

THE SKY IN DUST – METHODS AND PROSPECTS OF DUST ASTRONOMY. M. Landgraf, *ESA/ESOC, Robert-Bosch-Strasse 5, 64293 Darmstadt, Germany (Markus.Landgraf@esa.int)*, *LASP Boulder, CO, USA*, E. Grün, *HIGP Honolulu, HI, USA, MPI-K Heidelberg, Germany*, R. Srama, S. Helfert, S. Kempf, G. Moragas-Klostermeyer, M. Rachev, A. Srowig, *MPI-K Heidelberg, Germany*, S. Auer, *A&M Assoc., Basye, USA*, M. Horányi, Z. Sternovsky, *LASP Boulder, CO, USA*, D. Harris, *HIGP Honolulu, HI, USA*.

1 Introduction

Information about the make-up of the galaxy arrives in the Solar system in many forms: photons of different energies, classically collected by ground- and space-based telescopes, neutral and charged atomic particles, and solid macroscopic particles: cosmic dust particles. Dust particles, like photons, carry information from remote sites in space and time. This information can be analysed in order to understand the processes and mechanisms that are involved in the formation and evolution of solid matter in the galaxy. This approach is called “Dust Astronomy” which is carried out by means of a dust telescope on a dust observatory in space (Grün et al., 2005). The analysis of cosmic grains collected in the high atmosphere of the Earth has shown that each dust grain is a small world with various sub-grains featuring different galactic origin and evolution, which is identified on the basis of elementary and isotopic analysis (e.g. Bradley (2003)). Independent information about the origin and evolution of the grains coming from the kinematic properties of the arrival trajectory would be invaluable for linking the isotopic signature of the formation of heavy elements in old stars and supernovae to distinctive regions in our galaxy, e.g. known star-forming regions.

There are different types of dust particles in interplanetary space: dust from comets and asteroids and interstellar grains traversing the solar system. The most obvious sources of interplanetary dust are comets which move on eccentric orbits with a wide distribution of inclinations with respect to the ecliptic plane (Liou et al., 1999). The existence of distinctive low-inclination dust-bands (Dermott et al., 1984) shows that a significant fraction of meteoroids and dust grains in the zodiacal cloud have their origin in the asteroid belt.

We know from modelling (Liou et al., 1996) of the motion of dust in our solar system that a large mass fraction of it is expelled by close encounters with the giant planets. Also, the pressure exerted on sub-micron dust grains by solar radiation makes them leave the Solar System on hyperbolic trajectories after being released from the parent body. It can thus be safely assumed that the Solar System is a prolific source of interstellar dust. In analogy it is clear that other stars and solar systems form dust clouds around them as they move through the galaxy. When our Solar System moves through these clouds these extra-solar dust grains can be collected and analysed. It was one of the objectives of the Stardust mission (Brownlee et al., 1997) to collect interstellar dust embedded in the local interstellar cloud (LIC), which is known to exist from measurements by the Ulysses mission (Grün et al., 1993). Before a sample return of extra-solar dust from other sources can be attempted, the location and strength of sources must be identified. Here we propose the Cosmic Dune mission that is dedicated to characterise the interplanetary and interstellar

dust environment of the Solar System in terms of kinematic, elementary, and, to a limited extent, isotopic properties.

2 Dust Flux Distribution

In order to determine the streams of flux that cross a given point in the Solar System we can use the information collected by a host of in situ and ground-based measurements. Based on these measurements a meteoroid model (Dikarev et al., 2002) was implemented by the Max-Planck-Institut für Kernphysik under contract with the European Space Agency for operational use in the planning of interplanetary space missions. Here we use the same model in order to determine the dust flux distribution at a likely location of Cosmic Dune, the sun ward Lagrange point L_1 of the Earth-Sun system.

The ESA meteoroid model was set up based on data from lunar cratering record, in situ measurements by the Ulysses, Galileo, and Pioneer 10/11 space probes, and measurements of meteors in the Earth’s atmosphere by radar. In order to give the model predictive power outside the phase space where the measurements have been taken, the model invokes the canonical mechanisms of dust production, transportation, and destruction: mutual collisions of large objects, Poynting-Robertson drag, and grain-grain collisions. For more details see Dikarev et al. (2002). The model allows to predict the distribution of dust streams in the 7-dimensional phase space of mass, space, and velocity. We assume here that the measurements are performed at L_1 and that all grains with masses above 10^{-13} g are measured. This reduction of the phase space allows us to visualise the dust flux distribution as a sky-map.

The latter population is based mainly on data collected by the Ulysses spacecraft, which discovered (Grün et al., 1993) and characterised (Landgraf et al., 2000) the properties of the first known interstellar dust stream.

In addition to known dust sources, we can hope to discover new dust streams crossing the Solar System. It can be speculated that other solar systems expel dust like ours. Here we consider a much simplified picture of dust production by nearby stars. It is assumed that the dust is expelled in a radially symmetrical manner from a dust disk with thickness $\Delta\phi$ with an average velocity v as a result of equilibrium dust production by the disk with a constant rate \dot{N} . In this model each star carries along an infinitely expanding dust cloud through which our Sun moves due to the relative motion of the two stars, creating a mono-directional dust stream in our Solar System. The spatial density n of the extra-solar dust cloud is given by

$$n = \frac{\dot{N}}{2\pi r^2 v \Delta\phi}.$$

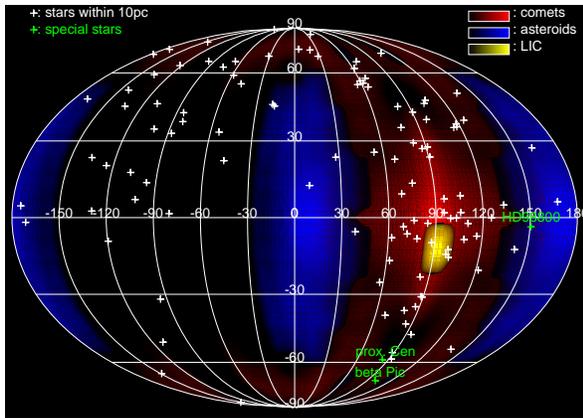


Figure 1: Distribution of dust sources on the sky for a spacecraft located at the L_1 Lagrangian point at the time of the spring equinox. The maximum flux level of grains bigger than 10^{-13} g from comets (red) is $70 \text{ m}^{-2} \text{ a}^{-1}$, for grains from asteroids (blue) $0.4 \text{ m}^{-2} \text{ a}^{-1}$, and from the LIC $600 \text{ m}^{-2} \text{ a}^{-1}$.

Assuming $r = 10 \text{ pc}$, $v = 10 \text{ km s}^{-1}$, $\Delta\phi = 20^\circ$, and $\dot{N} = 2 \times 10^{30} \text{ s}^{-1}$ (which corresponds to an equivalent $10^{-3} M_\oplus$ per year of 10^{-13} g-particles), we arrive at $n \approx 10^3 \text{ km}^{-3}$. At a typical relative velocity between stars of 10 km s^{-1} , this translates to a flux of approximately 300 particles per square metre and year. Knowing the positions and relative velocities of nearby stars, we can calculate the upstream directions of dust streams potentially coming from these stars. Figure 1 illustrates how interplanetary and interstellar dust sources are distributed over the sky.

3 Instrumentation

The instrumentation required to perform dust astronomy comprises devices for measuring the trajectory as well as the elementary and isotopic composition of cosmic dust grains. Such instrumentation is currently under development (Grün et al., 2005) or already available as flight hardware (Srama et al., 1999). We describe briefly the performance of a dedicated

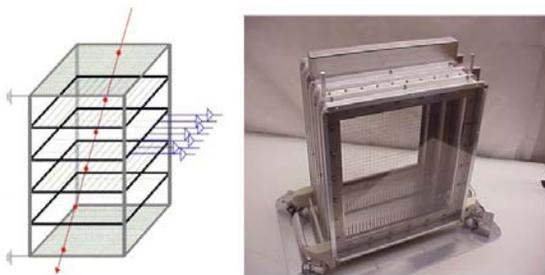


Figure 2: Schematics (left) and hardware (right) of the trajectory sensor. The charge signals induced by the passing dust grains are amplified and recorded for each of the wires in two pairs of grids oriented perpendicular to each other.

trajectory sensor and a large-area mass analyser (LAMA). Figure 2 shows the schematics of the trajectory sensor (Grün et al., 2005). 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^{-1} . First tests with a laboratory set-up have been performed and demonstrate the expected performance. An ASIC charge sensitive amplifier and an ASIC transient recorder have been developed with a RMS noise of about $1.5 \times 10^{-17} \text{ C}$. The principle of time-of-flight mass spectrometry is used to perform the elementary and isotopic analysis on the dust grains. The schematics of the instrument shown in figure 3 illustrate how ions generated upon impact are accelerated through the reflectron, where they are measured by a micro-channel plate. The time-resolved signal from the micro-channel plate produces the atomic mass spectrum when properly calibrated. The current lab models of LAMA achieve mass resolutions above 100, which is sufficient to characterise the elementary and isotopic composition of the most interesting constituents of cosmic dust grains.

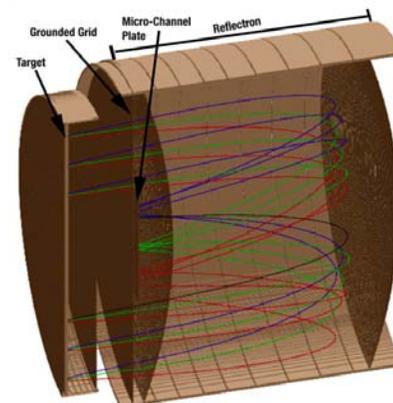


Figure 3: Cut-away schematics of the large-area mass analyser (for details see Grün et al. (2005)).

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