**Wednesday, 24.05.23, Asteroids & Comets**

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## Deficiency of Dust on Small Asteroid Ryugu – Upper Limit from Thermal Infrared Observations.

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The JAXA sample-return mission Hayabusa2 studied the small asteroid (162173) Ryugu through remote- sensing [1], deployment of the Lander MASCOT [2], and the successful return of two sets of samples to Earth [3]. One of the most surprising observations was the surface of Ryugu dominated by porous boulders with little finer particles and an apparent deficiency of dust [4-7]. Ryugu is less than 900m in diameter and similar observations have been made by NASA's OSIRIS-REx mission to similar-sized asteroid (101955) Bennu [9]. In particular, Bennu is also covered by porous, weak boulders with a maximum dust-layer thickness of 50µm [8]. The infrared spectra, which are very sensitive to the presence of dust, indicate that a very fine layer of dust is present [10]. Bennu also seams to actively eject particles into space [8] whereas Ryugu does not. The mechanisms behind the deficiency of dust on these small asteroids is not yet understood. At Freie Universität Berlin, a DFG-funded project will investigate potential mechanisms behind the lack of dust on Ryugu. Here we present results from the first phase of the project estimating an upper limit for the presence of dust. The presence of some small amount of dust on the boulders of Ryugu is hinted by lower contrast in the thermal infrared (TIR) spectra observed in-situ by the MARA instrument compared to laboratory measurement of the sample TIR spectra [11]. However, a 1D layered thermal model find upper limits for the thickness of a potential dust layer that are smaller than the mean size of the dust particles corresponding to the assumed thermal inertia of the dust layer. We conclude that the dust layer must be so subtle that the assumption of homogeneous, opaque layers in the thermal models no longer holds. Dust could be captured in cracks of the irregularly shaped boulder, resulting in lateral heterogeneity. The dust layer could also consist of very few grain layers.

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**Wednesday, 24.05.23, Asteroids & Comets**

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## Fine-grained Regolith Loss on Sub-km Asteroids

Hsiang-Wen Hsu, Xu Wang, Mihaly Horanyi

The surface properties of asteroids have been the focus of exploration and scientific study since the beginning of planetary sciences. The regolith particle size distribution is of particularly interest because it reflects the nature of surface shaping processes and has important implications in remote sensing observations and in situ exploration activities. Here we present a numerical model simulating regolith size distribution evolution considering three fundamental processes: thermal fragmentation, fragmentation and ejecta escape caused by impacts, and electrostatic dust removal. Each process has different effects on the regolith particle size distribution. Fragmentation processes act as a conveyor belt gradually transforming boulders to smaller and smaller grains. Impact ejecta escape and electrostatic dust transport serve as removal processes for fine-grained regolith. Most importantly, the combination of these three processes results in a coupled, non-linear evolution across grain size distribution. Our preliminary results show that, at 1 AU heliocentric distance, km-sized or smaller bodies where electrostatic dust removal could be active, fine-grained regolith is likely to be significantly depleted in ~106 years, leading to a lag-deposit-like surface scenery. The modeled grain size distribution is in reasonable agreement with measurements from recent asteroid sample return missions. These results are also relevant to other processes important to the evolution of asteroids, including space weathering and orbital evolution and will be discussed in this presentation.

**Wednesday, 24.05.23, Asteroids & Comets**

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## Triple main-belt comet 288P: a condensed showcase of asteroid evolution

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Main-belt comet 288P is dynamically a member of the main asteroid belt and probably native to this formation region. It is also one of the few known, so-called wide binaries, having components separated by approximately 100 times the radius of the largest component and directly observable in high-resolution telescope images. Indirect evidence suggests that one of the resolvable components may in itself be a close binary system, hence 288P would overall be a triple system. In addition, one of the components shows repetitive comet-like activity near perihelion, indicating the presence of near-surface water ice. The orientation of the mutual orbit and the short rotation periods of two of the three components suggest that the YORP effect played a role in spinning up the precursor component(s) and inducing break-up under centrifugal forces.

We here present the results of eleven years of Hubble observations of 288P that cover more than two of its revolutions about the sun and that have successively led us to deduce the properties of the system as outlined above. We also discuss potential evolutionary pathways that may have led to 288P's current state, and demonstrate the relevance of the interplay of various evolutionary processes in shaping asteroid evolution and activity.

**Wednesday, 24.05.23, Asteroids & Comets**

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## Activity of the Main-Belt Comet 324P/La Sagra

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Main-belt comets (MBCs) are comet-asteroid transition objects orbiting within the main asteroid belt. They exhibit cometary mass loss caused by the sublimation of volatile ices. One such object, the main-belt asteroid 324P/La Sagra (P/2010 R2), has been identified as a main-belt comet in consequence of its repeated dust emission activity during subsequent perihelion passages. The nature of this dust emission suggests that it is most likely driven by the sublimation of water ice, which is a common feature of MBCs. This study presents the results of the photometric analysis on 324P/La Sagra. We analyse archival data of 324P/La Sagra, taken from multiple telescopes in optical and infrared bands, to study its activity between 2010 and 2021. The results of the photometric analysis on optical data show absolute R-band total magnitudes and estimated total dust masses of the object to be consistent with previous publications. We confirm that the activity of the comet during the 2015 perihelion passage decreased significantly compared to the previous passage in 2010. Additionally, we analyse the most recent perihelion passage in 2021 to gain insight into the evolution of the activity of 324P/La Sagra over time. Our findings indicate that the activity during the 2021 passage has decreased compared to that in 2015. In this study, we also determine the geometric
albedo of the grains in the main-belt comet 324P/La Sagra using a combination of optical and infrared data. Our analysis reveals that the object has a geometric albedo of 0.065, consistent with the low albedo classification commonly attributed to 324P/La Sagra. These findings provide new insights into the evolution of the main-belt comet 324P/La Sagra. Additional observations may help further comprehend more fully its activity and physical properties.

**Wednesday, 24.05.23, Asteroids & Comets**

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## Space dust science on Wikipedia

The publicly available encyclopedia Wikipedia has become an important tool even in science. It can provide background information on wide areas of natural science and a repository of references to original research for in depth studies. While many languages have Wikipedia pages covering space dust themes but the English version (https://en.wikipedia.org/wiki/) has the widest range of influence for the public, students and researchers. There are overview pages on dust sciences: “Cosmic dust“, “Interplanetary dust cloud“, “Meteoroid“, “Micrometeoroid“, “Extraterrestrial materials“, “Presolar grains“, “Extraterrestrial diamonds“, and “Zodiacal light“. All spacecraft have Wikipedia presence with list of instrumentation, but there exist only a small number of pages dedicated to space dust instruments. The overview page “Space dust measurement“ compares the different approaches and provides references to results. It is requested that modern dust science issues are publicly displayed on Wikipedia.

**Wednesday, 24.05.23, Asteroids & Comets**

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## IMEX-Streams simulations for Earth's cometary meteoroid trail environment

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Dust trails along the orbits of comets were first observed by the Infrared Astronomical Satellite (IRAS); [Sykes et al., 1986]. Subsequent infrared observations found evidence that at least 80% of Jupiter-family comets are associated with dust trails [Reach et al., 2007]. These trails consist of the largest cometary particles (with sizes of approximately 0.1 mm to 1 cm) which are ejected at low speeds and remain very close to the comet orbit for several revolutions around the Sun, contrary to comet tails formed by smaller particles which disperse in space much more rapidly. When the Earth intercepts a cometary trail, the particles can collide with the atmosphere and show up as meteors and fireballs, generating a meteor shower. The Interplanetary Meteoroid Environment for eXploration (IMEX) dust streams in space model [Soja et al., 2015a,b] simulates recently created cometary meteoroid trails in the inner solar system, developed under ESA contract. IMEX is a physical model for dust dynamics and follows the orbital evolution of the trails of 420 comets. For each emitted particle, the trajectory is integrated individually including solar gravity, planetary perturbations as well as solar radiation pressure and Poynting-Robertson drag. The model calculates dust number density, flux and particle velocity. We apply the IMEX model to simulate the cometary meteoroid trail environment along the Earth's orbit between 2022 and 2035. We study trail traverses by DESTINY+, Lunar Gateway and other space missions close to the Earth.

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**Wednesday, 24.05.23, Asteroids & Comets**

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## Physical properties of dust particles collected in the coma of comet 67/P with COSIMA instrument onboard ROSETTA

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As part of the ESA ROSETTA science in-situ laboratory instrumentation to comet 67P/Churyumov-Gerasimenko, the instrument COSIMA collected dust in the size range from a few um to mm equivalent diameter in the inner coma of the comet. The particles were analysed with an optical microscope and a secondary ion mass spectrometer. The dust particles were collected on porous gold black targets with low impact velocity. We summarize the results and observations on the measured mechanical, optical and electrical parameters such as porosity, material strength, reflectance, electrical conductivity and relative permittivity of the dust particles.

**Wednesday, 24.05.23, IDPs**

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## Kuiper Belt Dust in the Inner Solar System

George J. Flynn and Lindsay P. Keller

Crystalline minerals in space accumulate damage from heavy solar flare ions, principally Fe, that can be used to measure the duration of their residence within tens of micrometers of the space-exposed surface, either as small dust grains in space or very near the surface in a parent body regolith. Comparison of the track density observed in space exposed materials by TEM with the measured track density in a well-dated lunar rock indicates a significant fraction of the 5 to 30 micron interplanetary dust particles collected by NASA from the Earth's stratosphere exhibit track densities higher than can be explained by their emission from asteroids or comets in the inner Solar System or by exposure in the regoliths of these bodies for times comparable with the exposure time of Itokowa regolith grains (Nature Astronomy, 6, 731-735, 2022). These Kuiper Belt dust particles were identified by their high track densities after deceleration in the Earth's upper atmosphere. The survival of these tracks provides some constraints on the orbital elements of these Kuiper Belt dust particles. Pulse heating experiments indicate that thermal annealing renders Fe-ion tracks invisible in the TEM in olivine heated to ~600 C or enstatite heated to ~700 C for 25 seconds. Both hydrous and anhydrous dust particles exhibit these high track densities, indicating that Kuiper Belt objects experienced aqueous processing, but that it was inadequate to fully hydrate the anhydrous minerals, leaving some track recording olivine or pyroxene. Modeling of entry heating indicates that, except for the small fraction of incident particles that enter at very shallow angles, these tracks would only survive in particles arriving from heliocentric orbits having relatively low eccentricity and inclination. Our results are inconsistent with some orbital evolution models that indicate very few dust particles produced in the Kuiper Belt can survive to reach the inner Solar System because of destruction by collisions with interstellar dust grains or ejection from the Solar System by gravitational encounters with the gas giant planets. It also suggests that the Kuiper Belt dust contribution to the Zodiacal Cloud is significantly higher than predicted in most dust models.

**Wednesday, 24.05.23 IDPs**

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## The Near-Sun Dust Environment: Observations from Parker Solar Probe

The zodiacal cloud spans from a few solar radii to beyond the Kuiper belt and is continuously evolving. It is sustained by particles shed from comets and asteroids and eroded by collisional grinding and sublimation. Before Parker Solar Probe (PSP), no spacecraft had ever transited the inner-most portions of zodiacal cloud within 0.3 au, where erosion is most prominent and meteoroid streams are most concentrated. As PSP's perihelion distances are well inside 0.3 au, its dust observations offer an unprecedented opportunity to understand zodiacal dust in the densest, most collisionally dynamic, and previously unexplored regions of the near-Sun dust environment. After multiple orbits with PSP, we find that its dust impact rates are consistent with at least three distinct populations: bound zodiacal dust grains on elliptic orbits (α-meteoroids), unbound β-meteoroids on hyperbolic orbits, and a third population of impactors that may be either direct observations of discrete meteoroid streams or their collisional by-products ("β-streams"). The β-stream from the Geminids meteoroid stream is a favorable candidate for the third impactor population. β-streams of varying intensities are expected to be produced by all meteoroid streams, particularly in the inner solar system, and are a universal phenomenon that should exist in exozodiacal disks. We discuss PSP observations of the dust environment in the very inner solar system. Specifically, we highlight the various observed populations, provide constraints on their relative densities and fluxes, discuss the erosion rate of zodiacal material, and present recent modeling efforts to better understand this intense and dynamic environment.

**Wednesday, 24.05.23, IDPs**

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## Earth's Space Particulate Environment; watch this Space!

Tony McDonnell (1, 2) and Simon Green (2)
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Knowledge of the Earth's microparticulate environment has been accumulated by a multitude of satellites and deep space probes. Early measurements and understanding are reviewed in McDonnell (1978) [1]. Therein, satellite data in the region of 1 AU is reviewed; notable reliable data includes Explorers 16 and 23, the Pegasus series and HEOS II in high eccentricity cislunar orbit. Pioneers 8 and 9, in deep space but also near 1 AU heliocentric distance, offered several years of microparticle data, although only summary results were published and the source data at the World Data Center DC were later erased. The Long Duration Exposure Facility, LDEF, later accumulated 5.75 years exposure in a stabilised Earth nadir pointing attitude and led to an abundance of impact features, including interplanetary fluxes from space pointing face [2,3]. Grün [4] was foremost in developing, from the data, a rationalised model of the flux mass distribution, identifying representative values for particle velocities and density amenable to computation. In association with Zook, dynamics of particle loss and replenishment of the Zodiacal cloud were modelled. Asteroids and comets have, traditionally, both vied as input sources for the cloud over the years but, more recently, extensive simulations of the dynamics and evolution by Nesvorny et al. [5] have supported the developing consensus; namely, that comets dominate the ecliptic population at 1 AU; asteroids must, of course play a role and are likely significant in the particulate cloud but at high ecliptic latitudes. Poynting-Robertson forces rapidly reduce the eccentricity of released cometary dust and also dominate orbital decay with short lifetimes. Formed, is a quasi-equilibrium cloud with key features: namely, a prolate co-rotational spheroid of low ecliptic elevation and eccentricity and of chondritic cometary origin. On the long Duration Exposure Facility, flux distributions provided supportive evidence for the Grun model, plus morphological evidence [6]. Chemical data of the chondritic nature of impactors is provided by the first capture cell samples retrieved on Space Shuttle STS 3 [7]. With the exception of Pioneers 8 and 9, none of the in-situ high sensitivity impact detectors have been able to point towards the Sun, thus limiting knowledge of the full dynamics of the sub-micron population and extending the Grun model apart from total flux estimates. Whereas discovery of interstellar dust entering the Solar System from the Ulysses Cosmic Dust detector [8] excited interest in the interstellar environment, potentially beta particles from other stars, our Sun's contribution can only be assessed currently by evidence from the Pioneers 8 and 9 instrument. Discovered by Berg and Grun [9], the smaller beta populations were noted but not resolved; those provide opportunity not only for direct assessment of mass outflow, but also study of the dynamics of the generation mechanism; will it be revealed? Opportunity for recovery of substantial quantities of the lost Pioneer source data has recently advanced by availability on-line of laboratory notebooks of the Pioneer principal investigator (O E Berg) [10], now made available at the WDC and further searches through notebooks of McDonnell, which reveal measurements on the Pioneer instrument flight spare and sub-system units performed in 1972 at NASA GSFC. New insights have resulted in calibration shortcomings and from the application of hypervelocity impact mechanics. We present updates to the earlier flux analyses presented at Dusty Visions 1, Madrid [11] to refine mass effluxes of Beta particles and explore generation mechanisms. Provisions for public access to all discovered Pioneer source data will be outlined.

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**Wednesday, 24.05.23, IDPs**

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## Micrometeoroid Impacts on to the X-Ray Telescope Mirrors of XMM-Newton and eROSITA/SRG

Peter Strub, Thomas Müller, Michael J. Freyberg, Georg Moragas-Klostermeyer, Pedro Rodríguez, Harald Krüger

Dust impacts have long been known as a potential hazard for space missions. X-Ray telescopes, due to their optical design, not only focus X-Rays onto the focal plane, but also dust particles entering the aperture close to the optical axis. At a grazing incidence onto the nested mirrors, incoming dust particles break up and their fragments emerge at an angle near the reflection angle and typically retain 80% of their original velocity. When these fragments hit the focal plane, they can damage the detectors, leading to single or multiple dead pixels in rows or clusters. In this project we present the data on 16 possible dust impact events observed during the missions of the SRG/eRosita and XMM/Newton X-Ray telescopes, and compare their directions and fluxes to simulation results from dust models of cometary trails, zodiacal dust, and interstellar dust in the solar system. As a result, we discuss the risk of micron-sized particles for space instrumentation.

**Wednesday, 24.05.23, IDPs**

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# Linking micrometeorites to their parental bodies – What can we learn from urban collections and experimentally produced analogs

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Micrometeorites (MMs) are extraterrestrial dust particles mostly between ~10 µm and 2 mm across that arrive on the Earth's surface [1,2], but typically undergo extensive melting and partial evaporation during atmospheric entry [3-5]. Heating during atmospheric entry and interaction with atmospheric oxygen modifies their initial texture and their mineralogical, chemical, and likely oxygen isotopic compositions [1–7]. Consequently, textures and compositions of MMs likely differ from those of their parent bodies [1]. However, MMs may inform about the nature of their parent bodies if (1) the modification of cosmic dust during atmospheric entry is understood and (2) if certain types of MMs can be linked to certain types of meteorite paren tbodies. To address these issues, we present initial results of a petrologic and oxygen isotope study of quenched melt spherules produced under controlled conditions in laser-irradiation experiments and of urban micrometeorites collected from rooftops i Genrmany. Using the laser irradiation facility of the Fraunhofer Ernst-Mach Institut (Germany) we have produced melt spherules by laser-induced flashheating of the H5 ordinary chondrite Hammadah al Hamra (HaH) 077. Melting of the chondrite sample in a 1-bar air atmosphere produced a meltspray that quickly solidified to glassy or cryptocrystalline spherules during flight. These spherules are similar in size (between ~10 µm and ~4 mm; typically 50–300 µm) and texture to MMs [8]. They resemble S-type, I-type, and G-type melted MMs ('cosmic spherules') as well as partially melted('scoriaceous') MMs [1,2]. Semi-quantitative SEM-EDS bulk analysis derived from the spherules' surfaces revealed compositional ranges consistent with average compositions of I-, G-, and S-type cosmic spherules. Oxygen isotope ratios of 14 laser-generated spherules of HaH 077 in the size range of 150 to 250 µm were analyzed by ion probe (SIMS at CRGP, Nancy). About 3 spots were measured per spherule. The oxygen isotope data ($\Delta^{17}O$, $\delta^{18}O$) of the laser-generated spherules plot close to the H chondrite field, but slightly deviate towards atmospheric oxygen. This suggests that apart from some possible isotope fractionation during evaporation, some exchange with atmospheric oxygen occurred even at very short time periods (<5 seconds) between heating and cooling (quenching) of the spherules. In addition to classical collection sites like the Antarctic, MMs collected from urban rooftops may be of specific value since their young age minimizes post-depositional alteration. Although rather difficult to separate from urban dust, urban MMs cover a similar range of compositional and textural types and can be considered complementary to Antarctic and deep-sea collections [e.g. 9]. Therefore we plan to include urban micrometeorites in future oxygen isotope studies. We conclude that microanalytical studies (including oxygen isotopes) on laser-generated spherules (using various chondrite types) in combination with equivalent studies on pristine (unaltered) micrometeorites derived from urban areas may significantly improve our understanding on how cosmic dust is modified during atmospheric entry. This would have implications for the correlation of micrometeorites to their cosmic sources.

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**Wednesday, 24.05.23, IDPs**

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## 26Al and 10Be in urban and Antarctic micrometeorites - Exploring their origin based on cosmic-ray exposure

Roughly 100 tons of extraterrestrial material released, e.g., from asteroid collision events or cometary sublimation enter the Earth's atmosphere each day. Part of this material reaches the Earth's surface as micrometeorites (MMs) – mostly submillimetre-sized spherical melted droplets. For more than a century MMs were collected only in remote environments such as deep-sea sediments or Antarctic firn and ice. However, since 2017 significant numbers of MMs have been recovered from urban areas, particularly the rooftops of buildings. In contrast to MMs originating from slow-accumulating environments that can have terrestrial ages of millions of years, cosmic spherules recovered from rooftops are not older than the buildings themselves and are therefore the youngest MMs ever collected. The study of the irradiation histories of MMs provides an important step towards identifying the origin and evolution of the cosmic dust in our Solar System. During their million-year-long space journey on spiral trajectories to Earth, the small interplanetary particles are exposed to cosmic radiation producing radionuclides such as 26Al and 10Be. Since the number of such cosmogenic nuclides increases with the time the MMs reside in interplanetary space, it is possible to estimate from which heliocentric distance in the Solar System they originated. However, the very small amounts of a few million atoms of the radionuclides within a MM decrease after deposition on Earth, i.e., with increasing terrestrial age. Hence, urban MMs, with insignificant terrestrial ages, provide for the first time the opportunity to measure the highest possible concentrations of long-lived radionuclides within MMs. We analyzed the 26Al and 10Be content of six urban MMs and, for comparison, six Antarctic MMs (which have terrestrial ages up to 780 kyr). These MMs with sizes of 90-500 µm were dissolved and, after stable carrier addition, 10Be and 26Al were chemically extracted and measured by accelerator mass spectrometry (AMS) at the Vienna Environmental Research Accelerator (VERA), Austria. This data was compared to results from numerical simulations calculating 26Al and 10Be concentrations in micrometeoroids using various orbital parameters, compositions, and irradiation profiles. This new approach can provide an independent constraint for identifying the dominant dust-producing sources in our Solar System.

**Wednesday, 24.05.23, IDPs**

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## The search for extraterrestrial organic matter in the Atacama Desert, Chile

Alessandro Airo & Jenny Feige
Museum für Naturkunde, Berlin, Leibniz-Institut für Evolutions- und Biodiversitätsforschung

Vast amounts of interplanetary dust particles, which encounter Earth, become part of sedimentary records, e.g., in form of micrometeorites. This cosmic dust contains extraterrestrial organic matter. Whether this material is preserved for millions of years in sedimentary deposits remains largely unknown. The benefit of searching for ancient cosmic organic matter in the Atacama Desert is mainly the continuous aridity enhancing the potential of preservation. The near lack of water minimizes abiotic chemical alteration of cosmic organic matter and reduces its degradation through biological activity. In the context of our NoSHADE (Novel perspectives on our Solar System History recorded in the Atacama Desert) project we will search for cosmic organic matter in up to 10 Myr old sediments.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

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## Distinguishing Isomeric Amino Acids Using Impact Ionization Mass Spectrometry

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Ocean-bearing moons, such as Enceladus orbiting Saturn or Europa orbiting Jupiter, offer potentially habitable environments. Enceladus and probably Europa release plumes of gas and ice grains into space, which originate from their subsurface oceans [1,2]. These plumes can be sampled using spaceborne impact ionization mass spectrometers (MS), as performed in the past by Cassini's Cosmic Dust Analyzer (CDA; [3]). Successor instruments with enhanced capabilities – such as the Surface Dust Analyzer (SUDA; [4]) on board NASA's upcoming Europa Clipper mission or a similar instrument for future Enceladus mission [5,6] – aim for the identification of biosignatures. Amino acids are essential building blocks of proteins and play a crucial role in the formation of water-based life as we know it, thus their identification on extraterrestrial water worlds is key to the search for life beyond Earth. Laboratory analogue experiments have demonstrated that modern impact ionization MS can detect amino acids [7] down to the ppb level, if they are entrapped in emitted ice grains, while distinguishing between abundance patterns of abiotic and biotic formation processes [8]. However, at any given molecular mass of an amino acid several isomers exist, which are indistinguishable by molecular peaks in recorded mass spectra. Some of these acids are more important for life as we know it than others [9]. Until now, it was unclear whether isomeric amino acids can be discriminated from each other, e.g., by fragmentation patterns in impact ionisation mass spectra. Here, using the same laboratory analogue technique, Laser Induced Liquid Beam Ion Desorption (LILBID; [10,11]), we conducted an analysis of eight isomeric amino acids with an identical molecular mass of 131.173 u. Although there are only subtle differences in their molecule structure, we reproducibly identified three amino acids due to their distinct fragmentation patterns. For the remaining five amino acids the fragmentation patterns allowed for a categorization into two distinct groups. Our results demonstrate the remarkable capabilities of impact ionization MS in identifying and distinguishing between isomeric amino acids in ice grains emanating from an ocean world. These findings provide the next step for detecting biosignatures in the Outer Solar System. By enabling us to differentiate between subtle variations in molecular structure in isomeric species, impact ionization MS offers excellent potential for the identification of extraterrestrial life forms, making it an invaluable tool for astrobiology research.

[1] F. Spahn et al., Science, 311, 1416-1418 (2006), [2] L. Roth et al., Science, 343, 171-174 (2014), [3] R. Srama et al., Space Sci. Rev., 114, 465-518 (2004), [4] S. Kempf et al., EPSC, 9, EPSC2014-229 (2014), [5] K. Reh et al., IEEE Aerospace Conference, pp. 1-8 (2016), [6] G. Mitri et al., Planet.Space Sci., 155, 73-90 (2018), [7] F. Klenner et al., Astrobiology, 20, 179-189 (2020), [8] F. Klenner et al., Astrobiology, 20, 1168-1184 (2020), [9] R. Häusler et al., Plant Sci., 229, 225-237 (2014), [10] F. Klenner et al., Rapid Commun. Mass Spectrom., 33, 1751-1760 (2019), [11] F. Klenner et al., Earth Space Sci., 9, e2022EA002313 (2022)

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Kranhold, Christian <christian.kranhold@uni-jena.de>

## Optical properties of dust mixtures for comet pebbles in the THz regime

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Comets belong to the oldest bodies in our solar system. They consist of volatile compounds such as water and CO ices, refractory materials (dust), and organics. In modern concepts of the early solar system, comets form from collapsing clouds of millimeter-sized pebbles. Due to their low temperature, comets emit thermal radiation in the GHz/THz frequency range, which has been measured by the MIRO instrument onboard ROSETTA. In this study, we investigate the absorption of refractory pebbles from pure $SiO_2$ and graphite dust mixtures in the THz regime, aiming at a determination of the emissivity at low temperatures.

Depending on the size distributions, the transmission spectra of pebble mono-layers show a general decrease in intensity with rising pebble size. Reducing the temperature from 300 K to 90 K, a clear trend in transmission has not been found. To discriminate between absorption and scattering losses in the extinction, we performed Mie calculations using optical constants from measurements ($SiO_2$) and literature data adapted to temperature and particle size (graphite). The effective optical constants are obtained by the Bruggeman mixing rule.Both the simulated and measured spectra show a dominant effect of the graphite in the mixtures, even at small proportions (5% by mass). This strong darkening effect argues against inorganic (graphitic) forms of carbon to be present in cometary materials in larger proportions. Organic carbonaceous compounds such as coal- or tar-like substances are much likelier to occur in cometary pebbles due to their one to two order of magnitudes smaller mass absorption coefficient.

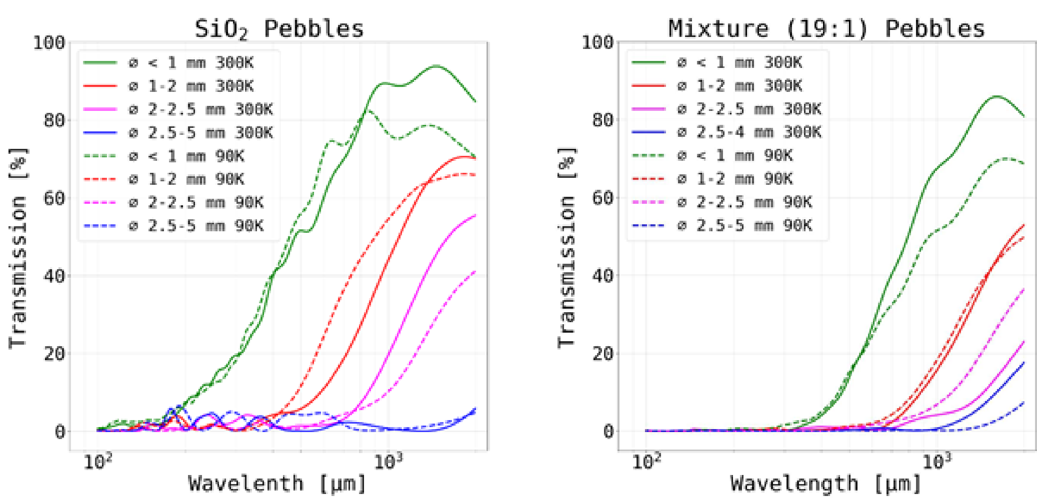


*Figure left side:* Transmission spectra of pure SiO2 pebbles depending on the pebble size and temperature; *figure right side:* Transmission spectra of $SiO_2$:graphite mixture (19:1) pebbles depending on the pebble size and temperature.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

O'Sullivan, Thomas <thomas.o-sullivan@community.isunet.edu>

## Discriminating structurally similar, single-ringed organic molecules in ice grains using an analogue experiment for impact ionization mass spectrometry

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Mass Spectrometers are an important part of the scientific payload on past and upcoming planetary space missions to study the composition of ice and dust grains in the solar system. Results from mass spectrometers on board the Cassini-Huygens mission at Enceladus revealed a substantial inventory of organic species in ice grains originating from a global subsurface, hydrothermally active, and putatively habitable ocean [1,2,3]. Compositional analysis of ice grains by the Cosmic Dust Analyzer (CDA), an impact ionization mass spectrometer, constrained some structural features of these organics, including low-mass nitrogen- and oxygen bearing functional groups as well as single-ringed aromatic compounds [3,4]. Low-mass aromatics are likely to have played a role in the emergence of life on Earth and may be linked to potential prebiotic or biogenic chemistry on icy moons [5,6]. Here, we study the fragmentation behaviour of single-ringed aromatic compounds [7] – benzoic acid and two isomeric derivatives, 2,3- and 2,5-dihydroxybenzoic acid (DHBA) – using laser-induced liquid beam ion desorption (LILBID), an analogue technique used to simulate the impact ionization mass spectra of ice grains in space [8]. We investigate the fragmentation behaviour and spectral appearance of each molecule over three simulated impact velocities - 4-6 km/s, 6.5-8.5 km/s and 9-11 km/s - in both positive and negative ion mode. We find that parent compounds can easily be distinguished from their derivatives via various spectral differences, including the (de)protonated molecular ion peaks appearing at different m/z values. Discriminating between structural isomers in LILBID is more challenging, but some insights can be revealed by considering intermolecular bonding regimes – hydrogen bonding involving the hydroxyl groups, in this case. The study of isomeric compounds will be an important aspect of future investigations at icy moons using impact ionization mass spectrometers, such as the SUrface Dust Analyzer (SUDA) on board the Europa Clipper [9]. This work will be extended to other classes of isomeric compounds - e.g. amino acids and fatty acids - and assist in elucidating the composition of organics in ice grains, relevant for future space missions to Enceladus and Europa.

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**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Mikula, Becca <Rebecca.Mikula@lasp.colorado.edu>

## Analysis of Impact Ionization Mass Spectra of Anthracene Dust Particles – a Pilot Study Characterizing Polycyclic Aromatic Hydrocarbons (PAHs) Using Dust Analyzer Instrument

Becca Mikula, Ph.D. Student, LASP, CU Boulder

A comprehensive laboratory study of the impact ionization of anthracene (a polycyclic aromatic hydrocarbon, PAH) dust particles has been conducted using the dust accelerator facility operated at the University of Colorado and a laboratory prototype of the Interstellar Dust Experiment (IDEX) dust analyzer instrument. PAHs are one of the main forms in which carbon can exist in interstellar space and such molecules were likely incorporated into the early solar system. The IDEX instrument is under development for the upcoming Interstellar Mapping and Acceleration Probe (IMAP) mission, where it will detect and analyze hundreds of interstellar and thousands of interplanetary dust particles, respectively. IDEX operates based on the impact ionization of individual dust particles. The generated ions are characteristic of the chemical composition of the impacting dust particles and are analyzed via time-of-flight (TOF) mass spectrometry. Although there have been several studies using inorganic materials such as minerals and metals, our understanding of the impact ionization of organic matter remains limited. A comprehensive laboratory study was performed by characterizing the impact ionization characteristics of anthracene dust particles impacting a gold target and the subsequent variation with impact speed over a range of 2 to 35 km/s. The collected TOF mass spectra are analyzed for maximum hydrocarbon size, fragmentation pattern, hydrogen/carbon atomic ratio, and hydrocarbon to carbon backbone ratio – all as a function of impactor velocity. The resulting enhanced understanding of the impact ionization properties of complex organics will aid the interpretation of mass spectra originating from organic dust particles in future missions such as IDEX/IMAP, or Interstellar Probe.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Li, Yanwei <li@irs.uni-stuttgart.de>

## Upgrades of a small dust accelerator

Yanwei Li, Universität Stuttgart, Institut für Raumfahrtsysteme

In this study, we describe the upgrade of a small electrostatic dust accelerator located at the University of Stuttgart. The newly developed dust source, focusing lens, differential detector and linac stage were successfully installed and tested in the beam-line. The input voltage range of the dust source was extended from 0 - 20 kV to 0 - 30 kV. A newly developed dust detector with two differential charge sensitive amplifiers is employed to monitor particles with speeds from several m/s to several km/s and with surface charges above 0.028 fC. The post-stage linac provides an additional acceleration ability with a total voltage of up to 120 kV. The entire system of this dust accelerator works without protection gas and without a complex high voltage terminal. The volumes to be pumped down are small and can be quickly evacuated. The new system was used to accelerate micron and submicron-sized metal particles or coated mineral materials. Improvements in the acceleration 10 system allow for a wider variety of dust materials and to new applications.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Doner, Alex <Alex.Doner@lasp.colorado.edu>

## Low Velocity Dust Impacts on Polyvinylidene Fluoride Films

Alex Doner[1], Mihály Horányi[1], John Fontanese[1]
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Polyvinylidene Fluoride (PVDF) dust impact detectors are simple and reliable instruments for measuring dust flux in space-like environments. These detectors have made their mark across the solar system on a variety of missions starting on Vega 1 and 2 while being used most notably on the New Horizons Spacecraft as the Student Dust Counter (SDC). PVDF films were first characterized by Simpson and Tuzzolino as viable dust detectors in 1985. They characterized that the impact from a hypervelocity particle created a crater in the surface of the film generating a charge pulse. That pulse can be measured with charge sensitive electronics and its amplitude can be directly calibrated to the mass and velocity of an impacting particle.

The Institute for Modeling Plasmas, Atmospheres, and Cosmic dusT (IMPACT) at the University of Colorado at Boulder is working on a new experiment to explore the minimum dust mass and velocity that still create a measurable depolarization impact charge. A new charge sensitive electronics was designed to increase the gain of the charge pulse and reduce the minimum detectable charge by a factor of five. These results may also reveal a potential interaction with the piezoelectric and pyroelectric properties of these films during dust impacts at low speeds (< 1 km/s). This talk will discuss our results to date and the potential use of PVDF detectors for low velocity dust impact measurements.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Sommer, Max <sommer@irs.uni-stuttgart.de>

## Measuring Micro-Debris In-Situ with the DESTINY+ Dust Analyzer

M. Sommer, Y. Li, R. Srama, J. Simolka, H. Strack, J. Glaeser, P. Froehlich, A. Exle, S. Ingerl , M. Bauer, A. Mocker, H. Krueger, P. Strub, M. Kobayashi, T. Hirai, and T. Arai

The DESTINY+ Dust Analyzer (DDA) is a planetary science instrument for the JAXA mission DESTINY+. For the first 2 years of the mission, the spacecraft will remain bound to the Earth on highly eccentric orbits, giving DDA the opportunity to sample debris dust, the smallest artificial objects in space. With its ability to analyze composition and dynamics of impacting grains, DDA is able to distinguish natural, interplanetary dust grains from artificial dust in orbit around the Earth. This micro-debris population is thought to stem primarily from solid rocket motor exhaust and poses a hazard to sensitive satellite surfaces. Here we discuss DDA's potential to study micro-debris on the basis of results obtained from ESA's MASTER model, as well as previous in-situ measurements in Earth-orbit.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

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## Detecting and analyzing interstellar and interplanetary dust particles with the IDEX instrument

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The Interstellar Dust Experiment (IDEX) instrument is under development for the Interstellar Mapping and Acceleration Probe (IMAP) mission to be launched in 2025. IDEX will detect and analyze interplanetary dust particles (IDP) and interstellar dust particles (ISP) reaching its orbit at Lagrange point L1. IDEX is an in situ high-resolution dust analyzer that provides the mass and elemental composition of individual impact events. The operation principle of the instrument is based on impact ionization, where the generated ions are analyzed in a time-of-flight fashion. IDEX operates over a wide dynamic range in terms of the impact-generated charge that is dictated by the expected wide ranges of impact speeds of IDP and ISP particles, and their mass distributions. The flight model of IDEX is in its build phase. Upon completion, the instrument will be tested for performance using the dust accelerator operated at the University of Colorado. There is an ongoing calibration effort that uses dust samples of known composition; the collected data are analyzed and will be used for determining the elemental composition of in situ data collected in the future. The laboratory calibration effort includes using organic particles (e.g., polycyclic aromatic hydrocarbon, or PAH) for the assessment of the complexity of organics in interstellar space.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Ershova, Anastasiia <Anastasiia.Ershova@oulu.fi>

## Fast code to derive the distribution of dust ejected from an atmosphereless body moving around the Sun

Anastasiia Ershova (University of Oulu, Finland; Freie Universität Berlin, Germany)
Jürgen Schmidt (Freie Universität Berlin, Germany; University of Oulu, Finland)

We present an elaborated version of the two-body dust cloud model by Ershova & Schmidt (2021). The original model describes non-stationary and asymmetric dust ejection from a motionless source on the surface of a spherical body (freely available package DUDI, https://github.com/Veyza/dudi). We further developed the model so that it can be applied to the case of a moving object ejecting dust. For example, for an active asteroid the gravity of the parent body is negligible and we can model the dynamics of the particles under the action of the central force exerted by the Sun. This allows us to include in addition to solar gravity also the effect of radiation pressure. Because both forces decrease with the square of the heliocentric distance, the formulae of the two-body problem are still applicable. Our model can also take into account the effect of re-collisions of dust particles with the parent body. The extension of DUDI for a moving source is efficient and allows us to explore in detail the distribution of dust around comets and active asteroids, which is essential for preparation of missions that perform compositional analysis of the dust (Cohen et al., 2019).
We directly apply the model to the dust emission of the near-Earth asteroid Phaethon (the parent object of the Geminid meteor shower) which is the scientific target of the DESTINY+ mission by the Japanese Space Agency JAXA carrying a German high-resolution mass spectrometer DESTINY+ Dust Analyzer (DDA) onboard (German Aerospace Center, 2020; Krüger et al., 2019). The launch of the mission is planned for 2024. We are to model the dust configuration around Phaethon at different orbital phases and to estimate the expected impact rate measured by the DDA.

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German Aerospace Center (2020). DESTINY+ Germany and Japan begin new asteroid mission.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Postberg, Frank <frank.postberg@fu-berlin.de> / Christian Fischer

## Dynamical analysis of mineral dust in the Saturnian system

Christian Fischer (1), Frank Postberg (2), Mario Trieloff (1), Jürgen Schmidt (2,3)
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Dust in the Saturnian system is dominated by ice grains from the active moon Enceladus [1][2][3][4] which are distributed mostly in the diffuse E ring. However, there is a much less abundant but significant population of non-icy mineral dust: 1859 sub-micron sized mineral dust grains were detected by the Cosmic Dust Analyser (CDA) aboard the Cassini spacecraft from 2004 to 2017. CDA inferred the composition of dust particles with an impact ionisation mass spectrometer. The compositional characterization of 36 interstellar dust particles recorded by CDA showed the potential of this approach [5]. In our previous dynamic analysis [7] a conservative approach had been used to determine the orbital parameters of grains detected by CDA. Considering that the majority of dust particles appear in time restricted groups called swarms we could statistically constrain their dynamical properties. Two main dynamic populations could be seen: retrograde potentially endogenous and polar potentially exogenous swarms. Compositional analysis showed that the dust particles appear as two main types: iron-rich sulfide and oxide particles (58%) and Mg-rich silicates (34%) while a small share (8%) consisted of mixed type particles [7]. Retrograde swarms contained a significantly higher fraction of iron rich grains compared to exogenous swarms. Here we present a refined approach to reconstruct the orbital parameters of these grains. Considering the occurrence of certain element mass lines [6] within the mass spectra, we can only derive a minimum impact velocity. From the assumption that the grains are bound to the Sun, we obtain as an upper bound for the impact speed onto CDA the escape velocity from the solar system at Saturn distance. Due to CDA's large field of view the impact direction is only constrained within a range of 56°. We take into account the angular dependence of the sensitive area of the impact Target of CDA to derive the probability distribution of impact directions for a given detection. Putting both of these constraints together we can determine a probability distribution density for the orbital elements which we use to evaluate the mean eccentricity and inclination for each swarm as well as for single detections. Again, two disjoint dynamic populations can be identified: almost certainly endogenous swarms with retrograde inclinations of about 170° and high-eccentricity exogenous swarms with nearly polar inclinations. The inclination of the retrograde endogenous particle is consistent with the previously suggested origin [7] from impact ejecta of Saturn's retrograde outer moons released by micro-meteoroid bombardment. In order to trace the origin of the exogenous particles their hyperbolic orbits in the Saturnian system are projected onto Saturn's Hill sphere. In this ongoing work we aim to identify potential sources like the Kuiper Belt and Oort Cloud or Centaur comets and present an updated compositional analysis with the potential to constrain the composition of the sources of the grains detected by CDA.

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**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Linti, Simon <s.linti@fu-berlin.de>

## Iron depleted silicates stemming from Saturn's main rings

Simon Linti[1], Hsiang-Wen Hsu[2], Christian Fischer[3], Mario Trieloff[3], Jon Hillier[1], Jürgen Schmidt[1,4], and Frank Postberg[1]

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[4]Space Physics and Astronomy Research Unit, University of Oulu, Finland

During Cassini's Grand Finale Orbits between April and September 2017, nanodust particles ejected from Saturn's main rings were sampled. These measurements were conducted by the Cosmic Dust Analyzer (CDA) [1], providing time-of-flight mass spectra of individual particles. Two main classes of nanoparticles were observed: water ice and silicates, with a particle number ratio of roughly 2:1 [2], which indicates a higher silicate abundance in the rings than determined with remote sensing techniques [3,4,5]. Dynamical models of the silicate population suggest a preferred C or D ring origin, with minor contributions from the outer main rings. Due to CDA's low mass resolution of m/dm = 20–50 [1], neighboring peaks of mineral- forming ions are unresolved in the mass spectra. Thus, the application of a deconvolution technique is required, to assess the elemental composition of the individual silicate particles. This approach is based on a technique used for the evaluation of interstellar dust particles [6]. After application of relative sensitivity factors [7], compensating for the specific ionization efficiencies of different element species, we find the abundances of Mg, Si and Ca to be similar to CI chondritic abundances. However, Fe is significantly depleted, on average by a factor of 2.3 for the Fe/Mg ratio. This discrepancy becomes even more significant when compared to the much higher Fe-content of exogenous IDPs [8] encountered in the Saturnian system by CDA, which are generally assumed to be the main pollutant and darkening agent in the main rings [4,5,9,10]. We discuss several scenarios that could explain the observed low iron content in the main ring silicates and the drastic compositional differences to contemporary IDPs falling onto the rings.

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[5] Zhang et al. (2017b), Icarus 294, 14–42. [6] Altobelli et al. (2016), Science 352, 312–318.
[7] Fiege et al. (2014), Icarus 241, 336–345. [8] Trieloff et al. (2023), EGU23-16469.
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**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

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## Indications for space weathering effects based on the compositional profile of the E ring

Lenz Nölle(1), Frank Postberg(1), Jürgen Schmidt(1,2), Fabian Klenner(1), Nozair Khawaja(1), Jon Hillier(1), Sascha Kempf(3), Sean Hsu(3), Ralf Srama(4)
(1) Institute of Geological Sciences, Freie Universität Berlin, Germany
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During Cassini's numerous passages through the E-ring the Cosmic Dust Analyzer (CDA) recorded thousands of time-of-flight mass spectra of microscopic water ice dust particles, ejected by Enceladus, that provide information about the grains' composition. This has shown the existence of three compositional main types of ice particles: Type 1 – poor in salts and organics, Type 2 – salt-poor but rich in organics and Type 3 – salt-rich.

In this work we investigated the compositional data with respect to the position of detection of the spectra for several orbital periods of Cassini, covering the space from inside the orbit of Enceladus to outside the orbit of Rhea. This radial mapping was conducted to study the potential impact of space weathering onto the radial particle composition, because the slow, radial outwards migration of the E-ring ice grains results in increasing exposure ages.

While around the orbital distance of Enceladus our results are in good agreement with earlier compositional analyses of E-ring ice grains in the moon's vicinity, at increasing distances to Saturn our results point at growing alterations of the proportion of compositional types by space weathering. We also report the discovery of a new type of ice grain (Type 5), exhibiting extreme salt-concentrations, presumably formed by plasma sputtering of Type 3 ice grains. Its proportion peaking close to the orbit of Rhea probably reflect E-ring dynamics and particle charging processes.

**Wednesday, 24.05.23,** 17:00 - 18:30 **Poster Session**

Hariprasad Mylapravan Gangadharan, <hariprasad.mylapravan.gangadharan@asml.com>

## Particulate control in EUV-induced H2 plasma in EUV lithographic tools

Hariprasad Mylapravan Gangadharan, Paul Jansen, Luuk Heijmans, Max Koole, Christiaan Cloin, Selwyn Cats, Vladimir Kvon, Ernst Galutschek, Seth Brussaard, Andrei Yakunin, and Mark van de Kerkhof

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EUV lithography scanner systems have entered High-Volume Manufacturing for state-of-the-art Integrated Circuits (IC), with critical dimensions down to 10 nm. This technology uses 13.5 nm EUV radiation, which is shaped and transmitted through a near-vacuum H2 background gas. This gas is excited into a low-density H2 plasma by the energetic EUV and DUV radiation from the Laser-Produced Plasma (LPP) in the EUV Source. In the vicinity of the walls and mirrors within the scanner system, this creates an environment rather similar to that near the surfaces of objects in space, especially when considered in combination with trace species such as N2, O2, H2O and hydrocarbons. This poster will discuss how insights on electrostatics and charging from astrophysics have been used to build understanding of particulate and molecular contamination, and how these were translated into prevention and control schemes to achieve near-zero contamination levels on critical imaging surfaces, compatible with the stringent manufacturing requirements for 10 nm lithography.

**Thursday, 25.05.23, Extrasolar Dust**

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## Calcium Isotope Studies of Silicate Stardust: Implications for Galactic Chemical Evolution

Isotopically anomalous dust grains that formed in the outflows of evolved stars and in the ejecta of stellar explosions are a minor, but important component of primitive Solar System materials. Such grains, which can be found today in primitive meteorites, interplanetary dust particles, and samples returned from comet Wild 2 and asteroid Ryugu, mostly escaped alteration and homogenization in the interstellar medium (ISM) and during formation of the protosolar nebula and disk [1]. Silicates are the most abundant type of presolar dust available for single grain analyses [2], followed by SiC, refractory oxides, graphite, and $Si_3N_4$. Based on their O-isotopic compositions, most (>99%) presolar silicates and oxides are divided into four distinct groups [3]. Low-mass (1.2–2.2 M) asymptotic giant branch (AGB) stars were identified as main stellar sources (~80%), followed by core-collapse supernovae (CCSNe). Additional contributions are evident for intermediate-mass (4–8 M) AGB stars undergoing hot bottom burning (HBB), and novae [e.g., 1]. Recent Mg isotope studies of presolar silicates showed that a significant fraction (~25 %) of the Group 1 and 2 grains, which represent ~85% of O-rich presolar grains, display large $^{25}$Mg-excesses, as well as significant $^{25}$Mg-depletions, and/or $^{26}$Mg-excesses, indicating CCSNe and their progenitors or, in some cases, intermediate-mass AGB stars or “Super-AGB-stars” as their stellar sources [e.g., 4,5]. Calcium isotope data for presolar oxide grains are rare, and for presolar silicates, none have been reported prior to this study. During the red giant phase, no material from zones with temperatures high enough to allow nuclear reactions involving Ca isotopes is mixed to the stellar surface. Only during the AGB phase modest enhancements of $^{42}$Ca/$^{40}$Ca and $^{43}$Ca/$^{40}$Ca are expected, with smaller enrichments of $^{44}$Ca/$^{40}$Ca, and with increasing isotopic shifts for AGB stars of increasing mass. The Ca-isotopic compositions of grains from low-mass AGB stars should largely reflect the initial compositions of their parent stars, governed by Galactic Chemical Evolution (GCE), similar to the trends observed for Mg and Si isotopes [e.g., 5]. While the $^{42}$Ca/$^{40}$Ca and $^{43}$Ca/$^{40}$Ca ratios of presolar oxides show a correlation with stellar metallicity, this is not the case for $^{44}$Ca/$^{40}$Ca [3], which displays a larger scatter than expected from AGB star models. In CCSNe, $^{40}$Ca, $^{42}$Ca, and $^{43}$Ca are produced in different nucleosynthetic settings than $^{44}$Ca. The latter is made mainly as radioactive $^{44}$Ti, and the most prolific $^{44}$Ti-producing SNe might be atypical and rare [6], potentially resulting in locally inhomogeneities in the ISM, which could explain the observed spread of $^{44}$Ca/$^{40}$Ca [e.g, 3]. Analysis of CCSN silicates ($^{25}$Mg-rich & $^{26}$Mg-rich Group 1/2, Group 4) will provide information on the occurrence of $^{44}$Ti in these stellar environments, complementing available data for carbonaceous SN grains (SiC, graphite). So far, two out of five $^{25}$Mg-rich Group 1 silicates show $^{44}$Ca-excesses consistent with $^{44}$Ti-decay. Comparison of the scatter of $^{44}$Ca/$^{40}$Ca in AGB star grains with $^{42}$Ca/$^{40}$Ca and other GCE-relevant isotopes (e.g., $^{25}$Mg/$^{24}$Mg, $^{29}$Si/$^{28}$Si) will yield additional information on the degree of heterogeneity in the ISM, and allow a more refined evaluation of potential GCE trends for Ca isotopes.

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**Thursday, 25.05.23, Extrasolar Dust**

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## New Insights into the Stellar Sources of Presolar Dust Grains

Primitive Solar System materials such as meteorites, interplanetary dust particles, and samples returned from comet Wild 2 and C-type asteroid Ryugu contain small concentrations of so-called presolar grains [1]. Presolar grains, except the presolar nanodiamonds, formed in the winds of evolved stars and in the ejecta of stellar explosions. They can be recognized by large isotope anomalies which are fingerprints of nucleosynthetic processes in their parent stars. The most abundant types of presolar grains with stellar origins are silicates and silicon carbide (SiC) which account for about 90% of all presolar grains. For both types of presolar grains low-mass (1-4 Msun) asymptotic giant branch (AGB) stars are considered to be the most important stellar sources. Contributions from supernovae (SNe) are evident as well. Until recently it was believed that grains from SNe are comparatively rare, with relative contributions of about 10% for silicates and 1-2% for SiC. However, recent isotope studies of presolar silicates and SiC grains with the NanoSIMS and availability of new SN models with consideration of H ingestion changed this view considerably. Silicates: Based on the O-isotopic compositions O-rich presolar dust is divided into four distinct isotope groups. Most abundant (about 80%) are Group 1 grains. It was consensus for a long time that Group 1 grains are exclusively from AGB stars. However, recent isotope studies revealed Mg isotope signatures in ~25% of presolar Group 1 (and related minor Group 2) silicates which suggest origins in core-collapse SNe and/or their supergiant progenitors [2]. The minor Group 4 (and some Group 3) grains were recognized as SN grains already for a long time. Together they account for another about 10% of presolar silicate grains from SNe. In total, the contribution of silicates from SNe may be >30% [2]. SiC: Based on C-, N-, and Si-isotopic compositions presolar SiC is divided into seven distinct populations: Mainstream, AB, C, X, Y, Z, and (putative) nova grains. It is generally accepted that mainstream, and the minor Y and Z grains, which together account for more than 90% of all SiC grains, formed in the winds of AGB stars. The C, X, and some fraction of nova grains make up the classical SN grains (1-2% of SiC). AB grains (5% of SiC) have multiple stellar sources. Recent studies have favored SNe as sources for more than 50% of AB grains, i.e., the contribution of SiC from SNe is >4% [2]. Hydrogen isotope studies of matter from comet 67P/Churyumov-Gerasimenko by the Rosetta mission suggest that this comet is particularly primitive and might have preserved large amounts of presolar matter, including presolar grains. Presolar grain abundances at the percent level would lead to C- and O-isotopic anomalies of 10% or larger at bulk scales of the refractory component [3], which, however, has not been observed so far.

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**Thursday, 25.05.23, Extrasolar Dust**

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## Current and near-future endeavours in dust-heliosphere research

Veerle Sterken, Lennart Baalmann, Silvan Hunziker

The core of the research in the Astrodust group at ETH Zürich consists of uncovering the dynamics of cosmic dust in the time-variable heliosphere. In this talk, we review the current status of research on interstellar dust dynamics and on heliospheric science from the point of view of simulations, calibrations, data analysis, and future mission concepts. We give prospects for how we can better understand the dust-heliosphere interactions, guided by the most important research questions related to the dust in its local environment. Finally, we highlight the Interstellar Probe, the DOLPHIN, and the SunCHASER mission concepts, the advantages of having a dust detector suite on the Lunar Gateway, and dust-heliosphere research with upcoming missions like IMAP, Europa Clipper, JUICE and Destiny+.

**Thursday, 25.05.23, Extrasolar Dust**

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## A multi-mission study of interstellar dust in the heliosphere: lessons about the past and for the future

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Many spacecraft have measured interstellar dust (ISD) over the past few decades, both via dedicated dust detectors (e.g. on Ulysses, Cassini) and also serendipitously from plasma wave antenna measurements of particle impacts (e.g. on Wind, STEREO, Voyager 1 & 2). These measurements cover overlapping, decade-long timeframes, and have been taken from various vantage points within the heliosphere, in the heliosheath, and also in the VLISM.

We aim to combine the gathered information into a holistic perspective of the dynamics of ISD in the heliosphere by comparing the rich data to state-of-the-art ISD simulations. This will allow us not only to better understand the effects of the heliosheath, including the heliosheath, on the dust flow, but also to constrain the parameter space of dust particle properties.

In this presentation, we will focus on data gathered by Wind and Ulysses, and what lessons for future plasma wave antenna and dust detector measurements it has taught us so far.

**Thursday, 25.05.23, Extrasolar Dust**

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# Populations of Exogenous Dust at Saturn seen by Cassini CDA

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We report on the final inventory of the exogenous dust populations measured by CASSINI Cosmic-Dust-Analyzer (CDA) during the fourteen years spent in the Saturnian system. The exogenous dust grains at Saturn are of interplanetary and interstellar origin. Using the different sub-systems of the CDA instrument, we identify various IDP populations, characterized by their injection speeds at Saturn's Hill sphere. We confirm in particular the relatively high abundance of IDP particles released by KBOs and/or Jupiter family comets and Centaurs. We also observe a lower contribution from particles with dynamical signature compatible with those released by Oort cloud or Halley-type comets. The insterstellar dust (ISD) population appears also clearly in our data set, with a clear extension to the micro-meter size regime.

**Thursday, 25.05.23, Dust Around Planets**

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## Micro-meteoroids falling into the Saturnian system detected by Cassini CDA

Juergen Schmidt, Sascha Kempf, Nicolas Altobelli, Jeffrey N. Cuzzi, Paul R. Estrada & Ralf Srama

The Cosmic Dust Analyzer onboard the Cassini Mission at Saturn possessed a system of entrance grids that allowed in principle to measure charge and velocity of grains entering the aperture of the instrument. The measurement is possible if the grain carries a sufficiently high charge so that the induced charge signal in the entrance grids stands out above the noise (e.g. induced by ambient plasma). Over its tour in the Saturn system the Cosmic Dust Analyzer registered a number of such dust particles of which 163 have a velocity vector that implies that they are not bound to the Saturn system. From these detections we have derived the exogenic mass flux into the Saturn system. Application to the rates of pollution of Saturn's rings and constraints on the ring age are presented in a companion talk (S. Kempf et al, this session). In this talk we present details on the size distribution of the grains and the method of deriving the flux from the data.

**Thursday, 25.05.23, Dust Around Planets**

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## The Age of Saturn's Rings Constrained by the Meteoroid Flux Into the System

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The origin of Saturn's ring is still not known. There is an ongoing argument whether Saturn's ring have been formed shortly after Saturn together with its satellites or they may actually be a recent phenomenon in the solar system. This possibility of young rings has been vigorously debated for nearly 40 years, since the Voyager flybys of Saturn. Over the years, the most powerful support for this hypothesis has turned out to be the puzzle of the rings' nearly pure water ice composition – unique in the family of planetary rings – in spite of the constant hail of rocky-carbon meteoroids from outside the Saturn system. However, three major uncertainties have left the 'young-ring' hypothesis unproven. Two of these have already been resolved by the Cassini mission: the amount of non-icy material currently in the rings, and the total ring mass. The third main constraint is the mass flux of non-icy meteoroids falling onto the rings. Here we report on the measurement of the meteoroid mass flux into the Saturnian system obtained by the charge-sensitive entrance grid system (QP) of the Cosmic Dust Analyser (CDA) on the Cassini spacecraft. The determination mass flux of non-icy material coming into the Saturn system completes the trifecta of constraints that are required to strongly support a youthful ring system. We analyzed the full CDA data set acquired after Cassini's arrival at Saturn in 2004. The CDA detections determine the incident particle orbits, and they come (surprisingly) not from comets as expected, but mostly from Kuiper Belt Objects (with at least one other population also apparent). This means that most of the particles have low speeds relative to Saturn and are strongly focused gravitationally, such that the flux at the rings is even larger than previously estimated. We have also found that the flux has a statistically significant upper size cutoff, meaning that our detection is robust to Cassini's finite observation time.

**Thursday, 25.05.23, Dust Around Planets**

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## Exploring the dusty environment in the vicinity of Saturn's F ring and the nearby moons

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In early 2017, the Cassini spacecraft orbited Saturn at highly inclined elliptical orbits, the so-called Ring-Grazing Orbits and explored the region at the outer boundary of Saturn's main rings. The spacecraft passed through the ring plane between the F ring and the co-orbital moons Janus and Epimetheus with an average speed of ~20 km/s. On many of these orbits Cassini's Cosmic Dust Analyzer (CDA) [1] directly sampled dust particles in this region and produced time-of-flight (TOF) mass spectra of these grains. We present a compositional analysis of dust particles detected within ±15 min from the ring plane crossings (RPXs) and compare the spectra of dust grains sampled during the Ring-Grazing Orbits with those of the E ring (Type 1 – almost pure water ice, Type 2 – organic enriched and Type 3 – salt rich) [2,3]. Here, we investigate, if these grains have a local origin, such as the F ring or the nearby moons Pandora, Janus and Epimetheus [5], or if the observed dust population is influenced by E ring material extending towards the main rings. We infer an E ring origin for most icy grains, which implies an inward extension of the E ring to at least 2.45 RS, overlapping the G ring. The icy grain types (Types 1, 2, & 3) are encountered in the E ring [2,3], although with different relative abundances [4]. In addition, a small fraction (~1%) of the spectra indicates the presence of mineral grains. Their compositions range from Fe-poor silicates to Fe-rich material, potentially oxides or sulfides. For the first time, we find a unique ice-mineral mix grain type [5] that implies a local source, or sources.

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**Thursday, 25.05.23, Dust Around Planets**

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## How Predator-Prey Dynamics Creates ‘Straw’ in the Strongest Density Waves

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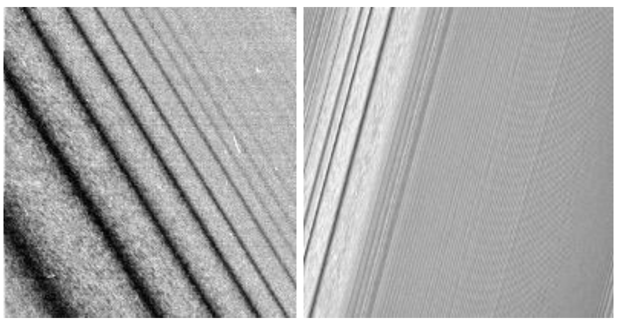
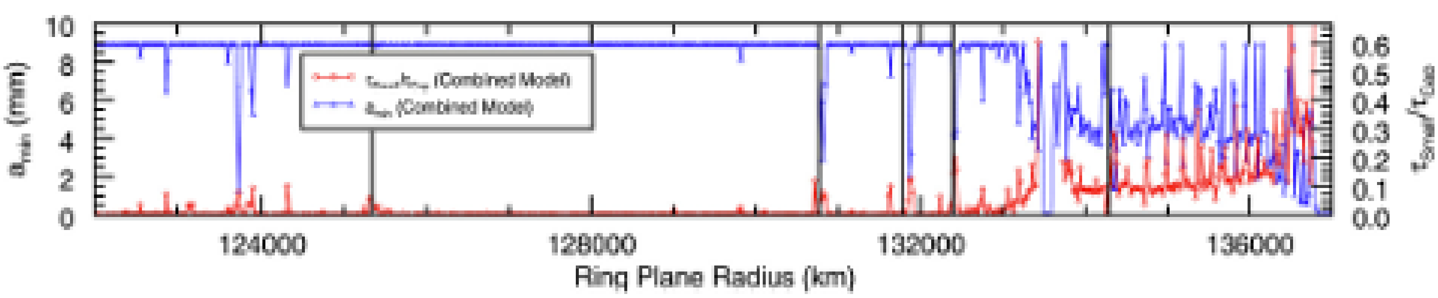
The Cassini cameras detected elongated structures in Saturn’s ring in highly perturbed regions near ring edges and within the strongest density waves. These ‘straw’ features are likely triggered by the periodic forcing arising from the nearby



moons. We investigate the temporal response to this forcing by interpretation of the ring occultation counting statistics. The varying geometry of Cassini star occultations by Saturn’s rings constrains both the size and shape of structures that block starlight. Statistics of UVIS star occultations measure structures as small as meters, on times scales of minutes to decades. We calculate the excess variance, skewness and kurtosis including the effects of irregular particle shadows, along with a granola bar model (GBM) for gaps, ghosts and clumps. We then use the statistics of ring occultations observed by the Cassini UVIS High Speed Photometer to characterize structures in Saturn’s rings. Skewness for small τ has a different sign for transparent and opaque structures, and can distinguish gaps from clumps. The higher order central moments are more sensitive to the extremes of the size distribution and opacity. To calculate the expected variance, skewness and kurtosis, we use the moments approach of Showalter and Nicholson (1990), extended to higher moments and removing their restrictions on fractional particle area δ <<1 and line-of-sight optical depth τ <<1. We include Poisson contributions, but ignore Sheppard’s corrections for data compression; and use the exact formulas, not Taylor expansions. The measured Cassini occultation statistics show the expected extrema and zero crossings. The observed excess variance shows aggregate growth following the passage of a density wave crest. For self-gravity wakes in the A ring, we find wake width W = 18-29m; typical wavelength S+W ~ 60m; H/W < 0.12, thus vertical height H < 4m. These results are consistent with a simple dynamical model of the rings, analogous to an ecological Predator-Prey interaction. Compression drives aggregation, which lags the forcing. Perturbed by passing density waves, self-gravity wakes grow and erode on orbital timescales with a full amplitude of 60%, and a phase lag **Δφ** ~45°. Our calculations show the periodic behavior of the wakes, and that collisions between these aggregates create an order of magnitude larger structures in the region driven by the




strongest density wave crests, which would be visible to the Cassini cameras the ‘straw’ seen at Saturn Orbit Insertion and in the Grand Finale. Ejecta from collisions and erosion form the dusty haloes around the density waves. The resonance driving produces both aggregates and small particles!

**Thursday, 25.05.23, Dust Around Planets**

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## Stochastic Charging Fuelling Saturn's Ring Rain and Dynamical Segregation of Dust Species

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In the final phase of the Cassini mission, the spacecraft's Cosmic Dust Analyzer (CDA) could directly observe the ring rain, a dusty connection between the rings and the planetary atmosphere. Utilizing the so called guiding center approximation to describe the motion of dust particles along magnetic field lines, one can directly link infalling dust to respective regions in the rings.(1) Up to one third of the detected infalling dust showed silicious spectra – an abundance compared to the ring composition of nearly pure water ice (> 95%). (4) Stripping pollutants from the rings in a cleaning process may mimick a low exposure time to interplanetary meteoroids and may let the rings appear younger than they are.(2) We examine the motion of a dust particle with a radius in the order of a few ten nanometers, matching simulations to recreate the observed dust signatures. Evaluating the effective potential for the movement of such a nano dust particle, including gravity and Lorentz force as dominant forces in the inner planetary system, it gets evident, that the particles can be trapped in an energetic well.(3) Thus, the dusty motes perform a stable, bound motion in the vicinity of their origin. We employed a basic model for the plasma environment (cf. (4)) to determine significant charging parameters, i.e. charging times and strength. These parameters were used to describe the stochastic charging of the nano-particles. As we describe analytically, this multiplicative noise process can increase the total energy of the particle(5), leading to an "overflow" of the energetic well. We observe, that with the particle composition, a spacial segregation occurs: siliceous particles show a tendency to fall onto the planet, while icy particles are transported outwards and removed from the planetary system, without necessarily cleaning the rings We are able to numerically produce density signatures that are comparable to the CDA findings and beyond that, our analytic description of the problem can give an intuitive insight on the behaviour of certain dust populations and ease the search for significant parameter sets in com- parable settings. (This work is partially supported by Deutsche Forschungsgemeinschaft, Sp384/33-2).

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**Thursday, 25.05.23, Dust Around Planets**

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## Simulating the Martian dust cycle: From source to sink

Demetrius Ramette & Prof. Dr. Kerstin Schepanski. FU Berlin / FB Geowissenschaften

Mars is known for its planet-encircling dust storms that occur every few Martian years. Even smaller-sized, regional dust storms are a frequent phenomenon on Mars. Dust plumes are transported by winds and deposited away from their source, thereby changing the radiative properties of the surface and atmosphere and thus modulating the atmospheric dynamics and energy balance. However, the understanding of the conditions and processes involved in the formation and decay of dust storms is still limited. In our study, we use General Circulation Model (GCM) simulations, which we initialize with remote sensing observations of the atmospheric column dust content, in order to investigate the formation of dust storms as well as dust transport pathways. We will present first results, in particular focusing on the localization of dust sources and sinks. We further aim at quantifying the redistribution of dust on the surface of Mars during planet-encircling dust storms. Ultimately, this work shall contribute to improving the representation of dust storms in GCMs.

**Thursday, 25.05.23, Icy Moons**

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## The Organic Inventory of Enceladus's Subsurface Ocean and Hydrothermal Processing of Organics in the Laboratory

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The subsurface ocean material from hydrothermal sites expelled through [1,2] the south polar fractured terrain of Enceladus as plume of gas and ice grains [3], and sampled in situ by Cassini's mass spectrometers; the Cosmic Dust Analyzer (CDA) and the Ion and Neutral Mass Spectrometer (INMS). Enceladus's ocean hosts a variety of organic molecules, spanning a range of chemical properties: high-mass (> 200 u) refractory insoluble organic material [4] and low-mass (< 100 u) volatile organics with oxygen-, nitrogen, and aromatic-ring-bearing functional groups [5]. Recent reanalysis of CDA and INMS data (presenting here) have tentatively revealed further diversity in the inventory of organics, including alkene functional groups and formaldehyde. The relationship between the organic compounds detected in ice grains by CDA to those involved in hydrothermal chemistry is currently poorly constrained, despite extensive efforts to understand the mass spectral appearance of such organic compounds in CDA impact ionization spectra of ice grains [4,5,6]. Laboratory simulations of Enceladus's subsurface chemistry [7,8] have thus far not considered how hydrothermally processed material would appear in impact ionization mass spectra, and therefore need to include measurements with analogue techniques for spaceborne instruments, such as laser-induced liquid beam ion desorption (LILBID). In the Planetary Science and Remote Sensing Group at Freie Universität Berlin, a newly established laboratory facility is used to simulate hydrothermal conditions in the depths of Enceladus's ocean, capable of operating at pressures of up to ~ 150 bar and temperatures of up to 300 °C, whilst still supporting sampling during the experiment. The first investigation with this new experimental setup assesses the processing of triglycine peptide (GGG) within the range of conditions (~ 80 °C and 80 bar) suggested for Enceladean hydrothermal systems [9]. Samples from the hydrothermal experiments were measured using the LILBID facility, and here we present spectra of both hydrothermally processed and unprocessed GGG samples, showing their fragmentation pathways.

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**Thursday, 25.05.23, Icy Moons**

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## Detection of phosphate in ice grains from Enceladus' ocean with implications for habitability in the outer solar system

Frank Postberg, Yasuhito Sekine, Fabian Klenner, Christopher R. Glein, Zenghui Zou, Bernd Abel, Kento Furuya, Jon K. Hillier, Nozair Khawaja, Sascha Kempf, Lenz Noelle, Takuya Saito, Juergen Schmidt, Takazo Shibuya, Ralf Srama, Shuya Tan

Enceladus's subsurface global ocean (1) can be probed by sampling the gaseous and icy material the moon expels into its cryovolcanic plume and - even further out - into Saturn's E ring (2,3,4,5). Hydrothermal outflows caused by tidal heating (4,5,6), together with rich organic chemistry (7,8) imply that the moon appears to be one of most habitable places in our solar system. Among the critical elements C, H, N, O, P and S that are considered to be essential for life, all except phosphorous have either been identified (5,7,8) or - in the case of sulfur - tentatively detected (9). Recent geochemical modelling claims that P will be severely depleted in ocean worlds and thus P could be a bottle neck for the emergence of life in subsurface oceans (10). Here we present results from a re-analysis of mass spectrometric data from Cassini's Cosmic Dust Analyzer (CDA), showing proof of sodium-phosphate salts in ice grains originating from Enceladus's subsurface ocean. We found a small number of ice grains whose spectra clearly indicate the presence of at least two sodium orthophosphates: $Na_3PO_4$ and $Na_2HPO_4$. These CDA spectra have been subsequently reproduced in the laboratory which enables the quantitative evaluation of CDA spectra (11). We infer phosphate concentrations in the Enceladus ocean in the order of a few mM, at least 100-times higher concentrations than in Earth's ocean. We carried out geochemical experiments and calculations showing that such high phosphate abundances can be achieved in Enceladus, either at the cold seafloor or in hydrothermal environments with moderate temperatures. The driver enabling the abundant availability of phosphate is the high observed concentration of dissolved carbonate species, which shift phosphate-carbonate mineral equilibria toward dissolution of solid phosphates into Enceladus' ocean. We show that interactions between chondritic rocks and $CO_2$-rich fluids generally lead to conditions where dissolved phosphate concentrations tend to maximize. Therefore P-rich oceans would commonly occur in ocean worlds beyond the $CO_2$ snow line and with that the availability of phosphorous would not be a limiting factor on the habitability of ocean worlds in the outer solar system in.

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**Thursday, 25.05.23, Icy Moons**

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## Enceladus dust plume model based on in situ data obtained with the Cassini Cosmic Dust Analyzer

Anastasiia Ershova (a), Jürgen Schmidt (a,b), Frank Postberg (b), Nozair Khawaja (b), Lenz Nölle (b), Ralf Srama (c), Sascha Kempf (d) and Ben S Southworth(e)

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We analyse data from the Cosmic Dust Analyzer (CDA) on board the Cassini spacecraft at Saturn that were recorded during traversals of the Enceladus dust plume. The focus of our work are profiles of relative abundances of grains of different compositional types obtained from mass spectra recorded with the Dust Analyzer (DA) subsystem during the flybys E5 and E17. The profile from E5, corresponding to a steep and fast traversal of the plume, was analyzed in previous work (Postberg et al. (2011)). Here we present another compositional profile obtained at a very different geometry during flyby E17, with a nearly horizontal traversal of the South Polar Terrain (SPT) at a

significantly lower relative velocity. Additionally, we employ rates of dust detections registered by the High-Rate-Detector (HRD) subsystem at two different Enceladus flybys (E7 and E21). We derive the ranges of grain sizes that were sampled by the two CDA subsystems at the respective flybys and use all CDA data sets to constrain the parameters of a new dust plume model that we construct from a recently developed mathematical description for dust ejection (Ershova and Schmidt (2021)) using the software package DUDI publicly available at https://github.com/Veyza/dudi. From our model we derive production rates of dust mass for the different compositional types of grains detected by CDA, with a total rate equal to or larger than about 30 kg/s. The contribution of salt-rich was previously believed to be dominant (Postberg et al. (2011)). But with the larger data set analyzed in this paper we find that its contribution is only about one percent by mass. The model can be used to predict numbers and mass of grains of various compositional types that a detector on a future mission would detect during a plume traversal.

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**Thursday, 25.05.23, Icy Moons**

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## Chemical Evolution Driven by Hydrothermal-Freeze Cycles within Enceladus

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Observations of Enceladus have shown water jets expelling from the surface. These jets originate from a subsurface ocean and formed Saturn's E-ring. Further observations of the plumes have led to the consensus that Enceladus likely holds a porous chondritic mineralogy, hydrothermal environments, and several building blocks necessary for the formation of life. Numerous research has documented the viability of synthesizing organic material in chondritic hydrothermal systems. This has given credence to life forming on chondritic ocean worlds. On Enceladus, a freezing phase is likely to occur during cycling at an overlying icy shell interface. As demonstrated by Miyakawa et al. (2002), this freezing phase is equally valuable in forming organic material. However, no previous experiment has attempted to explain these organics or how a hydrothermal freeze cycle could affect chemical evolution and variety. Our research aims to simulate possible geochemical cycling scenarios within Enceladus and to identify organic compounds and processes that could exist within its ocean. We subjected fluid mixtures similar in composition revealed by Cassini to several temperature ranges (150 to -20 ºC), pH ranges (9 – 10), and maximum pressures (8 to 40 MPa) thought to exist within Enceladus within a Au/Ti pressure vessel. During heating, sampling was taken in 24-hour intervals and stored at 4 ºC until analysis. Afterwards, samples were cooled to -20 ºC for 2 days. Cycling continued until no sufficient quantity of sample was leftover. Concurrently, long-term freezing of starting reactants occurred at -20 ºC and were sampled every week for 8 weeks. Analysis of samples was conducted through HPLC, H-NMR, and LCMS. Results indicate a wide array of amino acids (notably serine, histidine, and alanine) and other solid organic compounds formed. These products align with predicted pathways. A relationship between alanine and alpha-aminobutyric acid was observed between heating and cooling cycles, indicating potential redox cycling from an ice-drying phase. Solid organic compounds could be comparable to high-molecular weight organic matter found in Enceladus' plume by Cassini Cosmic Dust Analyzer.

**Thursday, 25.05.23, Icy Moons**

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## Detecting Cell Material in a Single Icy Dust Grain Emitted from Enceladus or Europa

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Saturn's moon Enceladus, and potentially Jupiter's moon Europa, emit plumes of gas and icy dust grains formed from subsurface water into space [1,2]. Impact ionization mass spectrometers, such as the Cosmic Dust Analyzer (CDA; [3]) on board the past Cassini mission, the SUrface Dust Analyzer (SUDA; [4]) on board NASA's upcoming Europa Clipper mission, or the ENceladus Ice Analyzer (ENIA), proposed for future Enceladus missions [5], are the only instruments capable of analyzing the compositions of single µm-sized emitted grains. Analyses of CDA mass spectra collected in the Saturnian System revealed that Enceladus hosts a variety of inorganic and organic compounds [6,7,8], with only 1-3 % of the analyzed grains containing organic material in enhanced concentrations [9]. This finding suggests that it could be advantageous to sample ice grains individually instead of analyzing the average composition of larger quantities which would mix a variety of inorganic and organic compounds and dilute the concentrations of potentially bio-relevant organics. To simulate a scenario, in which biosignatures are present only in very few of emitted grains with relatively high cell densities therein, we conducted laboratory analogue experiments with Sphingopyxis alaskensis, an ultrasmall bacterium extracted from various cold marine environments [10]. We used Laser Induced Liquid Beam Ion Desorption (LILBID) – a technique proven to accurately simulate ice grain mass spectra recorded in space [11,12,13,14,15]. Recent LILBID experiments demonstrated that bacterial DNA and lipids will be identifiable in mass spectra of emitted icy dust grains [16]. Here we present the next steps – LILBID experiments with untreated lysed bacterial cells, simulating the case of cell material, or small fractions thereof, in a single 15 µm diameter ice grain. This is a conservative approach given that Enceladan grains are typically 1-5 µm in diameter [17]. Our experiments demonstrate that biosignatures from a single bacterial cell – or fractions thereof – would be detectable in mass spectra of single ice grains, even if less than 1% of the cell constituents formed the nucleation core of a 15µm ice grain. Cationic mass spectra exhibit features due to protonated amino acids. Sequences of deprotonated fatty acids are identifiable in anionic mass spectra. A future impact ionization instrument like SUDA or ENIA would be capable of recording 10,000 – 100,000 individual ice grain spectra (cationic and anionic) during a single plume passage, allowing trace biosignatures to be detected, even if present in only 1 out of 100,000's of grains encountered during a multiple flyby mission.

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**Thursday, 25.05.23, Icy Moons**

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## Mass spectrometric fingerprints of organics in salt rich ice grains: implications for Europa Clipper

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Jupiter's icy moon Europa will be the target of NASA's Europa Clipper mission [1], with onboard the SUrface Dust Analyzer (SUDA) impact ionization mass spectrometer [2] which will analyse water ice grains ejected from the surface [3] or by potential plumes [4]. Calibration of the SUDA instrument is performed by using Laser Induced Liquid Beam Ion Desorption (LILBID) - a technique accurately reproducing impact ionization mass spectra of ice grains recorded by spaceborne missions [5]. LILBID experiments were performed to characterise the influence of Europa-relevant inorganic material on the analysis of organic-bearing ice grains by SUDA and to determine how a wide variety of organic molecules, from different chemical families, could be identified [6]. Different ice grain compositions were simulated by mixing an organic species and an inorganic matrix component which have been detected in high abundances in the surface of Europa [e.g., 7, 8] (NaCl, $MgSO_4$ or $H_2SO_4$ at 0.01M, 0.1M or 1M concentration). The investigated organics were chosen to cover a wide range of chemical families with different functional groups and were measured at concentrations between 0.1 and 5wt%. Results show that the organic species can be detected as molecular ions in all matrices, often form characteristic fragment ions, and form sodiated and chlorinated species in NaCl-rich ice grains [6] and a range of complexes with $Mg^{2+}$, $OH^-$, $HSO_4^-$ ions as well as $MgSO_4$ and $H_2SO_4$ molecules in $MgSO_4$-rich and $H_2SO_4$-rich ice grains. We emphasize the need of both cation and anion modes for the successful identification of a wide variety of organic species. Cation mode however usually enables a higher sensitivity to the organic species, especially in sulfuric acid matrices. In salt-rich matrices, the sensitivity to the organics typically decreases with the salt concentration due to suppression effects [9, 10]. General rules for the detection of organics in ice grains of typical Europa composition by the SUDA instrument were established and are applicable to a wider range of organic species in complex ice matrices. The recorded LILBID analogue spectra are part of a database [11] gathering analogue mass spectra of a wide range of compounds helping both the future interpretation of SUDA's data and mission planning.

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**Thursday, 25.05.23, Icy Moons**

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## Characterizing the mechanical and spectral properties of fresh ice deposit analogues on Enceladus and Europa

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Most planetary bodies in the outer solar system are composed largely of water ice, which can behave like granular materials at the surface conditions. These materials present a particle size distribution typically ranging between 10 and 100µm, which is the characteristic size of powders, a class of granular materials [1] that are subjects to potentially very high cohesion forces. This implies mechanical behavior different from those of more classical granular materials. In the particular case of Saturn's moon Enceladus, jet activity resulting in the deposition of very fine ice grains (~1-100 µm) at low temperature (~60-80K) suggests the formation of relatively stable powdery deposits [2]. Analogous processes could also be active on Europa [3, 4]. Characterizing the physical properties of these ice powders is essential for understanding the evolution of surface morphologies, the interaction with continuously falling grains, and anticipating the technical issues for future missions during landing and/or sampling of surface materials. This study aims at characterizing the mechanical and spectral behavior of micrometric ice powders, on a wide range of temperatures, from Jupiter to Saturn's moon conditions. The main goal is to quantify the evolution of internal parameters controlling the mechanical properties of ice powder, such as grain cohesion, with temperature, through various experiments, and to relate possible change in physical properties to spectral characteristics in order to better identify fresh ice deposit area from remote-sensing and to anticipate future landing. A first detailed experimental campaign performed on pure ice powder using a newly developed rotating drum device show strong dependence with temperature of the cohesive properties between 90 K and 150 K.  Preliminary mechanical results performed on ice-salt powder as well as spectral characterization will also be presented.

**Thursday, 25.05.23, Icy Moons**

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## Radiation Processing and Sputtering of Icy Surfaces

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Europa, one of the four Galilean moons of Jupiter, is not only a potential target for habitability, but it also is one of the most radiation-drenched bodies in our solar system.
While electrons penetrate the deepest, protons and other ions comprising of the radiation environment of Europa (H+, O+, and S+) contribute to near-surface chemistry and sputtering processes. For this reason, it is important to understand sputtering processes of icy analogs of Europa's surface and to understand which of these processes contribute most efficiently to damage and degrade potential biologically important molecules, should there be life existing in Europa's oceans or near-surface liquid pockets. In our Ice Spectroscopy Laboratory (ISL) at JPL, we have been actively engaged in conducting Europa analog studies simulating specifically surface and exosphere composition and exchange. We have shown that under Europa's surface conditions, water ice and frozen salt-brines at 100 K are as hard as concrete or granite and upon high energy particle bombardment (10-25 MeV electrons) their hardness drops slightly (Henderson, B. L., Gudipati, M. S., et al. (2019). Icarus 322: 114-120). The talk will present ongoing and future research at ISL to carryout quantitative studies on chemical reactions and sputtering processes of Europa's surface analogs involving electrons (100 eV – 25 MeV) and ions H+, O+, and S+ (<20 keV).

Acknowledgment: This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Funding from NASA through SSW and HW programs is acknowledged.

**Friday, 26.05.23, Missions and Instruments**

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## Dust detection by antenna instruments

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The possibility of detecting dust impacts using the body of a spacecraft as a detector has been known since the Voyager era. The impact of a dust particle on the surface of the spacecraft generates the transient impact plasma cloud. The combination of the re-collected charge by the spacecraft and the induced charging from the escaping charges from the impact plasma are responsible for the characteristic shape of the waveforms detected by the antennas. A model has been developed recently that allowed reconstructing the waveforms from first principles, when considering the geometry effects of the expanding plasma cloud with respect to the antennas [Shen et al., J. Geophys. Res. 10.1029/2021JA029645, 2021]. Industry standard numerical tools are employed for calculating the magnitude of the induced chare for the full 3D vicinity of the spacecraft. The existing numerical model has been extended by including the physical parameters of the expending plasma cloud in terms of the velocity distribution of the ions, and the geometrical properties of the expansion. By fitting the measured impact waveforms to the model, the impact location and/or the parameters of the impact plasma can be determined. This presentation will report on the latest progress made in comparing the full 3D theoretical model with measurements made at the dust accelerator facility operated at the University of Colorado.

**Friday, 26.05.23, Missions and Instruments**

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## A deep-learning approach to classify Cassini Cosmic Dust Analyzer signal data

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During its mission in the Saturnian system, the Cosmic Dust Analyzer (CDA) on board the spacecraft Cassini detected a large quantity of dust particles. Until now, around 30,000 time-of-flight mass-spectra have been classified manually and categorized in miscellaneous primary classes and, if applicable, corresponding sub-types. The resulting distribution of noise events, water-rich, mineral-enriched and other classes is highly skewed: while the former ones determine largely the number of known types (thousands or ten-thousands of known noise events and type 1, water-rich particles), less abundant detections like phosphate-rich ones (type 3-P) characterized only a tiny fraction of the overall distribution. In this work we show a deep-learning based approach, consisting of a data-processing pipeline, noise filter, and machine-human-expert feedback loop to train, evaluate and monitor a multi-label classifier to support one in categorizing the remaining unknown mass spectra. We focus especially on rare events that describe less than a per mill of the overall distribution and demonstrate potential data enrichment functionalities. Finally, we provide an outlook of future deep-learning and generative modeling based research ideas and suggestions how to productionize the shown results.

**Friday, 26.05.23, Missions and Instruments**

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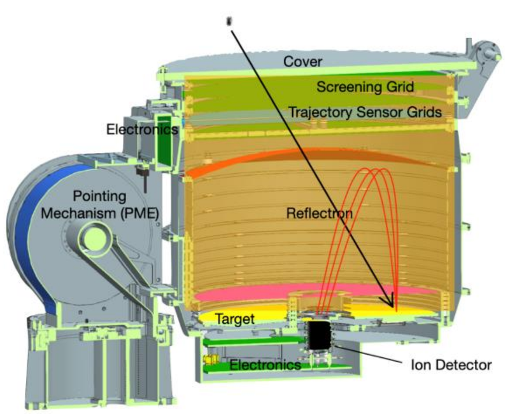
# The DESTINY+ Dust Analyser

J. Simolka, M. Bauer, A. Exle, P. Fröhlich, J. Gläser, S. Ingerl, Y. Li, F. Rieth, M. Sommer, H. Strack, H. Henkel, C. Wagner, and Ralf Srama

Cosmic dust is an important messenger that carries information about its origin and its journey through space. JAXAs DESTINY+ mission with its dust telescope — the DESTINY+ Dust Analyser (DDA) — provides the opportunity to investigate various dust populations that are present along its mission trajectory towards the active asteroid 3200 Phaethon. The prime mission has four distinctive phases that provide unique science opportunities. After launch into Earth orbit in 2024 the DESTINY+ S/C uses electric propulsion to continuously increase its orbit altitude. During this spiralling phase (1) DDA will systematically characterise the dust environment between Earth and Moon from altitudes of a few thousand kilometres and above. The lunar swing-by phase (2) provides the potential to measure lunar dust and initialises the cruise phase (3) with an interplanetary trajectory at ~1 AU distance from the sun. Here the interplanetary and interstellar dust populations of the inner solar system are investigated. During all phases DDA will link the dynamical and compositional properties of the measured individual dust particles. In 2028 the target body 3200 Phaethon is intersected on its inbound orbit around the sun. A single flyby at Phaethon with the closest approach around 500 km and a relative velocity of ~36 km/s represents the last phase (4) of the prime mission. The ejecta cloud and if present actively ejected dust are analysed to gain a better understanding of Phaethon's surface (and possibly sub-surface) properties and processes. Over the mission the speeds of the dust particles relative to the DESTINY+ S/C range from a few km/s up to ~70 km/s. The dust measurements are executed by the DDA instrument. The dust telescope with a mass of 12 kg and a power consumption of 35 W consists of a pointing mechanism, a sensor head and an electronics box. The figure shows a cross-section cut through the instrument to reveal its internal set-up (E-Box is not shown). The two axis mechanism provides a pointing range of 180° in azimuth and 90° in elevation . It allows to adjust the pointing orientation of the dust sensor independent from the S/C attitude. The sensor head is the sub-system for the dust measurements. It combines a trajectory sensor and a dust analyser to determine the dynamical and compositional properties of individual dust particles. A cover protects the sensor head interior during the ground handling and launch from contamination. When a dust particle enters the sensor head it passes through the trajectory sensor. This module consists of a plane with four charge sensitive electrode segments, embedded between two grounded grid planes. On its way through the trajectory sensor a charged particle induces a signal that is measured and comprises information about the particles incident angle, velocity and surface charge. The trajectory sensor is sensitive to particles carrying a surface charge of at least 0.3 fC. Located behind the trajectory sensor is the dust analyser. Time of flight mass spectrometry is used to analyse the plasma that is generated when a dust particle ionises at impact on the instrument's gold target. Electric fields separate the positive and negative charges, accelerate the cations and focus them onto the ion detector that outputs the mass spectrum. In the relevant ion mass range of silicates, carbon and metals the mass resolution is high enough so separate the individual atomic species. In addition to the mass spectrum, the negative plasma charges are measured at the target and the positive plasma charges at an ion grid and an ion ring in front of the ion detector. Signal processing takes place in the electronics box. All signal channels are continuously monitored by an FPGA. The relevant snippet of the signals are stored as soon as pre-set trigger conditions are met. The talk will give an overview of the DESTINY+ mission and the DDA instrument capabilities and its design. We will present the current development status and show measurement results that were obtained with the engineering model at the dust accelerator. The DDA instrument is a German contribution to the DESTINY+ mission. Funded by DLR, the University of Stuttgart leads the instrument development and is responsible for development of the pointing mechanism, sensor head with cover and the flight software. The electronics is developed by the industry partner von Hoerner & Sulger GmbH in Schwetzingen.



**Friday, 26.05.23, Missions and Instruments**

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# From the Cassini Cosmic Dust Detector to the Destiny+ Dust Analyser: Can we detect nanodust with in-situ dust detectors?

Ralf Srama, Jonas Simolka, Patrick Fröhlich, Jan Gläser, Yanwei Li, Anna Mocker, Heiko Strack
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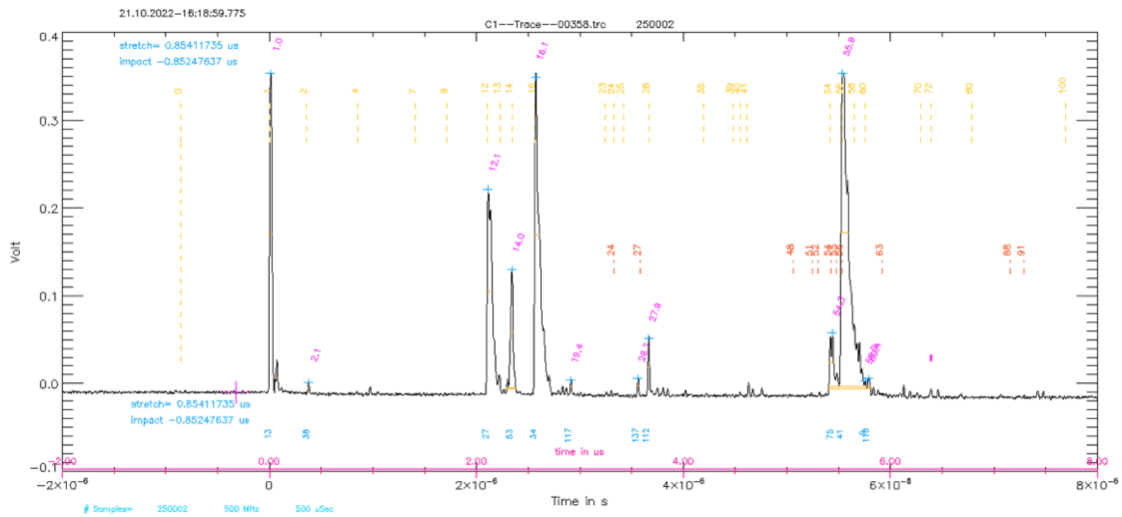
Dust Astronomy investigates the nature and the origin of dust particles in space. Typical instruments are time-of-flight mass spectrometers analysing the impact plasma of individual hypervelocity-impacts. The particle size distribution which are detected ranges from nanodust to approximately 100 micrometer. Nanodust has been measured in space for decades by in-situ dust detectors onboard Giotto, Ulysses, Galileo, Cassini or STEREO. CDA onboard Cassini detected nanoparticles in the outer Saturn system moving on unbound orbits and originating primarily from Saturn's E-ring. Although the instrument was built to detect micron and sub-micron sized particles, nano-sized grains were detected during the flyby at early Jupiter and in the outer environment at Saturn. Fast dust particles with sizes below 10 nm were measured by in-situ impact ionization and mass spectra were recorded. This scenario proves, that in-situ TOF-MS is well suited to analyse fast nanograins in space. But what are the detection limits in particle mass for current spectrometers? New dust impact data using the DESTINY+ Dust Analyser engineering model were recorded at the new Stuttgart dust accelerator facility. The results show, that new generation spectrometers like SUDA/Europa or DDA/DESTINY+ will provide compositional information of fast, nanometre-sized particles (<20 nm). The hunt for nanodiamonds in interplanetary or even interstellar space can start.




TOF-MS of an 21nm (radius) iron particle with 40 km/s onto the gold target of the Destiny+ Dust Analyser. The large peaks are H, C, N, O and Fe. The sensitivity for elemental ions is so high, that the peaks measured at the ion detector anode are in saturation. The data were recorded on Oct 21, 2022 (Event# 358) at the Stuttgart dust accelerator facility using an acceleration voltage of only 850 kV and a multiplier voltage of only -2200 V.

**Friday, 26.05.23, Missions and Instruments**

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## Modeling the II-TOF-MS Measurements of Interplanetary and Interstellar Dust Particles

Ethan Ayari, Mihály Horányi, Zoltan Sternovsky, Rebecca Mikula, Tobin Munsat (CU Boulder), and Neal J. Turner (JPL /Caltech), Jon Hillier (FU, Berlin)

Impact Ionization Time-of-Flight Mass Spectrometry (II-TOF-MS) provides in-situ composition measurements of cosmic dust particles. Since these measurements are finite in number, numerical reference spectra are being developed based on existing data. Synthesis of numerical mass spectra involves concurrent use of stoichiometric ratios and elemental relative sensitivity factors (RSFs) to determine mass line amplitudes. The line shapes are given by convolving each of these amplitudes with an Exponentially Modified Gaussian (EMG) distribution with parameters specific to both the mass line and the size and speed of the impacting particle. Realistic noise is generated randomly to simulate instrumental effects. This generation of random noise allows for the signal-to-noise ratio (SNR) of the spectra to be tuned. Because the probability of each mass line appearing in a spectrum is known to depend on the velocity of the impactor, well-established silicate experimental results have been implemented in the numerical spectra to reflect such trends. A proof of concept for olivine's solid series is illustrated in Figure 1. Numerical spectra are being developed for the olivine, pyroxene and feldspar mineral families due to their abundance and significance in Interstellar Dust (ISD), Interplanetary Dust Particles (IDP), and protoplanetary disks. Olivine samples have also been used to date the first appearance of dust in the solar nebula. Numerical reference spectra are useful for indicating deviations from chondritic ratios and other signs of early elemental processing. As modern statistical tools such as machine learning are involved in the identification process, reliable reference mass spectra will be needed to make them accurate. This talk will discuss the status of a large database of mass spectra to be ready for upcoming future interplanetary missions.

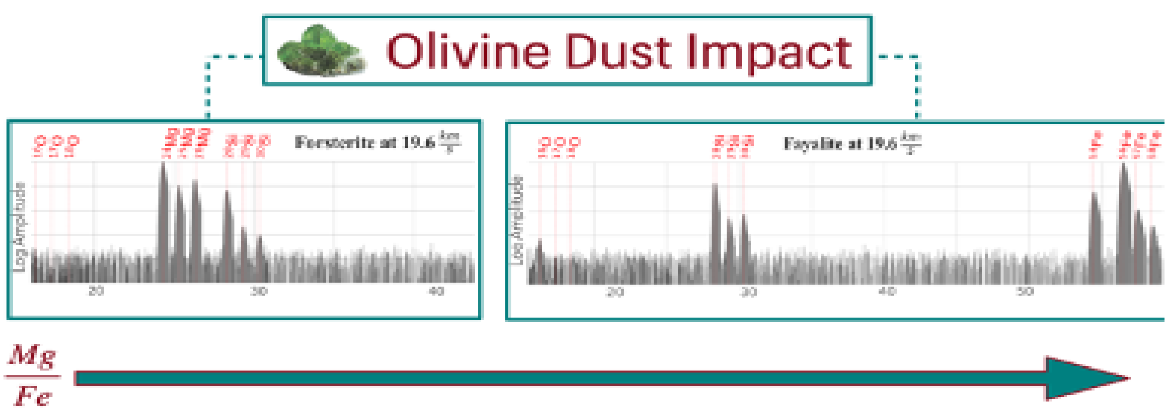


Figure 1: Proof of concept showing possible olivine numerical spectra using the end members of the solid series. Spectra for forsterite ($Mg_2SiO_4$, left), and fayalite ($Fe_2SiO_4$, right) are displayed.

**Friday, 26.05.23, Missions and Instruments**

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## LILBID-OLYMPIA: High Resolution Mass Spectrometry for the Calibration of Spaceborne Hypervelocity Ice Grain Detector

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Some icy moons in the outer solar system harbour subsurface oceans beneath their ice crusts. Enceladus and potentially Europa emit plumes containing gas and ice grains formed from the subsurface water[1,2]. Those ocean samples can be analysed during spacecraft flybys, providing access to the ocean's compositions[3]. Cassini's Cosmic Dust Analyser (CDA) sampled Enceladean ice grains, by producing impact ionisation mass spectra. Similarly, the Europa Clipper Surface Dust Analyser (SUDA) is built to characterise Europa's ocean. The calibration of those spaceborne hypervelocity detectors can be made in laboratories, thereby offering higher performances. While the acceleration of metallic and siliceous compounds to spacecraft-relevant velocities is managed[4], the acceleration of µm-sized icy grains to hypervelocity (>1 km/s) is a challenge[5,6]. Therefore, the LILBID (Laser Induced Liquid Bead Ion Desorption) technique is used with great success to reproduce mass spectra such as those recorded by CDA and are also a foundation of a spectral analogue data base for SUDA[7]. LILBID setups are usually coupled with a Time-of-Flight (TOF) mass spectrometer, with a mass resolution of ~800 m/Δm. Even though higher than that of CDA (20-50 m/Δm) or SUDA (200-300 m/Δm), the mass resolution of LILBID-TOF does not allow an unambiguous identification of chemical species, most notably organics. In this context, OLYMPIA (Orbitrap anaLYser MultiPle IonisAtion), an Orbitrap™ based mass spectrometer has been developed to be used as a new laboratory test bench. The Orbitrap™ is a Fourier Transform mass analyser commercialised by Themo Fisher Scientific, and is able to record mass spectra with an ultra-high mass resolution. By coupling the LILBID technique to OLYMPIA and its Orbitrap™ analyser, we are now able to record hypervelocity icy grains analogue mass spectra with significantly higher mass resolution[8] than the standard LILBID-TOF. The setup is currently able to measure $H_2O^+$ and $H_3O^+$ ions with a mass resolution of around 100 000 m/Δm (FWHM), with the spectral appearance matching mass spectra of ice grains recorded at impact speeds in the range of 15 to 18 km/s. Those results will be implemented in the aforementioned LILBID database, and will be useful for the calibration and future data interpretation of SUDA. This work also critically supports the development of an Orbitrap-based spaceborne hypervelocity dust detector.

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**Friday, 26.05.23, Missions and Instruments**

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## HANKA – Cubesat Space Dust Analyser

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Application of mass spectrometry for asteroid exploration has recently become a hot topic. Mass spectrometry can be used both in orbit and on the asteroid's surface for the analysis of space dust, micrometeorites and particles from larger objects. The HANKA (Hmotnostný ANalyzér pre Kozmické Aplikácie) space instrument was designed for the Czech satellite project SLAVIA. HANKA is a high-resolution mass spectrometer based on an electrostatic ion trap, which is a principal component of commercial instruments [1] established in biology and medicine research, the so-called Orbitrap™, and the space CosmOrbitrap prototype (developed by LPC2E Orleans [2]). HANKA will bring this new technology into space to combine a small CubeSat space version of this high mass resolution ion trap analyzer, with a velocity/charge detector and a hypervelocity impact ionization source.

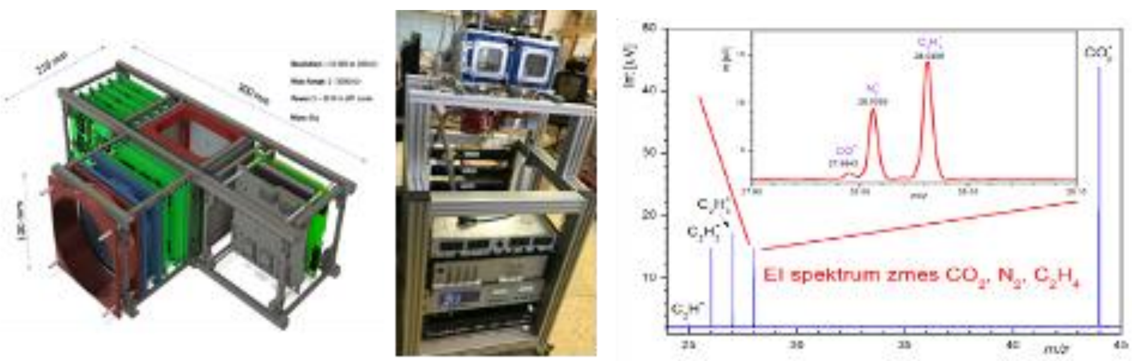


Fig. 1. HANKA – instrument design, laboratory prototype, and preliminary data from EI source

Based on the results obtained on the laboratory prototype, a miniature version of the high-resolution space mass spectrometer - HANKA - will be constructed. The proposed parameters of the Cubesat module HANKA are: Resolution: up to 50 000 at m/z 200, Mass Range: 2 - 3000m/z, Power: 10 W , Dimension: 200x200x100 mm (4U), Weight: 6kg The SLAVIA mission project is currently in the B1 phase, with an expected launch in 2027.

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**Friday, 26.05.23, Missions and Instruments**

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## The Science Case for in-situ Dust Investigation at Uranus

Hsiang-Wen Hsu, Frank Postberg, Juergen Schmidt, Mihaly Horanyi, Sascha Kempf

The Uranus Orbiter and Probe mission concept was ranked the highest in the US “Origin, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032” and a Uranus mission will be NASA’s next flagship mission. A modern dust composition analyzer on such a mission will provide critical, cross disciplinary information to address key scientific questions about the Uranus system. This includes processes in Uranus’ upper atmosphere, the origin and evolution of the ring-moon system, as well as dust-plasma interactions in the complex Uranian magnetosphere. In this presentation, we will discuss the targeted dust populations at Uranus, associated open science questions, as well as desired technology improvements that will maximize the science return for the ice giant mission.

**Friday, 26.05.23, Dust analogues and Lab experiments**

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## Recent laboratory results on dust charging and mobilization.

M. Horanyi, Xu Wang, Hsiang-Wen Hsu

Dust exposed to plasmas and/or UV radiation on the surface of airless planetary bodies collect charges and can develop large enough interparticle repulsive forces to eject them from the surface. The size distribution, charge state, initial speed, and angular distributions are all important quantities that can lead to shaping the physical and chemical properties of dust covered surfaces in space. The spokes in Saturn's rings, dust ponding, and the removal of submicron grains from small asteroids, are all examples where electrostatic effects have been suggested to explain the observations. Hazard due to dust charging and transport emerged as a significant technical challenge for the surging efforts for a sustained human exploration of the Moon. These problems are also of great recent interest in semiconductor manufacturing and dust contamination of high-energy particle accelerators, presenting an unusual opportunity for planetary and space sciences to contribute to finding solutions to dust related problems in industy and other areas of physics research. The talk will give a brief review of recent laboratory results and the development of new dust instrumentation.

**Friday, 26.05.23, Dust analogues and Lab experiments**

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## Synthesis and Characterization of Polypyrrole-Coated Anthracene Microparticles: A New Synthetic Mimic for Polyaromatic Hydrocarbon-based Cosmic Dust

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Polyaromatic hydrocarbons (PAHs) are found throughout the Universe. The ubiquity of these organic molecules means that they are of considerable interest in the context of cosmic dust, which typically travel at hypervelocities (> 1 km $s^{-1}$) within our Solar System. However, studying such fast-moving micrometer-sized particles in laboratory-based experiments requires suitable synthetic mimics. Herein we use ball-milling to produce microparticles of anthracene, which is the simplest member of the PAH family. Size control can be achieved by varying the milling time in the presence of a suitable anionic commercial polymeric dispersant (Morwet D-425). These anthracene microparticles are then coated with a thin overlayer of polypyrrole (PPy), which is an air-stable organic conducting polymer. The uncoated and PPy-coated anthracene microparticles are characterized in terms of their particle size, surface morphology and chemical structure using optical microscopy, scanning electron microscopy, laser diffraction, aqueous electrophoresis, FT-IR spectroscopy, Raman microscopy and XPS. Such microparticles can be accelerated up to 6 km $s^{-1}$ using a Light Gas Gun. Studies of the resulting impact craters indicate carbon debris so they are expected to serve as the first synthetic mimic for PAH-based cosmic dust. Moreover, preliminary hypervelocity experiments conducted by Prof. Z. Sternovsky's group at U. Colorado confirm that such PPy-coated anthracene microparticles can be fired at more than 20 km $s^{-1}$ using a high-voltage van de Graaff accelerator.

**Friday, 26.05.23, Dust analogues and Lab experiments**

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## Palladium coated cosmic dust analogues

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For acceleration to high velocities in an electrostatic dust accelerator, cosmic dust analogues must be capable of charging in the dust source. Typically this means the dust grains are either wholly conductive or have an applied layer of a conductive material. In the past, conductive coatings of polypyrrole or platinum have been successfully applied from aqueous solutions. However, these techniques are unsuitable for water-sensitive materials or hydrous minerals, as particle alteration or contamination may occur. To overcome these limitations, a non-aqueous coating technique has been developed, in which palladium coatings are deposited onto functionalised mineral grains using methanol as the solvent. Here we present the latest results from the application of this technique, and discuss its advantages and disadvantages with respect to other coating methods.

**Friday, 26.05.23, Dust analogues and Lab experiments**

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## Charged ice particle beams with selected narrow mass and kinetic energy distributions

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Small ice particles play an important role in atmospheric and extraterrestrial chemistry. Circumplanetary ice particles that are encountered by space probes at hypervelocities play a critical role in the determination of surface and subsurface properties of their source bodies. Here we present an apparatus for the generation of low-intensity beams of single mass selected charged ice particles in vacuum. They are produced via electrospray ionization of water at atmospheric pressure and undergo evaporative cooling when transferred to vacuum through an atmospheric vacuum interface. M/z selection is achieved through two subsequent quadrupole mass filters operated in the variable frequency mode within a range of m/z values 47 between 8×10 and 3×10 . Velocity and charge of the selected particles are measured using a non-destructive single pass image charge detector. From the known electrostatic acceleration potentials and settings of the quadrupoles the particle masses could be obtained and accurately be controlled. It has been shown that the droplets are frozen within the transit time of the apparatus such that ice particles are present after the quadrupole stages and finally detected. The demonstrated correspondence between particle mass and specific quadrupoles potentials in this device allows preparation of beams of single particles with a repetition rate between 0.1-1 Hz with various diameter distributions from 50 to 1000 nm at 30 to 250 eV of kinetic energy per charge. This corresponds to velocities and particle masses quickly available between 600m/s (80nm) and 50m/s (900nm) and particle charge numbers (positive) between 103-104[e], depending upon size.

**Friday, 26.05.23, Dust analogues and Lab experiments**

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## Generation of Charged Water Ice Particle Beams of Defined Size Distribution by SELINA

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Nanometer to micrometer size ice particles as constitute of cosmic dust can originate from comets, plumes on icy satellites, hypervelocity meteoroid impacts on different icy surfaces. Mass spectrometric measurements of the molecular composition of such ice grains from Enceladus with the Cosmic Dust Analyzer on the Cassini spacecraft revealed the presence of organic molecules with masses over 200 amu. For future missions thus it is essential to have laboratory source of hypervelocity ice particles, which facilitates testing of new generation of the space high resolution mass spectrometric detectors. This requirement can be divided into two conceptual parts: the ice particle generation and the ice particle acceleration. Here we present our instrument SELINA (Selected Ice Nanoparticle Accelerator) which resolves the ice particle generation part of the task. The highly charged water droplets are generated via electrospray ionization source with subsequent transfer from atmosphere pressure into the vacuum accompanied by the evaporative cooling and transition of water droplets from liquid phase to ice. The combination of two frequency controlled quadrupoles with differential pumping allows to produce charged particle beams of specified narrow size distributions within a range of 50-1000 nm diameter with 0.1-1 Hz repetition rates. The individual particle charge and velocity is measured by the non-destructive single pass charge detector. Special efforts were made to design SELINA as a compact transportable apparatus. As a result, all parts of instrument can be fitted on the two 19'' cart (except for mechanical pumps) including control electronics. This allows to combine SELINA particle source with different stationary accelerators.

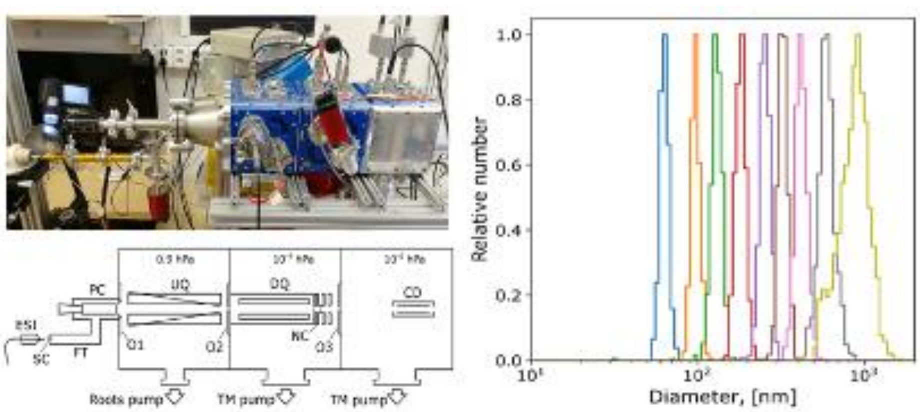


Figure 1. SELINA apparatus and its schematic representation (left) and distributions of selected particles (right).

**Friday, 26.05.23, Dust analogues and Lab experiments**

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## Fast ejecta particles generated from oblique impacts with regolith-like targets

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In this study, we present new insights into the distributions of fast ejecta from oblique hypervelocity impacts of 4 mm aluminum sphere at 4.1 km/s onto powdered target. Our object was characterize the size, angular and possible speed distributions of individual fast ejecta. Ejecta grains generated during impact are intercepted by arrays of thin Al foils with thicknesses of 20 µm, which are installed around the target. The methodology presented here enable us to analyze individual ejecta grains with related high speeds beyond the measurement threshold of optical analysis methods. The resulting impact holes were analyzed with computer vision methods. The study includes investigation of the influence of incident angle on the size distributions of high speed ejecta grains as well as their angular distributions.