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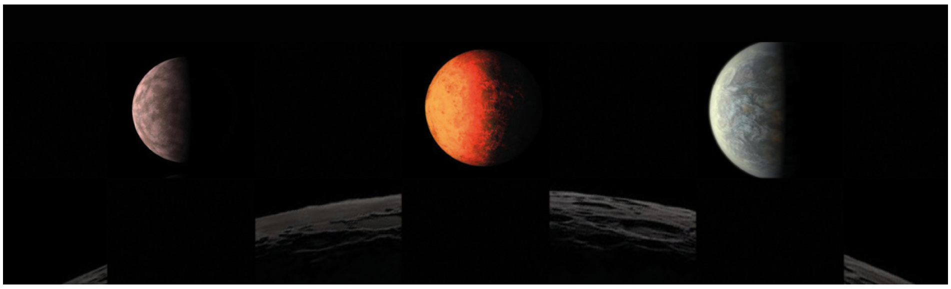

Book of Abstracts

Contents

Estimation of metallic resources of ordinary chondrite parent asteroids 1

Can the analysis of Mössbauer spectra of ordinary chondrites provide new insights into the evolution of the Solar System? 2

Elastic planetoids 3

Charcoal in proximal ejecta blankets of very small impact craters: What happens when an asteroid hits a tree. 4

Measurements of Earth's magnetic field anomalies caused by meteorite impacts 5

Revealing Mercury with BepiColombo: crustal formation and tectonics in geochemical terranes 6

Potential resources of the Moon 7

Evaluation of the impact of irregular geometry on the stability of lava tubes 8

Retrieval of phosphine as a biosignature: Forward modeling with petitRADTRANS . . . 9

TOI-201: Unveiling spectacular dynamics in a young multi-planet system 10

Formation and presence of molecular and crystalline structures in the NGC 6357 region 11

Observing the Martian surface and subsurface using the Marsis and Sharad radars 12

Evaluating the origin of Mars crustal magnetisation through a statistical analysis of the crustal magnetic anomalies orientations 13

What do we see, and what is overlooked? How can we improve our understanding of Martian volcanoes in the MARVEL project? 14

A swarm of mini-rovers supported by UAV as a Mars exploration concept - positioning aspects 15

The history of one compound megachondrule 16

Geochemistry, geochronology, and fall characteristics of the Ribbeck meteorite. 17

Protoplanetary cores drove chondrule formation 18

Spectroscopic measurements for possible cometary dust analogues 19

Characterization of rocky exoplanets in habitable zones: An astrobiological approach . . 20

The influence of dust on the radiance spectra of the Martian soil and atmosphere and the surface of Mercury . . . 21

A new method to evaluate the impact of spectral resolution and irradiation on spectral feature detectability . . . 22

Asteroid search and observation in citizen science projects: IASC, COIAS, and TDMP . . 23

Beyond Earth observation –Bridging the worlds of modern geospatial and planetary science . . . 24

Preparation of the natural lunar regolith simulant . . . 25

Extensive palaeo-dunefields on unusually steep slopes in eastern Noctis Labyrinthus, Mars . . . 26

On HCl in the Martian atmosphere during northern summers . . . 27

Vapour pressure equilibrium over sublimating ice scarps on Mars . . . 28

Martian analog in Himalayan region Ladakh - report from the Spaceward bound India 2025 . . . 29

Experimental investigation into the maturation of aeolian sands on Mars . . . 30

Aeolian processes in Meridiani Planum, Mars . . . 31

Using seafloor geomorphological classification schema and spatial analysis to predict geologic structure, with applications for other terrestrial planets . . . 32

Investigating the spatial and quantitative relationship between geomorphology and subsurface structures on the northern US Atlantic margin . . . 33

New ballistic trajectories model for Mars ground-truthed by the discovery of pyroclastic bombs in Ceraunius Fossae, Tharsis . . . 34

Geological reality and magma propagation models: accounting for fracturing . . . 35

The DAGGER project: Modelling magma propagation on Earth versus Mars . . . 36

A comparative analysis of dyke-assisted fracturing on Earth and Mars . . . 37

New modelling approach to evaluate fluvial erosion and deposition on Mars . . . 38

Identification of ore minerals on Mars based on data from Opportunity rover and research on terrestrial analogues . . . 39

Terraforming Mars –a feasibility study . . . 40

Leveraging low-thrust propulsion and simulated Neptune gravity-assist maneuvers to redirect Trans-Neptunian Objects for Mars terraforming: a comparative assessment of ΔV and impact time requirements . . . 41

Toward the first tree on Mars: energy balance simulations of growth conditions . . . 42

Cartographic visualization of the Mars terraforming process . . . 43

Do we really need to save Earth, If Space will save us? 44

RAF Analog Space Mission - First analog mission on mining heaps 45

Visiting laboratories of the Faculty of Geography and Geology of the Jagiellonian University 46

Small bodies in the Solar System / 14

Estimation of metallic resources of ordinary chondrite parent asteroids

Authors: Katarzyna Łuszczek[1]; Tadeusz Przylibski[1]

[1] *Politechnika Wrocławska, Wydział Geoinżynierii, Górnictwa i Geologii*

Although ordinary chondrites are stony meteorites they still contain significant amount of metals (up to 18.6wt%), mainly occurring as FeNi alloy grains. This makes ordinary chondrites and their parent rocks very important in extra-terrestrial metallic resource considerations, crucial for ISRU concept (In Situ Resource Utilization). S-type asteroids both belonging to Near Earth Asteroids (NEAs) and orbiting in main belt are ordinary chondrite parent bodies (e.g. Hebe, Eros, Toutatis, Flora, Itokawa). Due to the fact that their parent asteroids are undifferentiated objects, these metallic grains are homogenously distributed in the whole parent body structure.
Based on microscopic examinations, bulk chemical composition and EMP analysis estimations of Fe, Ni, Co, Cu resources was possible. Our results also consider the distribution of these metals in different mineral phases of FeNi alloy (kamacite and taenite), what is especially important for future mineral processing. Our calculations show potential geological resources of FeNi alloy grains of selected metals (Fe, Ni, Co, Cu, Cr, Au, Pd, Pt) on previously mentioned asteroids and in its regolith layer estimated on the basis of mineral and chemical composition of H, L, and LL chondrite groups. Our findings demonstrate the richest in metals among ordinary chondrites are H chondrites and their parent bodies –they contain 18.6wt% of ore minerals (FeNi grains). In case of mining Fe and Co can be obtainable mainly (over 90%) from kamacite. Comparable proportions of Ni can be extracted from kamacite (53%) and taenite (47%). Fe0 (metallic, native iron), Ni and Co content in kamacite and taenite was calculated for asteroid 6 Hebe. H chondrite parent bodies are polymetallic (Fe, Ni, Co, Cr, Cu, Au, Pt, Pd) deposits (Łuszczek and Przylibski, 2021).

Łuszczek K., Przylibski T.A., 2021 - Selected metal resources on H chondrite parent bodies, Planetary and Space Science, Vol. 206, https://doi.org/10.1016/j.pss.2021.105309

Small bodies in the Solar System / 28

Can the analysis of Mössbauer spectra of ordinary chondrites provide new insights into the evolution of the Solar System?

Authors: Martyna Jakubowska[1]; Agnieszka Grabias[2]; Jolanta Gałązka-Friedman[1]; Przemysław Duda[1]; Marek Woźniak[3]; Krzysztof Szopa[4]

[1] *Warsaw University of Technology, Faculty of Physics*

[2] *Łukasiewicz Research Network –Institute of Microelectronics and Photonics*

[3] *University of Warsaw, Faculty of Biology*

[4] *University of Silesia, Faculty of Natural Sciences*

A group of Polish physicists and mineralogists has been studying meteorites using Mössbauer spectroscopy for over 30 years [1].
Since Fe-57 is the isotope commonly used in Mössbauer spectroscopy, it is not surprising that this method is widely applied in the study of meteorites that often contain iron. For many years, our group has focused on ordinary chondrites. The Mössbauer spectra of ordinary chondrites typically consist of two doublets associated with silicates (olivine and pyroxene), as well as two sextets corresponding to metallic phases and troilite. In weathered samples, additional doublets corresponding to trivalent iron in an oxidized state also appear.
We have compiled a comprehensive Mössbauer dataset, which allowed us to develop a new classification method of ordinary chondrites called the 4M method (Meteorites, Mössbauer spectroscopy, Multidimensional discriminant analysis, Mahalanobis distance) [2].
Interestingly, the 4M classification method closely matches the traditional classification based on fayalite and ferrosilite contents determined by the electron microprobe analysis. These two methods are based on parameters characteristic for ordinary chondrites, which were shaped at very different stages of the evolution of the Solar System. We aim to answer a fundamental question: Why can these two distinct methods lead to the same classification results?

[1] J. Gałązka-Friedman et al., Postępy Fizyki, 75(2), 3 (2024), DOI: 10.61947/uw.PF.2024.75.2.3-16
[2] M. Woźniak, et al., Meteoritics & Planetary Science, 54(8), 1828-1839 (2019)
https://doi.org/10.1111/maps.13314

Small bodies in the Solar System / 49

Elastic planetoids

Authors: Andrzej Odrzywołek[1]; Bartosz Żbik[1]

[1] *Jagiellonian University in Krakow*

Modeling the internal structure of self-gravitating solid and liquid bodies presents a challenge, as existing approaches are often limited to either overly simplistic constant-density approximations or more complex numerical equations of state. We present a detailed analysis of a tractable and physically motivated model for perfectly elastic, spherically symmetric self-gravitating bodies in hydrostatic equilibrium. The model employs a logarithmic equation of state (logotropic EOS) with a non-zero initial density and constant bulk modulus. Importantly, scaling properties of the model allow all solutions to be derived from a single, universal solution of an ordinary differential equation, resembling the Lane-Emden and Chandrasekhar models. The model provides new insights into stability issues and reveals oscillatory asymptotic behavior in the mass-radius relation, including the existence of both a maximum mass and a maximum radius. We derive useful, simple analytical approximations for key properties, such as central overdensity, moment of inertia, binding energy, and gravitational potential, applicable to small, metallic bodies like asteroids and moons. These new approximations could aid future research, including space mining and the scientific characterization of small Solar System bodies.

[1] B. Żbik & A. Odrzywołek. "Elastic Planetoids". Astrophys. J. 988.2 (2025), p. 267. doi: 10.3847/1538-4357/ade8ef

Small bodies in the Solar System / 16

Charcoal in proximal ejecta blankets of very small impact craters: What happens when an asteroid hits a tree.

Authors: Anna Losiak[1]; Luke Alesbrook[2]; Mark Burchell[2]; Penny Wozniakiewicz[2]

[1] *Institute of Geological Sciences Polish Academy of Sciences*

[2] *School of Physics and Astronomy, University of Kent, UK*

Proximal ejecta blankets of very small (<200 m in diameter) impact craters can contain fragments of charcoal (Losiak et al. 2022). Those charcoals can be used to: precisely and accurately date impact structures, determine environmental effects of impacts of small asteroids, and potentially, better understand the energy distribution during formation of very small impact craters or identify impact origin of yet unknown structures. Previously, these charcoals were interpreted to represent pre-impact forest fires.

However, because the charcoal assemblages: 1) are found within the same stratigraphic and geomorphological context within numerous craters, 2) have 14C ages consistent with the timing of crater formation and 3) have reflectance properties unlike the wildfire charcoals, they appear to be produced by the impact events. However, their exact formation mechanism is unknown. The aim of the current study was to test whether impact charcoals can be formed by a shock wave passage as suggested by [10], and if so, under which conditions this occurs.

We have conducted 10 impact experiments using the University of Kent's horizontal two-stage light-gas gun [11]. Impactors were 2 mm stainless steel. We varied the following parameters: 1) impact velocity (1.0 to 7.0 km/s) and, thus, peak pressure (~1 to >15 GPa), 2) wood moisture content of the spruce target (40% fresh/green and 10% dried), and 3) air pressure (near vacuum: 1 mbar, and at 1 bar).

No production of charcoal, like that observed in the natural impact craters, was observed during any of the experiments. This was true even if conditions were the most favourable: velocity of 5 km/s, dry wood, with 1 bar atmosphere. However, there were slight signs of very small thermal damage. The latter may be related to condensation organic vapour plume (e.g. soot), which is distinct from charcoal.

Small bodies in the Solar System / 30

Measurements of Earth's magnetic field anomalies caused by meteorite impacts

Authors: Mikołaj Zawadzki[1]; Natalia Godlewska[1]; Szymon Oryński[2]

[1] *Uniwersytet Warszawski*

[2] *Institute of Geophysics Polish Academy of Sciences*

Meteorites that have impacted the Earth's surface in the past have created impact craters. Most of these craters have not been preserved in a form that allows for their contemporary identification, but some, especially in Central and Northern Europe, have been described and classified as geological structures formed by meteorite impacts. When a celestial body strikes the Earth's surface, it causes a temporary increase in temperature to several hundred degrees Celsius, sometimes exceeding the Curie temperature for ferromagnetic rocks and minerals that make up the near-surface layer. Magnetization is relatively stable from a geological time perspective. The magnetic record in magnetite is usually stable and is quite difficult to remagnetize (Fassbinder, 2015).

The impact leads to a change in the direction of magnetization in the minerals, which sometimes persists after the impact. This phenomenon is known as Thermoremanent Magnetization (TRM). It is characteristic of meteorite impact sites.

The project aims to conduct research in the field of applied geophysics and the magnetic properties of rock and mineral samples in the area of craters formed by meteorite impacts in the context of thermomagnetic anomalies.

As part of this project, proton magnetometer measurements have been conducted in the areas of the Morasko craters in Poland, the Dobele crater in Latvia, the Vepriai crater in Lithuania, and several craters in Estonia (Ilumestsa, Simuna, Tsõõrikmäe, Kärdla, Kaali). Samples from the Estonian craters have been collected for paleomagnetic studies and analyzed using a rotational magnetometer and a magnetic susceptibility instrument. The results of the magnetometric measurements are very promising and exhibit characteristic patterns of magnetic field anomalies typical of impact craters.

The project is funded under the 'Pearls of Science' program by the Ministry of Science and Higher Education of the Republic of Poland.

Mercury and the Moon - bodies without atmosphere / 44

Revealing Mercury with BepiColombo: crustal formation and tectonics in geochemical terranes

Author: Joanna Gurgurewicz[1]

Co-authors: Daniel Mège [1]; Sam Poppe [1]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk*

BepiColombo is the joint European Space Agency ESA and Japan Aerospace Exploration Agency JAXA mission to Mercury, launched in 2018. Of the two orbiters, the Mercury Planetary Orbiter has two infrared spectrometers onboard. Centrum Badań Kosmicznych PAN (CBK PAN) provided the pointing unit to the Mercury Radiometer and Thermal Infrared Spectrometer (MERTIS). In December 2024, MERTIS obtained its first data during fifth Mercury flyby. BepiColombo will achieve Mercury orbit insertion in November 2026 and the nominal science operations will begin in April 2027. The surface of Mercury displays broad regions of distinct geochemical compositions –terranes. They testify to a complex, yet elusive crustal evolution of Mercury. In CBK PAN, we will study the tectonic and volcanic processes at the border of these terranes using petrological, geochemical, and structural geology methods. The investigations will be based on the data obtained by MERTIS and other relevant instruments. We will focus in particular on areas where contractional structures intersect, or are intersected by, extensional structures. The priority sites include the borders of two geochemical terranes in the northern hemisphere: the high-magnesium terrane, and the low-fast terrane. We will additionally study the Rembrandt crater in the southern hemisphere. Rembrandt is the second largest impact structure of Mercury, after the Caloris basin, and similarly formed near the end of the Late Heavy Bombardment, testifying to the earliest tectonic activity recorded in the crust of the planet.

Mercury and the Moon - bodies without atmosphere / 33

Potential resources of the Moon

Authors: Tadeusz Przylibski[1]; Mateusz Szczęśniewicz[1]; Konrad Blutstein[1]

[1] *Wrocław University of Science and Technology, Faculty of Geoengineering, Mining and Geology, Laboratory of Geology and Mineral Engineering*

The homogeneity of the chemical and isotopic compositions of the Earth and the Moon facilitates the identification of potential mineral resources present and exploitable on the Moon. The current knowledge on the geological structure of the Earth's natural satellite also allows us to state that due to the greatest geochemical and geophysical activity of the surface layer of the Moon's crust - regolith, it is the regolith that is the most promising the Moon's raw material sphere (lunar resource sphere). The regolith contains increased concentrations of life-supporting raw materials (H_2O and O_2), fuels and energy raw materials (^3He, U, Th, H_2, and O_2), metallic raw materials (Fe, Ti, Zr, Hf, Eu, other REE, Cr, Ni, Co, Al, and Si), rock raw materials (regolith, breccias, basalts, anorthosites, and others) and chemicals raw materials (K, P, Cl, and S). Lunar regolith should be treated as a multi-component, pre-crushed ore, in which there are local enrichments of selected raw materials. Therefore, initially, the subject of exploitation and processing on the Moon will be regolith. The next deposit potential zones are areas where there are outcrops of basic and ultrabasic igneous rocks, which may be enriched in metals such as Cr, Ti, REE, and PGM, or places, where these rocks are covered by only thin layer of regolith. Such zones also include areas of occurrence of acidic igneous rocks, enriched in quartz, and perhaps also in many other valuable metals and chemical raw materials. The most important prospective areas in terms of the occurrence of raw materials in the regolith are the lunar maria, primarily the Procellarum KREEP Terrane, circumpolar areas, as well as areas on the far side of the Moon characterized by a regolith thickness exceeding 10 m.

Mercury and the Moon - bodies without atmosphere / 40

Evaluation of the impact of irregular geometry on the stability of lava tubes

Author: Marcin Chwała[1]

[1] *Politechnika Wrocławska*

The presentation will introduce a recently proposed approach for analyzing the irregular geometries of lava tubes and assessing their impact on cave stability. It is shown that irregularities can significantly influence predicted collapses and the safety conditions inside the caves. This enables preliminary estimates of lava tube dimensions on the Moon (and other planetary bodies) and allows forecasts of the environmental conditions that future robotic missions will have to deal with. Thousands of artificially generated irregular geometries have been analyzed, allowing for interesting observations regarding the geometry and types of the collapses. Lava tubes are of great interest due to their potential for hosting future bases and scientific instruments. They may also serve as valuable sites for sampling paleoregolith and conducting unique geological investigations. For these reasons, issues related to their structural stability are expected to attract increasing attention from the scientific community.

Exoplanets / 10

Retrieval of phosphine as a biosignature: Forward modeling with petitRADTRANS

Authors: Blake Sodikoff[1]; Ji Wang[1]

[1] *The Ohio State University*

Phosphine (PH3) has emerged as a potential biosignature gas, particularly in high-pressure, CO2-dominated exoplanetary atmospheres analogous to Venus. This research explores the feasibility of detecting trace amounts of phosphine using simulated transmission spectra from petitRADTRANS (pRT). The central research question investigates how varying phosphine mixing ratios influence the observability of spectral features and how these signals vary across instruments, resolutions, and atmospheric contexts. Our methodology involved generating high-resolution synthetic spectra with varying PH3 abundances and calculating the area under the curve (AUC) of the phosphine absorption feature near 10.5 μm to estimate detectability. Key findings suggest that AUC correlates consistently with phosphine concentration, though signal strength is strongly influenced by cloud opacity, atmospheric temperature, and spectral resolution. These results validate the AUC method as a simplified yet informative detection metric for iosignature retrieval pipelines. This study contributes to optimizing spectral analysis strategies for future observatories such as JWST and highlights the importance of forward modeling in constraining biosignature detection thresholds for habitable and Venuslike exoplanets.

Exoplanets / 17

TOI-201: Unveiling spectacular dynamics in a young multi-planet system

Author: Gracjan Maciejewski[1]

[1] *Uniwersytet Mikołaja Kopernika w Toruniu*

The TOI-201 system, featuring a young F-type star approximately 870 million years old, has emerged as one of the most intriguing planetary laboratories discovered so far. Our recent studies have unveiled a remarkable planetary architecture, including the detection of TOI-201 c - an additional massive gas giant with a 7.7-year orbital period. This discovery was facilitated by the analysis of transit timing variations (TTVs) in previously known gas giant TOI-201 b. Observations acquired with the space-born Transiting Exoplanet Survey Satellite confirmed the transit of TOI-201 c, revealing its orbital eccentricity of 0.64 and a mass of 14 Jupiter masses, cyclically diving into the system's habitable zone. Numerical simulations indicate that the system is dynamically stable over gigayear timescales, with TOI-201 b's transits expected to cease within a few thousand years. This evolving configuration provides a unique opportunity to investigate the long-term dynamical interactions and secular evolution within multi-planet systems. The TOI-201 system's youth and the presence of multiple giant planets make it an invaluable case study for testing theories of planet formation, migration, and dynamical evolution. In this talk, I will highlight how TTVs led to the discovery of TOI-201 c, explore the system's dramatic orbital architecture, and discuss what it tells us about the formation and dynamical evolution of giant planets.

Exoplanets / 23

Formation and presence of molecular and crystalline structures in the NGC 6357 region

Author: María Alejandra Lemus Nemocón[1]

Co-authors: Mario Armando Higuera Garzón [1]; María Claudia Ramírez-Tannus [2]

[1] *Observatorio Astronómico Nacional - Universidad Nacional de Colombia*

[2] *Max-Planck-Institut für Astronomie*

Understanding star and planet formation in extreme environments is crucial for uncovering the origins of our solar system. While most knowledge comes from nearby, isolated regions such as Taurus and Lupus, over half of all stars and planetary systems form in environments exposed to strong far-ultraviolet (FUV) radiation, emitted by massive OB stars, with energies below the Lyman limit (E < 13.6 eV).

NGC 6357—a young (~1–1.6 Myr), massive star-forming complex located 1690 pc away and hosting over 20 O-type stars—provides a unique opportunity to study the effects of FUV radiation on protoplanetary disks. This is the focus of the XUE (eXtreme UV Environments) collaboration.

Here, we present results from XUE2, a disk in the Pismis 24 cluster, based on spectra from JWST/MIRI and VLT/FORS2, complemented by photometric data. We first characterized the central star through spectrophotometric fitting, a fundamental step since protoplanetary disks are shaped by their host stars.

To evaluate the potential for rocky planet formation, we conducted a molecular and mineralogical analysis of the disk. We confirmed the presence of CO and tentatively detected CH_3^+, both key molecules for organic chemistry. Additionally, we identified silicates such as enstatite and forsterite —molecules and minerals also observed in disks exposed to lower irradiation levels.

These findings offer new insights into the composition of inner disk regions under strong FUV irradiation, helping to constrain the formation conditions of rocky planets in massive clusters—an essential contribution to understanding the origins of the diverse exoplanets observed today.

Mars Science / 47

Observing the Martian surface and subsurface using the Marsis and Sharad radars

Author: Wlodek Kofman[1]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk, IPAG/CNRS*

The sounding radar operating from the orbiting platforms for studying the surfaces and subsurface of planets began to be applied, systematically, in the early 2000s with the Japanese Selene mission to the moon and MARSIS and SHARAD for Mars. These radars work, by transmitting a low frequency pulse, in the altimetric mode and some SAR processing is implemented on board or on the received data on Earth. The ability of low frequency electromagnetic waves to penetrate subsurface, propagate through them, and interact with materials and structures is used to image them, detect layers, and determine their composition. In this conference, we will present and discuss, using selected examples of real data obtained by the MRO and MEX missions, the capabilities of radars to obtain measurements, their accuracy, and what physical parameters can be deduced from these measurements. We will discuss the data processing and kind of necessary information to be able to interpret measurements. Sounding radars are also relevant tools to determine the composition of the surface, since the radar-waves reflectivity is sensitive to the dielectric properties of the sounding materials. It also has the originality to be representative of the first tens of metres in depth of the surface (depending on the bandwidth).

Then we describe the radars built for Europa Clipper and JUICE missions that were launched to explore the Jupiter's satellites.

Mars Science / 42

Evaluating the origin of Mars crustal magnetisation through a statistical analysis of the crustal magnetic anomalies orientations

Author: Claudio Orlanducci[1]

Co-authors: Daniel Mège [1]; Benoit Langlais [2]; Anna Mittelholz [3]; Jérôme Dyment [4]; Joanna Gurgurewicz [1]; Sam Poppe [1]; Yoann Quesnel [5]; Pierre-Antoine Tesson [1]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk, Warszawa, Poland*

[2] *Laboratoire de Planétologie et Géosciences, Université de Nantes, Université d'Angers, CNRS, UMR 6112, Nantes, France*

[3] *Department of Earth and Planetary Sciences, ETH Zurich, Zurich, Switzerland*

[4] *Institut de Physique du Globe de Paris, Sorbonne Paris Cité, Université Paris Diderot, UMR CNRS 7154, 1 rue Jussieu, 75238 Paris 05, France*

[5] *Aix-Marseille Université, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France*

The Martian crust shows a magnetic contrast between the northern and southern hemispheres. Data from MGS and MAVEN reveal strong magnetization and E-W anomalies in the southern one whereas weak in both the northern one and within major impact basins. The origin of this magnetization remains uncertain. Exogenic (impacts) or endogenic (degree-1 convection or mantle plume) process could be the possible cause. This study analyses anomalies at the planetary scale to test the hypothesis of a global event. Intensity of anomalies was derived from the radial magnetic field on a 3393.3 km sphere. Thresholds of ≥200 nT and ≥500 nT were used to enhance the patterns. Mapping was performed using grid-based skeletonization. We classified the anomalies as radial or circumferential in relation to fictitious centres every 5° in latitude and longitude. We produced density maps and a geometrical best-fit analysis of the distribution of circumferential anomalies. We also conducted a tectonic structure orientation analysis in some areas around the fitted ellipse. The radial magnetic field highlights the main anomaly patterns. Results indicate that 50% of the anomalies likely stem from a single event, displaying global antipodality and forming an elliptical coherent system. The evidence is consistent with crustal magnetization as an outcome of a large impact, most likely the formation of the pre-Noachian Borealis basin (~4.5 Ga). This event may have generated the anomaly system, producing post-impact hydrothermal or igneous fluids circulating through fractures. Preliminary geological investigations support this interpretation, with tectonic structures aligned to the fitted ellipse and the dichotomy boundary. The remaining anomalies would originate from later processes.

Mars Science / 5

What do we see, and what is overlooked? How can we improve our understanding of Martian volcanoes in the MARVEL project?

Author: Bartosz Pieterek[1]

Co-author: Thomas Jones [2]

[1] *Geohazard Research Unit, Institute of Geology, Adam Mickiewicz University in Poznań*

[2] *Lancaster Environment Centre, Lancaster University*

Just after the Moon, Mars is among the most pioneering research areas, as it constitutes a critical step forward in planetary exploration. Nevertheless, high-resolution insights into Martian magmatic evolution remain limited and largely biased towards large-scale landforms. For decades, the narrative on Martian volcanism emphasized a global decline in explosive volcanism in favor of dominant effusive-origin features. Consequently, the small-scale volcanic features (<1 km), which could reveal new aspects of volcanic evolution, have been largely overlooked and inadequately addressed. Therefore, to significantly advance the current understanding of how volcanism has developed on Mars, the MARIVEL project (Modern Advances in high-Resolution Imaging of Volcanic Eruptive Landforms –unrevealing concealed Martian volcanic evolution by studying terrestrial analogues) aims to characterize and identify small-scale volcanic structures located in the planet's youngest provinces. Within the 4-year project (2025-2029), Martian remotely sensed observations will be supplemented by investigations of their terrestrial analogues to provide more in-depth insights. This will be achieved by the reconstruction of eruptive sequences and processes involved in the volcanic activity that will allow for generating critical data for the trans-planetary comparison. This type of comparative planetary research is currently underdeveloped due to the brief history of Martian exploration and limited coverage of high-resolution observations and their corresponding topographical models. Therefore, MARIVEL addresses this gap by integrating advanced topographic data with multiproxy analysis of volcanic landforms on Earth, seeking geological parallels, such as volcanic products and their morphological characteristics. This comprehensive approach will directly inform the future of Mars research focused on volcanism.

This study was funded by the National Science Centre of Poland (2024/53/B/ST10/00488).

Mars Science / 37

A swarm of mini-rovers supported by UAV as a Mars exploration concept - positioning aspects

Authors: Julia Stypułkowska[1]; Paweł Czernic[1]

[1] *Warsaw University of Technology*

The paper presents the progress made on the concept of a swarm of rovers assisted by a drone for mapping the surface of Mars. The concept we presented a year ago is still being developed and improved. This year's work focused on implementing and integrating a drone built specifically for our project and positioning aspects.

Positioning for Mars exploration is particularly challenging without Global Navigation Satellite System (GNSS) signals and reliable magnetic field data. This work investigates two complementary approaches to positioning in GNSS-denied environments: photogrammetric methods using a drone and radio-based distance estimation.

The first concept is based on the autonomous positioning of rovers using tagged control points placed on the rovers. This concept involves using photogrammetric data collected from the drone, processing it using Structure from Motion (SfM) algorithms, detecting coded markers, and determining the position of the rovers in a local reference frame.

The second approach, based on Wi-Fi and Bluetooth positioning, owing to their widespread availability and low cost, offers practical alternatives for distance estimation and localization based on Received Signal Strength Indicator (RSSI). The radio-based positioning approach evaluates a linear regression model, derived from the log-distance path loss formula, and a feedforward neural network for mapping RSSI values to distance, accounting for noise and signal variability. The resulting distance estimates are applied to trilateration techniques within a multi-robot system framework.

Combining UAV-supported photogrammetric positioning with radio-based techniques enables a more robust and resilient navigation system. While photogrammetry provides high-precision mapping and localization, radio-based methods add redundancy and extend reliability under harsh conditions. This hybrid approach enhances the autonomy of rover swarms, paving the way for future exploration missions on Mars.

Poster session - Board: 01 / **15**

The history of one compound megachondrule

Author: Ewa Koszowska[1]

Co-authors: Maciej Kania [1]; Michał Skiba [1]

[1] *Jagiellonian University in Krakow, Institute of Geological Sciences*

We studied a megachondrule from an unclassified meteorite from the Sahara Desert, acquired in 2010. The meteorite, measures ca. 4 × 5 cm, exhibits a glossy brown desert varnish, and is cut by numerous fractures.
Petrological, mineralogical, and chemical analyses (SEM-EDS), have led to the preliminary classification of the meteorite as an unequilibrated ordinary chondrite (L3, S3, W2/W3). Quantitative phase abundances indicate the following composition (in wt%): olivine (54), pyroxene (33), feldspar (5), goethite (3), and iron sulfides (5). In addition chromite, ilmenite and Fe-Ni phases are present.
Examination of a thin section reveals ca. 400 well-defined, closely packed chondrules, predominantly ellipsoidal or spherical, with diameters 0.62 - 0.85 mm. Moreover the meteorite contains megachondrules (or their fragments), compound chondrules, and clasts. Seven megachondrules of different types, with size > 2.5 mm were identified.
The investigated compound megachondrule measures 2.8 × 3.2 mm. It comprises a primary ellipsoidal megachondrule (2.1 × 2.8 mm) and a secondary megachondrule of variable thickness (0.3–0.5 mm) of enveloping type, both classified as porphyritic olivine (PO). Their similar chemical and mineralogical compositions suggest they are "siblings". We found olivines (Fa7 -35), low-Ca orthopyroxens, high-Ca clinopyroxenes (pigeonite and augite) and high-Ca plagioclase (bytownite) mesostais.
Additionally, three secondary porphyritic pyroxene-olivine (PPO) adhering type chondrules, (0.3 to 0.4 mm in diameter) are attached to the enveloping chondrule. They can be determined as "independent"in comparison to megachondrules (PO), due to its mesostasis enriched in Na and higher proportion of pyroxenes relative to olivines.
The presence of compound chondrules suggests dynamic conditions within the early solar nebula, where chondrule formation likely occurred through a multi-stage process. Proposed sequence of these cosmic events is presented in the study.

Poster session - Board: 02 / **43**

Geochemistry, geochronology, and fall characteristics of the Ribbeck meteorite.

Author: Aleksander Błasiak[1]

[1] *AGH University of Krakow*

Asteroid 2024 BX1 was discovered just 3 hours before it entered the Earth's atmosphere, which happened on January 21, 2024. This allowed acquisition of 17 recordings from the fireball stations, on the basis of which, the strewn field was precisely calculated and the heliocentric orbit of this meteoroid was determined. The aphelion distance of this asteroid's orbit (Q=1.838 AU) lies in the innermost region of the asteroid belt, suggesting that the parent body for aubrites are E/X-type asteroids from the Hungaria family and the main framework mineral is enstatite ($Mg_2Si_2O_6$).
The author went to the area of the strewn field and found a piece of a meteorite, which was subjected to further analysis. A series of studies were conducted using Raman spectroscopy, electron microscopy (SEM), electron microprobe (EPMA) and laser ablation with inductively induced plasma coupled mass spectrometry (LA-ICP-MS). Interpretation of the results allowed the identification of previously undescribed mineral phases, including K-bearing minerals such as roedderite.
The presence of roedderite underscores that the parent body must have been highly differentiated to concentrate potassium as a major mineral component. In situ Rb/Sr geochronology was performed on roedderite within the Ribbeck aubrite, yielding a weighted average of 4582 ± 23 Ma (MSWD: 0.42; n:16). The age records the aubrite formation and was not reset by later events, unlike the more sensitive K-Ar and (U-Th)/He methods that have been used to date this meteorite.

Poster session - Board: 03 / **9**

Protoplanetary cores drove chondrule formation

Author: Mohamad Ali-Dib[1]

[1] *NYUAD*

Chondrules are small spherical objects that formed at high temperatures early in the history of the Solar System. The key compositional characteristics of chondrules may be well explained by high gas pressures in their formation environment. However, such high gas pressures are widely considered astrophysically unreasonable. Here, we propose that chondrules were formed via the processing of dust grains in the dust-rich envelopes of planetary embryos, before getting ejected via convective diffusion. We show that this scenario can explain many salient constraints on chondrule formation, including formation locations; mass and time-scale of chondrule production; repeat chondrule heating events; heating time-scales; and, most crucially, high prevailing gas pressures. Our work suggests that high gas pressures may indeed have prevailed during the formation of chondrules, reconciling previous analytical observations, experimental evidence, and theory. We suggest that chondrules are mostly the products rather than the precursors of planetary embryo formation - a result that would have important implications for our understanding of the early history of the Solar System.

Poster session - Board: 04 / **8**

Spectroscopic measurements for possible cometary dust analogues

Authors: Marcin Wesołowski[1]; Piotr Potera[2]

[1] *Instytut Nauk Fizycznych Uniwersytet Rzeszowski*

[2] *Instytut Inżynierii Materiałowej Uniwersytet Rzeszowski*

We present new spectroscopic measurement results for two sample dust analogues: charcoal derived from walnut wood and willow wood, respectively. These measurements were performed in our laboratory using a Cary 5000 spectrometer with an integrating sphere. This measurement setup enabled the measurement of hemispherical albedo as a function of wavelength in the range of 200 to 2500 nm. The obtained hemispherical albedo values ranged from 0.10 to 10.89%. Based on the spectral profiles obtained from the measurements, Bond albedo and geometric albedo values were calculated for selected possible analogues of the cometary refractory material. In the case of walnut charcoal, the Bond albedo values ranged from 1.39 to 2.15%, while the geometric albedo values ranged from 5.49 to 8.49%. In the case of willow charcoal, the Bond albedo value ranged from 1.29 to 2.49%, while the geometric albedo value ranged from 5.09 to 9.87%. The obtained geometric albedo calculations were compared with the actual geometric albedo of comet 67P/Churyumov-Gerasimenko, which is 6.5 ± 0.2% at 649 nm, with local variations of up to 16% in the Hapi region. This analysis showed that the obtained geometric albedo values fit within the wide range of local variations of the geometric albedo for comet 67P/Churyumov-Gerasimenko.

Poster session - Board: 05 / **4**

Characterization of rocky exoplanets in habitable zones: An astrobiological approach

Author: Maria Valentina Vega Caro[1]

[1] *Physics, Universidad Nacional de Colombia*

Rocky exoplanets, defined by their predominantly silicate and metal composition, represent a fascinating frontier in contemporary astrobiology, as their study allows us to explore conditions that could sustain life forms beyond our solar system. Complementary to this, those rocky planets that orbit in the habitable zone, which refers to the region around a star where the temperature allows for the existence of liquid water on the surface, becomes an essential criterion for selecting targets in the search for life outside planet Earth.
The identification of exoplanets in the habitable zone, especially those that share characteristics with Earth, gives us a perspective on the diversity of planetary environments that could exist in the universe. Additionally, the study of these worlds allows us to explore fundamental concepts in the physics and chemistry of processes that lead to the formation of complex organic molecules. Research on the interaction between exoplanets and their host stars also provides us with information about how initial conditions in a planetary system can influence the evolution of its atmosphere and its impact on habitability. With the advancement of tools like the James Webb telescope, we will be able to detect biomarkers such as methane and oxygen, reinforcing the importance of a multidisciplinary approach in the exploration of life in the cosmos.
This work focuses on the characterization of rocky planets located in habitable zones, with the aim of finding possible candidates for future astrobiological research. For this purpose, habitable zones will be identified based on the spectral type of host stars. Subsequently, the physical and orbital properties of these confirmed exoplanets in these planetary systems will be studied. Finally, prioritization criteria will be established for those planets with the highest probability of harboring conditions conducive to life.

Poster session - Board: 06 / **39**

The influence of dust on the radiance spectra of the Martian soil and atmosphere and the surface of Mercury

Author: Maria I. Błęcka[1]

Co-author: Wlodek Kofman [2]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk*

[2] *CBK PAN, IPAG/CNRS*

This work is an extension of the topic addressed in the article (M.I Błęcka; PSS, 2024) concerning the influence of the mineralogy of the Martian surface on the detectability of trace gases in its atmosphere. Currently, the modelling has been extended to include the presence of dust in the Martian atmosphere. The spectral range of the simulation is wide, from 3.0μm to 20μm, which requires the modelling of both scattering and thermal emission from the surface and dust. Some simulation results for various mineralogical compositions of dust are shown
The spectral range of the code used allows, after some modifications, simulations of the expected spectra from the MERTIS spectrometer (Bepi Colombo mission) operating in the 7-14μm range.
Unlike Mars, Mercury has a very rarefied atmosphere (exosphere), which only slightly alters the signal coming from the surface. The situation is different when dust appears above the surface, e.g. after a meteorite impact, which is a fairly common phenomenon on Mercury. The first attempts to model the radiance from Mercury in this situation are shown.

Poster session - Board: 07 / **25**

A new method to evaluate the impact of spectral resolution and irradiation on spectral feature detectability

Author: Bernadett D. Pál[1]

[1] *Konkoly Observatory*

Space weathering is a fundamental process that alters the surfaces of airless planetary bodies, modifying their optical, structural and chemical properties, complicating remote compositional interpretation. To support optimized spectral band selection, especially for low-cost CubeSat instruments, the influence of instrumental resolution and irradiation on peak detectability in meteorite spectra was evaluated.

Spectral coarsening was simulated with a C++ code by convolving laboratory reflectance spectra with a Gaussian line spread function. The Gaussian kernel width was set by the desired full-width at half maximum (FWHM), and downsampling was applied at half the FWHM to satisfy the Nyquist criterion. This process was done to smooth the spectrum and reduce the number of data points, replicating the spectra recorded with a lower resolution spectrometer. Peak visibility was quantified using peak area and height within fixed spectral windows centered on known mineral features. The peak area was calculated via trapezoidal approximation, and peak height was defined as the difference between the peak maximum and a flat baseline.

A peak was classified as undetectable when either its area dropped below 25% or its height below 30% of the original value. To statistically characterize resolution thresholds for spectral degradation, Kaplan–Meier survival analysis was applied. Peaks were grouped by mineral type, and the disappearance of a peak was treated as the event in the analysis. The resulting Kaplan-Meier graphs indicate how feature visibility declines with increasing spectral coarsening, and help determine the lowest resolution to detect important mineral features.First results showed that irradiation accelerates peak loss, though major bands of feldspar, pyroxene, and spinel remain detectable at moderate resolution. These findings could define practical limits for mineral identification and guide the design of low-cost IR instruments.

Poster session - Board: 08 / **20**

Asteroid search and observation in citizen science projects: IASC, COIAS, and TDMP

Author: Maria Wicher[1]

[1] *Polish Astrobiology Society / Polish Society of Amateur Astronomers*

Citizen science is a form of participation and collaboration that actively involves non-scientists in scientific research. It is used in a wide range of areas, including ecology, medicine, and astronomy. In recent years, citizen science has emerged as a powerful tool in astronomical research, enabling people from all over the world, regardless of their age, nationality, faith or gender, to contribute to real scientific discoveries. In the field of asteroid search and observation, citizen scientists can currently help professional astronomers in three projects: International Astronomical Search Collaboration (IASC), The Daily Minor Planet (TDMP), and Come on! Impacting ASteroids (COIAS). This is particularly evident in the context of Planetary Defense, where detection and tracking of Near-Earth Objects (NEOs) are critical for assessing potential impact threats. The talk attempts to analyze these projects and presents a first-hand experience from an active participant involved in each of them. This work shows my observations, research, and discoveries of asteroids as a citizen scientist and high school student. The presentation will cover different types of minor planets, including Main-Belt Asteroids, Near-Earth Objects, Jupiter Trojans, and Trans-Neptunian objects, illustrating how citizen science contributes to our broader understanding of the Solar System dynamics.

Poster session - Board: 09 / **45**

Beyond Earth observation –Bridging the worlds of modern geospatial and planetary science

Author: Wojciech Bylica[1]

Co-authors: Jan Musiał [1]; Jędrzej Bojanowski [1]; Marcin Niemyjski [1]

[1] *CloudFerro S.A.*

Earth Observation has undergone a significant transformation, progressing from the first temporally consistent satellite archives (e.g. Copernicus) into cloud-native, AI–ready ecosystems that now underpin climate research, disaster response and policy frameworks. Planetary science, driven by renewed lunar exploration, appears to be approaching a similar paradigm shift. The central challenge is not merely the acquisition of mission data, but its integration into platforms that are open, interoperable, and capable of supporting advanced, cross-disciplinary analyses.
BeyondEarth-STAC represents our conceptual approach to such a platform: an open lunar data lake harmonizing multi-mission datasets through the Spatio-Temporal Asset Catalog (STAC) standard. It currently consolidates terabytes of imagery, elevation models, hyperspectral measurements and surface composition maps. However, its significance lies less in the data volume than in the adoption of an reproducible approach and interoperable architecture. This framework extends to planetary science the same developments that are transforming Earth Observation: scalable cloud processing, semantic search, integration with advanced machine learning techniques.
The future of planetary data platforms will be multimodal. Embedding imagery, spectral information and geophysical measurements into unified representations could enable cross-domain reasoning and facilitate applications ranging from landing site assessment to predictive modelling of resource distribution.
If Earth Observation platforms today contribute to global climate monitoring and governance, planetary data lakes may play an analogous role in enabling sustainable lunar activities. They have the potential to become shared, transparent knowledge bases supporting international collaboration and long-term human presence on the Moon.

Poster session - Board: 10 / **46**

Preparation of the natural lunar regolith simulant

Author: Mateusz Szczęśniewicz[1]

[1] *Politechnika Wrocławska*

The development of advanced technologies for lunar exploration, including rovers, drills, and sample collection systems, requires access to reliable regolith simulants. However, the availability of natural lunar regolith simulants is limited, and many existing substitutes do not fully reflect the chemical and mechanical properties of lunar soil. This study focuses on the identification and utilisation of Lower Silesian basalts as a raw material for producing a natural lunar regolith simulant. Comprehensive geochemical analyses were conducted to compare basaltic rocks and dust from mining sites in Lower Silesia with Apollo and Luna mission samples. The results indicate that Lower Silesian basalts show geochemical similarities to lunar basalts, particularly in aluminium, silicon, iron, magnesium, and calcium content, with only minor differences in sodium and potassium levels. Moreover, the particle size distribution of basaltic dust closely resembles that of fine lunar regolith, and its direct use without additional processing offers a cost-effective and sustainable solution by reducing mining waste. Preliminary research on the production of glass, a key component of lunar regolith, has been conducted. The ongoing research aims to refine production methods and test the geotechnical and mechanical properties of the simulant, providing a valuable tool for future lunar exploration technologies.

Mars Science / 38

Extensive palaeo-dunefields on unusually steep slopes in eastern Noctis Labyrinthus, Mars

Author: Matt Telfer[1]

Co-authors: Mackenzie Day [2]; Matt Chojnacki [3]

[1] *University of Plymouth*

[2] *Department Earth, Planetary, and Space Sciences, UCLA*

[3] *Planetary Science Institute, Lakewood*

Here we report spatial analysis of a large number of bedform patterns in eastern Noctis Labyrinthus (NL), Mars, which occur preferentially on very large, steep (up to ~30°) slopes, and interpret the features as extensive palaeo-dunefields. We base this aeolian genesis for the features on: i) their frequently oblique orientation to hillslopes, ii) their apparent interaction with topography (consistent with atmospheric transport), and iii) their planform morphology. However, the dunefields also exhibit a number of characteristics that make these dunes highly unusual, viz: i) the dunes preferentially occur not within topographic basins and valley floors, but upon the huge slopes of the valleys of Noctis Labyrinthus, ii) these underlying slopes are in many cases atypically steep for dune formation, with bedforms occurring on slopes of up to ~32° and iii) cratering of the dunes confirms their antiquity and induration, and their identity as palaeodunes.
We used data from the HiRISE and CTX sensors on the Mars Reconnaissance Orbiter within a GIS framework to conduct spatial analysis of the palaeodunes. We used an automated crest detection algorithm to derive ~30 000 segments of crestline, and slope and aspect were derived from the MOLA DEM. Dunes are found on slopes approaching the angle of repose at around 32°; the mean slope underlying the bedforms is ~17°, and around 40% of them are founds on slopes in excess of 20°. Using crater-counting methods, we derive a modelled surface age of 4.8 Ma +/- 0.1 Ma. We propose that the dunefields result from past westward transport and result from deposition on unusual accommodation spaces. We consider the possible depositional and subsequent post-induration erosional processes that are consistent with the observed geometries, and propose two models that appear consistent with both fundamental physical principles and present-day observations.

Mars Science / 32

On HCl in the Martian atmosphere during northern summers

Author: Daniel Mège[1]

Co-authors: Alexander Trokhimovskiy [2]; Oleg Korablev [2]; Kevin Olsen [3]; Anna Fedorova [2]; Sandrine Guerlet [4]; Benjamin Taysum [5]; Pierre-Antoine Tesson [6]; Mikhail Luginin [2]; Franck Montmessin [7]; Pavel Vlasov [2]; Alexey Grigoriev [2]; Juan Alday [8]; Denis Belyaev [2]; Nikolay Ignatiev [2]; Andrey Patrakeev [2]; Nikita Kokonkov [2]; Yuriy Ivanov [9]; Joanna Gurgurewicz [6]; Antoine Pommerol [10]; Gabriele Cremonese [11]; Nicolas Thomas [10]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk, Warszawa, Poland; University of Bern, CH*

[2] *IKI, Russia*

[3] *University of Oxford, UK*

[4] *LMD/CNRS, Paris*

[5] *DLR Berlin, DE*

[6] *Centrum Badań Kosmicznych Polskiej Akademii Nauk*

[7] *LATMOS/CNRS, France*

[8] *The Open University, UK*

[9] *Main Astronomical Observatory NAS, UA*

[10] *University of Bern, CH*

[11] *OAPD/INAF, Italy*

One of the primary objectives of the ExoMars Trace Gas Orbiter (TGO) mission was to search for previously undetected trace gases that could be diagnostic of active geology or a biosphere. The first such gas was hydrogen chloride (HCl), detected with the ACS and NOMAD spectrometer suites. The presence of HCl on Mars was expected to be an indication of active magmatic processes. However, HCl was found to be widespread and we quickly identified a pronounced seasonal cycle in HCl. These aspects indicated that its behaviour was mainly governed by strong photochemical interactions linked to water vapour. The original source of HCl, its sinks, and how its abundance is regulated over time remain a mystery.

ACS MIR is a cross-dispersion spectrometer operating in solar occultation geometry, which provides excellent sensitivity to weak absorption signatures and vertical structure. HCl was discovered in perihelion data shortly after the 2018 Mars Global Dust Storm in Mars year 34, and its signal disappeared shortly after the late season storm. A similar trend has since been observed in the following Mars years (MYs), with HCl returning alongside warm atmospheric temperatures, increasing water vapour content, and dust activity - all driven by southern summer occurring at perihelion. Modeling work to define HCl behaviour leave the unanswered question: if HCl has a limited photochemical lifetime, what sources are replenishing atmospheric chlorine?

In MY35, two exceptional detections were made by ACS MIR in northern summer, near aphelion, around Alba Mons. We performed a dedicated search for HCl in MY 37, and in MY38 accompanied this time by NOMAD and the iSHELL spectrograph of the IRTF ground telescope. New observations detected HCl again in the Alba Mons area. They will be discussed using data from the CaSSIS camera of TGO, HiRISE on MRO, and MOLA from MGS.

Mars Science / 29

Vapour pressure equilibrium over sublimating ice scarps on Mars

Author: Tomasz Mikołajków[1]

[1] *Uniwersytet Warszawski*

About one-third of the Martian surface contains water ice within the shallow ground. Many researchers see the thermodynamics of that ice as crucial for Martian climate history research and as possible source of water during future missions.
Shallow ice affects geomorphology as the ground cemented by the ice in pores turns into a solid rock. In some places exposed scarps show uncovered ice layers, mixed with dust to some extent. Such places are visible from the orbit and yield detailed investigation.
To better understand processes in the surface of those scarps, a detailed numerical model was created to simulate environmental effects, taking into account thermodynamics of heat within the ice and air above.
Presented are results of calculating recession rate of the surface and comparison of the theoretical results to the satellite observations.

Mars Science / 11

Martian analog in Himalayan region Ladakh - report from the Spaceward bound India 2025

Author: Agata Kołodziejczyk[1]

[1] *Faculty of Space Technologies, AGH University of Kraków*

The mission was to explore a Mars-like environment in the valley of Tso Kar, one of the highest-altitude salt lakes, located at an elevation of 4,500 metres above sea level. This unique astrobiological area perfectly simulates conditions on the Red Planet. The team's main tasks were six path finder experiments included searching for and collecting samples of extremophilic organisms from the soil surface and hydrothermal hot springs. Air, water and soil samples were analysed. The team examined the Puga hot spring and Tso Kar Lake for their potential as sites for astrobiological research. Additionally, valuable data was collected on how the human circulatory system adapts to high-altitude conditions and low oxygen levels. This presentation reveals the potential of future collaborations in Ladakh region, especially in the astrobiological aspect for future Martian missions.

Mars Science / 13

Experimental investigation into the maturation of aeolian sands on Mars

Authors: Anna Baker[1]; Devon Burr[2]; Rachel Fry[3]

[1] *Northern Arizona University*

[2] *Formerly of Northern Arizona University*

[3] *U.S. Geological Survey, Astrogeology Science Center and Northern Arizona University*

On Earth and Mars, aeolian (wind) transport causes sand grains to break down, which can result in mineralogic and textural changes to the sand. The nature of those changes currently represents a knowledge gap on Mars. Filling this knowledge gap could advance capabilities for provenance research that uses mineralogy to identify the sand sources of Martian dune fields. More broadly, understanding how Mars sands evolve (mature) with transport is important for understanding the geologic history and cycling of sediments, as well as dust production.

To address this knowledge gap, we are conducting laboratory experiments simulating the effects of aeolian transport on Mars-analog sediments. We developed the Sand AbrasioN Device for Aeolian Research (SANDAR), a modified air mill that uses pressurized air to circulate sand around a small abrasion chamber (Baker et al., in review). The SANDAR matches natural aeolian transport in terms of the kinetic energy of colliding sand grains as well as the microtextures produced on the surfaces of grains. These findings validate that it effectively simulates the mechanical effects of aeolian processes.

We used the SANDAR to conduct an abrasion experiment with a customized version of Mars Global Simulant-1, a synthetic compositional simulant for Mars soil made by Space Resource Technologies. We collected visible/near-infrared spectroscopy data on the sample as it was abraded and observed spectral changes consistent with a loss of Mg-sulfate (epsomite) and ferrihydrite. We are also conducting monomineralic experiments to individually compare the abrasion rates of the major mineral components of Martian sand. Thus far, we have found that Mg-sulfate (kieserite) abrades more quickly than olivine, which abrades more quickly than pyroxene (augite). These early results suggest that mature aeolian sands on Mars may be depleted in Mg-sulfate and ferrihydrite, somewhat depleted in olivine, and enriched in pyroxene.

Mars Science / 48

Aeolian processes in Meridiani Planum, Mars

Author: Joanna Kozakiewicz[1]

Co-authors: Dominika Maj [2]; Dorota Salata [2]; Leszek Nowak [1]; Maciej Kania [2]; Mateusz Sobucki [2]; Nikodem Frodyma [1]; Szymon Mol [2]

[1] *Jagiellonian University in Krakow, Faculty of Physics, Astronomy and Applied Computer Science*

[2] *Jagiellonian University in Krakow, Faculty of Geography and Geology*

Aeolian processes, such as accumulation, erosion, and transport, were investigated in the western part of Meridiani Planum. This is an equatorial region of Mars that was explored by the NASA Opportunity Rover of the Mars Exploration Rover mission. This area is also fully covered by high-resolution images taken by the HiRISE and CTX cameras of the Mars Reconnaissance Orbiter mission. The studied area consists of two geomorphological units: the plains, covered by sparsely distributed small impact craters, and Endeavour crater, older than the plains, large impact crater (22 km in diameter).

The aim of the work was to determine the present and past wind patterns, the activity of various aeolian landforms, the size and shape of transported grains, and the changes in the intensity of aeolian processes in Meridiani Planum. The region was investigated in a period of 10 Mars years using simultaneous data from the surface and from orbit, providing a unique insight into aeolian processes on Mars. It was found that on Mars: (i) there are seasonal changes in wind patterns, (ii) medium sand grains are trapped in craters, and (iii) aeolian ripples have the same morphometry even if they are characterized by different particle size distributions.

Today, in Meridiani Planum erosion dominates, but in the past a high sand supply allowed for the formation of large coarse-grained ripples and dunes. Coarse sand particles (0.5-2.0 mm in diameter) and even gravel particles (> 2 mm) are transported by wind, but only over short distances, which do not allow grains from both geomorphological units to mix. The transport path of fine sand grains (< 0.25 mm) is very long (probably global). However, the small amounts of medium and fine sand available for transport resulted in the stagnation and erosion of the dunes and coarse-grained ripples. Aeolian accumulation occurs mainly on the floors of the small impact craters (< 30 m in diameter), where fine sand ripples can rarely be found.

Mars Science / 24

Using seafloor geomorphological classification schema and spatial analysis to predict geologic structure, with applications for other terrestrial planets

Author: Emma Morgan[1]

[1] *Mississippi State University*

The surface topography of Mars is well-known but understanding of its subsurface structure is substantially more limited. Given this, identifying correlative relationships between the geomorphology of topographic features and subsurface faults in an analogue setting can potentially be applied to topographic data from Mars to yield insight into structural features and associated processes there. The Cascadia margin is chosen as an Earth analogue, for a Martian fault zone, Valles Marineris, and a potential subduction system found on Tharsis Plateau are chosen. The selected areas on Mars are likely to have significant sediment deposition, water-related landforms, and numerous faults, similar to the Cascadia margin. First, we use geomorphologic phonotypes, bathymetric position index (BPI), and the coastal and marine ecological classification standard (CMECS) to quantitatively classify surface geomorphic features in topographic data. Next, we record the values of these geomorphic schema along mapped fault locations. From there, initial spatial correlation analysis is conducted to evaluate the degree to which geomorphic units are related to fault locations throughout the study area. Additionally, spatial distribution modeling (Maximum Entropy) is used to develop predictive models of the probability of fault presence based upon collective morphologic schema values. K-fold cross validation is used to quantify the accuracy of resulting predictive models. Finally, these models will be applied to topographic data from the selected sites on Mars to map the probability of potential fault presence. These results may be helpful in identifying potential areas of interest on Mars, and other terrestrial bodies, for future research.

Mars Science / 36

Investigating the spatial and quantitative relationship between geomorphology and subsurface structures on the northern US Atlantic margin

Author: Andrea Stiles[1]

[1] *Mississippi State University*

Expansive digital elevation models (DEMs) of surface topography are now available for many terrestrial planetary bodies. However, subsurface data for these bodies, particularly fault information, remains limited. Establishing a predictive relationship between DEM derived surface morphology and subsurface structures, like faults, could yield insight into tectonic and geologic processes on Earth and other planets. Accordingly, my research investigates this relationship by examining spatial correlation between faults and seafloor geomorphology, with the goal of applying these insights to analogous geological settings on other terrestrial planets like Mars.

I am using seismic interpretation software to analyze subsurface data from the US Atlantic Continental Margin, to identify and map fault locations. Spatial correlation between mapped fault locations and quantitative classifications of seafloor geomorphology derived from high-resolution (100 m) bathymetry data, are evaluated through maximum entropy modeling to develop a predictive model of fault presence. Geomorphological classifications used include slope, aspect, rugosity, bathymetric position index, and geomorphologic phonotypes.

Using seismic interpretation to map subsurface features and DEM data to map coincident geomorphological classifications, I am developing a framework to predict subsurface faulting from surface topography data. I will apply the resulting predictive model to an analogous location within a sedimentary basin on Mars, analyzing HiRISE images and DEMs. The goal of this is to determine whether a predictive model developed in similar geomorphic landscapes can be used to infer subsurface structure in the Martian crust. Ultimately, this analog based approach could enhance our ability to predict subsurface structural features and associated geologic processes based upon planetary surface data.

Poster session - Board: 11 / **6**

New ballistic trajectories model for Mars ground-truthed by the discovery of pyroclastic bombs in Ceraunius Fossae, Tharsis

Author: Bartosz Pieterek[1]

Co-authors: Thomas Jones [2]; Chiedozie C. Ogbuagu [2]

[1] *Geohazard Research Unit, Institute of Geology, Adam Mickiewicz University in Poznań*

[2] *Lancaster Environment Centre, Lancaster University*

Numerical modelling is essential in planetary sciences to simulate, explore, and understand the magmatic processes that are otherwise inaccessible for direct study. Models often rely on uncertain parameters, mainly due to remotely sensed observations or assumptions, leading to false confidence or uncertain interpretations. Therefore, real, ground-truthed data gathered from the planetary surface allows scientists to develop conceptual and numerical models of volcanic processes. At present, growing evidence points to explosive eruptions being widespread, albeit of variable magnitude, throughout the Martian geological record. Therefore, to characterize Martian explosive eruptions both qualitatively and quantitatively, we utilized a new ballistic emplacement model, encompassing a variable drag coefficient, to newly documented small-scale, conical-shaped volcanic edifices located at the edge of Ceraunius Fossae in Tharsis. They comprise coarser pyroclastic material such as spatter and show accumulations of volcanic bombs on the cone slopes and bases, observable in the high-resolution images. By integrating the sizes and spatial distribution of the mapped volcanic bombs with the ballistic emplacement model, we calculated their exit velocities (mean value of 72 m s-1) and maximum heights attained during flight for a given bomb density and launch angle. Overall, our model results were able to reproduce the observed bomb range to within ± 1 m difference for the horizontal range, and the resting bomb elevations upon landing to within <4 m for a 37° launch angle, <7 m (for 81.8°) and <17 m (for 89°), across both densities of 1500 and 2700 kg m-3. These findings, based on ground-truthed observations, enhance the accuracy, confidence, and interpretability of numerical models in revealing the evolution of Martian explosive eruptions.
This study was funded by the National Science Centre of Poland (2024/53/B/ST10/00488).

Poster session - Board: 12 / **12**

Geological reality and magma propagation models: accounting for fracturing

Author: Sam Poppe[1]

[1] *Centrum Badan Kosmicznych Polskiej Akademii Nauk*

Understanding magma propagation mechanisms and ascent paths towards the surface is essential in interpreting deformation features such as dyke-induced grabens and intrusive domes at the surface of rocky planetary bodies, and characterizing the underlying volcanic and igneous plumbing systems (VIPS). Forward models reveal dominant mechanisms of magma propagation below the surface. Those forward models then inform numerical inversions of geophysical data. The majority of those models assume that magma propagation trajectories can be satisfactorily described by the opening of a tensile crack in a homogeneous, linearly elastic crust. This presentation will show where non-elastic deformation processes may dominate instead. Results show that pre-existing structural fabrics can guide dike trajectories, that intrusion tip geometry and progressive host rock damage affect changes in propagation mode over time, that standard inversion methods fail to accurately estimate parameters of analogue intrusions from experimental surface displacements, and that simulating dynamic fracturing in host rocks during magma propagation is essential in capturing realistic patterns of host rock displacement, stress and strain. This work shows that it is essential to improve our insights of the role of geological complexities in steering magma intrusion trajectories to drastically improve our understanding of VIPS on rocky planetary bodies such as the Moon, Mars, and beyond.

Poster session - Board: 13 / **18**

The DAGGER project: Modelling magma propagation on Earth versus Mars

Author: Sam Poppe[1]

Co-authors: Tegan Havard [1]; Amisha Baiju [1]; Daniel Mège [1]; Steffi Burchardt [2]; Claire Harnett [3]; Michael Heap [4]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk, Warszawa, Poland*

[2] *Department of Earth Sciences, Uppsala University, Uppsala, Sweden, and Center for Natural Hazard and Disaster Science (CNDS), Sweden*

[3] *UCD School of Earth Sciences, UCD University College Dublin, Dublin, Ireland*

[4] *Université de Strasbourg, CNRS, Institut Terre et Environnement de Strasbourg, Strasbourg, France, and Institut Universitaire de France (IUF), Paris, France*

On Earth, intrusions of dykes in the shallow crust can induce graben formation. Graben and fracture features are also seen in the Tharsis volcanic province on Mars and are proposed to form through similar mechanisms. 'Marsquake'clusters were detected below Cerberus Fossae, one such graben and fracture system, by the InSight mission seismometer between 2019 and 2022. To generate these marsquakes, two plausible scenarios include: (1) the emplacement of a magma dyke segment, or (2) relaxation of the host rock around previously intruded dyke segments that contract when cooling. However, as on Earth, the subsurface magma processes cannot be directly observed. Most analytical and numerical models simplify magma-induced deformation to linearly elastic and assume a fully intact host rock. This does not account for inelastic deformation processes or the reduced bulk crustal rock strength linked to heavily fractured crust, which is particularly pertinent to Mars.
The DAGGER project will pioneer a two-dimensional (2D) numerical model using the Discrete Element Method (DEM) to simulate a dyke intrusion in shallow planetary crust, assessing the inelastic deformation including fracturing, and also test a three-dimensional (3D) approach. Field campaigns to eastern Iceland are used to collect drone imagery for photogrammetry and geological measurements, scanline data on fractures around intrusions in different host rocks, and host rock samples to determine bulk rock strength in the laboratory that will serve to calibrate the numerical models. The model will first be applied to simulate conditions analogue to Earth, then to Mars, allowing testing of different magma-induced marsquake mechanisms. Furthermore, our approach will improve the upscaling of intact rock sample strengths to crustal scale bulk rock strengths, and contribute to more robust modelling and interpretation of volcanic plumbing systems and their ground deformation on rocky planetary bodies.

Poster session - Board: 14 / **19**

A comparative analysis of dyke-assisted fracturing on Earth and Mars

Author: Amisha Baiju[1]

Co-authors: Sam Poppe [1]; Paul Cortinovis [2]; Daniel Mège [1]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk, Warszawa, Poland*

[2] *Université de Strasbourg, CNRS, Institut Terre et Environnement de Strasbourg, Strasbourg, France*

Graben and fracture systems are prominent extensional structures found on multiple planetary bodies, though their scale, morphology, and formation mechanisms vary significantly across environments. The formation of these structures is closely linked to magma dyke emplacement and lithospheric flexure in regions such as Cerberus Fossae on Mars, where InSight seismic data indicate ongoing tectono-magmatic activity (1). These Martian features contrast with Earth's smaller tectonic grabens and with Lunar and Venusian analogues formed under different thermal and tectonic conditions. The study of Martian grabens and fracture systems is crucial as they not only record lithospheric deformation but also reveal potential connections between magmatism, water release, and recent tectonic activity.
A case study from the Cerberus Fossae region illustrates how graben structures cut across elevated topography and intersect older, infilled fractures, indicating successive episodes of deformation. Detailed structural mapping done using images from the Mars Reconnaissance Orbiter (MRO) Context Camera (CTX), complemented by high-resolution images from the High Resolution Imaging Science Experiment (HiRISE), provides valuable constraints on the evolution, propagation mechanisms, and potential links to dyke emplacement processes in the Martian crust.
By connecting magma propagation processes with graben morphology across different planetary bodies, this study offers insights into crustal deformation under varying gravity, thermal, and tectonic conditions. Our project aims to refine models of dyke-assisted faulting, enhance the interpretation of planetary tectonics, and evaluate how magma intrusions may influence recent Martian seismicity and hydrological events.
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References:
Stähler et al., 2022, Nature Astronomy

Poster session - Board: 15 / **26**

New modelling approach to evaluate fluvial erosion and deposition on Mars

Author: Vilmos Steinmann[1]

[1] *HUN-REN Reserach Centre for Astronomy and Earth Sciences, Konkoly Thege Miklós Observatory*

In the context of studying the surface of Mars, it is imperative to undertake a thorough examination of the past and present changes to the surface. The analysis of morphological features formed by ancient water flow enables the drawing of conclusions regarding the velocity and duration of the processes that formerly shaped the planet's surface. The execution of studies of this nature necessitates the utilisation of an erosion model, the parameters and equations of which are such that they permit application not only to Earth, but also to conditions on Mars, for example. The presented results are based on precipitation data from the Zafit catchment area in Israel using QGIS and GRASS GIS, an Earth analogue of Mars, and show the height and velocity of water accumulating in the Tinto B river valley, located next to a well studied Martian area, Tinto Vallis, as well as the modelled erosion and accumulation rates. The objective of the research is to devise a model that can accurately estimate the location and amount of eroded and deposited material. In addition, the model will determine the location and size of rocks and grains that may be transported by river water, to target future sampling missions. Furthermore, the model will provide estimates and refinements of the time scale over which the planet's valleys and flood channels were formed, as well as the location of finest grains and longest water coverage. The uniqueness of the concept is well demonstrated by the fact that no model has yet been developed that would determine the runoff and erosion-accumulation conditions on the surface of Mars using physical parameters and data from terrestrial Mars analogues.

Poster session - Board: 16 / **34**

Identification of ore minerals on Mars based on data from Opportunity rover and research on terrestrial analogues

Author: Natalia Zalewska[1]

Co-authors: Leszek Czechowski [1]; Jakub Ciążela [2]; Beata Marciniak- Maliszewska [3]; Anna Kunert [4]; Ewa Borowska [5]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk*

[2] *Instytut Nauk Geologicznych Polskiej Akademii Nauk*

[3] *Uniwersytet Warszawski*

[4] *Spectro-Lab*

[5] *Extremo Technologies Faculty of Environmental Engineering Wroclaw University of Science and Technology*

In our study, we compare Martian concretions and some chosen terrestrial analogs. Data of Martian concretions were obtained by the MiniTES spectrometer on the Opportunity rover. Terrestrial analogues include spherules from the Dakota and Navajo formations (Utah, USA) and the Trovants from Romania. These analogs were examined using X-ray (Microprobe and EDS) and microscopic techniques to determine their mineralogical composition. One of the key findings was the presence of elements such as copper, as well as iron oxides and sulfides, in the terrestrial analogues, indicating a high degree of mineralization. Correspondingly, MiniTES data revealed spectral signatures consistent with ore-related minerals such as e.g. pyrite, ilmenite, hematite, and jarosite. These minerals are known indicators of metal ores, including copper, gold, and silver, i.e. elements important for future exploitation. Our results suggest that both the Martian environment and its Earth analogues may harbor conditions favorable for ore mineral formation. This has significant implications for the planning of future missions to Mars, particularly in the context of identifying potential sites for resource
extraction. The results suggest that at least some of the concretions in Meridiani Planum may have formed through low-temperature ore-related processes, analogous to those observed in terrestrial settings. This supports the hypothesis that ancient Martian environments may have hosted localized hydrothermal systems or prolonged groundwater circulation favorable to increase metal concentration. As such, these findings strengthen the case that the Martian subsurface could have supported formation of complex mineral structures and also geochemical processes conducive to the accumulation of potentially economically valuable resources.

Poster session - Board: 17 / **27**

Terraforming Mars –a feasibility study

Author: Leszek Czechowski[1]

[1] *Centrum Badań Kosmicznych Polskiej Akademii Nauk*

In this paper, we develop the terraforming ideas proposed in "Energy Problems of Terraforming Mars" (www.hou.usra.edu/meetings/lpsc2025/pdf/1858.pdf). We consider terraforming enabling humans to live on the surface of Mars without space suits.
There could be a number of reasons why Earth may become uninhabitable and terraforming Mars would be necessary, for example: (1) the eruptions of a series of supervolcanoes and increased volcanic activity; (2) accelerated global warming leading to extreme temperatures; (3) unrestricted nuclear war; etc. The source of matter for new Martian atmosphere will be minor bodies from the outer parts of the Solar System. The Kuiper Belt is the best source. Calculations indicate that app. 1,000 bodies with a diameter of 20 km will be sufficient to create a sufficiently dense atmosphere. The technologies necessary to implement the proposed terraforming are currently being developed and should be available for use in about 40 years. We also demonstrate that the total energy required to carry out terraforming is comparable to the energy currently produced by humanity. The shortest time required could be 70 years, although a more realistic is over 200 years. It seems be very long but in fact various projects lasted similar time, e.g. the Achtermeer polder was started in the 16th century, and the construction of the Sagrada Familia in Barcelona in 1882. An important factor facilitating terraforming is gravitational assist, which allows for a significant change in velocity with little energy expenditure. This maneuver is widely used today in spaceflight. It is quite difficult and requires precise maneuvering. Our research group is conducting calculations of this process. Some of these results will be presented at this conference. They confirm the feasibility of the proposed version of terraforming. The proposed methods can also be applied to other projects.

Poster session - Board: 18 / **22**

Leveraging low-thrust propulsion and simulated Neptune gravity-assist maneuvers to redirect Trans-Neptunian Objects for Mars terraforming: a comparative assessment of ΔV and impact time requirements

Author: Arkadiusz Hess[1]

Co-authors: Leszek Czechowski [2]; Ryszard Gabryszewski [2]

[1] *Uniwersytet Warszawski*

[2] *Centrum Badań Kosmicznych Polskiej Akademii Nauk*

Providing enough water remains a key challenge in the context of terraforming Mars. One interesting method is to redirect small water-rich bodies to hit the surface. While the prevailing focus of dynamical studies has been on Main Belt objects as the source, Trans-Neptunian Objects (TNOs) represent a more attractive source because of their significantly higher volatile content, including water ice.

In this study, we build on Czechowski (2025) [www.hou.usra.edu/meetings/lpsc2025/pdf/1858.pdf] analysis of the problem of redirecting TNOs onto collision trajectories with Mars. Two test cases were examined: a classical Kuiper Belt Object (KBO) and a Scattered Disk Object (SDO). A preliminary analysis of a non-optimal, retrograde thrust deceleration indicated prohibitive ΔV requirements in the range of 20-22 km/s. In order to drastically reduce these requirements, we performed a comprehensive optimization of the thrust vector over time for a very low thrust magnitude of $4{\times}10^{-10}$ km/s^2. We used advanced optimization algorithms, including the Covariance Matrix Adaptation Evolution Strategy (CMA-ES) and the Differential Evolution algorithm. We also analyzed Neptune gravity-assist trajectories to evaluate possible energy savings. For bodies in the moderate-to-high eccentricity range, it was found that even a single Neptune assist provides a more pronounced ΔV reduction than the low-thrust maneuver alone.

The application of an optimized thrust profile, characterized by discrete changes in thrust direction, enabled a reduction of the total impulse required by nearly an order of magnitude. For the analyzed cases, the required ΔV was successfully reduced to below 3.5 km/s. A gravity assist from Neptune further reduced the ΔV requirements below this threshold.

These results show that the extremely low thrust requirements make missions aimed at steering TNOs onto collision trajectories with Mars feasible with emerging propulsion technologies.

Poster session - Board: 19 / **35**

Toward the first tree on Mars: energy balance simulations of growth conditions

Authors: Agnieszka Wendland[1]; Robert Olszewski[1]; Piotr Pałka[1]; Melinda Kahre[2]; Alison F C Bridger[3]; Christian Körner[4]; Christopher McKay[2]

[1] *Politechnika Warszawska*

[2] *NASA Ames Research Center*

[3] *San Jose State University*

[4] *University of Basel*

We developed a high-resolution surface energy balance model for Mars using a 4002-cell Goldberg polyhedron. The model accounted for radiation, heat diffusion between cells, CO_2 phase changes, subsurface exchange, and atmospheric heat transport. We calibrated parameters against Viking lander data and Mars GCMs, and then applied the model to assess the combined effects of elevated CO_2 pressure and artificial greenhouse forcing on surface temperatures.
The atmospheric conditions existing on Mars today make the existence of life impossible. Sustained tree growth demands growing seasons of 110 sols, with daily temperatures ranging from >–6℃ (minimum) to < 40℃ (maximum), and mean values >6℃. The requirements for plant growth on Mars have been considered in the context of terraforming and for low-pressure greenhouses. The total pressure must be above ~10 kPa, and while a high percentage of CO_2 is acceptable, O_2 is needed for respiration at a level of ~ 0.1 kPa. Water must be available, and the temperatures must be in the range required for growth. Here, we focus on temperature as this is the fundamental environmental variable that changes during terraforming, and it controls the CO_2 cycle and the formation of liquid water. O2 levels in a thick warmer atmosphere remain an important separate concern. Focusing on the temperature, it must be several tens of degrees higher, while its diurnal fluctuations should be much lower.
We present results for an assumed CO_2 surface pressure of 10 kPa, which is known to support plant growth. We find that temperatures suitable for trees to grow occur when the added, artificial, greenhouse thermal infrared gray opacity is ~0.27 optical depths. Surprisingly, the conditions that allow plant growth do not occur first within the tropics (±25°) but in the Hellas Basin region. A further increase in the greenhouse effect expands the area suitable for plant growth in the southern hemisphere.

Poster session - Board: 20 / **41**

Cartographic visualization of the Mars terraforming process

Author: Miłosz Gnat[1]

Co-author: Robert Olszewski [1]

[1] *Politechnika Warszawska, Wydział Geodezji i Kartografii*

Current atmospheric conditions on Mars make it impossible for life forms known on Earth to exist. Scientific research indicates that by artificially enhancing the greenhouse effect, it is possible to change the climate of Mars so that it is similar to conditions on Earth.
Research conducted using energy balance simulations at high spatial and temporal resolution indicates that for a CO_2 atmosphere with a pressure of 10 kPa, surface temperatures suitable for plant growth occur when the artificial, greenhouse thermal-infrared grey opacity (tau) is ~0.39 optical depths. The results of the Mars terraforming process for various parameters of the simulation model indicate that for an atmosphere composed of CO_2 with a pressure of 50 kPa and a strong greenhouse effect (tau = 0.5), much of Mars would indeed become a "red planet"with a climate too hot for terrestrial life to exist there.
The authors of the article believe that the results are interesting for both scientists and science enthusiasts. To present the results in an interactive cartographic animation in a virtual reality environment, both standard GIS tools and the Unreal game engine were used. Based on their model of the terraforming process on Mars, the authors developed a methodology for cartographically presenting this process. This methodology considers spatial variations in altitude and climate on Mars as well as changes over time. The visualization shows the melting of Mars's polar ice caps, the formation of zones conducive to plant growth, and the progressive "reddening" of the Red Planet as greenhouse gas levels increase.

Poster session - Board: 21 / **21**

Do we really need to save Earth, If Space will save us?

Author: Błażej Niewiarowski[1]

[1] *Jagiellonian University in Krakow*

The concept of sustainable development has long been considered a central framework for addressing environmental and economic challenges on Earth. Yet, the accelerating progress in space technologies raises an important and controversial question: does the expansion of humanity into space make sustainability obsolete? The prospect of asteroid mining eliminating the scarcity of rare earth elements, the potential of nuclear fusion as both a terrestrial and extraterrestrial energy source, or the colonization of Mars as a "Planet B"seems, at first glance, to undermine the very rationale of sustainability as a constraint.

This paper argues, however, that space exploration and sustainability should not be perceived as mutually exclusive. On the contrary, they can be mutually reinforcing. Historical precedents, such as the development of Earth observation satellites during the space race, have already demonstrated how space technologies contribute directly to environmental monitoring and climate science. Looking ahead, asteroid mining could secure resources for renewable technologies, while In-Situ Resource Utilization (ISRU) concepts may inspire novel approaches to carbon management on Earth.

The paper concludes by suggesting that space exploration may not signify the end of sustainability but rather its transformation—towards a broader, interplanetary paradigm of sustainable development.

Poster session - Board: 22 / **31**

RAF Analog Space Mission - First analog mission on mining heaps

Author: Natalia Godlewska[1]

Co-authors: Filip Kaczorowski [1]; Mikołaj Zawadzki [1]; Norbert Nieścior [1]; Piotr Lorek [2]

[1] *University of Warsaw, Faculty of Physics*

[2] *University of Warsaw, Faculty of Biology*

For ten days, a post-mining heap from the coal mine in Bytom was transformed into an analog space base. This place became a hub of scientific activity as young researchers from the Scientific Club of Geophysics at the University of Warsaw embarked on an innovative project to simulate Martian conditions. The mission, named RAF-Analog Space Mission, aimed to replicate space conditions, test behaviors and principles applicable in outer space, and conduct essential scientific research.

The mission team comprised three students: Natalia Godlewska, Co-leader of the project, Mission Commander; Norbert Nieścior, Geolab Officer; and Piotr Lorek, Biolab Officer. These "astronauts" spent ten days living and working in a specially designed analog space base on the heap. The mission's primary objective was to conduct various scientific studies, including geophysical, geological, psychological, and astrobiological research.

The central phase of the project involved setting up a mobile base composed of a camper (serving as the living quarters) and a delivery van (serving as the scientific laboratory), connected by an airlock. This setup, located on approximately 30 square meters, provided a controlled environment simulating Martian conditions. The participants followed strict protocols, leaving the base only in space suits to maintain the illusion of being on Mars.

Analog space bases are terrestrial simulations of space conditions—in this case, Martian conditions. Analog astronauts strive to live and operate under space-like rules and constraints. The base allowed the team to experience and adapt to the challenges of life on Mars.

51

Visiting laboratories of the Faculty of Geography and Geology of the Jagiellonian University

Additional registration is required to visit the laboratories. Registration will open soon.