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ORIGINAL ARTICLE

DuneXpress

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Abstract The DuneXpress observatory will characterize interstellar and interplanetary dust in-situ, in order to provide crucial information not achievable with remote sensing astronomical methods. Galactic interstellar dust constitutes the solid phase of matter from which stars and planetary systems form. Interplanetary dust, from comets and asteroids, represents remnant material from bodies at different stages of early solar system evolution. Thus, studies of interstellar and interplanetary dust with DuneXpress in Earth orbit will provide a comparison between the composition of the interstellar medium and primitive planetary objects. Hence DuneXpress will provide insights into the physical conditions during planetary system formation. This comparison of interstellar and interplanetary dust addresses directly themes of highest priority in astrophysics and solar system science, which are described in ESA's Cosmic Vision. The discoveries of interstellar dust in the outer and inner solar system during the last decade suggest an innovative approach to the characteriza-

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tion of cosmic dust. DuneXpress establishes the next logical step beyond NASA's Stardust mission, with four major advancements in cosmic dust research: (1) analysis of the elemental and isotopic composition of individual interstellar grains passing through the solar system, (2) determination of the size distribution of interstellar dust at 1 AU from 10^{-14} to 10^{-9} g, (3) characterization of the interstellar dust flow through the planetary system, (4) establish the interrelation of interplanetary dust with comets and asteroids. Additionally, in supporting the dust science objectives, DuneXpress will characterize dust charging in the solar wind and in the Earth's magnetotail. The science payload consists of two dust telescopes of a total of 0.1 m^2 sensitive area, three dust cameras totaling 0.4 m^2 sensitive area, and a nano-dust detector. The dust telescopes measure high-resolution mass spectra of both positive and negative ions released upon impact of dust particles. The dust cameras employ different detection methods and are optimized for (1) large area impact detection and trajectory analysis of submicron sized and larger dust grains, (2) the determination of physical properties, such as flux, mass, speed, and electrical charge. A nano-dust detector searches for nanometer-sized dust particles in interplanetary space. A plasma monitor supports the dust charge measurements, thereby, providing additional information on the dust particles. About 1,000 grains are expected to be recorded by this payload every year, with 20% of these grains providing elemental composition. During the mission submicron to micron-sized interstellar grains are expected to be recorded in statistically significant numbers. DuneXpress will open

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a new window to dusty universe that will provide unprecedented information on cosmic dust and on the objects from which it is derived.

Keywords Interstellar dust · Interplanetary dust · Cometary dust · Asteroidal dust · Dust astronomy · Chemical composition · Isotopic composition · Size distribution · Interstellar dust flow

1 Introduction

DuneXpress is a proposal for a dust astronomy mission that makes use of the information carried by dust particles in space about their birth at a remote site in space and time that is not accessible to direct investigation [28]. A first incarnation of such a proposal was in 2001 when ESA called for mission ideas that re-use the Mars Express platform. The "Cosmic DUNE" dust observatory was proposed using state-of-the art instruments like the Cassini and Stardust dust analyzers and a crude collimator system for directionality and speed measurements. The scientific idea was already then to link the origin of dust grains with their chemical composition. Because of its attractive science goal this mission got a technical assessment by ESA but was, finally, not selected for flight because of a mismatch of the modest mission requirements and the superior capabilities of the Mars Express system.

Since then major advancements in dust instrumentation have been made which vastly enhance the dust trajectory measurement and chemical analysis capabilities in order to cope with the low flux of cosmic dust particles in interplanetary space. The DuneXpress mission has been proposed to ESA in response to its Cosmic Vision call as an innovative and highly cost effective means of performing dust astronomy with interstellar and interplanetary dust. The mission is proposed by a large international science team from 10 European countries, Japan, Russia, and USA.

2 Science goals

2.1 Interstellar dust

The dust evolution cycle follows meandering paths from stardust to stardust. From the stellar winds of evolved stars, new dust is formed and is injected into interstellar space. Young stardust is mixed with old heavily-processed diffuse interstellar dust, and is subject to passing supernova shocks and ultraviolet radiation. Dusty clouds form. The protostar environment is a fertile ground for solids on all size scales, from dust grains to planets, to form. Star formation in cool molecular clouds becomes both a sink of old dust and a source of new dust. A typical dust grain anywhere in space will have undergone several cycles.

About 90% of the stellar mass loss, which contributes to the interstellar medium (ISM), is provided by asymptotic giant branch (AGB) and post-AGB stars. Stars that are in their late evolutionary stages lose up to 10^{-4} solar masses per year. In the cooling, expanding gas flows from these stars, solid dust particles condense [59]. The carbon-to-oxygen ratio in the stellar atmospheres determines whether carbon-rich particles or silicates and metal oxides form. In circumstellar envelopes, evidence of silicate dust appears in spectral bands at 10 and 18 μm [16]. For example, the strongest of the mid-infrared bands in the 20 to 50 μm wavelength region can be attributed to Mg-rich (Fe-poor) olivine and pyroxene particles. In the stellar atmosphere of O-rich stars, metal oxides can form. However, the only direct evidence is a distinct band at 13 μm, tentatively linked with aluminium oxide. In a carbon-rich circumstellar environment, a variety of carbon compounds can form, which act as seed particles for the nucleation of some types of amorphous carbon and polycyclic aromatic hydrocarbons (PAHs). In a carbon circumstellar environment, silicon carbide (SiC) and other oxygen-free solids can form. Dust is emitted not only from evolved stars, but also from supernovae, Wolf-Rayet (WC) stars, and novae [2].

Once ejected from stars, dust particles populate interstellar space (see review [15]). The chemical evolution of interstellar dust in the ISM directly reflects the metallicity of the galaxy. It has been found [17] that the dust contains about 40% of the total mass of heavy elements in the Galaxy, e.g. Fe, Mg, Si as well as C and O [38, 57].

In diffuse interstellar clouds, the grains lose their volatile constituents due to ultraviolet irradiation [22], thermal sputtering and grain-grain collisions in supernova shock fronts [33]. In dense clouds, dust particles encounter favorable conditions for both condensation of gas species on their surfaces, and aggregation via collisions resulting in grain growth. Chemical processing of the icy coating by UV and ion bombardment can produce complex molecules of organic refractory material on the dust grain's surface. Ultimately, an ISD grain can be incorporated (and destroyed) in a newly forming star, or, it can become part of a planetary system. In this way, ISD grains are repeatedly recycled through the galactic evolution process [15]. Multi-component models interstellar grains have been developed by Mathis [42] and Li and Greenberg [41] that attempt to account for various observational behavior and cosmic abundance constraints.

The solar system is located at the edge of the local bubble which was excavated by supernova explosions in the neighboring star-forming regions of the Scorpius-Centaurus and Orion Associations [19, 20]. Currently, the solar system is passing through a cluster of interstellar cloudlets that emerged from this bubble within the last 10^4 to 10^6 years [7].

More than a decade ago, ISD was positively identified inside the planetary system. After its fly-by of Jupiter, the dust detector onboard the Ulysses spacecraft detected impacts of micron and submicron-sized particles (10^{-14} to 10^{-11} g) predominantly from a direction that was opposite to the expected impact direction of interplanetary dust grains [26]. It was found that the impact velocities exceeded the local solar system escape velocity, even if radiation pressure effects were neglected [27]. Subsequent analysis showed that the motion of the interstellar grains through the solar system was parallel to the flow of neutral interstellar hydrogen and helium gas [20], both traveling at a speed of 26 km/s. The interstellar dust flow persisted at higher latitudes above the ecliptic plane, even over the poles of the Sun, whereas interplanetary dust is strongly depleted away from the ecliptic plane. From Mercury to Saturn, interstellar grains have been identified traversing the solar system. [1, 39, 40].

Questions concerning interstellar dust that will be addressed by DuneXpress include: What is the elemental composition of interstellar dust grains and its variability? What are the differences between genuine stardust and grains that have been processed in the interstellar medium? What is the nature of carbonaceous dust and of organic precursor molecules for life? What is the metallicity of the local interstellar medium? What are the sizes of compositionally different grains? Is today's interstellar material different from the ancient material incorporated into interplanetary dust? What is the size distribution of interstellar dust at 1 AU and what is the variation in flow direction and its dispersion with particle size? How time-variable is the interstellar dust flow of various sizes?

2.2 Interplanetary dust

Planet formation began with a flattened protostellar accretion disk [5, 29, 43] of gas and dust. In the earliest formation phases dust particles underwent significant alteration by heating, vaporization and recondensation. This explains common isotopic characteristics present throughout the solar system.

Comets, which formed in the outer solar system, are the least altered objects surviving from the formation of the solar system. Silicates form the most significant part of the refractory component in comets. Analysis of dust from comet Wild 2 by the Stardust mission [8, 46] demonstrates that cometary silicates are a mix of crystalline grains and glassy amorphous grains. The high temperature crystalline grains (CAIs) must have been formed in the inner solar nebula and subsequently transported (radial mixing) to the comet formation zone or they may be true stardust formed in the atmosphere of another star.

Further evidence for relatively unaltered interstellar material being released from comets, can be gathered from the collection of fluffy stratospheric IDPs. Tiny submicrometer spheroids are likely either solar nebula or presolar interstellar grains [6]. In addition, IDP isotopic anomalies of H, N, O indicate a presolar or interstellar origin. Dust particles that carry organic components are of special interest, possibly providing the building blocks for eventual life on Earth. Recently, cometary dust has been discovered to be rich in organics [34, 35]. Carbonaceous meteorites contain a substantial amount of carbon and exhibit evidence of many organic molecules [47].

Dust in a planetary system is the most processed of the different populations of cosmic dust. Interplanetary dust is permanently replenished by dust ejected from cometary nuclei and released from collisions of bigger objects. Impacts onto the surfaces of asteroids and Kuiper belt objects, and catastrophic collisions within the belts, generate fragments that show-up e.g. as dust bands in the asteroid belt. Since the composition of asteroid surfaces reveal processed compact silicate or metal-rich material, the interplanetary dust compositions should reflect the larger body's surface, however, the recovery of carbonaceous chondrite material from fallen meteorites indicates that there are also relatively primitive compositions to be sampled, particularly in the Near Earth Object population.

DuneXpress addresses the following questions concerning interplanetary dust: What is the ratio of cometary versus asteroidal particles at 1 AU and how much do they differ chemically? What are the orbital characteristics of different types of cometary and asteroidal particles at 1 AU?

DuneXpress has the following scientific objectives:

– Analysis of the elemental and isotopic composition of individual interstellar grains passing through the solar system
– Determination of the size distribution of interstellar dust at 1 AU

– Characterisation of the interstellar dust flow
– Establish the interrelation of interstellar, cometary and asteroidal dust

Since DuneXpress uses electric dust charges to measure precise dust trajectories a supporting science goal is the characterization of the plasma and dust charging environment at DuneXpress' Orbit.

In order to achieve these scientific objectives the payload must be able to accomplish the following measurement goals:

– Measure dust charges down to 10^{-16} Coulomb
  At a potential of +5 V a dust particle of 0.2 μm in radius and 1000 kg/m^3 density has a mass of 8×10^{-17} kg and carries a charge of 10^{-16} C. Most of the interstellar grains observed in the planetary system were bigger than 0.2 μm in radius; therefore, their charge will be accessible to dust instrumentation of 10^{-16} C sensitivity.
– Determine dust trajectories with an accuracy of better than 3% in speed and 3° in direction in order to distinguish interstellar from interplanetary dust by their trajectories
  Sub-micron sized interstellar dust grains move on hyperbolic orbits through the planetary system with a speed $v^\infty \sim$26 km/s outside the gravitational attraction of the sun. Interplanetary particles both of cometary or asteroidal origin move on bound orbits about the sun. At a speed accuracy of better than 3% interstellar particles are easily distinguished from interplanetary particles. This accuracy is also sufficient to separate young cometary particles (eccentricity $e > 0.5$) from asteroidal particles ($e < 0.4$).
– Analyze the elemental and isotopic composition of individual cosmic dust grains at a mass resolution $M/\Delta M > 10$ and determine the physical properties of individual dust grains at the low dust fluxes in interplanetary space
  First compositional analyses of cometary dust have been achieved by the dust mass analyzers, PIA and PUMA onboard the Giotto and VeGa spaceprobes [32, 36]. Stardust's CIDA instrument was again an impact mass analyzer employing a reflectron stage in order to provide high resolution mass spectra [35, 37]. Because of the very high dust fluxes expected near the comet only very small

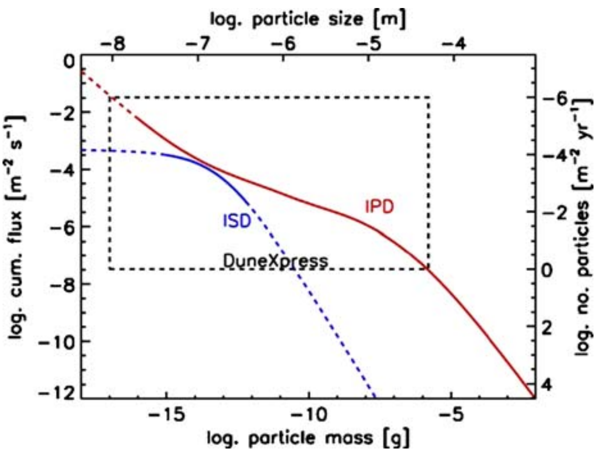

Fig. 1 Interplanetary and interstellar dust fluxes and DuneXpress measurement range

sensitive areas of ≤0.01 m^2 were necessary to obtain sufficient numbers of high resolution dust mass spectra.

In order to obtain statistically significant numbers of dust grains the total sensitive area of the DuneXpress instruments is much larger than any previous dust analyzer. With a total area of 0.5 m^2 it takes two years to detect 1,000 interstellar grains, 200 of which will be with high-resolution chemical analysis; also about three times more interplanetary particles will be analyzed (Fig. 1). DuneXpress will provide unique distinction between interplanetary dust of cometary or asteroidal origin and interstellar grains and precise size dependent dust flux measurements, capabilities which are beyond those of the Stardust mission.

3 Instrumentation

DuneXpress will employ highly sensitive dust instrumentation that has been enhanced on the basis of previous space instrumentation. The payload consists of two Dust Telescopes, i.e. combinations of Dust Trajectory Sensors (DTS) and Large-Area Mass Analyzers (LAMA), three Dust Cameras i.e. combinations DTS and Impact Detectors of various kinds, a dust detector for nanometer-sized dust (Aluminum Film Interplanetary Dust Detector, AFIDD), and a Plasma Monitor (PLASMON).

3.1 Dust trajectory sensors (DTS)

Dust particles' trajectories are determined by the measurement of the electric signals that are induced when a charged grain flies through a position sensitive electrode system. The objective of the trajectory sensor is to measure dust charges in the range 10^{-16} to 10^{-13} C and dust speeds in the range 6 to 100 km/s.

The trajectory sensor consists of four sensor grids mounted between two electrical shielding grids (Fig. 2). Each sensor grid consists of 16 parallel wire electrodes (wires separated by 20 mm), each electrode is connected to a separate charge-sensitive amplifier. The wire directions of adjacent sensor grids are orthogonal.

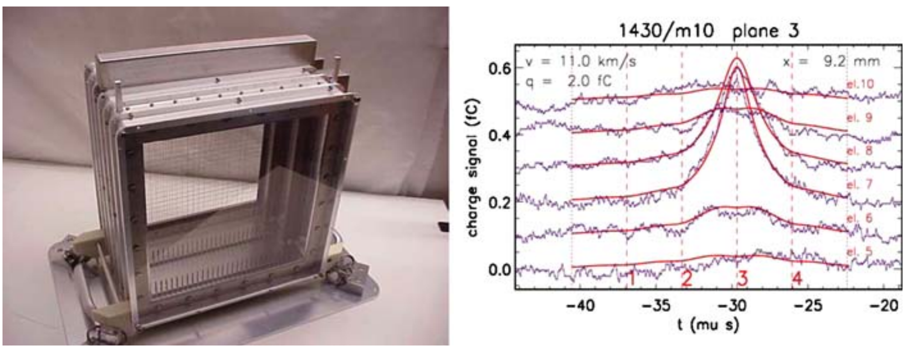

Fig. 2 Dust trajectory sensor lab set-up for dust accelerator tests (*left*). Charge signals of a dust particles recorded at six electrodes closest to the particle trajectory in one plane (*right*). Theoretical signals (*red*) are shown for comparison

Key elements of the trajectory sensor are the charge-sensitive amplifier (CSA) and the transient recorder. An Application Specific Integrated Circuit (ASIC) version was developed in cooperation with the Kirchhoff Institute for Physics of the Heidelberg University. It consists of two individual chips: the front-end and the transient recorder chip. The front-end chip contains the CSA and a logarithmic amplifier. For a 5 pF electrode capacitance the rms noise performance is 1.5×10^{-17} C (95 electrons), in a bandwidth from 10 kHz to 10 MHz. The transient recorder chip has 32 channels of analogue-digital converters with an accuracy of 10 bits and digital pipelines of 1,000 samples depth, each. An external trigger signal (e.g. derived from the dust impact onto an impact detector placed behind the trajectory sensor) stops the recording and all data is serially readout.

Dust accelerator tests at the Max-Planck-Institute for Nuclear Physics have been performed with the described set-up. The tests were performed with iron particles with speeds up to 30 km/s (0.1 to 1 μm grain size) which demonstrate the expected performance [52].

Dust Trajectory Sensors are part of all Dust Telescopes and Dust Cameras on board DuneXpress. Trigger signals to stop recording and start data read-out cycle will be provided by the impact detectors.

3.2 Dust telescope 1 (DT1)

The Dust Research Group at the Max-Planck-Institute for Nuclear Physics has a long history of applying dust composition analyzers on space missions. The Dust Telescope [52, 53] proposed for DuneXpress is the latest development which is based on dust analyzers flown on Helios [14], the Halley missions [36], on Stardust [35] and on Cassini [54]. A Dust Telescope is a combination of a trajectory sensor with an analyzer for the elemental composition of micrometeoroids [53]. The integration of the two subsystems to one high-performance detector allows for a simultaneous

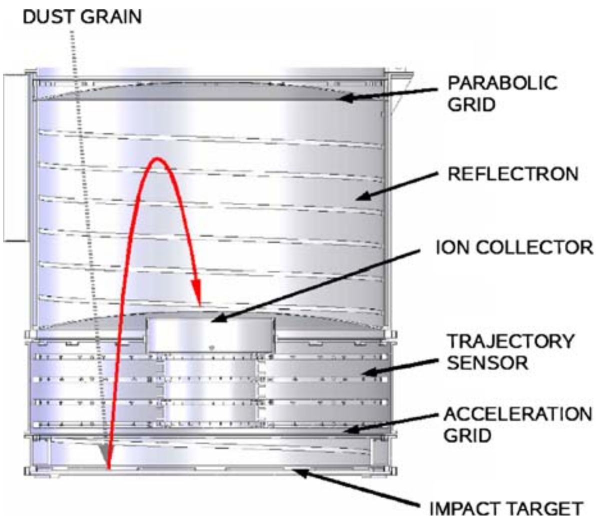

Fig. 3 Cross section of the dust telescope. It consists of the impact and ion acceleration section (*bottom*), a round trajectory sensor surrounding the central ion collector (*middle*), and the reflectron bounded by two parabolic grids (*top*). The dust particle (*black*) impacts onto the target (*bottom plate*) and the impact generated ions are focused onto the ion detector by a reflectron (*red line*). A cover protects the spectrometer from contaminations

measurement of the dust properties mass, velocity vector, surface charge and composition (Fig. 3).

The large area spectrometer is based upon impact ionization of hyper-velocity dust impacts onto a ring shaped target plate. This time-of-flight system uses a reflectron for an increased mass resolution and provides the elemental composition of individual micrometeoroids with a mass resolution between $M/\Delta M = 100$ and 300. Although a similar instrument was already flown onboard Stardust, this spectrometer has a 10 times larger sensitive area and a slightly higher mass resolution. This was shown by laboratory measurements using a laboratory model of the large area mass analyzer [51].

A decontamination heater at the target is operated every 3 month and will ensure a clean surface of the impact target. The telescope operates continuously and has no special requirements.

3.3 Dust telescope 2 (DT2)

The second Dust Telescope, funded by NASA, has been developed at the Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder [55, 56]. The Dust Trajectory Sensor part of the instrument is identical to that described above; it will be installed in front of the Large-Area Mass Analyzer (LAMA). This alternative design of the LAMA instrument is very compact and eliminates curved grids and uses only flat or ring electrodes. Changing the polarity of the bias voltages allows measuring both positive and negative ion spectra.

A laboratory prototype of the LAMA instrument has been tested using laser ablation and calibrated at the Heidelberg dust accelerator facility. This prototype instrument has a 64 cm diameter target plate with a 0.15 m^2 effective area. Proposed for this mission is the smaller version of LAMA with a 40 cm diameter target plate. The engineering model of the hardware is shown in Fig. 4. A cover (installed in front

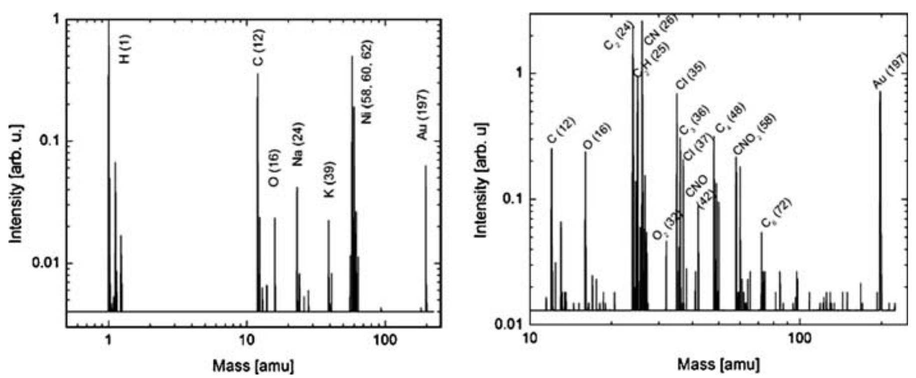

Fig. 4 Positive (*left*) and negative (*right*) impact mass spectra. Positive spectrum from a 33 km/s impact of a Ni dust particle on an Au surface. Negative spectrum from Ni particle at 27 km/s on a piece of the gold coated Allende meteorite. The peaks corresponding to the target material and the three isotopes of the projectile material are clearly recognized. The peaks of H, C, O, Na and K are from the contaminations present on the target surface. The mass resolution of the instrument is calculated from the full width at half maximum (FWHM) of the peaks and it varies from $M/\Delta M \geq 125$ to $M/\Delta M \approx 500$ with a typical value of $M/\Delta M \approx 200$

of DTS) protects the interior from contamination before launch and in the early cruise phase.

3.4 PVDF dust camera 1 (DC1)

This instrument uses a polyvinylidene fluoride (PVDF) film to measure the mass of a dust particle passing through a trajectory sensor. The PVDF film consists of a permanently polarized material. A particle impacting the sensor surface makes a crater (or hole) which produces a local destruction of dipoles. This results in a rapid current pulse (of order 10 μs) which can be detected by relatively simple electronics. The pulse signal (charge liberated) depends on particle mass and velocity.

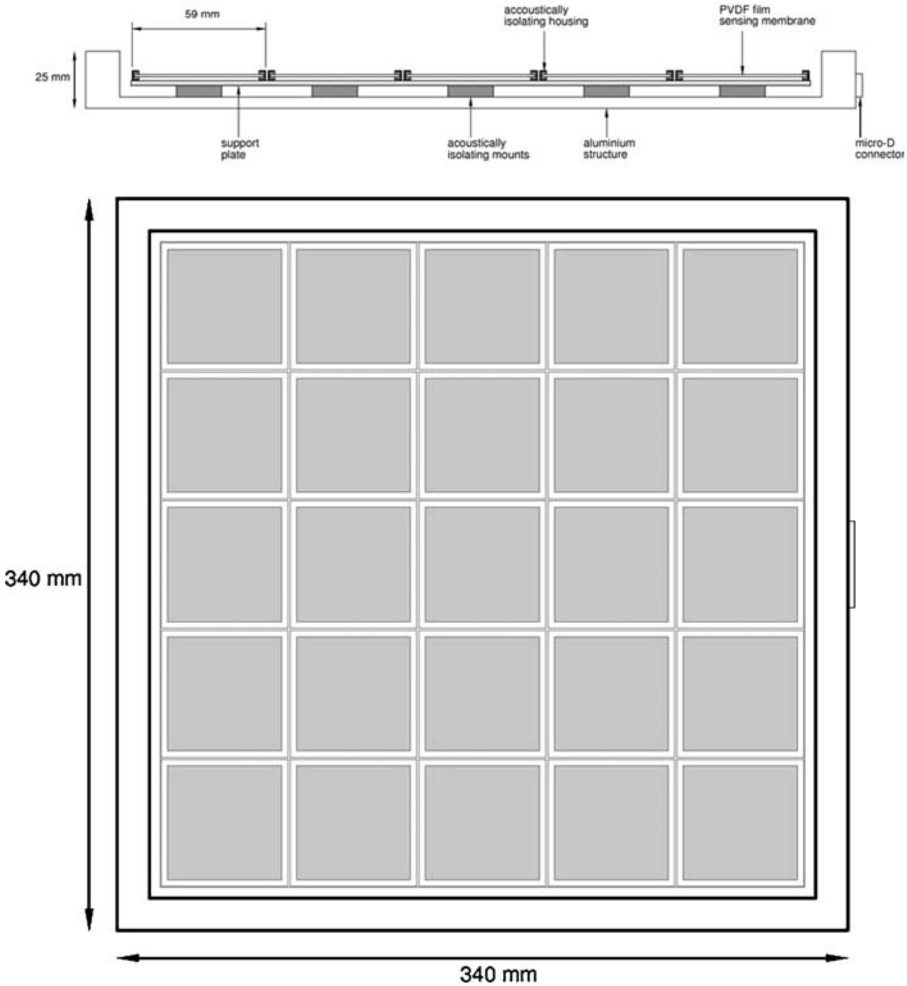

Fig. 5 Side and plan views of the PVDF dust detector. The trajectory sensor in front of the detector is not shown

PVDF foils have been developed into dust impact detectors (e.g. [48–50] and successfully flown on various missions: the DUCMA instruments on the Vega 1 and 2 Halley missions, the Dust Flux Monitor aboard the Stardust spacecraft [58], and the High Rate Detector instrument that is currently flying aboard Cassini as part of the Cassini Cosmic Dust Analyzer, CDA [54].

This instrument comprises 25 discrete (in a 5 × 5 array) PVDF film modules, each with approximate dimensions 6 × 6 cm (Fig. 5), mounted on a acoustically isolated plate. For maximum sensitivity, thin PVDF is used (6 μm thick with 70 nm thick conducting layers on both sides). The segmented detector (25 modules) also allows discrimination between impact sites.

3.5 Dust camera 2 (DC2)

In this instrument, an impact/momentum sensor (Dust Camera 2 – DC2) is placed behind the trajectory sensor. The impact/momentum sensor was developed for the GIADA instrument [11–13] onboard the Rosetta mission. The detection method is based on a metal diaphragm exposed to the impact of grains. The plate is equipped with piezoelectric sensors (PZT, e.g., lead zirconate titanate crystals); their number is adequate to have multiple measurements of a single impact, which give impact position and an intrinsic redundancy in the sensor.

DC2 for DuneXpress has a sensitive area of 0.1 m^2 that is achieved by integrating several parallel modules. The typical structure of one of its sub-modules is represented in Fig. 6. DC2 consists of 9 of these modules mounted behind a trajectory sensor.

The performances of several types of impact sensors have been checked in the past, both in laboratory and in space [18]. Tests have been performed with dust grains at different velocities (from 10 m/s to 20 km/s), sizes (up to some hundred μm) and composition (e.g., silicates, carbon). Referring to previous experiences made on

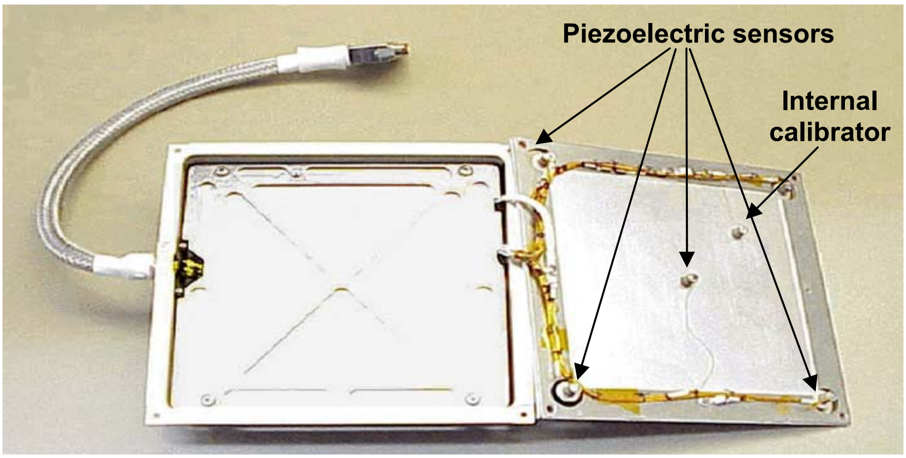

Fig. 6 An example of impact sensor with PZT's developed for GIADA. The system is open to show the positioning of the piezoelectric sensors below the aluminium sensing plate

specific configurations [11–13], a minimum momentum of 6.5×10^{-10} kg m s^{-1} can be detected.

3.6 Dust camera 3 (DC3)

This instrument utilizes the process of impact ionization, which occurs when a particle at hypervelocity impacts a target. In-situ data from such instruments have been obtained over several decades; e.g. detectors on Pioneers 8 and 9 [4, 60], HEOS-2 [30], Helios [23], Hiten [31]. The Galileo [24] and Ulysses [25] detectors have returned unprecedented data, and now, the Cassini CDA [54] offers a similar ionization detector, but with the capability to resolve time of flight mass spectra of impacting dust (e.g. [44]). Impact ionization techniques are thus reliable and well tested in space.

In this instrument, a particle impacts a flat target plate (at 0 V), and impact cations are accelerated towards an electrode grid (at −100 V). The total charge collection at this electrode is related to the particle mass and velocity (by $mv^{3.4}$). As velocity is independently determined by the trajectory sensor, the mass of the particle can thus be obtained.

The instrument comprises 25 sensing modules, each 9 × 9 cm, mounted in a 5 × 5 array similar to DC1.

3.7 The Aluminium Film Interplanetary Dust Detector (AFIDD)

The Aluminium Film Interplanetary Dust Detector (AFIDD) will detect hypervelocity impacts by nanometer scale dust particles at typical dust velocities. AFIDD's high sensitivity provides access to new populations of both interplanetary and interstellar dust, whose source bodies, dynamics and evolution differ significantly from those of larger particles.

A 10–100 nm Al film determines a penetration threshold for particles [21, 45]). The Al films are supported by the interchannel walls of a microchannel plate (MCP) detector and are freestanding over the open areas of the microchannels. Electrons

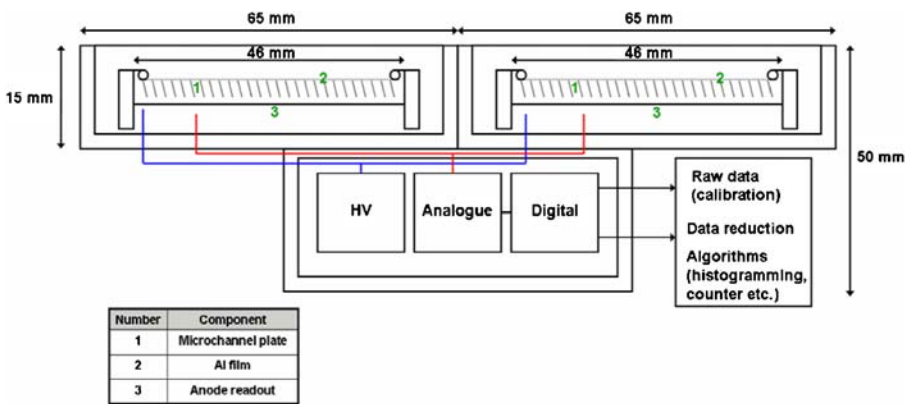

Fig. 7 Aluminium film interplanetary dust detector (AFIDD) architecture

in the plasma produced by a hypervelocity perforation induce an electron avalanche resulting in a detectable electron pulse.

Filmed MCPs exposed outside of the International Space Station (ISS) have been demonstrated as highly sensitive passive detectors of nanometer scale dust particles [9, 10]. AFIDD consists of four circular, MCP detectors bearing Al films with two thicknesses, 2 × 10 and 2 × 100 nm. Figure 7 shows the AFIDD architecture.

3.8 Plasma monitor – PLASMON

PLASMON [3] is a plasma monitor consisting of a magnetometer, an electrostatic plasma analyser and a Faraday cup (Fig. 8). All three sensors are integrated in the 300 g spherical PLASMON sensor. The sensors are controlled by a single DPU which serves as the interface to the spacecraft.

Using channeltrons in a counting mode, a small electrostatic plasma analyzer measures the electron and ion distribution in a wide energy range. Hemispherical deflection plates are used to analyze the energy distribution in 32 steps. Assuming a radial solar wind bulk velocity, all major plasma parameters such as electron and proton densities, temperatures, and proton bulk velocities can be derived.

The magnetic field is measured with a vector compensated ringcore fluxgate magnetometer. The resolution of the magnetometer is only restricted by the sensor noise (<5 pT $Hz^{-0.5}$ at 1 Hz). DC-magnetic fields generated by the spacecraft will be compensated internally by dedicated coils in-situ (i.e. pre-launch spacecraft calibration is not needed).

3.9 Common interface data unit (CIDU)

The redundant Common Interface Data Unit comprise the data interface between the platform bus and the seven instruments. The instrument data routing between the bus and the individual instruments is activated by a ground command to the CIDU. Each CIDU includes a mass memory of 4 GB to store instrument data until they are downloaded to the bus and transmitted to ground at 20 kbps. Data from instruments are regularly collected according a predefined scheme, which can be altered by command.

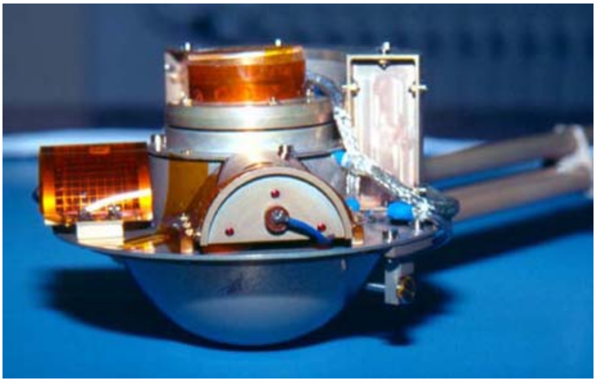

Fig. 8 The PLASMON sensor. The instruments consists of an ion analyzer, an electron analyzer, a Faraday cup, and a magnetometer

Table 1 Instrument characteristics

Instrument	DT1	DT2	DC1	DC2	DC3	AFIDD	PLASMON	CIDU
Sensitive area (m^2)	0.05	0.05	0.1	0.1	0.2	0.004	n.a.	n.a.
Detector	LAMA	LAMA	PVDF	Piezo crystals	Impact ionization	Al film, MCP	Plasma analyzers	n.a.
Mass (kg)	15	19	4.9	5.6	8	1	1.3	1.2
Volume[a,b] (cm^3)	44×49	48×48	$30 \times 30 \times 34$	$36 \times 36 \times 29$	$50 \times 50 \times 23$	$13 \times 13 \times 2$	$15 \times 15 \times 15$	$15 \times 11 \times 7$
Power (W)	16	25	8	< 30	9	2	1,5	3,5
Heritage	Giotto, Stardust, Cassini	Giotto, Stardust, Cassini	Cassini, VeGa, Stardust	Cassini, Rosetta	Cassini, HEOS-2, Galileo	Bepi Colombo, ISS	Rostta-Philae	ExoMars

n.a. Not applicable

[a]Volume: L × W × H or Diam. × H

[b]sensor dimensions

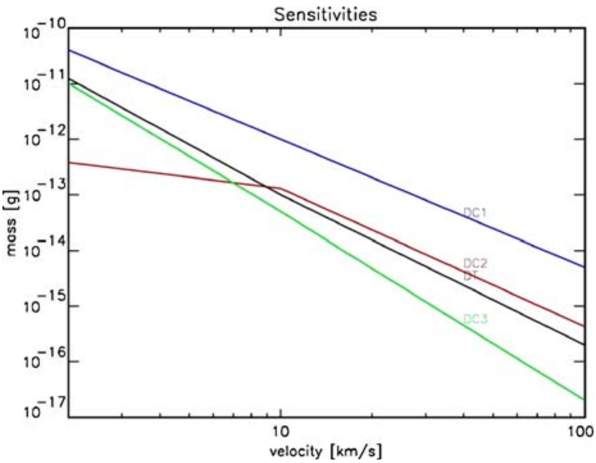

Fig. 9 Sensitivity ranges of various impact detectors used in DuneXpress

3.10 Summary instrument characteristics

The characteristics of the DuneXpress payload is summarized in Table 1. All dust instruments are co-aligned with the line of sight (LOS) in -x direction. PLASMON LOS in approx. sun direction (+*x*). DT1, DT2, and AFIDD have cover release mechanisms; PLASMON has a boom release mechanism. The sensitivity ranges of various impact detectors used in DuneXpress are displayed in Fig. 9.

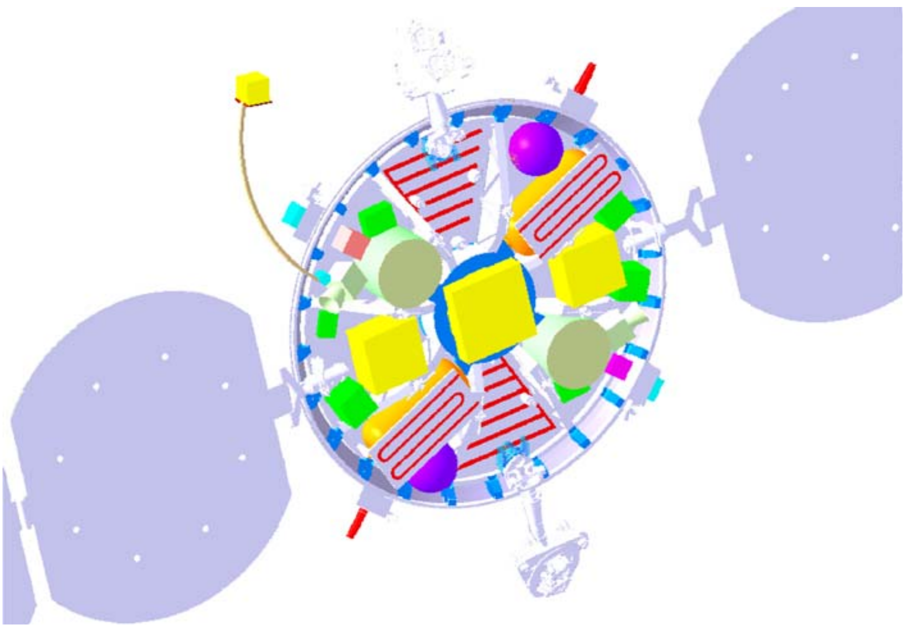

Fig. 10 DuneXpress spacecraft with instruments (*light and dark green*)

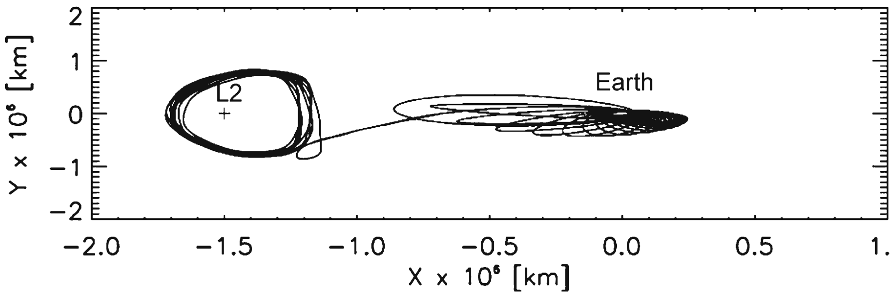

Fig. 11 Transfer trajectory and halo orbit around L2

4 Mission

The DuneXpress spacecraft is based on the ConeXpress platform developed by Dutch Space (Fig. 10). ConeXpress is a generic multi-mission platform for high orbit missions that makes use of an Ariane 5 adapter as its primary structure. Its electric propulsion system (216.5 kg Xenon propellant) will get DuneXpress to its orbit around the L2 point after insertion in GTO by Ariane 5. This platform will be adapted to meet the specific needs of the DuneXpress mission. The S/C mass is 1,200 kg, with two drivable wings of three panels each generating a power output of 4 kW. Communication is provided by an omnidirectional S-band and an X-band system that will use a 0.5 m parabolic antenna reflector. DuneXpress will be three-axis stabilised using star trackers as primary sensors and reaction wheels for actuation.

DuneXpress will be launched into GTO as an auxiliary payload of an Ariane 5 ECA flight. From there, (1) the perigee will be raised to 20,000 km, (2) the apogee will be brought to 1.5 million km, and (3) the spacecraft will be injected into a halo orbit around L2 where scientific operation will begin (Fig. 11). The spacecraft provides pointing of the dust telescope to better than one degree. The measurements will be divided into observation segments of fixed duration from a few days to about 4 weeks. Within a segment, the spacecraft will maintain a fixed orientation, while all instruments collect data simultaneously (staring mode). For a few days in between observational segments, data will be downloaded and new commands will be received. Within 2 years observation time 1,000 interstellar grains will be measured, 200 of which will be with high-resolution chemical analysis; also about three times more interplanetary particles will be analysed. The spacecraft will take sufficient fuel to enable scientific measurements of over 4 years.

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