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Space dust and Earth's temperature

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Abstract

The increase of the space dust amount in the Solar system results in the total cooldown of the Earth. This may negatively tell on the evolutionary processes in the ecosystems.
We have calculated the decrease of the Earth's temperature versus different space dust concentrations in the Solar system.

1. Introduction

Based on the study of zodiacal light, it has been determined that the dust concentration near the Earth orbit is 10^{-15}–10^{-13} cm^{-3} [2].
The meteoroid matter average concentration in the near-Earth space is ~10^{-14} cm^{-3} [1], i.e. is close to the basic concentration of dust particles in the Earth orbit area.
The space dust concentration in the Solar system with its very slight long-term changes provides the invariableness of the solar constant and the heat balance of our planet [5, 6, 8].
Far more visible may prove to be the decrease of the Solar constant due to the absorption of the Solar emission by the interstellar dust, in case the Solar system enters a thick galactic dust cloud [3].

2. Absorption of solar emission by space dust

The planet temperature can normally be determined from the heat balance equation binding the flux of energy from the Sun to a planet and the flux of energy emitted be the latter (regardless of the energy coming from the planetary interior) [4, 7]:

$$\sigma T^4 = \frac{1}{4}(1-A)I = \frac{1}{4}(1-A)\frac{I_{\oplus}}{a^2} \qquad (1)$$

where I – the solar constant for a planet with the semi-major axis a. For the Earth $a_{\oplus}$=1 AU=15·10^7 km, the Solar constant $I_{\oplus}$=1370 W·m^{-2}. With the Earth's albedo A=0.30 and no greenhouse effect, the average global temperature of the Earth T=255K; in actual fact, subject to the greenhouse effect, T=288 K.
In case the Solar system enters a space dust cloud, the solar constant decreases and the Earth cools down.
Herein I in the context of the availability of the obscuring matter between the Earth and the Sun ($a_{\oplus}$=1 AU) is less than $I_{\oplus}$ and is determined from Bouguer's law:

$$I = I_{\oplus} \cdot e^{-k}, \qquad (2)$$

where k (AU)$^{-1}$ – the dust matter absorption coefficient in the optical spectrum range.
Thus, the Earth's temperature subject to the existence of the dust layer between itself and the Sun is determined as

$$T = \left(\frac{1-A}{4\sigma}\right)^{1/4} \cdot I_{\oplus}^{\frac{1}{4}} \cdot \exp\left(-\frac{1}{4}k\right). \qquad (3)$$

Figure 1 shows the Earth's temperature change ΔT for different Δk as a function of the absorption coefficient k. With low Δk it is insignificant. However, if the dust matter absorption coefficient is k=1 (AU)$^{-1}$ (Δk=1), the solar constant for the Earth will decrease e times, up to I=502.6 W/m^2, and the planet temperature will significantly go down: $T_e = 255 \cdot e^{-0.25}$ ≈198 K =-75 °C. Even with the greenhouse effect raising the average global temperature of the Earth by ΔT≈33°C, it will remain negative (T=-42°C). This drop of temperature may cause the ecocatastrophe and, probably, the vanishing of life.
In such a case, the Sun will get weaker only by one magnitude; its visual exo-atmospheric brightness will be

$$m = m_{\odot} + 2.5\log\frac{I_{\odot}}{I} = m_{\odot} + 2.5\log e = -25.7, \quad (4)$$

where $m_{\odot}$=-26.8 – its current visible exo-atmospheric brightness and will slightly go red (the color index B-V will increase by 0.7^m). And the man's eye will not note this change in the Sun's brightness.

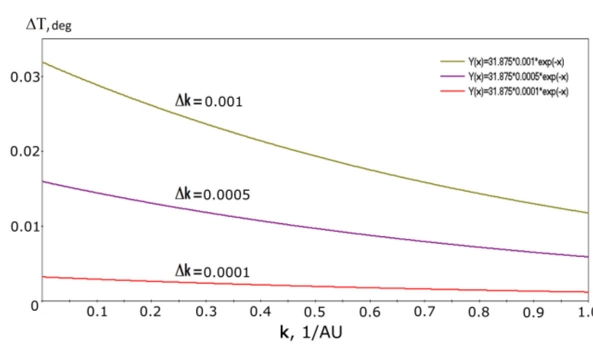

Figure 1: The change of the Earth' temperature with different space dust absorption coefficients

3. Space dust absorption coefficient

The interstellar extinction near the Sun approach in the galactic disc is 2^m per 1 kpc in the V band and varies with the wave length as $\lambda^{-1,3}$. For a star in the galactic disc which is 1 kpc away from us, the absorption in the U, B, and V bands will be $2{,}0^m$, $2{,}7^m$, and $3{,}5^m$, consequently, and the color indices (U–B) and (B–V) will increase by $0{,}8^m$ and $0{,}7^m$.
That means that with the congruence of stellar magnitudes characterizing the absorption, the concentration of particles in the Solar system is supposed to be $206265 \cdot 10^3$ times as high as in the Milky Way (herein 206265 – the number of astronomical units per parsec). For instance, with k=1 the extinction of light in the Solar system is Δm=1.1 mag/AU, and in the interstellar space – Δm≈20 mag/kpc, which conforms with the absorption in a thick dust cloud.
In the context of the interstellar absorption according to the Mie theory, they consider the case of particles with the 0.5 μ in radius which have the refraction coefficient of 1.33. For this, the coefficient of absorption k is related to the particle concentration n as

$$k = nm. \qquad (5)$$

For Δm=1 kpk^{-1}, the absorption coefficient per particle is $m=10^{-8}$ cm^{-2}, the volumetric coefficient – $\alpha=3 \cdot 10^{-22}$ cm^{-1}. Hence, $n_0=k/m=3 \cdot 10^{-14}$ cm^{-3}.
And the absorption coefficient in terms of 1 AU will be $k=4{,}5 \cdot 10^{-9}$ $(\text{AU})^{-1}$. That is, with the current dust concentration in the Solar system, there is basically no absorption of the solar emission.

4. Solar Motion in Milky Way and Dust in Solar System

Very often we hear the ideas that while moving around the Milky Way centre the Sun enters thick clouds of space dust. This results in the temperature reduction consequently followed by the ice period advent and planet-scale vanishing of life [6, 8, 10]. They refer to glacial periods and the related origination rates of species during the past half billion years [2, 8].
Indeed, the galactic disc makes one revolution nearly during 230 million years. The spiral pattern – density wave – rotates like a rigid body, i.e. with a similar angular rate. Difference between these angular rates is the frequency of the Sun meeting spiral branches [7]. The point is that the spiral pattern rotation rate cannot to be determined directly from observations and is not yet know at present. There is a concept that the Sun is located in the area of the captured rotation of the disc and spiral pattern – "corotation" – and very rarely meets the spiral pattern [7].

5. Summary

Calculations show that even with the increase of dust concentration in the Solar system by five orders of magnitude will not lead to a considerable Earth temperature fall.
According to the current data the Sun can very unlikely enter a thick dust cloud while moving in the Milky Way.

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GRAAL project: in situ optical detection of dust concentration from the Earth's orbit

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Abstract

We present here a new concept of instrument, based of optical aerosols counter, to better estimate the concentration and size distribution of incoming interplanetary material in the Earth's atmosphere. This concept, called GRAAL, could be in the Earth's orbit onboard a micro-satellite or within the International Space Station.

1. Introduction

The amount of interplanetary dust impacting the Earth atmosphere is still not well estimated, in terms of total mass, size distribution and concentration of the particles [1]. These particles come mainly from Jupiter family comets; they could have various structures and compositions as shown by results of the Rosetta mission on dust particles [2]. Even if the amount of such particles is small in the Earth atmosphere, their presence could be non-negligible, and their detection from local measurements inside the atmosphere could be confused with particles coming from the Earth surface. Also, such solid particles inside the middle and the upper atmosphere could skew the remote sensing observations of events in the troposphere (like pollution) from satellite instruments. We propose to apply the counting technique used in routine in the Earth's atmosphere for determining the concentration of liquid and solid aerosols, to the detection of these interplanetary particles. The main differences with the atmospheric measurements are the very low concentrations, the high speed of the particles in respect with the instrument (at least several km/s) and the space conditions.

2. Aerosol counter LOAC

We have developed recently an innovative design of aerosols counter, called LOAC (Light Optical Aerosols Counter), which provides the concentrations for 19 size classes of solid and liquid particles in the 0.2-100 micrometers size range [3]. LOAC provides also an estimate of the typology of the particles from their light absorbing properties (transparent, semi-transparent, absorbing). The particles are injected through a laser beam via a pumping system, and two photodiodes record the light scattered. This instrument combines the measurements at two different scattering angles. The first is around 15°, being insensitive to the refractive index and porosity of the particles, to retrieve the size of the particles; the second one is around 60°, being very sensitive to the nature of the particles, to estimate the typology. LOAC is designed mainly to detect the optical size (or equivalent diameter) of the irregular shaped particles. LOAC has been ~~is~~ used in routine for 6 years on the ground and from all kinds of balloons to study the events in the troposphere like urban pollution and for the stratospheric aerosols monitoring.

3. GRAAL concept

An updated version of LOAC is in development for space applications, essentially for in situ measurements of planetary atmospheres (telluric and giants planets). LOAC can also be modified for the detection of high velocity particles from Earth's orbit, using fast electronics and a light source of several cm long instead of a laser beam. This is the GRAAL project, "GRains Above the Atmosphere with Light optical aerosols counter", dedicated to the determination of the size and concentration of ~~the~~ incoming materials to the Earth's atmosphere. This instrument could perform measurements from a micro-satellite, or even better from the International Space Station, while always facing Earth. No pump is needed since the particles will cross an open cell oriented towards Earth's surface. Figure 1 presents the instrumental design. We expect to detect particles from about 1 micrometer to several hundreds of micrometers, as those detected by the Rosetta mission in the inner coma of comet 67P. Using two photodiodes as for LOAC "balloon" could provide an estimate of the typology of the detected particles.

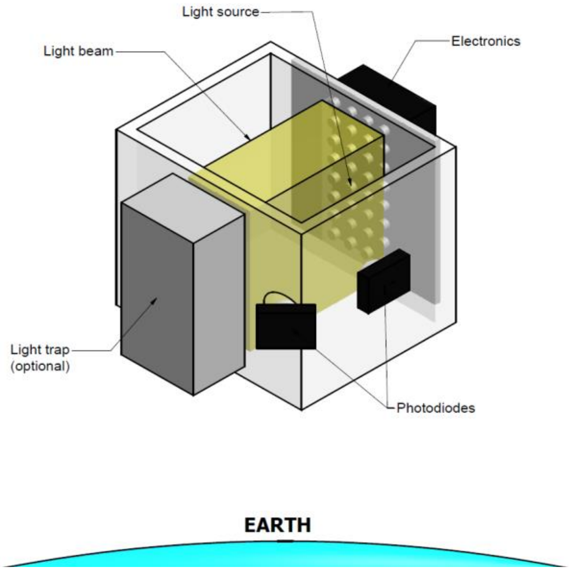

Figure 1: GRAAL concept.

4. Expected measurements

The expected mean velocity of the incoming interplanetary particles could be of about 15 km/s [4,5]; a secondary mode is expected at a few km/s, coming from space debris contamination. Considering the proposed geometry of measurements, we expect to detect several particles per day greater than 1 micrometer in background condition, up to several tens of particles during major–shooting stars events. This estimate is based on the 30 years-old data of the impact measurements from MIR station and LDEF experiment [6], as shown in Figure 2.

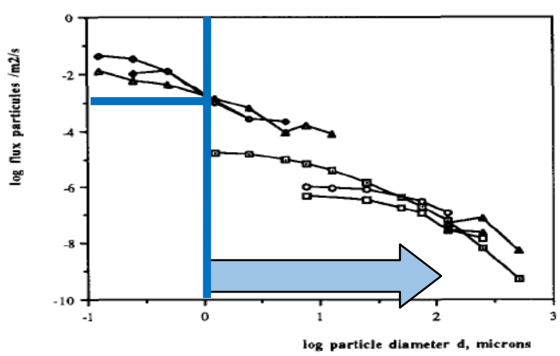

Figure 2: Expected size distribution detected by GRAAL (blue arrow), based on Mendeville (1991) concentrations

5. Summary and Conclusions

The GRAAL concept is an innovative approach to better characterize the incoming material in Earth atmosphere, in complement with traditional techniques as ground-based collection, atmospheric collections, optical and radar meteor counting. GRAAL project has been recently proposed to the French space agency CNES. Depending of funding and launching opportunities, the instrument could be realized in about 3 years.

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Characterisation of the Outer Solar System dust by Cassini-CDA

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Introduction

We analyse 13 years of data acquired by the Cosmic Dust Analyser (CDA) and its Entrance Grid (EG), Chemical Analyser Target (CAT) and Impact Ionisation Detector (IID) subsystems on-board the Cassini spacecraft around Saturn. We confirm the presence of exogenous dust, originating from the interplanetary space and permanently crossing the Saturnian system. We analyse the range of possible heliocentric orbital elements in order to identify their possible origin. We observe large particles whose dynamics is compatible with 'old' collisional debris from the Kuiper-Belt, migrating inward the Solar System under influence of the Poynting-Robertson drag, or relatively fresh grains from recently discovered cometary activity of Centaurs. A population of particles entering the Saturn's system with high velocities can be linked to Halley-type comets as parent bodies. Smaller particles detected by the CAT subsystem, could also have active Centaurs as their parent bodies.

1. Data analysis

The major difficulty we are facing is the identification of comparatively very rare exogenous particles in an environment dominated by E ring particles. In the densest regions of the E ring, the CDA instrument is saturated by E ring impactors, therefore 'masking' contributions from other sources. Fortunately, the Cassini spacecraft has been flying on orbits for a wide range of inclinations and eccentricities while touring Saturn during the past seven years such that regions with reduced E ring contribution can be exploited for our study. Regions more favorable for the search of exogenous particles are typically as far as possible from Saturn, or, 'far enough' from the equatorial plane of Saturn, in order to avoid the bulk of the E ring particles, as well as regions were the plasma density saturates the EG subsystem. When EG data could be acquired, the particles orbital elements can be constrained to sufficient accuracy to inambiguously discriminate E ring particles from interplanetary dust particles (IDPs). CAT data are used to estimate the impact speed of the particles from the Time-of-flight spectra recorded upon impacts on the chemical analyser target. Although uncertainties in impact direction and speed determination exist, we find a population of relatively small exogenous particles, whose heliocentric orbital elements can be constrained as they cross the Saturn's Hill's radius (Fig.1 and Fig 2.).

2. Results and Discussion

The orbital elements of the IDPs are plotted on Fig. 1. The presence of IDP raining onto the Saturn's system is by itself an important result providing constraints on evolutionnary processes like, for example, the compositional evolution of atmosphere-less icy surfaces (icy moons and Saturn's main ring system) and of the atmospheres of Titan and Saturn. As importantly, from its vantage point at Saturn, about 10 AU from the Sun, the CASSINI-CDA data cast light on the dust populations of the outer solar system, their parent bodies and generation process.

We find that Jupiter Family Comets (JFCs) cannot be a dominant source for the dust that CDA measures at Saturn. In turn, our measurements appear in good qualitative and quantitative agreement with the dynamical signature of KBO dust expected at Saturn. We find, however, that KBO dust cannot be distinguished at Saturn dynamically from particles released by Centaurs/TNOs, whose cometary-like activity at large heliocentric distances has been recently discovered. Grains released by Halley types comets, with high-heliocentric inclinations are reported, in addition to the interstellar dust flow as reported by previous mission (Ulysses, Galileo in particular).

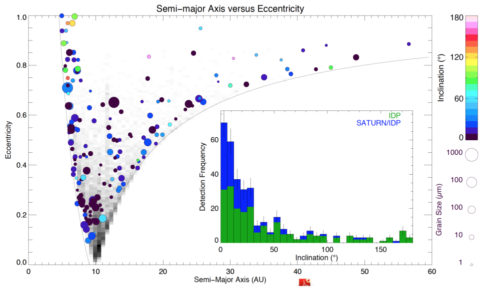

Figure 1: Orbital elements of the exogenous particles detected by the EG subsystem. The circles represent the heliocentric orbital elements of all exogenous solutions in an eccentricity versus semi-major axis plot. The symbol color indicates the inclination of the IDP orbits with respect to the ecliptic and the symbol size scales with the particle radius. The inset shows the corresponding inclination distribution.

Hints on particle composition and possible particle streams are discussed.

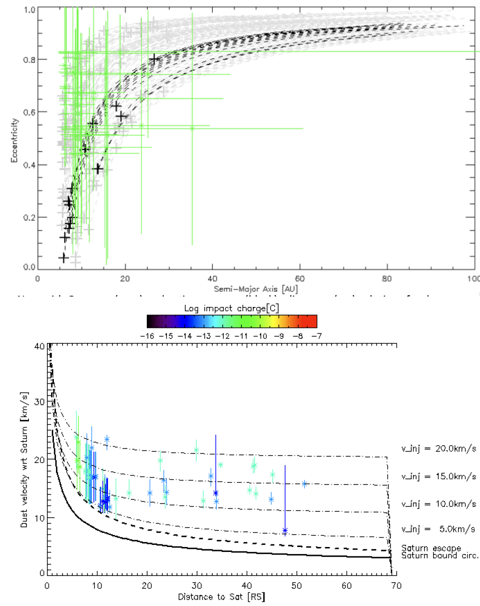

Figure 2: Lower panel: velocity of the particles detected with the CAT subsystem with respect to Saturn, compared to the escape velocity, and the velocities expected as function of the radial distance to Saturn, for particles injected inside the Saturn's system with various injection speeds and undergoing gravitation focusing. Upper panel: eccentricity versus semi-major axis plot of the exogenous particles. The grey crosses are the (a,e) values for known Centaurs and the black crosses indicate known active Centaurs. The dashed lines correspond to the (a,e) values that a grain released from a given Centaur can have depening on its solar radiation pressure to gravity ratio.

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Dust simulations for the Destiny$^+$ mission to (3200) Phaethon

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Abstract

The JAXA/ISAS Destiny$^+$ spacecraft will be launched to the active asteroid (3200) Phaethon in early 2023. Among the proposed core payload is an in-situ dust instrument based on the Cassini Cosmic Dust Analyzer (Srama et al., 2011). We use the ESA Interplanetary Meteoroid Engineering Model (IMEM, Dikarev et al., 2005a,b), and the interstellar dust module of the Interplanetary Meteoroid environment for EXploration model (IMEX; Sterken et al., 2013; Strub et al., 2018) to study detection conditions and fluences of interplanetary and interstellar dust with a dust analyzer on board DESTINY$^+$.

1. The Destiny$^+$ Mission

The DESTINY$^+$ (Demonstration and Experiment of Space Technology for INterplanetary voYage Phaethon fLyby with reUSable Probe) mission has been selected by the Japanese space agency JAXA/ISAS (Kawakatsu and Itawa, 2013; Arai et al., 2018). The mission target is the active near-Earth asteroid (3200) Phaethon. The spacecraft will be launched in early 2023, a close flyby of Phaethon is planned for August 2026 at a heliocentric distance of 0.87 AU.

One of the science instruments on board will be the DESTINY$^+$ Dust Analyzer (DDA; Kobayashi et al., 2018). DDA is an upgrade of the Cassini Cosmic Dust Analyzer (CDA) which very successfully investigated dust throughout the Saturnian system (Srama et al., 2011). DDA will be an impact ionization time-of-flight mass spectrometer capable of analyzing submicron and micron sized dust grains with a mass resolution of $m/\Delta m \approx 150$. DDA will measure the mass, velocity vector, charge, elemental and isotopic composition of impacting dust grains during its four years of interplanetary voyage between Venus' and Earth's orbits, as well as during the close fly-by at Phaethon.

2. Dust Simulations

We study the detection conditions of interplanetary and interstellar dust particles for the DDA instrument. For interplanetary dust, we use the Interplanetary Meteoroid Engineering Model (IMEM; Dikarev et al., 2005a,b). We simulate interstellar dust with the interstellar dust module of the Interplanetary Meteoroid environment for EXploration model (IMEX; Sterken et al., 2012, 2013; Strub et al., 2013, 2018). Both models simulate dust densities in interplanetary space, and they are the most up to date models for the dynamics of micrometer and sub-micrometer sized dust in the inner solar system presently available. The close fly-by at Phaethon is not considered in this work.

The IMEM model is based on infrared observations of the zodiacal cloud by the Cosmic Background Explorer (COBE) DIRBE instrument, in-situ flux measurements by the dust detectors on board the Galileo and Ulysses spacecraft, and the crater size distributions on lunar rock samples retrieved by the Apollo missions. It simulates the dynamics of cometary and asteroidal dust in the planetary system.

The IMEX interstellar dust (ISD) model consistently follows the dynamics of micrometer and submicrometer sized interstellar particles ($0.05\,\mu\mathrm{m}$ to $5\,\mu\mathrm{m}$) that are exposed to solar gravity, solar radiation pressure and the time-varying interplanetary magnetic field (IMF). In the model, the dust density in the solar system is calibrated with the Ulysses interstellar dust measurements (Strub et al., 2015) which is the largest continuous interstellar dust data set from a dedicated dust instrument presently existing. Due to the variable IMF, the IMEX ISD model is time-dependent, contrary to IMEM. We use IMEM and IMEX to study the time-resolved flux and dynamics of interplanetary and interstellar dust particles in the inner solar system and the requirements to detect these particles with DDA.

Trajectory data for DESTINY$^+$ were provided by JAXA/ISAS (data set 4800014). The trajectory covers a time period of 1474 days, from 24 September 2024 to 07 October 2028, beginning with the spacecraft's escape from Earth orbit.

3. Results

- The dust flux, average impact speed and impact direction of interplanetary and interstellar dust grains onto DDA are strongly variable in time. The modulation is largely due to the spacecraft motion around the Sun, but also due to size-dependent forces acting on the grains, leading to grain size-dependent variations in dust spatial density.
- A statistically significant number of interplanetary and interstellar dust particles can be detected and analysed in-situ with DDA during the interplanetary cruise of DESTINY$^+$, which is presently planned to last four years.
- Impact speeds of interstellar impactors can exceed $60\,\mathrm{km\,s^{-1}}$, while those of interplanetary grains are in the range $5-20\,\mathrm{km\,s^{-1}}$.
- During long mission periods the grain impact speed can be used as a descriminator between interstellar and interplanetary particles and likely also to distinguish between cometary and asteroidal grains.
- The average approach direction of small ISD grains ($\lesssim 0.3\,\mu\mathrm{m}$) is rather independent of grain size.
- Larger ISD grains which are dominated by gravity can be preferentially detected in the gravitational focussing region downstream of the Sun. The approach direction of these grains significantly differs from that of the smaller grains.

Acknowledgements

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Visible-Near Infrared micro-spectroscopy of interplanetary dust particles

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Abstract

Meteorites have always been considered as representative of the surface of the asteroids of the main belt. However it has been recently reported that some chondritic porous interplanetary dust particles (CP-IDPs), typical size around 20 µm, sample bodies that formed in the outer region (> 5 AU) of the solar system [1], since their reflectance spectra are similar to those obtained from the remote sensing measurements of these asteroids (e.g. low-density icy asteroids C-, P-, and D-types). We present here preliminary results obtained from the visible-near infrared (Vis-NIR, 0.4-1.1 µm) micro-spectroscopy that we developed to analyze different extraterrestrial (E.T.) materials such as meteorites and the tiny IDPs as well as minerals found in the E.T. material.

1. Introduction

CP-IDPs are assumed to be the most pristine extraterrestrial particles available in the laboratory for studies with high spatial resolution analytical techniques. In the last decade, we have conducted several studies on these tiny particles using mid- and Far-infrared (2-50 µm) micro-spectroscopy (IR) performed on the French synchrotron SOLEIL [2, 3]. This technique is non-destructive, gives information on the mineralogy and organics of the samples [2] and allows comparison with astronomical data [3]. A full study of the IDPs requires the combination of different analytical techniques including those which are destructive. In this study, we enlarge our spectroscopic investigation to the Vis-NIR. The IDPs are allocated by NASA and sent between two glass-slide droplet containers, which are not suitable for IR micro-spectroscopy. We aim in this study to acquire spectra from different IDPs *in-situ* in their containers in the Vis-NIR in order to i/ have a first characterization of the IDPs before transferring them to other substrates for complementary analyses ii/ provide data in the Vis-NIR range of the IDPs to be compared with the remote sensing data from the asteroids' surfaces. iii/ to complete with IR and Raman measurements for a better understanding and interpretation of the Vis-NIR spectra and thus the observational data. Currently little has been reported on this topic, Bradley et al. have compared in the visible range the signatures of some CP-IDPs and CS-IDPs (Chondritic Smooth) [4], but more data are necessary to better elucidate the comparison with asteroidal spectra.

2. Experimental procedure

We installed in a clean room a Vis-NIR spectrometer (Maya2000 Pro from Ocean Optics) coupled through a Vis-NIR optical fiber (100 µm in diameter used for the collection of the reflected light by the samples) to an objective X6.3 of an optical microscope (Zeiss) [5]. With this objective the collecting spot is reduced to 20 µm. This value is in the same order than the IDPs' sizes. The samples are illuminated by a 1000 µm diameter optical fiber coupled to a halogen light source. The angle between the two fibers is about 45°. Before measuring the IDPs we collected spectra from minerals (olivine, pyroxene) as well as some carbonaceous meteorites such as Allende (CV), Frontier Mountain 95002 (CO) and Gilgoin (H5), DAG684 (Eucrite) in order to compare our micro-measurements to the macro-measurements reported elsewhere [6,7]. These samples have been used as powder dispersed on a glass slide (olivine and meteorites) as well as individual grains of ~ 20 µm in size, and a pressed pellet (pyroxene). Two analyzed IDPs W7068 B37 (9 µm size) and L2079 C18 (35x27 µm size) are transferred onto a diamond window. We also analyzed L2071 E34 (22x20 µm) and W7068 C40 (25x23 µm) which are still on their substrate as sent by NASA. We performed measurements on the IDPs in different locations, when the collecting spot is smaller than the IDP, and also by rotating the glass slide exposing thus different sides of the sample to the illuminating light. We then averaged the different spectra.

3. Results and Discussion

The obtained spectra from olivine and pyroxene exhibit the signatures of the two minerals about 600, 800 and 1050 nm for olivine and the specific band around 900 nm for pyroxene. These spectra are in a total agreement with what is found in macro-measurements. These results validated our analytical procedure. However, when we use this analytical procedure for individual grains of these minerals (~ 20 µm in size) the obtained spectra drastically decrease above 800 nm. We first explain this phenomenon by possible effects of diffusion and scattering of the light in the grains leading to the loose of the signal. Figure 1 below shows the spectra obtained for the IDPs. The reflectance levels reported here are in a good agreement with those of Bradley et al. in the range 400-800 nm [4]. The IDP W7068 B37 has a lower reflectance level, this can be explained by its size (9 µm) smaller than the spot size of detection (20 µm), other measurements are planed with a 50 µm fiber (spot of ~ 10 µm) for this IDP. The IDPs L2079 C18 and L2071 E34 have same levels around 4%. The IDP W7068 C40 has a reflectance level 3 fold higher. The composition of these samples will be investigated thanks to the next synchrotron IR micro-spectroscopy measurements. These encouraging preliminary results indicate that it is possible to classify our IDPs according to their level of reflectance in the 400-800 nm range. In future work, we will extend these measurements to about 20 IDPs and look for possible trends.

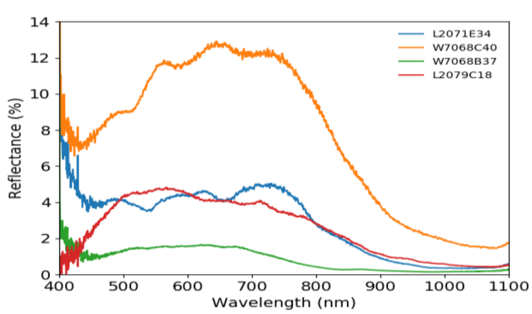

Figure 1: The Vis-NIR spectra of the four studied IDPs.

Acknowledgements

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Apparent hyperbolic meteoroid orbits

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Abstract

The identification of interstellar particles among detected meteors is a challenging task involving a careful data treatment and a detailed error analysis. In fact, a hyperbolic orbit is the only easily measurable property of a meteoroid that might indicate an interstellar origin. However, the semi-major axis *a*, which defines the type of the orbit, strongly depends upon the derived heliocentric velocity v_H and so speed measurements are central to this discussion. We demonstrated how sensitive the influence of the measurement errors on the resulting orbit is [1].

The effect of measurement errors on the resulting orbit

Interstellar meteors are expected to arrive at Earth with speeds exceeding the Sun's escape velocity, typically, by a few kms^{-1}; but they may also arrive with almost zero excess velocity. Identifying such a small effect requires extremely high accuracy measurements. Therefore, on the one hand, possible interstellar meteors remain hidden within the error bars; on the other hand, measurement errors can transfer near-parabolic orbits over the parabolic limit and create an artificial population of hyperbolic meteors, often interpreted as of interstellar origin. The error required for this change need not be large. The higher the heliocentric velocity v_H of the meteoroid, the smaller the error needed. This effect can be demonstrated by a diagram showing the correlation between the non-atmospheric velocity v_{inf} (or geocentric velocity v_G) and the angular elongation of the apparent radiant from the apex, ε_A [2] (figure 1). Meteors are distributed in a very narrow zone of the diagram, where the possibility of discriminating between orbits of different semi-major axes is most demanding. It is clearly seen that for large *a*, the value of the semi-major axis derived is strongly affected by any small errors in the measured speed or radiant position. Consequently, concentrations of shower meteors with known local sources (the Perseids, Orionids, Lyrids and Leonids) are present among hyperbolic orbits. A detailed error analysis of the same sample as used for figure 1 showed that the vast majority of hyperbolic orbits (red crosses in figure 1) were only apparent, and their proportion in the data shrank massively from 11% to 0.02% [3].

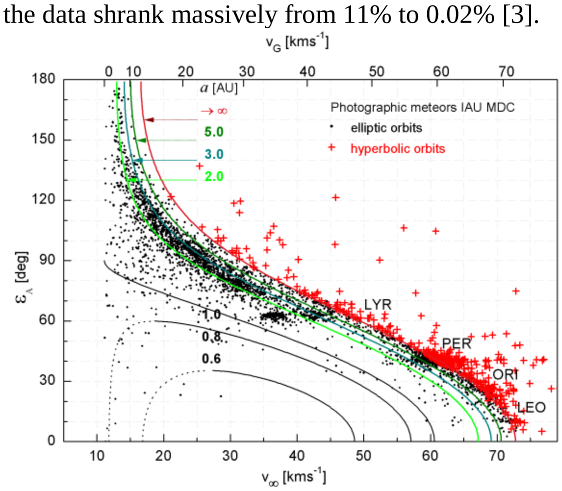

Figure 1: The angular elongation of the apparent radiant from the apex ε_A is plotted against the non-atmospheric velocity of meteors v_{inf}, using rough photographic data of the IAU MDC [4]. The curves, representing the relation between ε_A and v_G, are constructed for different values of semi-major axes *a*.

Acknowledgements

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The Large Interstellar Polarisation Survey

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Abstract

It is well known that the dust properties of the diffuse interstellar medium vary over large scales (see e.g. the Planck mission). In this contribution we present our study on the variations in dust properties on smaller scales as inferred from optical spectro-polarimetry of bright stars in the Galactic disk. We give an overview of our Large Interstellar Polarisation Survey, the obtained linear polarisation data, and present first results obtained from applying dust models simultaneously to both extinction and polarisation curves. We demonstrate that it is crucial to select single-cloud lines-of-sight to find new correlations between dust model input variables and observational parameters that are obscured (washed-out) when multi-cloud sightlines are included.

1. Interstellar polarisation

With the goal of acquiring additional constraints on the properties of interstellar dust grains in the diffuse-to-translucent interstellar medium we started LIPS (Large Interstellar Polarisation Survey). LIPS uses spectro-polarimetric facilities in both hemispheres, FORS2 at the Very Large Telescope and ISIS at the William Herschel Telescope. The FORS2 polarisation spectra presented in this contribution have a wavelength range from 380 to 950 nm at a spectral resolving power of $\sim$880. With the southern part of the program we obtained 127 linear polarisation spectra of 101 targets. The selected targets are bright ($V < 8$ mag), early-type (O and B) stars that probe primarily diffuse-to-translucent clouds. The northern part of the survey targeted about 30 additional sightlines. With a few exceptions the targets are widely spread along the galactic disk ($|b| < 30^o$). The LIPS sample complements that obtained with HPOL (at 10-25 Å spectral resolution), nearly doubling the sample of sightlines with moderate-resolution spectro-polarimetry (most surveys to date used broad-band polarimetry).

2. Results

2.1. Serkowski parametrisation

The Serkowski curve is a parametrisation to describe the linear polarisation signal of interstellar dust grains

$$p(\lambda)/p_{\max} = \exp\left[-K \ln^2(\lambda_{\max}/\lambda)\right], \qquad (1)$$

where $p_{\max}$ sets the peak polarisation, K the width of the curve, and $\lambda_{\max}$ the wavelength corresponding to $p_{\max}$.

As reported in [1] the Serkowski-curve parameters could be accurately derived for 76 different lines-of-sight. In addition we reported the wavelength gradient of the polarisation angle. We find a good agreement for targets with previously published polarisation curves and/or Serkowski parameters.

2.2. Dust model fitting

In [3] and [2] we combined the linear polarisation spectra from LIPS with the UV-visual extinction curves for a subset of 59 sightlines. These data are fitted with a dust model composed of silicate and carbon particles with a distribution of sizes from the sub-micron to the molecular. The model also includes stochastically heated PAHs. The observed polarisation is reproduced by large (> 6 nm) prolate silicate grains. It is noteworthy to add that including the polarisation measurements reduces the average dust size by about a factor of two and results in a steeper dust size distribution. The model fitting confirms several correlations between extinction and Serkowski curve parameters with (model) dust parameters. Despite large cloud-to-cloud variations in the derived dust characteristics, we find that when we average a sufficiently large number of single-cloud or multiple-cloud sightlines we retrieve similar mean dust parameters.

2.3. Single-cloud sightlines

High-resolution archival UVES data for 32 targets allowed us to establish whether each of these sightlines is dominated by a single cloud or probes multiple clouds. The absorption profiles due to interstellar atomic (calcium, natrium and kalium) gas revealed that the majority of these sightlines intersect two or more clouds, while 8 are clearly dominated by a single absorbing cloud. For this sample we find that the maximum value of the linear polarisation is smaller in multiple-cloud sightlines than in single-cloud sightlines, indicative of a depolarisation effect of the incoming radiation. For single-clouds the typical dust abundances are [C]/[H] = 92 ppm and [Si]/[H] = 20 ppm.

This classification process also allowed us to find new, previously undetected, correlations between different model and observational parameters that are only valid in single-cloud lines-of-sight. For instance we revealed a strong correlation between the mass ratio of silicate and carbon dust and both the extinction bump and the far UV rise. Furthermore, for single clouds the correlation between the total-to-selective visual extinction ratio R_V and the average amorphous carbon grain size is also stronger, as well as the high negative correlation between R_V and the exponent of the dust size distribution.

3. Summary and Conclusions

LIPS provides a large new set of spectro-polarimetric measurements of dust grains in the diffuse-to-translucent interstellar medium. The reduced data, intensity and polarisation spectra, are available from CDS/ViZier (catalogue reference J/A+A/608/A146). This catalogue also provides synthetic broadband polarimetry in the BVRI filters, as well as the Serkowski-curve parameters and wavelength gradient of the polarisation position angle for the interstellar polarisation along 76 different lines of sight.

Combining polarisation measurements with extinction data provides additional constraints for the interstellar dust models. Already established correlations between different model and observational parameters are more pronounced for single-cloud sightlines. Furthermore, selecting single-cloud sightlines allowed us to find hitherto undetected correlations between model input variables and observational parameters.

To confirm these results (obtained for a relatively small set of targets) we need to obtain many more linear polarisation spectra of single-cloud sightlines, either by identifying additional sightlines in the LIPS sample (using archival or follow-up optical spectroscopy) or by spectro-polarimetric follow-up of other single-cloud lines-of-sight to be selected from auxiliary data.

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Non-Gravitational reorganisation of the dust tails of C/2006 P1 and C/2011 L4

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Abstract

We present results from a new application of Finson & Probstein's [1] model of cometary dust tails. The dominant forces of radiation pressure and gravity acting on dust both follow inverse square laws, so the structure of the tail can be explained by adjusting the Keplerian orbits of ejected material. Each particle is parameterized by its ratio of radiation pressure to gravity - beta, and its time of ejection from the nucleus. A temporal map is extracted from dust tail images, displayed for the first time directly in the beta and emission time parameter space.

Figure 1: The dust tail of C/2006 P1 from STEREO A HI-1 (enhanced), with the Sun below the image. After the re-organisation, the original striae and new sunward facing structures are visible.

We use this technique to examine the extensive tails of C/2006 P1 (McNaught) and C/2011 L4 Pan-STARRS, pictured in figures 1 and 2 respectively; using data from the STEREO SECCHI and SOHO LASCO instruments, as well as ground based images.

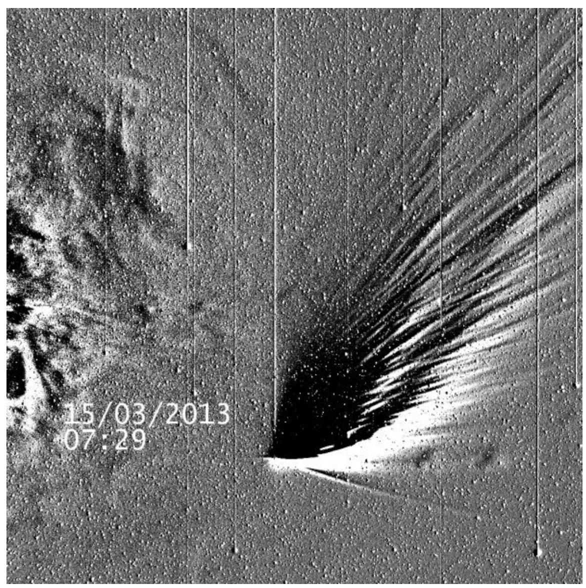

Figure 2: The dust tail of C/2011 L4 from STEREO B HI-1 (difference image), with the Sun to the left. The original striae are visible, along with several more sunwardly aligned features.

Our technique has allowed for the formation of striated features in a cometary tail to be resolved for the first time at comet McNaught. The nature of the formation mechanism of these striae remains an open question in cometary physics.

There is clear evidence that non-gravitational forces affect the morphology of striae in the dust tails of both comets. At McNaught, this appears to be from charged dust interaction as the comet crosses the Heliospheric Current Sheet. Here, we investigate what explanation there may be for the dust re-organisation at Pan-STARRS.

After the tail is affected at both comets, it appears to form new coherent dust features. We investigate also what explanations there may be for the formation of new features, which form well after the typical timescale for striae formation. We investigate what relation their structure has to the solar wind and structure within the heliosphere.

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The measurement of micron sized impact fragment using delay line detector

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Abstract

ATHENA is a successor of the X-ray mission XMM-Newton telescope. A special issue for the ATHENA telescope is the possible scattering of micron sized particles through the mirror shells, which might damage on the CCD optical system. The generation of scattering fragment particles upon hypervelocity impact under an oblique angle is of central interest for this project. The ejecta generation is characterized by the distributions of size, mass, velocity and ejection angles. In this study, we employ MCP detector with delay line anode to monitor impact ejecta.

1. Introduction

Experiments showed that the number of secondary impacts from oblique impact angles is more than two orders of magnitude higher than from primary impacts [1]. In the past, two detection methods were used to measure micron sized impact ejecta grains depending on the size of the impacting particles: Particles with diameters larger than 10 μm were accelerated in plasma drag- and light gas gun accelerators to speed between several hundred m/s and about 3 m/s. The ejecta generation was studied for impacts of glass spheres onto ice targets in dependence on the target temperature and the impact angle. A setup of thin films was used to record the size distribution and the ejection angle of the secondary particles [2]. The flight time and subsequently the speed of the secondary particles was measured with piezo detectors. The detection method for smaller and faster dust particles (μm and sub-μm) uses the light flash generated by impacting secondary particles onto the entrance window of a photomultiplier (PMT) [3] .

In this study, we employ MCP detector with delay line anode to monitor impact ejecta. The ejecta speed can be determined from the flight time between the primary impact and the impacts of the ejecta on MCP. Studies investigating the glow of the primary impact showed a direct relation between the MCP amplitude and the particle mass and the impact velocity. This allows to use the results of the intensity measurement for the estimation of the particle mass and size. The MCP detector with delay line anode is high resolution 2D imaging and timing device for fragment particle at high rates with limited multi-hit capability.

2 Experimental set up

The 20 kV dust accelerator located at Institute of Space systems (IRS), University of Stuttgart, is used in order to obtain experimental results of the delay line detector system. The detection systems for secondary ejecta particles resulting from the interaction between the dust particle and the mirror surface are placed behind the mirror. The target mirror disk is placed behind the tube detector (see Figure 1). The mirror could be tilted with respect to the direction of the incident dust particle to enable different grazing incidence angles with angular resolution better than 0.02 degrees. The setup offers the option to move the mirror laterally out of the particle path so that the effect of the direct dust particle impingement could be tested. Both the tube and the top electrode were connected with charge sensitive amplifier for signal detection. There is also a positive bias voltage added above the mirror target to collect the electrons generated by primary impact. In order to avoid the influence on the trajectory of tiny ejecta particles with surface charge, the voltage is only selected as +100 V. We can check if the particle passed through the tube and touched the mirror. The individual particle charge and speed parameters are obtained by the tube detector, and the mass of the particle can be calculated.

3. Primary experimental results

Micron sized iron (ρ = 7.8 g/cm^3) particles are used to test the experimental set up, and platinum coated ortho-pyroxene to (ρ = 3.4 g/cm^3) particles are used

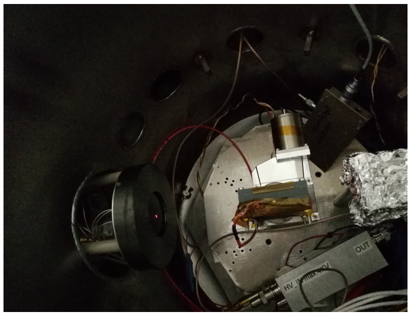

Figure 1: Experimental set up in vacuum chamber at 20 KV dust accelerator.

to simulate the mineral dust grains in the interplanetary space. The delay line detector system can be used measure micron and submicron sized dust grains with the speeds of between 100 m/s and 6 km/s. Figure 2 shows the calibration results of iron particles. The gain of MCP is adjusted by two different voltages (1800 V and 1950 V). The amplitude obtained by the MCP is similar with impact ionization charge:

$$A = \alpha \times m \times v^{\beta} \tag{1}$$

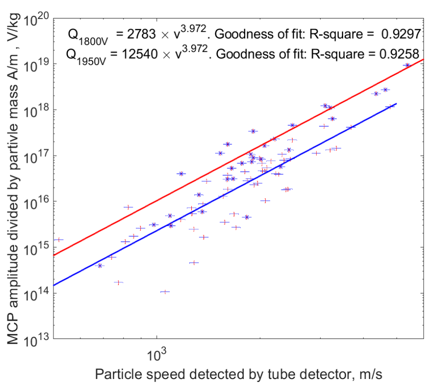

Figure 2: Calibration of MCP amplitude to mass ratio and dust particle speed.

The typical signal for an impact fragment group is shown in Figure 3 . Each peak is related to a single fragment impact. The analysis showed that the speeds of impact fragments are lower than the incident dust projectile.

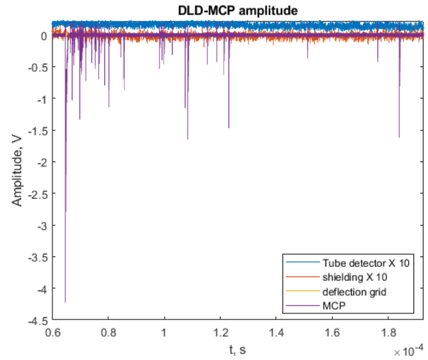

Figure 3: Calibration of MCP amplitude and dust particle parameters.

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Dust Astronomy with the DESTINY+ Dust Analyser

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Abstract

DESTINY+ is an interplanetary mission by JAXA/ISAS to the inner Solar System with a flyby at the active asteroid 3200 Phaethon in the year 2026. The science payload includes the new Dust Telescope "DESTINY+ Dust Analyser" (DDA), which is optimised to perform compositional measurements of individual micrometeoroid impacts. Mass spectrometry of the impact plasma is combined with particle trajectory information. This paper summarises the characteristics of the DESTINY+ Dust Analyser and describes its science goals in context to earlier Cassini results.

Scientific Goals

Galactic interstellar dust represents the solid material from which stars and planetary systems form. Interplanetary dust from comets and asteroids represent remnant material from small bodies of objects from the early Solar System. DESTINY+ studies compositional differences between the solid material of the interstellar medium and of material from primitive planetary objects in the inner Solar System. The results promise deeper insight into the physical conditions during our Solar System formation and DESTINY+ forms a bridge between planetary science and astrophysics.

The discovery of interstellar dust in the outer and inner solar system in recent decades has enabled a new innovative approach to the characterisation of galactic cosmic dust. DESTINY+ will address major questions like (1) What is the origin and nature of the dust particles that constantly fall onto the earth? (2) What is the fraction and composition of organic material in interplanetary and interstellar matter? (3) How do active asteroids work?

The in-situ methods of Dust Astronomy complement and extend the results achieved so far. DESTINY+ is the next logical step after the successful missions of Stardust, Rosetta and Cassini. In particular, the following questions are addressed:

- In-situ analysis of the elementary and isotopic composition of individual cosmic dust particles including their organic constituents

- Characterisation of dust emission of the active asteroid 3200 Phaethon

- Determination of the size distribution of interstellar dust

- Characterisation of the interaction of interstellar matter with the heliosphere

- Determination and criteria for cometary and asteroidal interplanetary dust particles

- Improvement of meteoroid models for the inner solar system

DESTINY+ Dust Analyser

The DESTINY+ Dust Analyser (DDA) determines the particle density, composition (m/dm>150, mass range 1-1000 amu), electric charge (>0.15 fC) and mass (10e-19 kg to 10e-12 kg) of the smallest dust particles. Dust impact rates are measured for rates as low as 1/week up to 20/sec. DDA consists of two sensor heads, a 2-axis gimbal mechanism and an electronics box. The measuring principle is based on impact ionization, time-of-flight mass spectrometry and charge induction. The sensitivity (particle size, trace elements) and mass resolution has been improved up to a factor of 10 compared to the Cassini dust instrument. The properties of DDA are similar to the SUDA instrument onboard the Europa mission. The fast flyby at Phaethon with a speed of 33 km/s allows compositional analysis of nanograins as small as 50 nm radius. Its combined sensitive area (2 head) is 310 cm^2. For the first time, a dust sensor head allows the simultaneous operation of two spectrometers. Different spectrometer voltages will analyse cations and anions during all phases of the mission without the need to switch voltages. The measurement of anions is mandatory for the understanding of organic dust components in the mass spectra. The instrument is currently undergoing a Phase A study.

Open questions after Cassini

The Cosmic Dust Analyzer (CDA) onboard the Cassini mission measured the properties of micron sized dust particles in the planetary system. The instrument was operated during the cruise phase starting in 1999 and remained switched on until Saturn Orbit Insertion. Between 2004 and 2017 CDA performed successfully measurements in the Saturnian system and made many exciting discoveries and measurements: Dust streams from the inner and outer ring system, dust grain potentials, dust grain composition of ring particles, dust size and density distributions in the outer ring system, the G ring detection, the Enceladus dust plumes and significant dust fluxes outside the known E ring. Dedicated measurement campaigns were attributed to icy satellite flybys, interstellar dust observations and nanograin-magnetosphere interactions. Finally, the ring rain of between the main ring system and Saturn was characterised.

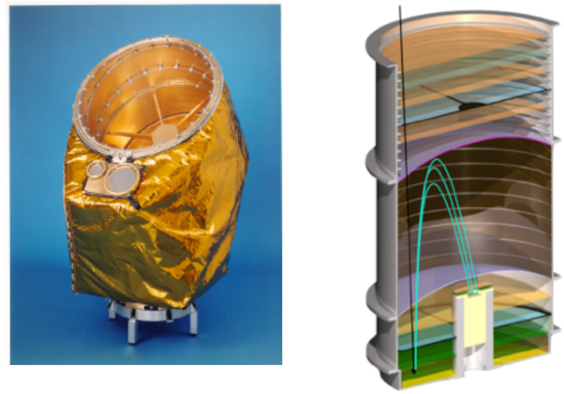

Fig. 1 The Cassini Cosmic Dust Analyser (left) and cross section of DDA (right). The instrument contains a ring shaped target (green) and a reflectron-type TOF mass spectrometer. Charge induction grids allow a dust trajectory determination. The cross section shows one sensor head. The gimbal, the instrument cover and the electronics box is not shown.

Interstellar dust was even measured twice: first, in the early cruise phase at 1 AU, and second, at Saturn during an almost one year long integration campaign. The second campaign succeeded to measure, for the first time, the composition of interstellar dust grains by an in-situ TOF mass spectrometer in space. The interstellar dust particles were identified and analysed. However, the mass spectrometer resolution was not high enough to clearly separate all elemental isotopes. DDA will fill this knowledge gap. Furthermore, the analysis of interplanetary dust particles by Cassini was compromised during cruise and during the Saturn tour. During cruise, the pointing profile was insufficient to measure a significant number of interplanetary dust grains. DESTINY+ promises the analysis of a statistical meaningful sample of interplanetary dust particles.

Acknowledgements

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Mineral dust in the Saturnian system

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Abstract

We present the chemical composition and potential origin of about 1800 sub-micron sized mineral dust grains detected in the Saturnian system by the Cosmic Dust Analyser aboard the Cassini space craft. The data set spans over the entire duration of the Cassini mission from 2004 to 2017. We use dynamical analysis to reconstruct orbital parameters in order to trace back the origin of the dust particles. The mass spectra recorded by the CDA gives insights into the chemical composition of the mineral particles and allows for further conclusions on their origin.

1. Introduction

The CDA records cationic mass spectra after impact ionization of individual micron and sub-micron sized grains. Mineral dust only takes up a small fraction within the large CDA spectra data set which is dominated by an overwhelming number of hundreds of thousands ice grain detections in Saturn's E ring. We employed several machine learning algorithms to identify and extract all mineral spectra from the CDA data base. Eventually a surprisingly large number of 1797 mineral dust spectra were found and, since late 2017, are subject to our compositional and dynamical analysis.
Several potential sources for mineral grains are in principle possible. Endogenic dust particles might result from impact ejecta of Saturn's outer moons released by micro-meteoroid bombardment. Interstellar dust, Kuiper Belt object, comets and the Oort Cloud are potential sources for exogenic dust grains crossing the Saturnian system on hyperbolic orbits. By analyzing the composition of these grains and linking them to their origin by a dynamical analysis we aim to characterize the composition of these sources or source bodies. The successful compositional characterization of 36 interstellar dust particles recorded by CDA [1] showed the potential of this approach. We give a progress report of this ongoing work.

2. Results

Our analysis shows that a greater part of the mineral grains are detected in groups. We define 36 swarms where at least 10 particles are detected with less than 3000 s time difference between two events. Some of these swarms can be dynamically determined to be of endogenic or exogenic origin. Endogenic swarm candidates noticeably accumulate at inclination between 150° indicating they originate from retrograde satellites including Phoebe. Most exogenic swarms enter the Saturnian system from similar directions, passing through the Saturnian system nearly perpendicularly to the planet's equatorial plane and are suggestive to be of cometary origin.
The composition of mineral spectra can be separated into two distinctive groups, iron rich minerals (58 %) and iron poor but mostly Mg rich minerals (34 %), only a minor fraction of spectra (8 %) do not belong to each of these two groups. The iron rich spectra are composed of sulfides, oxides and metallic iron, with no other metal exceeding the detection threshold. The iron poor minerals in cotranst are silicates and show other metallic constituents like Na, Mg, Al, Ca, K in varying concentration. In most cases Mg is the most abundant metal.
It can be shown that bound retrograde swarms contain a significantly higher fraction of iron rich grains whereas in exogenic candidates this fraction is significantly lower. This is just the first results of a three year project in the course of which we aim to study composition and dynamic of mineral grains at Saturn in greater detail.

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