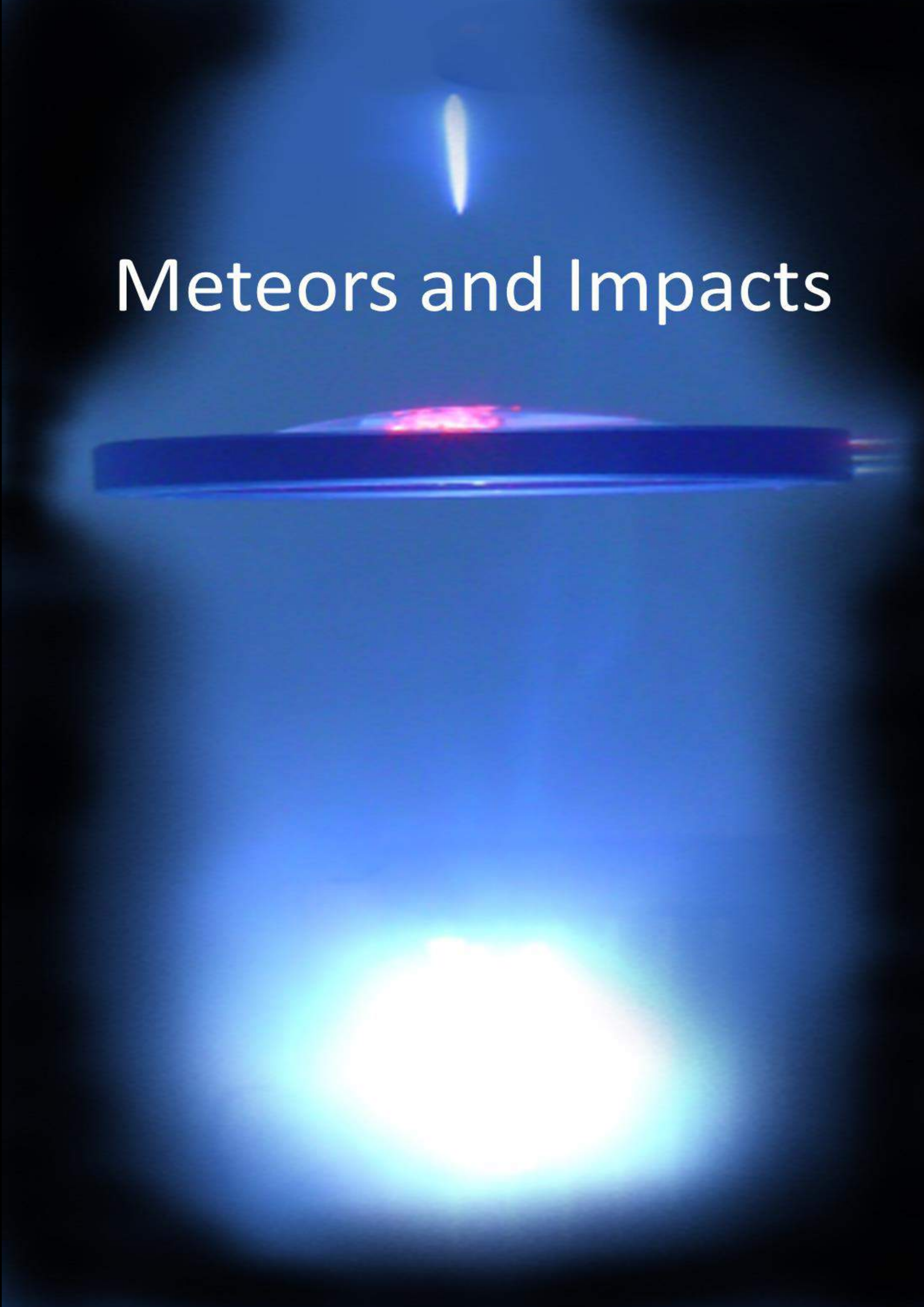


Life from Hell? Pop culture movies like "Armageddon" and the well-known Chicxulub event, which ended the era of dinosaurs, lead people to view impacts solely as devastating events. Indeed, for the modern biosphere, they are catastrophic. However, asteroids and, to some extent, comets bombarding Earth in the first few hundred million years after our planet formed, crafted the world as we know it—with its atmosphere, oceans, rare elements in the crust, and probably life itself. The transfer and deposition of volatiles and organic compounds from the colder parts of the Solar System to a hot, hostile desert world, alongside the energy for chemical transformations provided by impact plasma (see Panel A), were crucial factors in creating a prebiotic milieu. We hypothesize that impact craters provided the conditions and ingredients necessary for forming a plausible prebiotic soup, the origin of life—heat, organics, minerals, and trace elements (see Panel B). A wide range of experiments have demonstrated the chemistry of prebiotic synthesis both directly and after impacts. For simulating direct impact plasma consequences, high-power lasers, such as those at the PALS Center of the Institute of Plasma Physics at the Czech Academy of Sciences, have been employed (Panel C). How life truly began remains unknown. This question may finally be answered when the bottom-up chemical synthesis approach and the top-down research simplifying the earliest living chemical systems converge.



Prebiotic Soup: In collaboration with Mendel University, we have extended our hypothesis of post-impact synthesis in craters to the formation of quantum dots upon UV radiation. These nanostructures may have played a peculiar role as early enzymes, capable of catalyzing the first prebiotic or early biotic reactions.

Meteors and Impacts



Meteors and Impacts

...shooting stars in a test tube.

Our research endeavors in meteoritics, particularly through innovative applications of Laser-Induced Breakdown Spectroscopy (LIBS), have significantly advanced our understanding of meteor spectra, elemental compositions, and the dynamic processes associated with meteor plasmas. By employing a multifaceted approach, we have aimed to enhance both theoretical understanding and practical applications of meteor analysis and simulation, utilizing cutting-edge technologies and methodologies.

One of our key achievements lies in the development and application of advanced spectral analysis techniques. Through the use of artificial neural networks, novel iterative algorithms and data from high power laser experiments, we have successfully characterized crucial plasma parameters such as temperature, electron density, and ionization states from LIBS data with remarkable speed and precision. This method offers significant improvements over traditional techniques, making it invaluable for both industrial and scientific applications.

The controlled laboratory experiments have simulated high-energy processes occurring during meteor entry into Earth's atmosphere, shedding light on ablation, disintegration, and plasma formation processes relevant to meteoroids. Through numerical modeling and simulation, we have developed sophisticated models to interpret observational data under various conditions, enhancing the accuracy of spectral analysis.

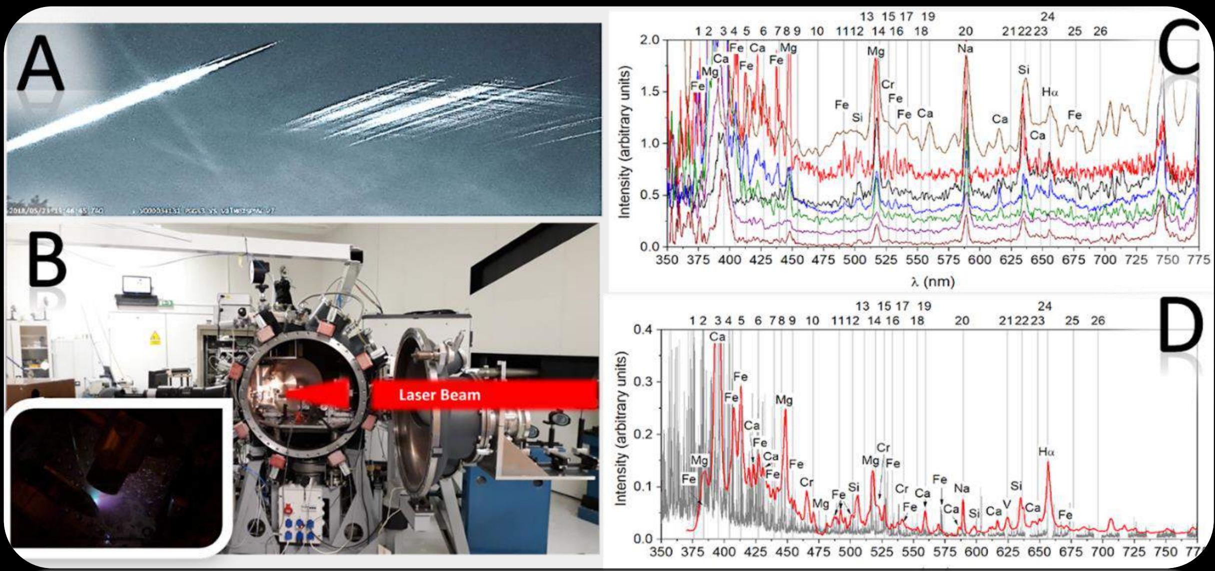
Our interdisciplinary approach extends beyond meteor science, exploring applications in space missions, space debris surveillance, and the study of exoplanetary atmospheres. By simulating extreme states of matter and high-energy events, our research supports a wide range of scientific inquiries and practical applications in space exploration and planetary defense.

Relevant projects:
21-11366S Simulation of meteoroid and asteroid explosion event by terawatt-class laser, in collaboration with PALS Center of the Institute of Plasma Physics of the Czech Academy of Sciences and Faculty of Nuclear Research and Engineering of the Czech Technical University in Prague (GAČR); 18-27653S Simulation of Meteor Plasma using Terawatt Laser: Experiments, Theory and Real Observations, in collaboration with PALS Center of the Institute of Plasma Physics of the Czech Academy of Sciences (GAČR); Collaborative projects between the institutes of the Czech Academy of Sciences and regional partners, including cooperation with the Valašské Meziříčí Observatory: R200401521 Development of Meteor Observation and Spectroscopy; R200401801 SeLOS - Joint Laboratory for Observational Spectroscopy; R200402101 Ground Support for Space Missions.

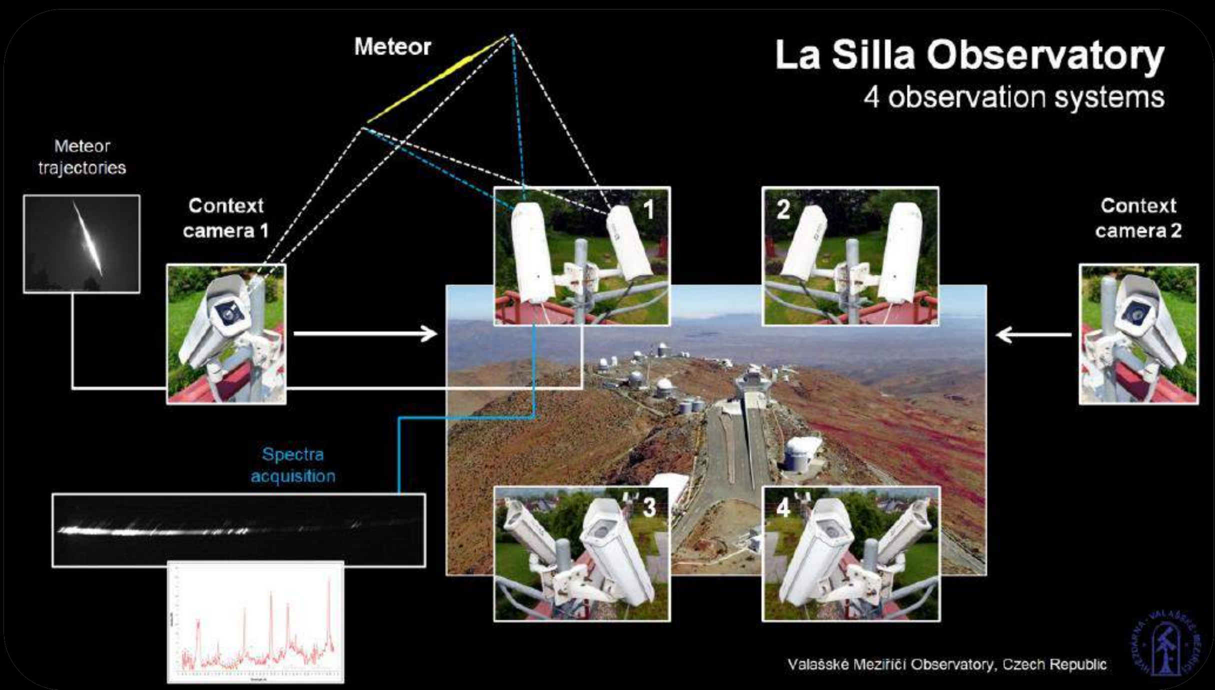
Selected papers for further reading:

Probing Plasma Physics and Elemental Composition of a Leonid Meteor by Fitting Complex Plasma Radiation Model Parameters: P. Kubelík, J. Koukal, L. Lenža, J. Srba, V. Laitl, R. Křížová, A. Křivková, S. Civiš, V.E. Chernov, M. Ferus, Monthly Notices of the Royal Astronomical Society, stac1600, 2022.

Simulating asteroid impacts and meteor events by high-power lasers: from the laboratory to spaceborne missions: M. Ferus, A. Knížek, G. Cassone, P.B. Rimmer, H. Changela, E. Chatzitheodoridis, I. Uwarova, J. Žabka, P. Kbáth, F. Saija, H. Saeidfirozeh, L. Lenža, M. Krůs, L. Petera, L. Nejdl, P. Kubelík, A. Křivková, D. Černý, M. Divoký, M. Pisařík, T. Kohout, L. Palamakumbure, B. Drtinová, K. Hlouchová, N. Schmidt, Z. Martins, J. Yáñez, S. Civiš, P. Pořízka, P. Mocek, J. Petri, S. Klinkner, Front. Astron. Space Sci., 10, 1-12, 2023.

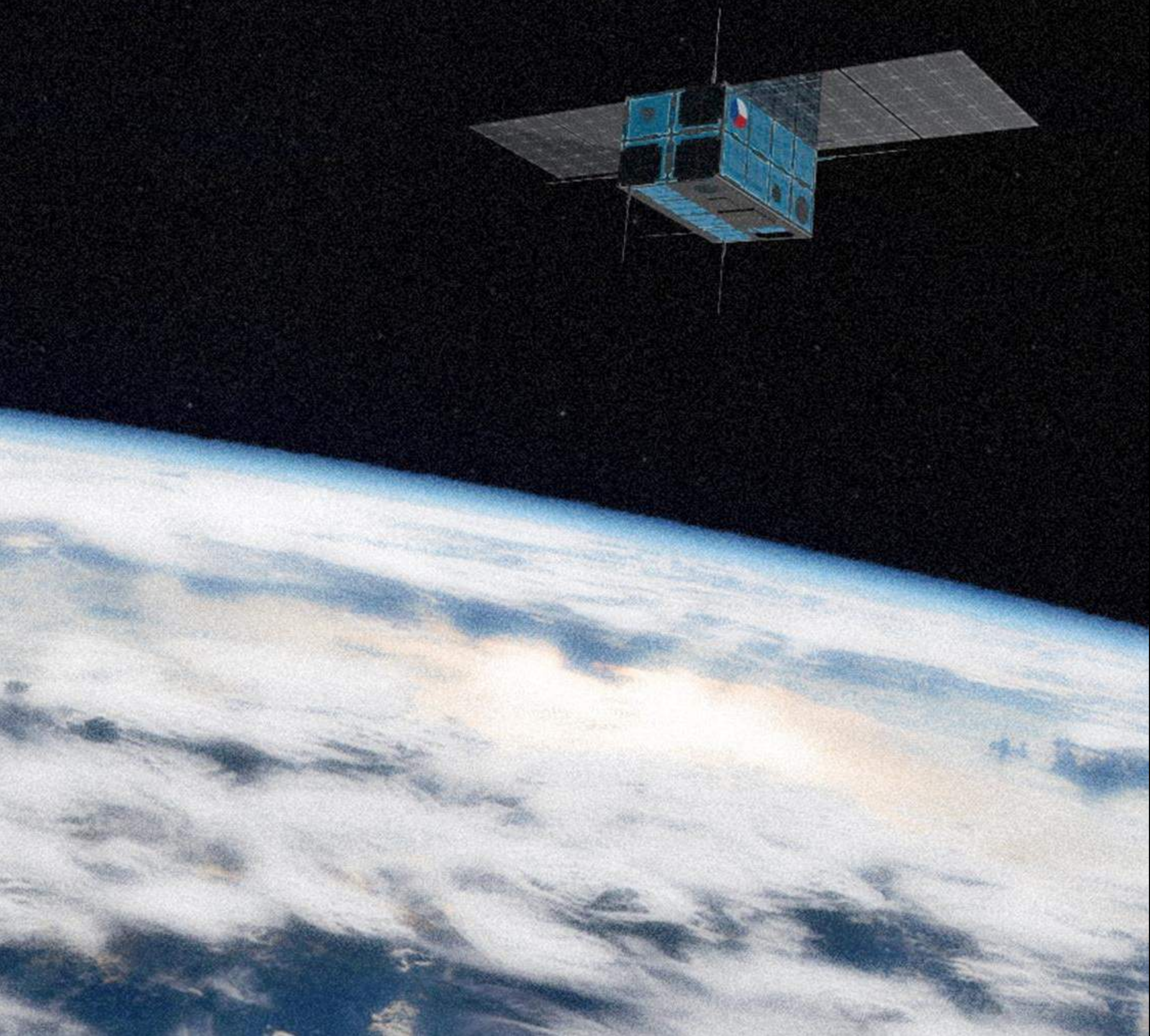


Meteor Plasma Simulated by a Laser Shot to Meteorite Material: Meteors represent a complex natural phenomenon that is difficult to explore in a laboratory setting. Lasers, alongside burners in wind tunnels, are among the few laboratory tools that can approximate some characteristics of meteor plasma. A key challenge is the spectral analysis of meteor plasma and the rigorous determination of the elemental composition of a meteoroid body, which is surrounded by plasma emitting characteristic lines of evaporated elements (see Panel A). High-power lasers such as PALS (Institute of Plasma Physics, CAS) or HiLASE (Institute of Physics, CAS) can create a substantial fireball (see Panel B) by ablating meteorite specimens. The spectra of meteors recorded by ground-based spectrographs located at Valašské Meziříčí Observatory (see Panel C) can then be compared to such simulations (see Panel D). Computational extrapolation of spectra recorded under known parameters can help ensure the accuracy of the qualitative and quantitative analysis of real meteor spectra.



Expanding Meteor Spectroscopy to a Top-Class European Observatory: We have recently proposed a project to build a network of meteor spectrographs and context video observation cameras at the La Silla Observatory of the European Southern Observatory (ESO). The project has been accepted, and the network, which will support future satellite observations of meteors, is set to be launched soon.

Space Technologies



Space Technologies

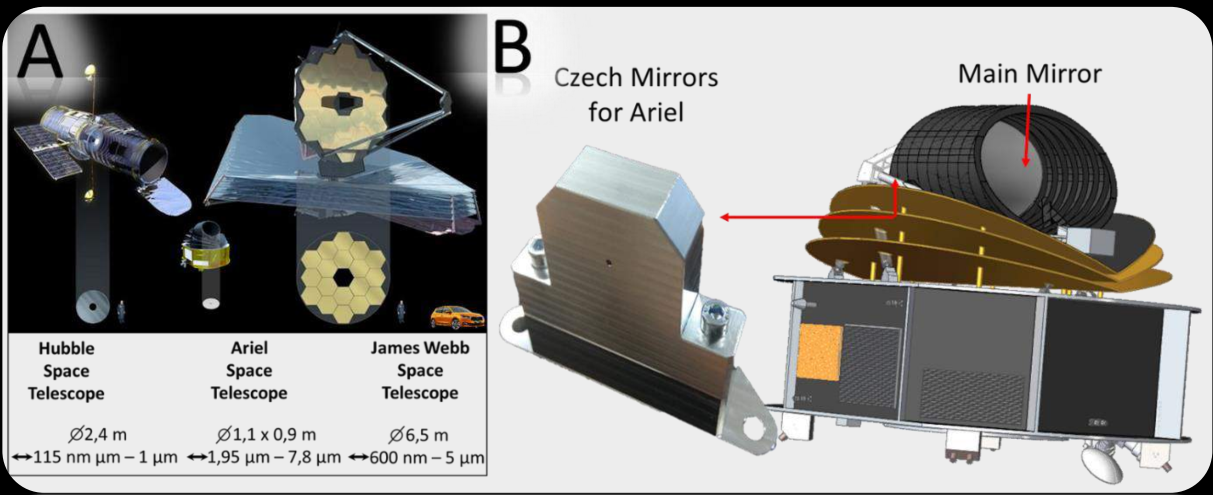
...how physical chemists may fly to space.

Our institute has recently been involved in multiple national as well as international space missions, serving as both coordinator and partner. The following list summarizes our ongoing projects as well as the ideas and concepts we are dreaming about:

Ariel Space Telescope

Our institute serves as the parent organization of both national Co-PIs in the European Space Agency's Ariel mission, which is dedicated to exploring exoplanets by observing their chemical compositions. Recently, Ariel achieved a significant milestone by successfully completing the Preliminary Design Review (PDR) phase. This accomplishment marks a crucial advancement for the mission, as it ensures that all technical and scientific specifications have been met, paving the way for a planned launch in 2029. The Czech Republic's involvement in the Ariel mission is led by scientists from the J. Heyrovský Institute of Physical Chemistry of the Czech Academy of Sciences, with technical development provided by the Research Center for Special Optics and Optoelectronic Systems TOPTEC in Turnov.

Relevant project: PEA 4000131855 Manufacturing and testing of mirrors for the ARIEL satellite mission, in collaboration with TOPTEC (MEYS, MTCR, ESA); R200402401 Stellar Observational and Laboratory Spectroscopy - Support for the Ariel Space Telescope (CAS).

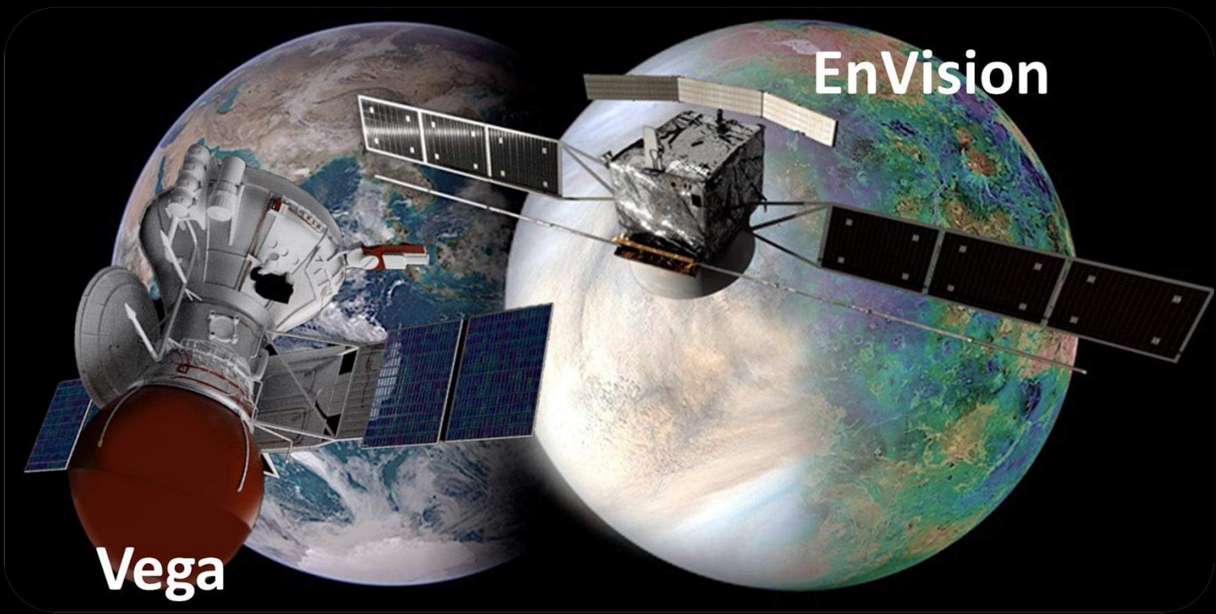


Small Satellite - Great Data. We are proudly involved in the coordination and scientific contributions to the Ariel Space Telescope mission. Although this telescope is smaller than the JWST or Hubble (see Panel A), its value lies in its focused, systematic exploration of the environments and compositions of nearly a thousand exoplanets. Besides creating spectral datasets that support this endeavor, our efforts include exploring plasmatic, photochemical, and prebiotic processes on other worlds. Our scientists serve as Co-PIs (Co-Principal Investigators) of the mission on behalf of the Czech Republic. Additionally, the secondary mirrors are manufactured by TOPTEC, a company within the Institute of Plasma Physics of the Czech Academy of Sciences, as part of a joint project (see Panel B).

EnVision

EnVision will conduct high-resolution radar mapping of Venus and atmospheric studies. The mission will help scientists understand the relationships between Venus' geological activity and its atmosphere and will investigate why Venus and Earth have taken such different evolutionary paths. The EnVision mission is scheduled to launch in 2031, with the first data from Venus expected to be transmitted by the probe in 2033/2034. The Czech side, led by scientists from the J. Heyrovský Institute of Physical Chemistry of the Czech Academy of Sciences, will be responsible for the development, testing, and production of electronic boards for the VenSpec-H instrument, which is intended to be one of the three spectrometers of the probe focused on high-resolution spectrum imaging of Venus' atmosphere. The development is coordinated by BIRA, Belgium. Scientists from the Institute of Geophysics of the Czech Academy of Sciences and the Czech Geological Survey will also be involved in the project. The development and production of electronic boards will be further ensured by Czech companies selected through an ESA tender.

Relevant project: Prodex PEA 4000143801 - EnVision VenSpec-H Electronics, in collaboration with Geophysical Institute CAS and Czech Geological Survey (MEYS, MTCR, ESA).

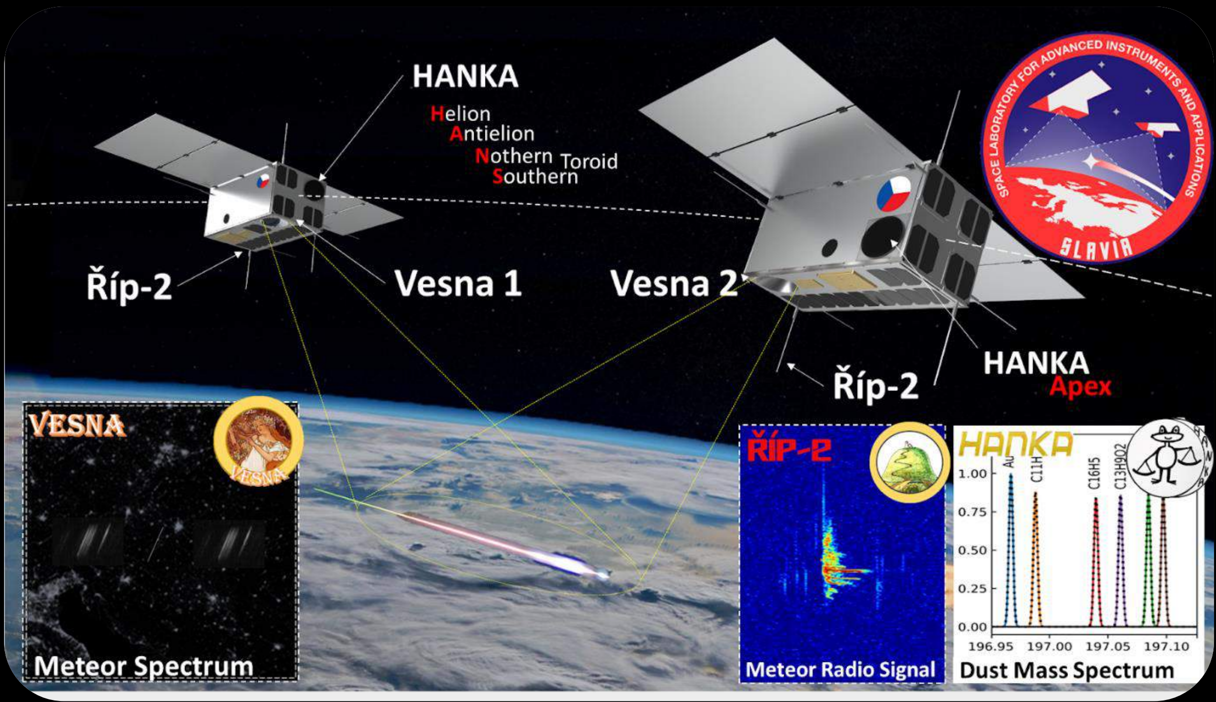


Czechia Returns to Venus - A Stellar Comeback to the Mysterious Planet: Not only does the next decade herald a significant international return to Venus with three major missions (EnVision, Da Vinci, and Veritas), but it also marks a meaningful comeback for Czech science and industry. In 1986, Venus was explored by two Soviet probes, Vega, for which the Czechoslovak industry constructed the instrument platform unit. Our institute is now the proud coordinator of the electronic systems construction for the EnVision mission, set to reach Venus almost 50 years after Vega.

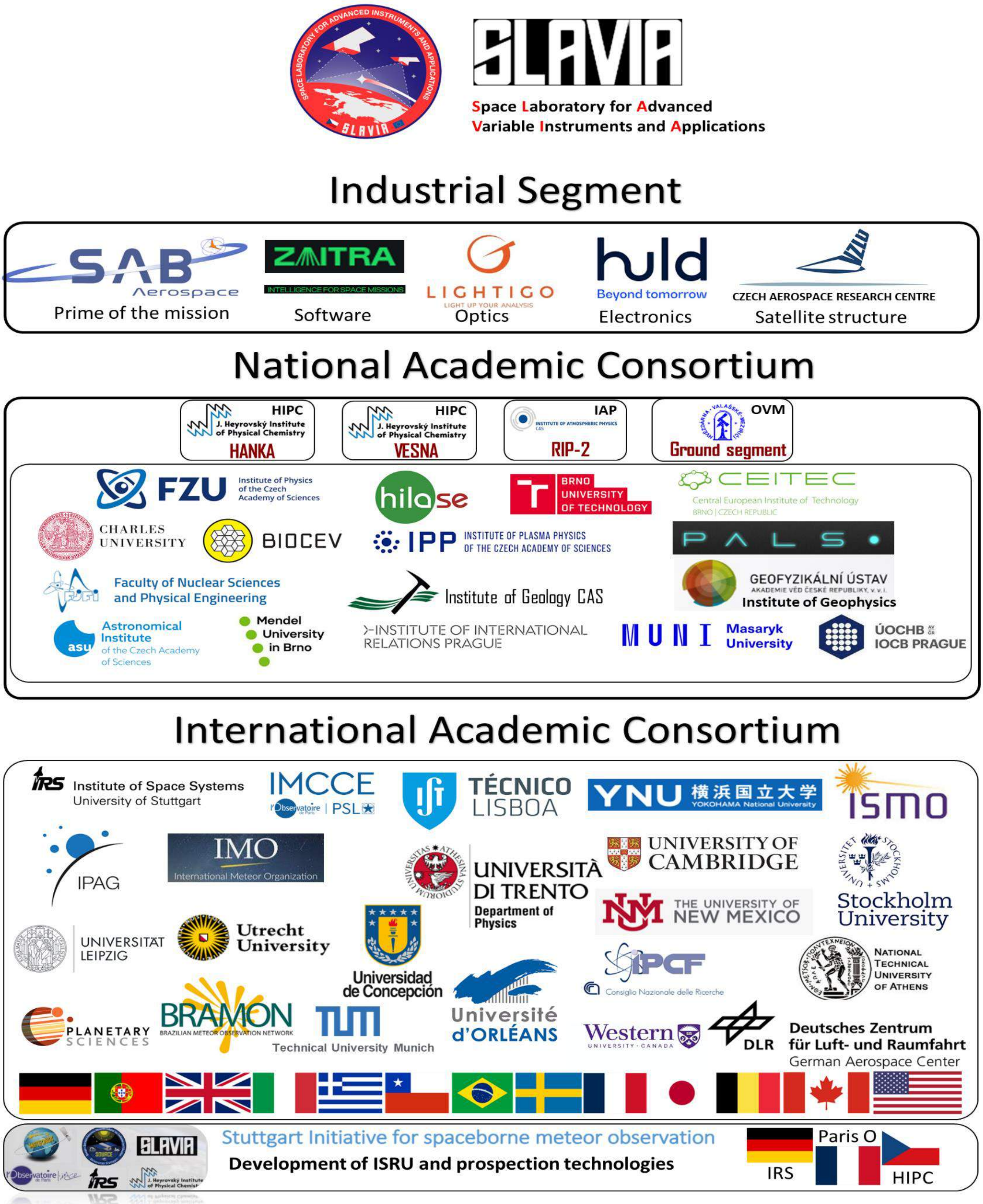
SLAVIA

The Space Laboratory for Advanced Variable Instruments and Applications, SLAVIA, was the name of two CubeSat-type microsatellites designed for the exploration of interplanetary matter. The main goal was demonstrating entirely new technologies for prospecting mineral resources on celestial bodies. The technical part of the mission was led by S.A.B. Aerospace, and the industrial consortium including subcontractors involves a wide range of Czech companies such as VZLÚ, HULD, ZAITRA, Lightigo, and others. The scientific consortium is very broad both domestically and internationally. Our institute is the leader and also responsible for development of hyperspectral camera for observation of atmospheric plasma and meteors (VESNA) and advanced miniaturized mass spectrometer for analysis of interplanetary dust (HANKA). The construction of the antenna system with the Říp-2 analyzer is supervised by scientists from the Institute of Atmospheric Physics. The ground segment is led by the Valašské Meziříčí Observatory, which has a long tradition in meteor spectroscopy. International and domestic cooperation has involved experts from leading institutions and universities. In June 2023, the mission preparation concluded the Feasibility Study. However, the SLAVIA mission was not selected for support under the Ambitious Missions program. Currently, the development of the instrument part is still underway.

Relevant project: ITT3 - Ambitious Project SLAVIA (MTCR and ESA).



To the Treasures of the Universe : The SLAVIA mission was focused on uncovering the treasures above our heads—the knowledge of near-Earth objects such as meteoroids, asteroids, and interplanetary dust, alongside the exploration of natural resources. Key innovations include hyperspectral remote elemental analysis provided by the Vesna camera, high-resolution spectrometry by the HANKA Orbitrap instrument, and plasma surveys conducted by the Říp-2 antenna. SLAVIA involved two satellites, enabling not just spectral analysis and detection, but also ranging through stereoscopic observations. Positioned in Sun Synchronous Orbit, the satellites could orient the HANKA entrance slit towards all primary sources of interplanetary dust streaming toward Earth—from the apparent direction of Earth's movement (Apex), from and opposite the Sun (Helion, Antihelion), and from the north and south (N/S Toroids). The mission was designed by our institute and the Institute of Atmospheric Physics of the Czech Academy of Sciences under engineering leadership of the prime industrial company, the S.A.B. Aerospace and their partners.



SLAVIA Consortium: SLAVIA was, and we hope it will be again in the future, one of the broadest collaborative projects of our institute. The industrial segment was led by S.A.B. Aerospace and funded at the feasibility study stage by the Ambitious mission program (ESA, MTCR). Currently, the development of all the onboard devices continues at our institution as well as at the Institute of Atmospheric Physics for other missions such as IOSLAB Space Rider and VZLUSAT3. In the future, SLAVIA may fly to space.

HyperSpec camera for VZLUSAT3, Space Rider (IOSLAB) and SLAVIA missions

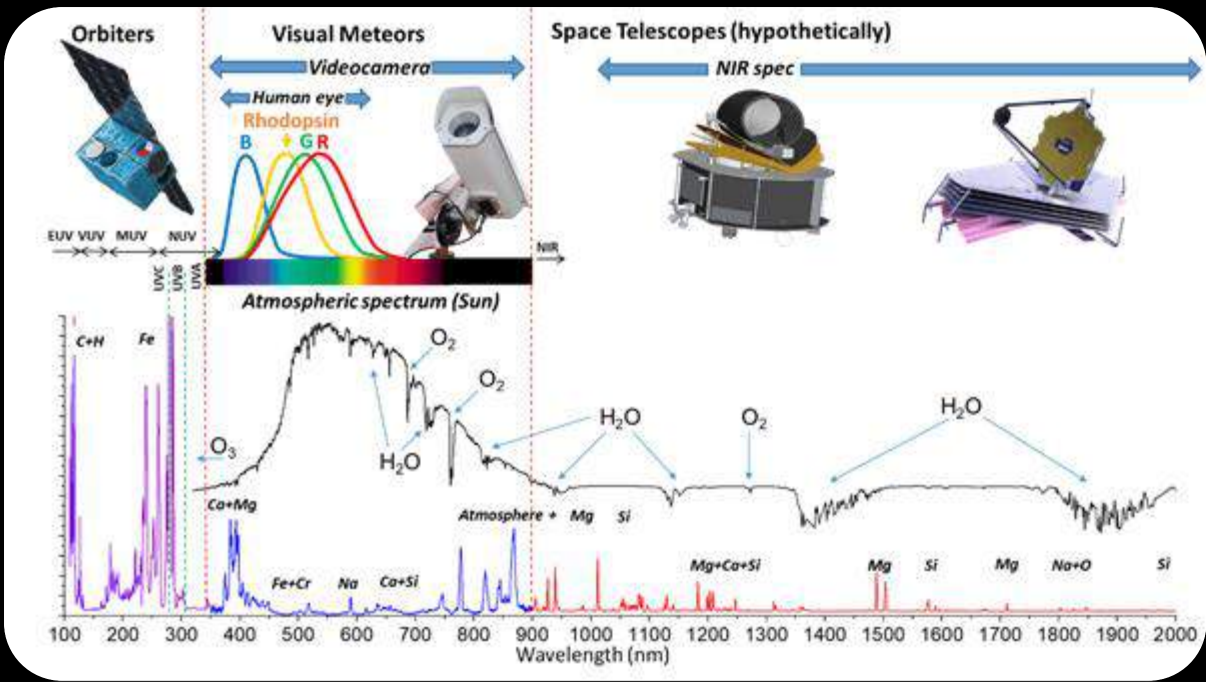
The Hyperspectral Camera (HyperSpec) represents a cutting-edge leap in the field of spaceborne observation technology. The development is now lead by our institute in tight collaboration with the main partners for its industrial development: esc Aerospace, Czech Aerospace Research Center (VZLÚ), HiLASE center of the Physical Institute of the Czech Academy of Sciences and Lightigo Space company. Designed to operate within the ultraviolet (UV) to visible spectrum (200 – 600 nm), HyperSpec will capture and analyze light emitted by plasma events in the Earth's atmosphere. This encompasses a broad array of phenomena, from the atmospheric entries of meteoroids and man-made objects to lightning, Transient Luminous Events (TLEs), auroras, Upper-Atmosphere Phenomena (UAP), airglow, and even human-initiated events such as explosions and rocket launches. The target is to develop a widely applicable off-shell Hyperspectral Camera Device reaching size of max 2U (4U in case of double camera option optimized for two spectral ranges). The primary advantage lies in its ability to observe any region on Earth, providing critical data unobstructed by atmospheric absorption by O_3, O_2, H_2O, and aerosols, especially in the UV range below approximately 350 nm inaccessible by ground-based observation. One of the most significant features of the HyperSpec optical design is an option to extract detailed spectral data from image records. This concept allows for visual stereoscopic recording, which is instrumental in calculating the trajectories of observed objects or phenomena. Through sophisticated fitting processes that involve essential plasma physical parameters such as temperature, electron density, and structure, we can detect and quantify a wide range of atomic, ionic, and molecular species. These include, but are not limited to, Fe, Mg, Ca, Ti, Cr, Si, Mn, Na, Al, Co, Li, Sr, Ni, O, N, Ar, H, N_2, O_2, CaO, FeO, AlO, and others. This comprehensive detection capability enables simultaneous elemental analysis, visual observation, and trajectory tracking of the observed subjects. The development of HyperSpec is part of a stepwise approach to advancing hyperspectral camera technology for space applications. This progression includes several sub-projects of the following instruments:

- **MORANA**: A preliminary version intended for testing and verifying technology in spaceborne or stratospheric conditions. MORANA is slated for deployment aboard stratospheric balloons. The core idea is to qualify the optics combined with an industrial ViS and UV cameras (MORANA ViS and MORANA UV) for spaceborne applications. Currently, MORANA ViS and UV table-top demonstrators are tested in the laboratory and MORANA ViS for stratospheric flights in collaboration with Technecium Center and Spacemanic company.
- **FREYA**: The current focus, a prototype version of the Hyperspectral Camera, is scheduled for development between 2023 and 2026. FREYA is designed as a more advanced and comprehensive tool for spectral observation, building on the foundations laid by MORANA, but designed strictly towards spaceborne application. The camera is now accepted as payload for VZLUSAT3 and IOSLAB platform of the Space Rider missions being under preparation by the Czech Aerospace Research Center (VZLÚ) and S.A.B. Aerospace respectively.
- **VESNA**: A specialized hyperspectral camera, tailored for the spectral observation of visible and UV radiation associated with meteor events. VESNA is intended for deployment in

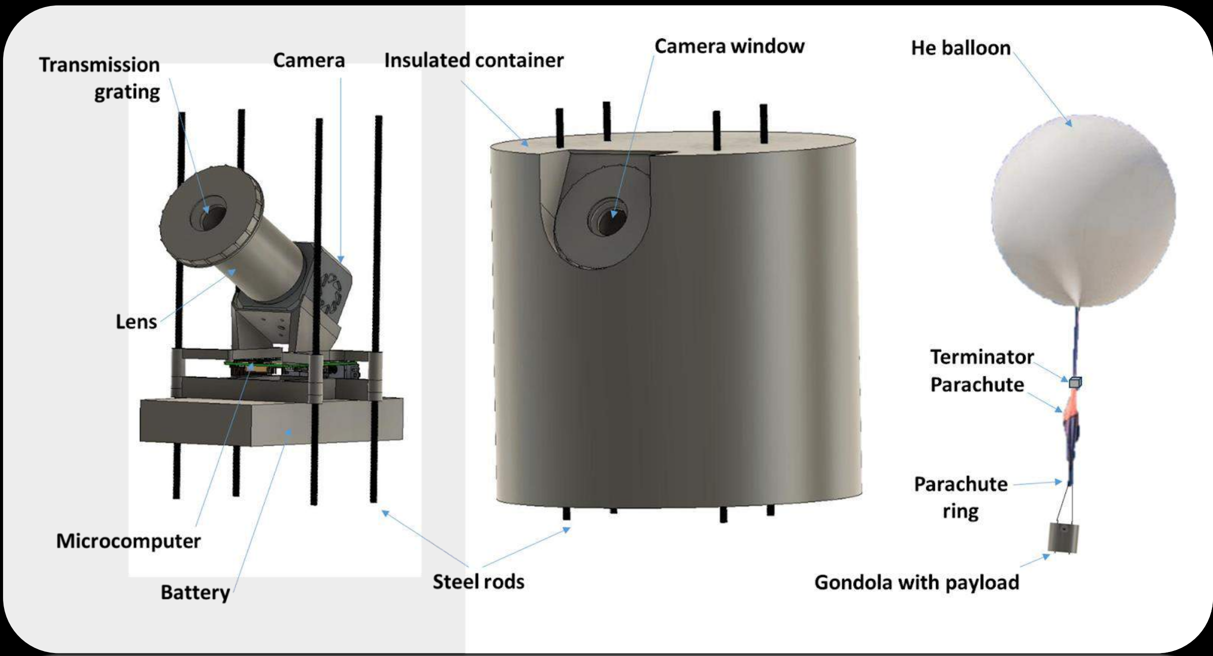
the CubeSat mission SLAVIA, focusing on a more specific application area compared to its predecessors.

The ongoing development of the Hyperspectral Camera represents a significant advancement in spaceborne spectral observation, facilitated by the miniaturized CubeSat platform. This initiative promises to offer groundbreaking insights into a myriad of atmospheric phenomena. Beyond merely showcasing technological progress, this endeavor also facilitates a deeper comprehension of planetary atmospheres and interactions within the space environment.

Relevant project: NCK T002000009/07 Compact optical hyperspectral camera FREYA for CubeSat missions, in collaboration with the Czech Aerospace Research Center (VZLÚ), HiLASE Center of Physical Institute of the Czech Academy of Sciences and esc Aerospace (TAČR).



Why shall we observe meteor plasma from space? The spectrum of Leonid meteor compiled for spectral ranges from UV to NIR shows the regions typically observable by naked eye or ground based videocamera. However, these spectral ranges are limited by atmospheric transmission embedded in the figure. Orbiters allow to overcome this limitation to both UV (likely accessible by a CubeSat equipped with HyperSpec device) and NIR (operated by space telescopes) regions.

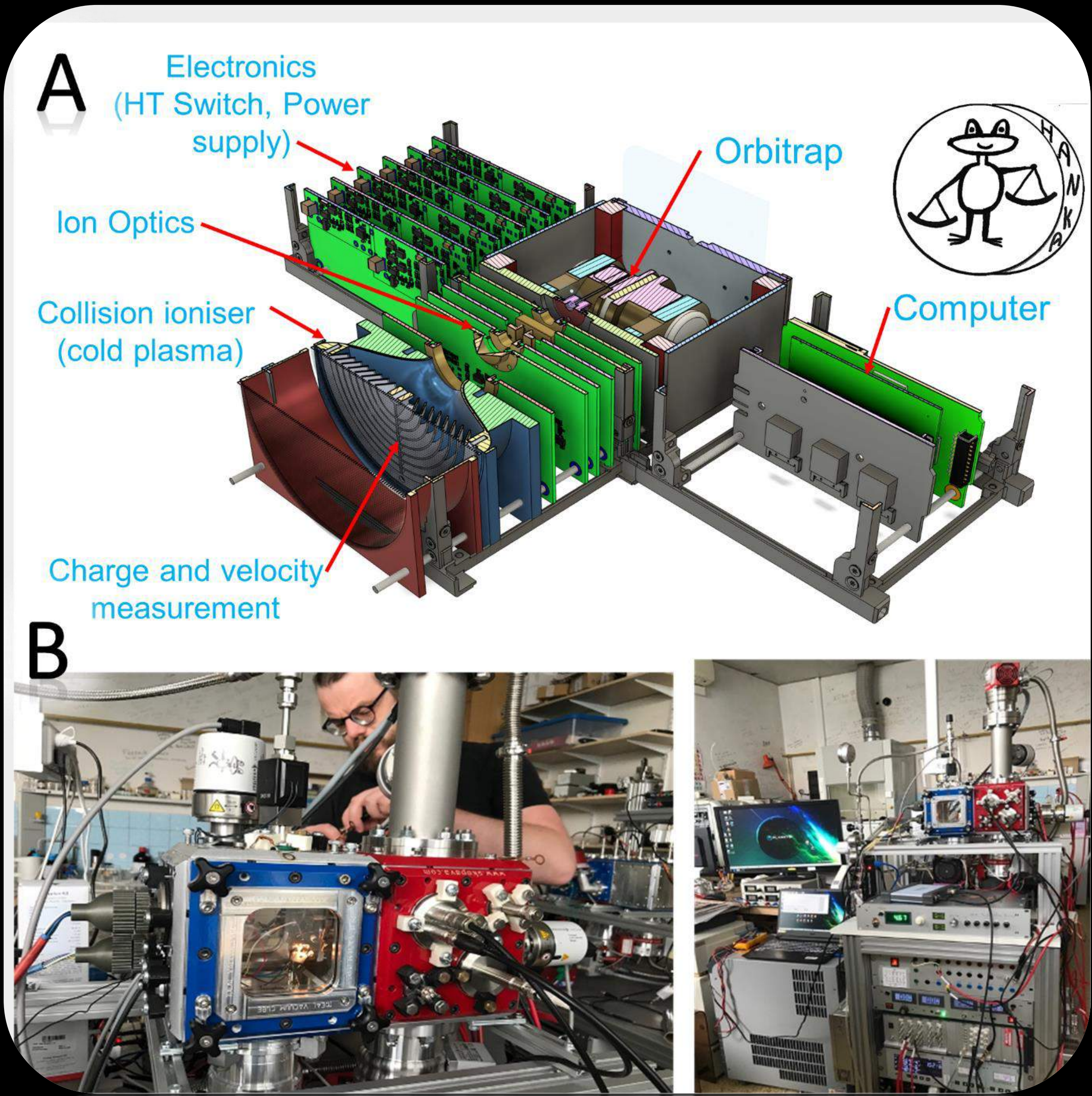


Reaching the Shooting Stars: From an Observatory to a Stratospheric Balloon; From a Balloon to Orbit: The development of the hyperspectral camera for spectral analysis of meteors and other plasmatic events in the atmosphere began seven years ago through a joint effort with the Observatory Valašské Meziříčí, focusing on astronomical spectrographs. This work inspired the SLAVIA mission and led to an independent effort exclusively dedicated to building our own spectrograph. This instrument is widely applicable for any CubeSat mission as an off-the-shelf component. A central intermediate step in this development will be the observation of meteor spectra from stratospheric balloons, scheduled for 2024 in collaboration with Spacemanic, Valašské Meziříčí Observatory and Technecium Center Pardubice.

High Resolution Orbitrap Mass Spectrometer HANKA

The HANKA instrument, a collaborative effort between Czech and European partners, stands at the forefront of space exploration technology, poised to revolutionize our understanding of celestial bodies and resource utilization beyond Earth. Functioning as a high-resolution mass spectrometer, HANKA is specifically engineered to analyze space particles, including complex organic mixtures found on celestial bodies like Saturn's moon Enceladus. What sets HANKA apart is its innovative design, integrating cutting-edge technology. HANKA's operational principle involves capturing particles on a rotating target and subsequently ionizing them using laser ablation or other methods like collisions with Cs^{+} ions or electron beams. Once ionized, the particles produce a cold plasma that is optically analyzed to determine the elemental composition. Additionally, the plasma ionizes the molecules in the sample, which are then identified using a high-resolution mass analyzer. This comprehensive approach enables HANKA to provide detailed molecular and elemental compositions, offering insights into the geological and chemical makeup of celestial bodies.

The instrument's development represents a significant leap forward in space instrumentation, with the potential to advance our understanding of planetary surfaces and their mineral resources. Its compact size, weighing only 5 kg and consuming 25 W, makes it suitable for deployment on CubeSat spacecraft or other space probes, facilitating in-situ exploration and resource mapping. Moreover, HANKA's multidisciplinary team of scientists and engineers ensures the successful integration of its complex technologies, paving the way for future breakthroughs in space exploration and resource utilization.



Unique Solution for a Mass Spectrometer: Can you imagine a highly precise mass spectrometer, based on revolutionary technology and a novel physical principle, that's compact enough to fit inside a shoebox? This device offers unprecedented resolution, enabling the detection of molecules, elements, and their isotopes. It's versatile enough to be sent into space aboard a fleet of inexpensive CubeSats, or mounted on any fleet of rovers exploring the surfaces of Mars or the Moon. Such a device is nearing completion in the laboratories of our institute and is poised to become a cornerstone of both scientific and industrial projects.

LILA

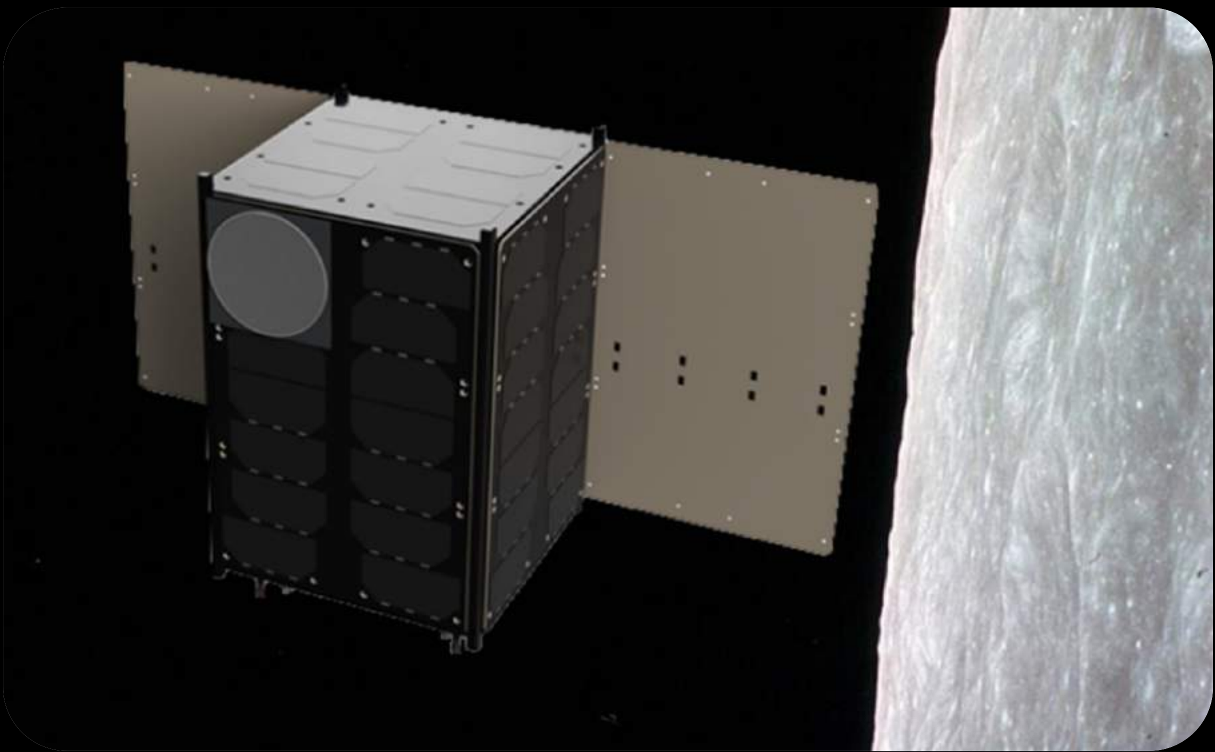
The LILA concept aims to revolutionize space material analysis by developing an innovative method for instant and reliable remote characterization of rock composition during planetary exploration. It involves the integration of laser ablation mass spectrometry (LAMS) provided by HANKA instrument and laser-induced breakdown spectroscopy (LIBS) into a single payload, known as LILA, with shared laser sources and advanced mass spectrometers. By adapting these techniques to vacuum conditions, LILA will enable comprehensive elemental and molecular analysis of captured samples, surpassing current state-of-the-art capabilities. Through laboratory testing and the implementation of novel machine learning algorithms, LILA promises rapid and accurate analytical information, critical for in-situ resource mapping on lunar rovers or asteroid landers. The combination of LIBS and LAMS data will provide detailed insights into rock composition, including mineral distribution and the detection of otherwise invisible minerals. These breakthrough capabilities hold immense potential for advancing planetary exploration and in-space resource utilization efforts, aligning closely with the goals of enabling breakthrough technologies and strengthening European scientific excellence in space exploration. The concept of the rover equipped with the LILA system is currently under development in collaboration with the team from the Czech Technical University. The LIBS as well as orbitrap MS is being developed in wide collaboration with our industrial and academic partners.

Relevant project: 23-05186K Characterization of laser-induced plasmas under simulated conditions of selected celestial bodies, in collaboration with the Czech Technical University in Brno, CEITEC and Federal Institute for Materials Research and Testing, Berlin (GAČR-DFG).

Rover LILA - From Resource Prospection to a Wealth of Knowledge: Our concept introduces the LILA system, a rover equipped with an arm that houses the high-resolution orbitrap mass spectrometer, HANKA. This arm can extend to reach the surface and nearby stones. The sample is ablated by a laser, and the resulting emission spectra are recorded for bulk analysis using LIBS (Laser-Induced Breakdown Spectroscopy). Simultaneously, the atomized and ionized material is captured by ion optics and subjected to mass spectrometric analysis in the orbitrap, which, thanks to its extremely high resolution of 50,000, enables the detection of trace volatiles, elements, isotopes, organics, and more.

LADA

The mission was planned to address several important problems supporting the Terrae Novae program, including exploring the Moon’s resources and scientific challenges, understanding the Moon’s environment, and contributing to new technologies. To accomplish these objectives, the CubeSat platform (12U Corvus) will be equipped with the high-resolution orbitrap mass spectrometer HANKA. HANKA (Hmotnostní ANalysátor pro Kosmické Aplikace) is a high-resolution orbitrap mass spectrometer dedicated to exploring the lunar dust cloud in the Low Lunar Orbit (LLO) with a resolving power of up to R=50,000. This instrument is pivotal in exploring both the quantitative and qualitative characteristics of the lunar dust cloud, including particle mass, distribution, dynamics, concentration, and detailed chemical, mineralogical, and isotopic compositions. Key challenges addressed by the LADA mission utilizing HANKA include hazard evaluation for lunar orbital operations and the formulation of strategies for lunar exploratory endeavors, particularly for in-situ resource utilization. The mission is poised to enhance our scientific understanding of lunar origin and geologic processes, assisting in the identification of viable targets for future missions. Aligned with the European Space Agency's (ESA) lunar exploration goals, LADA aims to reinforce Europe's role in space exploration, supporting the objectives of the Artemis program and laying the groundwork for Martian exploration initiatives. The mission was developed in collaboration with Spacemanic company; however, it was not selected under the ESA Idea Program.



With LADA to the Moon - Introducing a New Lunar Satellite Concept: We have recently developed a concept for a lunar satellite that orbits the Moon, analyzing the lunar dust cloud. This mission, in conjunction with the LILA lunar rover, introduces another application of the HANKA orbitrap mass spectrometer.

Touch the (Exo)Planets

Touch the (Exo)Planets – The Exhibition

Just a few decades ago, there was no scientific evidence that planets existed around other stars. Alien worlds were vividly described only in science fiction novels. During the era of the JWST space telescope, followed a few years later by the Ariel telescope, we bring some distant worlds within your reach. You can view them as real star travelers—seeing planets and exoplanets, their surfaces, and even exploring their mineralogical and rock compositions. Your journey begins with an introduction to the cosmic telescopes of the future: JWST and Ariel. You will examine meteorites and primitive minerals—from similar materials, planets are formed in nebulae, and you will travel in time to a completely foreign, different, yet so close world—the early Earth. Your journey concludes at fantastic worlds, about whose shape and existence humanity had no idea just a few decades ago.

Wishing you a pleasant journey, authors Martin Ferus and Libor Lenža, along with everyone without whom the exhibition could not have been created: master carpenter Jaroslav Prchal, geologist Jiří Špalek, master of 3D printing and graphic designer David Černý, glassmaker Ivan Černý, colleagues Lukáš Petera, Antonín Knížek, and others from and beyond the teams of the Department of Spectroscopy at ÚFCH JH and the Valašské Meziříčí Observatory. Special thanks to the management and staff of Děčín Castle for providing the space, and immense help with the preparations and organization.

Enjoy the journey around the distant worlds and don't hesitate to touch!

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What will you see?

Among the instruments developed at our institute and the space missions we participate in, the exhibition displays planets that you can touch, complete with surface relief and specimens of minerals and rocks that represent their expected composition. It should be highlighted that we still do not know enough about distant worlds to present more than scientific expectations combined with artistic license. The following paragraphs will provide translations of the legends and descriptions of the exhibited items. May this serve as a memory of your visit to this unique exhibition.

1. **Ariel and SLAVIA mission:** We are displaying a model of the SLAVIA satellite, assembled from Lego during the mission's preparation. This model has served as a tool for discussions over mission design and strategy. Scientists often say they play with toys; this is a real toy that has served sophisticated purposes. At the exhibition, you can also see a life-size model of SLAVIA, featuring a meteor hyperspectral camera VESNA lens at the bottom, the entry of the orbitrap spectrometer HANKA on the side, and a set of antennas from the Říp-2 radio detection system. Additionally, a small demonstrator also illustrates the strategy of meteor observation performed by our institute in collaboration with the Observatory Valašské Meziříčí—ground-based meteor spectrography from the observatory, a stratospheric balloon on a mission at the same altitude where most bolides end their visible atmospheric trajectory, and a SLAVIA satellite tandem in orbit.
   Ariel Mission: A model of the Ariel space telescope, manufactured from a 3D printer, is displayed alongside another model that shows its size in comparison to the JWST. As can be seen, Ariel is smaller, but the benefit of this mission lies in its strict focus solely on exoplanets, which allows it to record data for the characterization of environmental conditions of over 1000 exoworlds.

2. **The first Czech Cosmonaut:** "Hello, Vladimír!" echoed through the Flight Control Center in Korolyov, Moscow district. From the screen, the first Czechoslovak astronaut, Vladimír Remek, greeted his colleague Oldřich Pelčák with a friendly wink from aboard the space

station Salyut 6, accompanied by three Soviet colleagues. "Hello!" he replied. It was 1978. On Thursday, March 2nd, at 4:30 PM Central European Time, the Soyuz rocket launched spacecraft number 28. Aboard were Soviet cosmonaut Alexei Alexandrovich Gubarev and Czechoslovak cosmonaut Vladimír Remek. Czechoslovaks became the third nation in history to send an astronaut into space. The crew joined their colleagues on the Salyut 6 space station, and Remek brought along a practical gift: a dental drill. The Soviet astronaut program aimed to strengthen friendly relations among socialist countries. It quickly expanded to include Soviet allies and other nations, with representatives from 19 countries participating in 26 flights by 1996, including American astronaut Norman Thagard in 1995. Despite the undeniable national and global success of Czechoslovak science, it is important to acknowledge the darker aspects of that era: thousands of political prisoners watched Remek's flight from their cells, and Czechoslovakia had been occupied by the Soviet army just ten years earlier. Public protests human rights violations were brutally suppressed by the communist regime.

3. **Early Minerals:** The universe began with the Big Bang, as often stated in lectures. What followed was the formation of protons and electrons from highly energetic photon collisions, leading to the creation of neutrons and the first light atomic nuclei: hydrogen, helium, lithium, beryllium, and boron. As the early universe rapidly expanded and cooled, there wasn't enough time or energy for further atomic nucleus formation. However, a few hundred million years later, the first stars began to form. Within these stars, under intense heat and pressure from gravity, elements continued to form. Supernovae and neutron star collisions then dispersed nearly all the elements found in the periodic table into space, giving rise to primordial minerals such as diamond, graphite, moissanite, and others. These minerals scattered into interstellar dust clouds, from which new stars and planets formed. Through processes like annealing, melting, crystallization, and the action of water, more minerals and rocks formed during the development of interplanetary dust, asteroids, planetesimals, and planets. Meteorites provide samples of interplanetary material, each with diverse origins. Carbonaceous chondrites are minimally altered aggregates of original interstellar dust. Metallic meteorites originate from the cores of shattered small asteroids, while achondrites come from their crusts. Lunar and Martian meteorites were ejected to Earth by large asteroid impacts on their surfaces. Categorizing meteorites is complex, depending on their origin and formation process, as illustrated in the graphic overview below.

4. **Early Hadean Earth:** In 1956, radioactive element dating provided a crucial answer about Earth's development: its age. American geochemist Clair C. Patterson determined it to be 4.55 billion years old, with a margin of ± 70 million years. This age is about one-third the age of the entire universe. From a primordial nebula in the Milky Way's frigid interstellar space, the Sun and thousands of other stars formed in a stellar nursery. This region likely began collapsing due to a shockwave from a nearby dying star's explosion, sparking new life. Over tens of millions of years, instabilities in the rotating gas-dust disk around the young Sun led to the creation of rocky and gaseous planets. Initially, there were likely more planets, but some were ejected from unstable orbits, helping to stabilize the remaining eight planets. One rogue planet, Theia, collided with Earth's embryo, forming the Moon and shaping Earth as we know it. Early Earth's atmosphere was thick and suffocating, composed of carbon dioxide, superheated steam, hydrogen, and mineral vapors. Its surface was covered with lava fields, volcanoes, and impact craters. The lack of liquid water and plate tectonics limited the variety of minerals and rocks, which were primarily volcanic, including

anorthosite (gabbro), basalt, pegmatite, and komatiite. Initial minerals like analcime, stilbite, topaz, and beryl formed through rock melting. Earth resembled a cauldron of lava with a thin crust. The oldest terrestrial rocks, from Acasta Gneiss in Canada, date back to about 4 billion years, marking the Hadean eon, devoid of typical fossil evidence. However, resilient zircons from this time, dating up to 4.4 billion years, reveal the story of Earth's early oceans and the emergence of life. Erosion and later tectonic processes have erased much of this early surface. Clues about Earth's early history also come from studying lunar meteorites. A sample from Apollo 14, breccia 14321 or "Big Bertha," likely contains terrestrial meteorites about 4.1 billion years old, including basalt, orthoclase, labradorite, and olivine.

5. **Late Hadean Earth:** Liquid water appeared on Earth 4.325 billion years ago under extreme conditions: pressures over 200 bars and temperatures above 300°C. Despite the harsh environment, life began. As Earth cooled, it featured volcanoes, impact craters, rivers, lakes, and hydrothermal regions. Volcanic rocks and minerals altered by water formed new minerals through hydrothermal activity and evaporation. The Blue Planet was a volcanic world, marked by volcanoes, impact craters, and cracks in the Earth's crust, with numerous hydrothermal regions, rivers, and lakes. Volcanic rocks such as gabbro, komatiite, anorthosite, and volcanic minerals were altered by water, leading to the formation of new minerals through hydrothermal activity (sphalerite, stibnite, nickeline, galenite, hedenbergite, phlogopite) and evaporation (evaporites, ulexite, gypsum, colemanite, barite). Indirect evidence suggests life might have existed 4.1 to 4.28 billion years ago, but how it emerged remains a mystery. One theory is that organic compounds in hot craters formed RNA chains in the presence of catalytic metals and porous minerals. Repeated cycles of hydrothermal activity and flooding helped these chains reproduce and evolve into complex chemical systems, eventually giving rise to primitive bacterial cells. Other theories propose life began at volcanic sites or deep-sea hydrothermal vents. The exact origins remain uncertain.

6. **Archean Earth:** Earth has always been a planet of volcanoes, dynamically shaping and reshaping the landscape. Volcanic activity creates and destroys, fostering a fragile stability suitable for life. During the Archean eon, Earth resembled barren regions like modern Iceland, deserts, or volcanic plains. Volcanic and igneous rocks (diorite, granite, granodiorite) and metamorphic rocks (cordierite, kyanite, amphibolite) dominated the landscape, shaped by impacts, volcanoes, wind, and water erosion. The atmosphere lacked oxygen, evidenced by pyrite pebbles from South Africa, which would erode quickly if exposed to air. Methane smog gave the sky an orange hue. While oceans teemed with primitive single-celled life, land was barren. Coastal and deep-sea hydrothermal vent areas hosted colonies of bacteria, including stromatolites, with fossils dating back 3.7 billion years found in Greenland. These microbes used simple chemicals (carbon dioxide, nitrogen) for energy, producing methane, hydrogen, or hydrogen sulfide. Over a billion years later, photosynthesizing organisms revolutionized energy acquisition, producing oxygen and turning Earth red by oxidizing iron in rocks, creating minerals like hematite. This oxygenation led to the Great Oxygenation Event, causing a global ice age. Eventually, Earth thawed, and the oxygen-rich atmosphere formed an ozone layer, protecting life from UV radiation, allowing it to colonize land and thrive everywhere. The fine-tuning of the universe for life and Earth’s suitability as a haven for it raises questions of coincidence, natural law, or something more profound.

7. **Modern Earth and Moon:** Despite changing views on Earth's uniqueness, exoplanet studies suggest Earth is indeed exceptional. Earth provides a stable environment at a suitable distance from its star, with its rotation axis stabilized by the Moon, preventing it from tipping over. Plate tectonics drive element cycles, influencing global climate and magnetic field stability. Unlike extreme planets like Mars or Venus, Earth features a rich variety of rocks and minerals, from common types like basalt and granite to rare metal ores and gemstones. The International Mineralogical Association has identified 5,327 mineral types, forming rocks through various geological processes. About three-quarters of Earth's surface rocks are sediments, 15% are volcanic, and the rest are metamorphic, shaped by high pressures and temperatures related to tectonic activity. Volumetrically, 65% of Earth's rocks are volcanic, 27% are metamorphic, and 8% are sedimentary. Earth's surface diversity results from processes like water, wind, and tectonics, unlike Venus and Mars, where other processes dominate. Venus experiences intense thermochemical weathering due to its hot atmosphere, while Mars is shaped by winds, frost, UV radiation, and salt solutions. A detailed study of other planets might reveal unique minerals and rocks not found on Earth. Common Earth minerals include feldspars (alumosilicates), quartz (silicon dioxide), calcite, aragonite (calcium carbonate), and clays like kaolinite. Volcanic rocks include basalt (plagioclase, pyroxenes, and olivine), its intrusive equivalent gabbro, and granite (quartz and feldspar), typical of the continental crust. Pyroxenes like enstatite, augite, diopside, and micas like muscovite and biotite, are also prevalent.

8. **Mars**: It has always intrigued humanity. Its red color linked it with war gods across ancient cultures: the Babylonians named it after Nergal, Greeks called it Pyroeis, and Romans named it Mars, their god of war. In the late 19th century, astronomers like Giovanni Schiaparelli and Percival Lowell believed Mars had oceans, mountains, forests, and even canals built by an advanced civilization. However, these were optical illusions, and by the early 20th century, spectral observations revealed Mars as a cold desert with a thin atmosphere, rich in iron oxides giving it its red color. The surface pressure is 130 times lower than Earth's, and while liquid water has been confirmed, methane detections and potential fossilized cyanobacteria in Martian meteorites suggest possible microbial life. Mars is a vast desert, though water has existed there. The Mariner 9 mission in 1971 found ancient river valleys, indicating liquid water was present around 3.8 billion years ago, concurrent with early life on Earth. Today, water exists as subsurface ice and underground lakes, with seasonal flows observed by the Mars Reconnaissance Orbiter in 2006. Mars's red color is due to iron-rich minerals. Its surface includes basalt and andesite, hematite, magnetite, siderite, and goethite, indicating past water activity. Volcanic minerals like feldspars, enstatite, albit, chromite, anorthite, apatite, and diopside, alongside minerals formed by water like halite, talc, calcite, quartz, and chlorite, are found on Mars. Sulfur is abundant, constituting about 6% of the Martian surface, compared to 0.03-0.09% of Earth's crust. Sulfates like gypsum, magnesium sulfate, and iron sulfates make Mars's surface potentially salty and toxic. The salt content questions the feasibility of growing food on Mars, as depicted in the movie "The Martian."

9. **Venus:** The second planet from the Sun, appears close to the Sun in the sky and is visible either as a morning star (before sunrise) or an evening star (after sunset) when it reaches its greatest elongation. Occasionally, Venus passes between Earth and the Sun, appearing to transit across the Sun's disk. In 1761, Russian physicist Mikhail V. Lomonosov discovered Venus's atmosphere by observing light refraction, sparking speculation about life on the

planet. In 1854, British thinker William Whewell speculated about a tropical paradise on Venus, and in the early 20th century, astronomer Charles Abbot sought spectral evidence of water and oxygen. As late as 1955, Soviet astronomer Gavril Tikhov reported observing vegetation. However, in 1962, the American Mariner 2 probe revealed Venus as a volcanic world with a dense, toxic atmosphere dominated by carbon dioxide and sulfuric acid clouds, crushing pressure, and surface temperatures hot enough to melt lead. Venus's surface is younger than Earth's, likely due to ongoing volcanic activity. Some speculate that Venus once had liquid water, oceans, and continents, but a cataclysmic event around 600 million years ago triggered massive volcanic activity, irreversibly heating the planet. Now, 90% of Venus's surface consists of lava plains, shield volcanoes, and flat volcanic domes, with rare stratovolcanoes. The surface's low density, comparable to sandstone, suggests a pyroclastic origin, with materials like basalt and conductive minerals such as hematite, magnetite, and pyrite indicated by radar reflections. Geochemists theorize chemical reactions between Venus's hot atmosphere and surface produce stable minerals like gypsum, albite, cordierite, enstatite, quartz, and hematite, aligning with the atmospheric composition and maintaining surface-atmosphere chemical equilibrium.

10. **Titan:** Research probes have successfully landed on only four major bodies in the Solar System: The Soviet Luna 9 probe made the first smooth landing on the Moon in 1966, Venera 7 touched down on Venus in 1970, transmitting data for 23 minutes, Viking 1 landed on Mars in 1976, and in 2005, the Huygens probe landed on Saturn's moon, Titan. Titan is a peculiar world. It is the only other body in the Solar System, besides Earth, with a thick atmosphere primarily composed of nitrogen (N_2). The surface pressure is 1.5 times that of Earth's, but similarities end there: Titan's surface temperature is -183°C, and its oceans are composed of 70% liquid methane, 14% ethane, and 16% liquid nitrogen. The land, consisting of water ice and rock, covers about a fifth of the surface, with a suspected subsurface ocean of water. These conditions may resemble early Earth when crucial chemical compounds for life were forming. Huygens' landing photos revealed a landscape with seas, mountains, and plains scattered with strange round boulders. From a distance, Titan appears bluish with ochre-red cloud layers. Titan's rocks are thought to resemble primitive carbonaceous chondrites, ancient meteorites from early Solar System asteroids that have remained largely unchanged. The model of Titan's landscape primarily depicts the terrain and colors rather than its mineralogy or chemical composition, as liquid hydrocarbons and toxic cyanides cannot be safely displayed at Earth temperatures.

11. **51-Pegasi b:** The first exoplanet discovered and confirmed in 1995 by Michel Mayor and Didier Queloz orbits a main-sequence star. These scientists received the Nobel Prize for this discovery in 2019. The atmosphere of hot Jupiters is primarily composed of hydrogen with about 10% helium. Surprisingly, water vapor has also been detected in Dimidium's atmosphere, likely on the planet's cooler side, along with traces of carbon monoxide. The atmospheres of hot Jupiters contain clouds primarily made of quartz (silicon dioxide), which, when tinted brown by iron impurities, can be seen in the displayed model. Glass sand is also displayed to illustrate the composition of upper atmospheric clouds where cooled quartz melt forms a solid aerosol (dust clouds). Hot clouds of molten quartz are present in the lower, hotter atmospheric layers. Additionally, vapors of sodium, potassium, and iron are found in the atmosphere, with these metals exhibited preserved in kerosene and benzene to prevent air moisture contact, as they react violently with water to form sodium and potassium hydroxides. Spectral analysis of Dimidium has also revealed titanium dioxide,

present on Earth as rutile and anatase. In Dimidium's hot atmosphere, titanium monoxide (TiO) was discovered, representing an unstable binary compound of titanium and oxygen. The atmospheres of gas giants also contain phosphorus, displayed as red phosphorus, which, along with other forms (black and white phosphorus), likely contributes to the colorful bands seen in gas giant atmospheres.

12. **Proxima b:** Nature offers countless surprises, one of which is the existence of an Earth-like planet orbiting our closest star, Proxima Centauri, in the constellation Centaurus, 4.25 light-years away. Proxima, along with stars Rigil and Toliman, forms the Alpha Centauri system. From the surface of the planet, one could witness an amazing view of three suns, although Rigil and Toliman would appear as very bright points in the sky. Current space probes would take over 80,000 years to reach Proxima. What makes a planet habitable? We are on the brink of discovering answers with upcoming space telescope missions like the JWST and Ariel, which will confirm or refute the hypothesis that the presence of liquid water on planets is defined by the habitable zone.
    What might Proxima b look like? We know its year lasts only 11 days. Proxima b is likely colder than Earth, with an equilibrium temperature of 234 K, which falls within the range for liquid water (175 – 307 K) and is close to Earth's 255 K. Proxima b is probably a very cold planet, predominantly covered in water ice. Its surface is likely composed of basalt and gabbro, with sands and erratic boulders carried by glacial flows. While equilibrium temperature alone may not reveal such details, large space telescopes might. For instance, Venus has an equilibrium temperature of 260 K, yet it is extremely hot due to its atmospheric composition and greenhouse gases.
    Earth itself has experienced vast climate changes: it was a tropical paradise for tens of millions of years during the age of dinosaurs and later became a hot steppe. Before the era of trilobites, Earth was completely frozen. The potential habitability of Proxima b, therefore, depends not only on its equilibrium temperature but also on the specifics of its atmosphere and other environmental factors.

13. **Trappist-h:** In the constellation Aquarius, 39 light-years from Earth, lies a miniature system surrounding a red dwarf star. The star, Trappist-1, is about one-tenth the size of our Sun and has roughly one-third of its surface temperature. Seven planets orbit it at distances much closer than that between Earth and the Sun. The surface of these oceanic planets is likely covered with ice, similar to Jupiter's moon Europa or Saturn's moon Enceladus. Despite the extreme cold of space (e.g., Europa's poles reach -220°C, below nitrogen's freezing point), the interiors of these moons and planets are warm due to residual accretion heat and radioactive decay, similar to Earth. When a planet is cold on the outside but warm inside, surface ice melts at the interface, forming a crust that periodically cracks and refreezes. This creates deep valleys and, occasionally, cryovolcanoes that emit water, steam, and gases instead of molten rock. These cryovolcanoes provide valuable insights into the subsurface composition. Probes analyzing water plumes from Europa and Enceladus found that the subsurface oceans are alkaline, containing sodium chloride (table salt) and sodium bicarbonate (baking soda) at concentrations of 1-3%. Dissolved gases such as ammonia, hydrogen, carbon dioxide, methane, and trace argon were also detected. Geochemical evidence suggests these icy oceans are in contact with rocky seabeds, likely composed of basalt, gabbro, and dolerite, similar to Earth's ocean floors. The presence of hydrogen indicates serpentinization processes, where minerals like fayalite, ferrosilite, and forsterite in olivines and pyroxenes react with water, producing magnetite, quartz, and hydrogen.

These reactions occur at temperatures of several hundred degrees Celsius and pressures of several hundred atmospheres. In deep oceans, pressures increase by 100 atmospheres per kilometer of water depth, easily achieving the necessary conditions for serpentinization. The oceans on Europa, Enceladus, or Trappist-1h could reach depths of tens of kilometers, far exceeding the depth where the Titanic wreck rests.

14. **Gliese 832 c:** Is a super-Earth really better than Earth? Perhaps, but living there might not be so "super" for us. On the surface of Gliese 832 c, we would weigh 2.4 times more than on Earth. Imagine becoming almost a 200-kilogram giant. We might survive, but... A super-Earth is not a planet superior to Earth but rather one that is larger. Consequently, these planets have stronger gravitational fields, which can negatively affect their habitability, potentially leading to high atmospheric density and surface temperatures. However, this doesn't rule out the possibility of some form of life existing there. Future observations by space telescopes like JWST and Ariel may reveal more. Currently, we know very little about the rock and mineral composition of exoplanets. We can only speculate that natural processes on exoplanets are similar to those on Earth. On the super-Earth Gliese 832 c, we might expect volcanic rocks such as basalt, dolerite, and gabbro, typical of oceanic crust, and granite, forming the continental crust on Earth. Some scientists believe that super-Earths might lack plate tectonics, meaning their rock and mineral cycles could be limited, making their surfaces geologically simpler than Earth's. The initial conditions of exoplanet formation, such as their distance from their parent star and the resulting pressure and temperature within, also determine their rock and mineral composition. The universe may be rich in various types of planets and their surfaces, rocks, and minerals. Will we find rocks and minerals similar to Earth's or entirely different? Laboratory experiments simulating extreme conditions with diamond anvils or powerful lasers can provide clues. Spectral analysis of the exoplanet LHS 3844b, which is very close to its star with surface temperatures exceeding 1000°C, revealed lava similar to the lunar maria or Mercury's plains. This suggests that rock and mineral compositions in exoplanetary systems might be similar to those in our Solar System. Therefore, we modeled the surface of Gliese 832 c to resemble Earth's volcanic regions.

15. **Kepler 22b:** The planet is located 620 light-years away, orbiting a star slightly smaller than the Sun in the constellation Cygnus. It completes an orbit in 290 Earth days. As a super-Earth, its radius is 2.4 times that of Earth. Scientists believe that its surface might consist of low-density materials, suggesting a thick atmosphere or a vast ocean. On an ocean planet, one could expect minerals and rocks typical of Earth's oceanic crust, such as basalts, gabbro, and its deep-sea equivalent dolerite—a dark, coarse-grained rock rich in amphibole and biotite. Theoretical models suggest that the atmosphere of ocean planets mainly consists of water vapor (90%), carbon dioxide (5%), and ammonia (5%). Earth's oceans are composed of 97% sodium chloride, with a salinity of about 3.5%. However, the Dead Sea, Earth's saltiest body of water, contains up to 34.2% salts, primarily magnesium chloride (50.8%), sodium chloride (30.4%), calcium chloride (14.4%), and potassium chloride (4.4%). This variation indicates that the exact composition of ocean water on exoplanets could differ based on their salinity, surface composition, and atmosphere. Carbon dioxide and ammonia in the atmosphere are soluble in water, forming ammonium hydroxide and carbonic acid solutions, which can react to produce various salts. For an atmosphere with these gases to remain stable, it must be in equilibrium with the ocean chemistry and surface composition; otherwise, the atmospheric composition would change over time.

16. Sputnik: On October 4, 1957, at 10:28 PM local time, the engines of the R-7 rocket roared to life at the Baikonur Cosmodrome in the Kazakh steppe, launching Sputnik 1 into space. Its designer, Sergei Korolev, referred to it as the "Simple Satellite" (Простейший Спутник-1). Deviating from the original plans, Sputnik was not equipped with scientific instruments and served as a technological demonstrator. Despite this, its launch marked a clear first in the intensifying Cold War, causing hysteria in the USA. For scientists and the public, it symbolized a technological triumph and a significant step in space exploration. Sputnik 1 orbited Earth every 96 minutes on a highly elliptical path (apogee at 939 km and perigee at 215 km). Contact was lost on October 26, 1957, and the satellite burned up in the atmosphere on January 4, 1958. Interestingly, in September 2013, Voyager 1, launched in 1977, exited the Solar System. However, records from a high-speed camera during a nuclear test on August 27, 1957, indicate that a metal plate cover was ejected into space at 55.5 km/s, potentially making it the first human-made object to leave the Solar System long before Voyager 1 and 2.

Lectures

Solar System exploration missions and space instrument developments: Outlook for the future

Jean-Pierre Lebreton

LPC2E (CNRS-UO-CNES), Orleans, France

The time span from initial idea to launch of Large ESA planetary missions (e.g. Rosetta-early 90's to 2004; JUICE -Mid2000 to 2022; and the newly advertised L4 mission - priority target Enceladus for launch in mid-2040 takes 20-25 years or more and a further 10-15 years of flight operations. The most ambitious L4 mission architecture may include an orbiter and a lander. It's time to prepare concept studies and early development of instruments for the L4 mission. The family of Orbitrap-based space instruments under development, offers a great potential for making discoveries. The cubesat-sized HANKA is one such example. Early opportunities for space demonstration should be pursued. Close collaboration between instrument developers and industry is key to success.

Space Chemistry and Technology: Connecting Excellence in Academia with Industry

Bernd Abel

of Chemical Technology, University Leipzig

In the contribution we will briefly highlight 3 examples of the activities of the Abel group in collaboration together with international groups and companies in Germany, Czech Republic, and USA, that are relevant for Space Chemistry and Technology in the near future.

· Laboratory analogue experiments generating libraries for past, present and future space missions, such as CASSINI, JUICE, and the upcoming Europa Clipper. The role of new instrumental developments as future enabling technologies.

· Cooperation on satellite technology/chemistry with DLR and OHB (Germany)

· Role and possibilities of academic spin-offs for future space related technologies

The overview will show how instrumental Physical Chemistry may be the key to open the gateway to space in the future, and it is explicitly intended to stimulate further discussions with interested participants of the meeting from academia and industry.

The List of Participants

Abel	Bernd	bernd.abel@uni-leipzig.de
Adam	Vojtěch	vojtech.adam@mendelu.cz
Baudisch	Miroslav	miroslav.baudisch@seznam.cz
Baudischová	Vlasta	mudr.baudischova@centrum.cz
Bouwman	Jordy	Jordy.Bouwman@lasp.colorado.edu
Brož	Petr	petr.broz@ig.cas.cz
Cassone	Giuseppe	87cassone@gmail.com
Čermáková	Iva	iva.cermakova@cgc-instruments.com
Černý	David	davidcernydavid@gmail.com
Čuba	Václav	vaclav.cuba@fjfi.cvut.cz
De Luca	Antonio	antonio.de.luca@ext.esa.int
Dryahina	Kseniya	kseniya.dryahina@jh-inst.cas.cz
Dudáš	Juraj	dudas@vzlu.cz
Fárník	Michal	michal.farnik@jh-inst.cas.cz
Fedor	Juraj	juraj.fedor@jh-inst.cas.cz
Ferus	Martin	martinferus@email.cz
Ferusová	Růžena	ruzena.ferusova@jh-inst.cas.cz
Hof	Martin	martin.hof@jh-inst.cas.cz
Kabáth	Petr	petr.kabath@asu.cas.cz
Kaiser	Jozef	Jozef.Kaiser@ceitec.vutbr.cz
Kolář	Jan	jan.kolar@czechspace.cz
Kozlíková	Klára	kozlikova@zamekdecin.cz
Křivková	Anna	anna.krivkova@jh-inst.cas.cz
Kukol	Jan	jan.kukol@skopava.com
Kuneš	Michal	michal.kunes@czechinvest.org
Květina	Petr	petrkvetina@gmail.com
Lammer	Helmut	Helmut.Lammer@oeaw.ac.at
Lebreton	Jean-Pierre	jean-pierre.lebreton@cnrs-orleans.fr
Macúchová	Karolína	karolina.macuchova@hilase.cz
Macháčková	Miroslava	miroslava.machackova@jh-inst.cas.cz
Mata	Martin	mata@icuk.cz
Matouš	Bohuslav	matous@hapteplice.cz
Malečková	Michaela	michaela.maleckova@jh-inst.cas.cz
Moravec	Zdeněk	moravec@hapteplice.cz
Müllerová	Ilona	mullerova@kav.cas.cz
Nejdl	Lukáš	lukasnejdl@gmail.com
Němečková	Kateřina	nemeckova.kata@gmail.com,
Nosek	Jakub	jakub.nosek@one3d.cz
Nováková	Julie	julie.novakova@gmail.com
Papula	Martin	martin.papula@activair.cz
Plešek	Jiří	plesek@it.cas.cz
Pokorná	Hana	svatonova@muni.cz
Pořízka	Pavel	pavel.porizka@ceitec.vutbr.cz
Poskočilová	Miroslava	reditel@zamekdecin.cz
Přech	Lubomír	lubomir.prech@matfyz.cuni.cz
Rozehnal	Marek	rozehnal@lightigo.com

Saija	Franz	saija@ipcf.cnr.it
Seget	Lukáš	lukas.seget@sawtronics.cz
Schäffer	Matúš	matus.schaffer@one3d.cz
Smrž	Martin	martin.smrz@hilase.cz
Snížková	Zuzana	snizkova@pragolab.cz
Spesyvyi	Anatolii	anatolii.spesyvyi@jh-inst.cas.cz
Sternovsky	Zoltan	Zoltan.Sternovsky@lasp.colorado.edu
Strnadová	Veronika	veronika.strnadova@geology.cz
Sysala	Richard	richard.sysala@evolvsys.cz
Uwarova	Inna	iuwarowa@sabaerospace.cz
Vanda	Jan	vandaj@fzu.cz
Varady	Michal	dekan.prf@ujep.cz
Weiter	Jaroslav	jaroslav.weiter@sawtronics.cz
Woitke	Peter	Peter.Woitke@oeaw.ac.at
Zvolánková	Eliška	zvolankova@ssc.cas.cz
Žabka	Ján	jan.zabka@jh-inst.cas.cz
Zelinka	Radim	radim.zelinka@mendelu.cz
Zelenka	Ondřej	ondrej.zelenka@asu.cas.cz

Participating Institutions

Posters

HANKA

CubeSat Space Dust Analyser

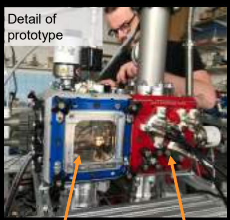
M. Malečková[1], J. Žabka[1], Y. Zymak[1,2], M. Polášek[1], B. Cherville[1], J. Jašík[1], A. Spesyvyi[1], M. Lacko[1], M. Kashkoul[1], A. Sanderink[3,4], M. Nezvedová[1], N. Sixtová[1], A. Charvát[5], B. Abel[5]

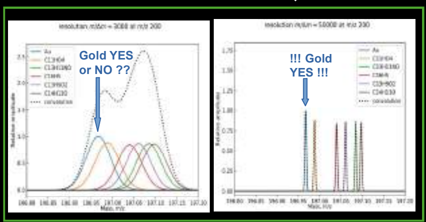
[1] J. Heyrovský Institute of Physical Chemistry, CAS, Dolejškova 3, 182 23 Prague 8, Czechia
[2] ELI Beamlines, Institute of Physics, CAS, Na Slovance 2, Prague 182 21, Czechia
[3] Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), UMR7328, CNRS/Université d'Orléans, 3A, Avenue de la Recherche Scientifique, 45071 Orléans, France
[4] Institut für Geologische Wissenschaften, FU Berlin, Malteserstraße 74-100, D-12249 Berlin, Germany
[5] Institute of Chemical Technology and Wilhelm Ostwald-Institute of Physical and Theoretical Chemistry, 04103 Leipzig, Germany; Leibniz Institute of Surface Engineering, 04318 Leipzig, Germany

HANKA (*H*motnostní *AN*alyzátor pro *K*osmické *A*plikace)
„Miniature High-Resolution Mass Spectrometer for *in-situ measurement* in Space"

LABORATORY PROTOTYPE

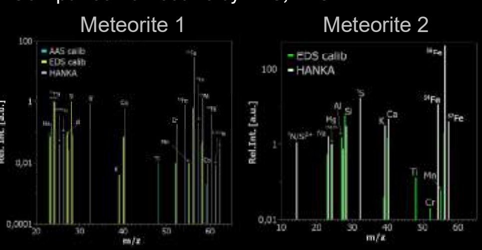
Resolving power: up to **50 000** at m/z 200
Mass range: m/z **2 - 3000**



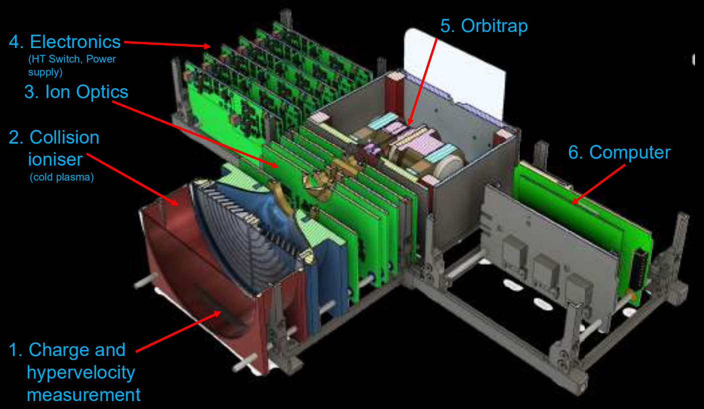


PRELIMINARY STUDY

Elemental composition of meteorites from Mars
Comparison of results by EDS, AAS with HANKA



CubeSat SPACE VERSION



Small-size: 200 x 200 x 100 mm (**4U**)

Light weight: **< 6 kg**

Power consumption: **5 – 10 W***

*depending on mode

POSSIBLE APPLICATIONS

Astrochemistry | Isotopic dating (Astrogeology) | Laboratory analogous simulators | Astrobiology | Space mining

[1] Makarov, A.; Anal. Chem. 2000, 72, 1156–1162.
[2] Briois C., Thissen R., Thirkell L., et al.; Planet Space Sci. 2016, 131, 33-45.
[3] Zymak Y., Zabka J., Polášek M., et al.; al.; Aerospace 2023, 10(6), 522.

ACKNOWLEDGEMENT
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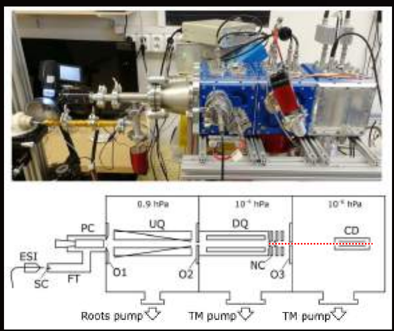
SELINA: COSMIC DUST GENERATOR AND ACCELERATOR FOR SPACE MASS SPECTROMETRY PROBES

A. Spesyvyi,[1] J. Žabka,[1] M. Polášek,[1] A. Charvat,[2] J. Schmidt,[3] F. Postberg,[3] B. Abel[2]

[1] J. Heyrovský Institute of Physical Chemistry of the CAS, Dolejškova 2155/3, 18223 Prague 8, Czech Republic
[2] Institute of Chemical Technology, and Wilhelm-Ostwald-Institute of Physical and Theoretical Chemistry, Linnestrasse 3, D-04103 Leipzig, Germany, and Leibniz Institute of Surface Engineering, Permoserstrasse 15, D-04318 Leipzig, Germany
[3] Institute of Geological Sciences, Freie Universität Berlin, Malteserstraße 74-100, D-12249 Berlin, Germany

SELINA

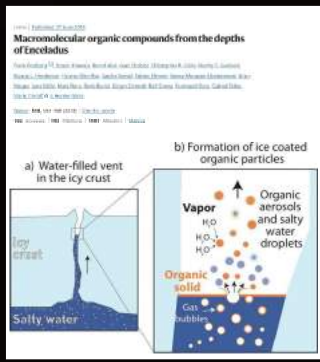


- *IdealVac* ™ modular vacuum 6x6x6'' chambers
- Removable flanges with various feedthroughs
- Fast changes and test of designs
- Bespoke flanges can be machined

Abstract

Nanometer to micrometer size ice particles as constitute of cosmic dust can originate from comets, plumes on icy satellites, hypervelocity meteoroid impacts on different icy surfaces. Mass spectrometric measurements of the molecular composition of such ice grains from Enceladus with the Cosmic Dust Analyzer on the Cassini spacecraft revealed the presence of organic molecules with masses over 200 amu. For future missions thus it is essential to have laboratory source of hypervelocity ice particles, which facilitates testing of new generation of the space high resolution mass spectrometric detectors. This requirement can be divided into two conceptual parts: the ice particle generation and the ice particle acceleration. We have developed instrument **SELINA (Selected Ice Nanoparticle Accelerator)** which resolves the ice particle generation part of the task. On the basis of our mass spectrometry experience we have applied and combined existing techniques to produce well defined beam of size selected icy nanoparticles on the output of the apparatus.

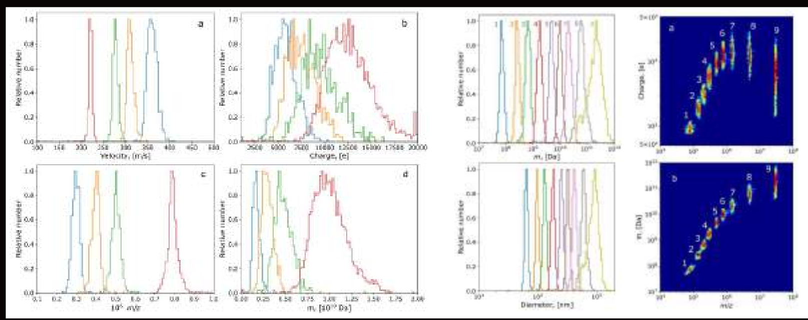
The highly charged water droplets are generated via electrospray ionization source with subsequent transfer from atmosphere pressure into the vacuum accompanied by the evaporative cooling and transition of water droplets from liquid phase to ice. The combination of two frequency controlled quadrupoles with differential pumping allows to produce charged particle beams of specified narrow size distributions within a range of 50-1000 nm diameter with 0.1-1 Hz repetition rates. The individual particle charge and velocity is measured by the non-destructive single pass charge detector. Special efforts were made to design SELINA as a compact transportable apparatus. As a result, all parts of instrument can be fitted on the two 19'' cart (except for mechanical pumps) including control electronics. This allows to combine SELINA particle source with different stationary accelerators.



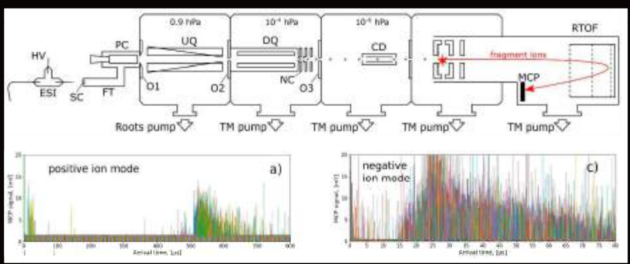
ESI for charged droplets generation

- **HV +1 to +6 kV** to spray water or water with admixtures (NaCl 0.01-0.2M)
- HV typically applied on liquid through T-union
- Various emitters 10-100 um ID
- Typical flow-rate 50-1000 nL/min

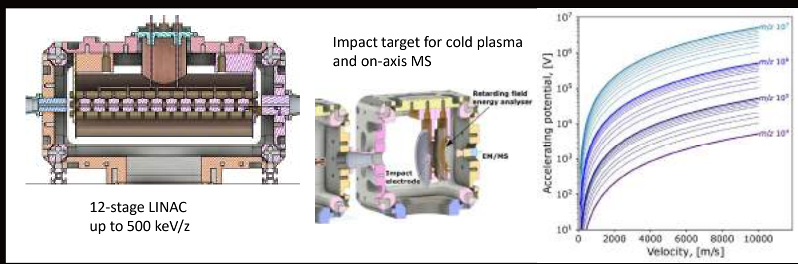
Exemplar mass (size) selected beams



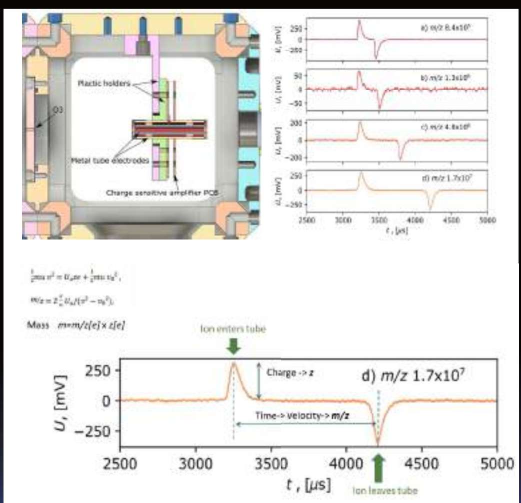
SELINA-HIMS: dust acceleration via TOF



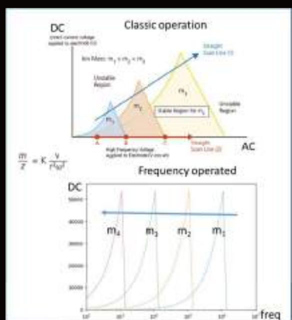
Post-accelerator design and impact ionization MS



Charge detection mass spectrometry



Frequency controlled quadrupoles for guiding and selection



Upstream Quadrupole UQ with slanted wires

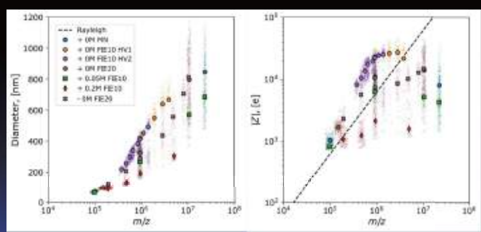
- 1 hPa
- Non-resolving (no DC component)
- Ion guide to thermalize particles to UQ potential
- *f* 1-200 kHz, fix AC 200 V, DC ±35 V
- *m/z* 1e3 to 4e7 range

Downstream Quadrupole DQ

- 1e-4 hPa
- Resolving (DC component defines resolution)
- *f* 0.5-200/65 kHz, fix AC 100/200 V, DC ±50 V
- *m/z* 5e3 to 1e9 range

Salinity effect on size and charge

With higher salinity of water the electrospraying is less effective to produce high mass/high charge droplets in decent amounts. However it is managable at salinity levels below 0.05M. Supporting source of neutral droplets with desired salinity levels can be used to overcome existing ESI source limitations.

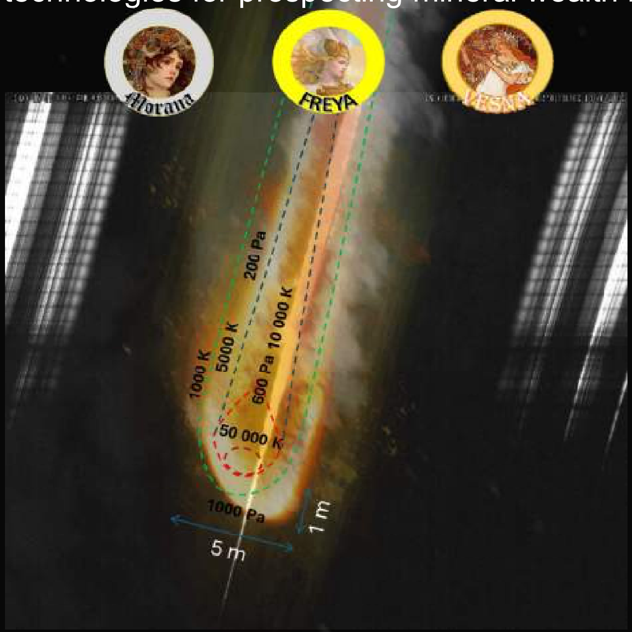


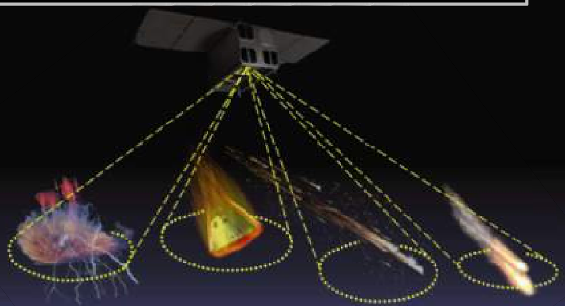
Acknowledgments

Joint project of J. Heyrovský Institute of Physical Chemistry of the CAS, v. v. i., Prague and Leibniz Institute of Surface Engineering (IOM), Leipzig
German Science Foundation (DFG) through grant AB 63/25-1 and the Czech Science Foundation (grant no. 21-11931J)

Spectroscopy of Meteors

In collaboration with the observatory in Valašské Meziříčí, our institute is deeply engaged in the observation and precise detection of elements using spectral analysis of meteors. These measurements, combined with calculations of their trajectories and origins, reveal sources of mineral wealth in the bodies of the Solar System. This has led to the concept of the SLAVIA satellite mission, which aims to lay the groundwork for the analysis of meteors and their origins from an orbital path, unobstructed and anywhere in the world. Technologies, including the revolutionary mass analyzer HANKA for the detection of trace elements in cosmic dust, would subsequently be applicable for missions to the Moon and asteroids. The Czech Republic would become a powerhouse in unique instruments for prospecting natural resources in space, which are in the sights of both ESA and NASA. After completing the feasibility study for the SLAVIA mission, the next step is the development of the spectral cameras MORANA, FREYA, and VESNA. These will also be tested during stratospheric flights and space missions such as upcoming VZLUSAT3 and Space Rider. Our goal is to enter the field of technologies for prospecting mineral wealth in space along with Czech space companies after 2030.





We observe a shooting star when a small body, typically from an asteroid or comet, enters Earth's atmosphere at altitudes of 80-120 km. This phenomenon can be viewed from space without interference from weather, dust, or the ozone layer, which blocks the ultraviolet spectrum. This visibility is crucial for detecting key elements in prospecting cosmic mineral wealth and mapping solar system sources.

The spectrum of a shooting star is captured in the image by a camera equipped with a transmission grating. Image analysis then extracts the spectrum, with each line corresponding to a particular element's transition. The intensity indicates its abundance. This spectral fingerprint can also be linked to other meteor events, such as lightning or the atmospheric entry of spacecraft or space debris.

Missions Objectives

- Detecting and identifying atmospheric entries of natural and man-made object can aid in mitigating hazards associated with these entries
- Military and Surveillance Applications
- Space Debris Monitoring and Analysis: Tracking the trajectory and composition of debris helps in the assessment of potential risks
- Measurement and Analysis for Scientific or Engineering Studies

Contact on behalf of the team: martinferus@email.cz, libor@nva.cz

We also acknowledge partners supporting SLAVIA mission (see The Booklet).

Prospecting of Lunar regolith:

Laser-Induced Breakdown Spectroscopy payload

Pavel Pořízka, Patrik Cebo, Jan Novotný, Inna Uwarowa,
Marek Rozehnal and Jozef Kaiser

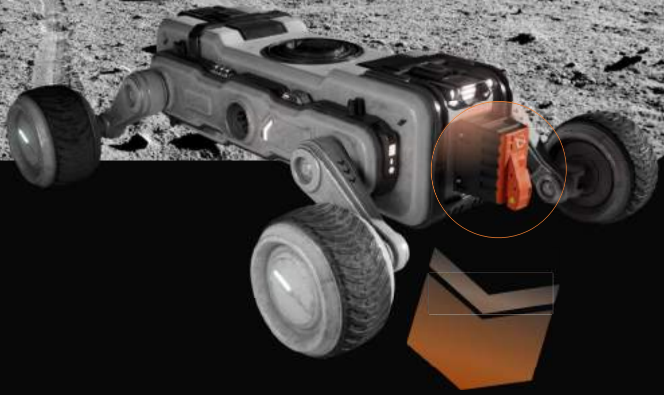
Understanding the lunar resource potential was identified as one of the three domains in Strategic Knowledge Gaps when the scientific activities should go beyond exploration objectives and support future establishment of a human presence on the Moon. We address the detection of volatiles in lunar regolith by developing scientific instruments capable of deployment in relevant conditions on the Moon. We propose the Laser-Induced Breakdown Spectroscopy (LIBS) technique which is well suited for robotic in-situ exploration.

LIBS allows for rapid data acquisition with optical access only, eliminating the need for sample preparation. Hence, we have suggested the so-called In-Situ Resource Analyzer (ISRA) payload that will be designed for rover prospecting missions while also targeting further segments of In-Situ Resource value chain (incl. mining, beneficiation and utilization). We aim to have a flight-ready model until 2030.

ISRA payload

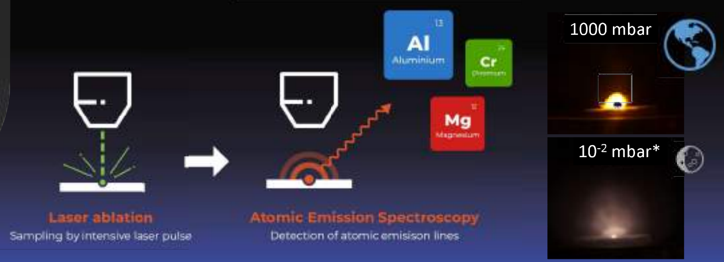
The development of the ISRA payload and analytical methodology is divided into four segments solved in parallel.

- **LIBS under simulated lunar conditions**
  - analysis under deep vacuum, plasma physics
  - creating data libraries, machine learning
  - partners: JH IPCh (CAS), DLR
- **Critical instrumentation**
  - space-grade, high-power laser source
  - spectrometer and detection unit
  - partners: Crytur, Hilase, DLR
- **System integration**
  - 1st stage: lander or rover mission
  - mission requirements
  - partners: LIST, ESRIC
  - potential rovers: Offworld, iSpace, Lunar Outpost



In-Situ Resource Analyzer (ISRA) payload by Lightigo Space

Laser-Induced Breakdown Spectroscopy (LIBS)



BRNO UNIVERSITY OF TECHNOLOGY CEITEC LASER SPECTROSCOPY LIGHTIGO SPACE J. Heyrovský Institute of Physical Chemistry Czech Academy of Sciences

Venus and EnVision

Venus is enveloped by a dense atmosphere and acidic clouds, obscuring its surface from visibility in the visible light spectrum. The atmosphere is predominantly composed of CO_2, resulting in an extreme greenhouse effect. Consequently, the average surface temperature on Venus reaches 464°C. To date, the planet has been primarily mapped using radar imagery, and only a few probes have successfully landed; however, their operational lifespans are severely limited by the inability to sustain cooling of their electronic systems for extended periods. The upcoming EnVision spacecraft is equipped with several instruments designed to conduct detailed observations of Venus and may help unravel some of its mysteries. Its launch is scheduled for 2031, with the first data from the vicinity of Venus expected in mid-2033.

How have the surface and interior of Venus evolved?

What is history of possible past Venusian water

How geologically active is Venus?

Source of PH3 and UV-absorber?

How are Venus' atmosphere and climate shaped by geological processes?

EnVision payload

- **VenSAR**, an S-band reflectarray radar, will map Venus's surface with spatial resolutions ranging from 10 m to 30 m.
- **VenSpec-U, VenSpec-H, and VenSpec-M**, operating in the UV and infrared spectra, will map trace gases above and below the clouds, volcanic gas plumes, and surface composition.
- **Subsurface Sounding Radar (SRS)** will probe for underground layering and buried boundaries within the top kilometer of the subsurface.
- **RSE (Gravity and radio science investigation)** will utilize radio tracking to map the planet's gravity field, providing insights into Venus's internal structure and atmospheric properties through radio occultation.

Our scientific results:

- Photochemical production of hydrides in the atmosphere.
- Model of planetary chemistry investigating OCS-CO-CO_2

Our involvement into the VenSpec-H instrument:

- Development and Testing of Electronic Components, procurement of:
  - PROC prototype board and associated harness
  - FPGA prototype board and associated harness
  - LLI EEE parts for all EM and EFM boards
- Technological Feedback and Recommendations
- Preliminary Data Set Composition for Testing
- National Project Management and Coordination.
- Preparation for Future Phases

Contact on behalf of the team: nemeckova.kata@gmail.com

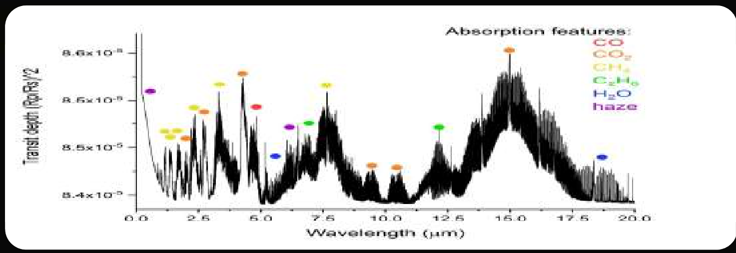
J. Heyrovský Institute · Institute of Geophysics of the Czech Academy of Sciences · Czech Geological Survey · esa · ÖAW IWF · IPCF Istituto per i Processi Chimico Fisici · Hvězdárna Valašské Meziříčí

Exoplanets and the Search for Life

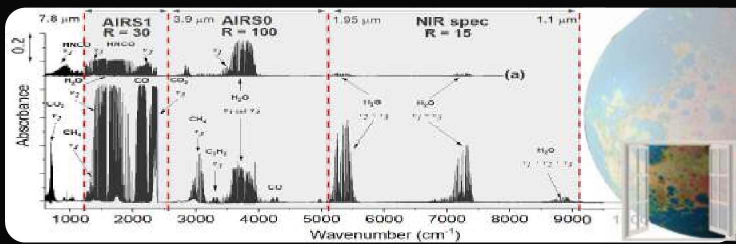
The origin of life on Earth remains elusive, prompting the question: what could be the way forward? Upcoming observations of terrestrial exoplanets offer a unique opportunity to answer this fundamental question by studying other planetary systems. By observing how physical and chemical environments similar to early Earth evolve, we can gain insights into our own Hadean eon, even though direct information from this time has long been erased from Earth's geological record. Therefore, a careful investigation of the chemistry on young exoplanets is essential. Preparing reference materials for spectroscopic observations is critically important. The detection methods used promise to identify specific intermediates of chemical and physical processes known to be prebiotically plausible.

Quest for Biosignatures

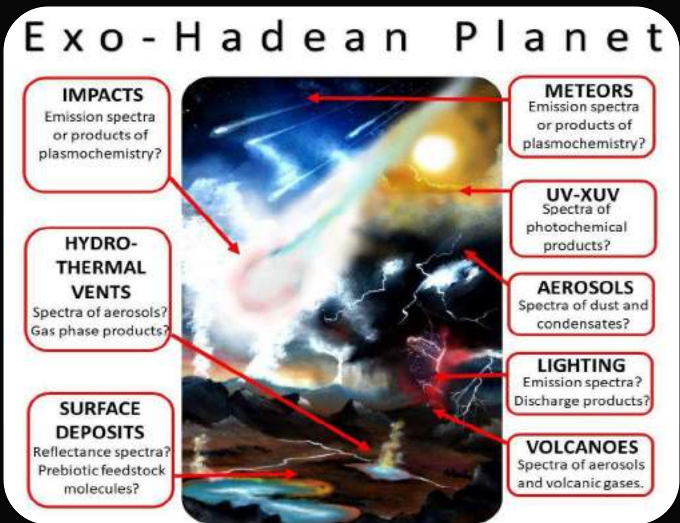
Researchers focus on the detection of biosignatures, signs of life, in the atmospheres of exoplanets. By analyzing the light spectra of planets, we can identify the presence of gases that could indicate biological activity. These gases include oxygen, methane, and water vapor, among others. What is a prebiotic signature of a world with evolving life? We are trying to answer this question with high power laser experiments.

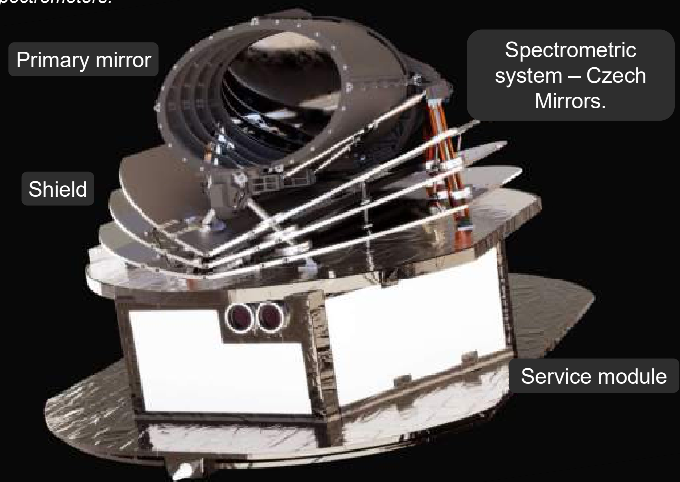


A modeled transit spectrum of a hypothetical Archean Earth under an Archean Sun.



A window to the past: Spectral signatures of atmospheric constituents together with HNCO, one of the prebiotic feedstock molecules, in the operational range of Ariel spectrometers.





ARIEL - Atmospheric Remote-sensing Infrared Exoplanet Large-survey

The European Space Agency’s next-generation mission to observe the chemical makeup of distant extrasolar planets has passed a major milestone after successfully completing its preliminary design review. This review demonstrated that the mission's payload design meets all required technical and scientific specifications, and no showstoppers were identified for the planned launch in 2029. The Czech Republic is also participating in the Ariel mission under the leadership of experts from the J. Heyrovský Institute of Physical Chemistry of the CAS. Toptec center of the Instiute of Plasma Physics is manufacturer of secondary mirrors.

Contact on behalf of the team: martinferus@email.cz

J. Heyrovský Institute · FZU · IPP · IPCF Istituto per i Processi Chimico-Fisici · Faculty of Nuclear Sciences and Physical Engineering CTU in Prague · esa · ÖAW · Zlínský kraj · Astronomical Institute of the Czech Academy of Sciences · Mendel University in Brno · University of Cambridge

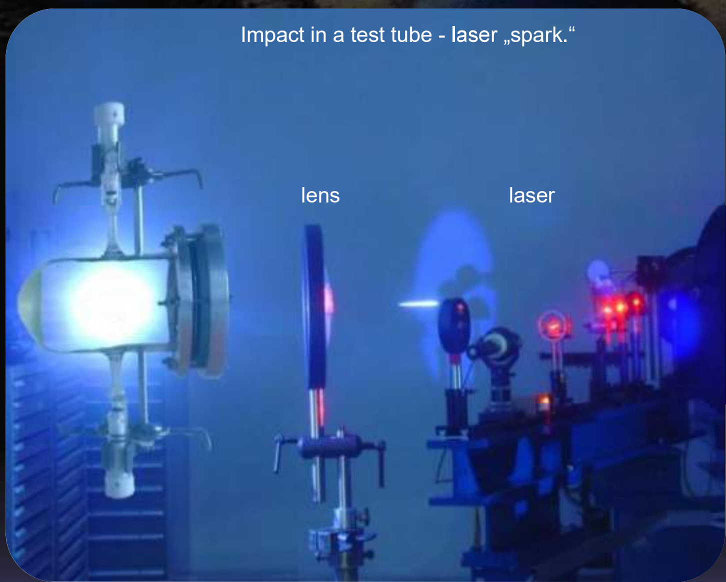
Origin of Life

Our laboratory experiments have demonstrated that asteroid and comet impacts provide both essential chemical compounds and the energy required to synthesize the fundamental components of prebiotic soup, including the building blocks of the genetic code, amino acids, and sugars. For two decades, the J. Heyrovský Institute of Physical Chemistry has committed to replicating the chemistry and physics of cataclysmic impact events using state-of-the-art PALS and HiLASE laser facilities. These high-power laser experiments have led to a surprising discovery: prebiotic substances can be directly formed through the action of plasma that simulates the impact of asteroids on a mixture of simple chemicals. The research continues to explore the chemistry that occurs for hundreds of thousands of years post-impact, where niches with prebiotic soup are formed. These environments, rich in chemicals and minerals and subject to cyclic drying, wetting, and UV flux, are favorable for the origin of the first living structures in hot ponds.

We hypothesize that post-impact lagoon harboured prebiotic processes.

Using space telescopes could provide evidence that a distant planet is undergoing a period of heavy bombardments, suggesting that life may be forming there in a similar manner.

PALS high-power laser



Impact in a test tube - laser „spark.“

Contact on behalf of the team: martinferus@email.cz