Interstellar dust simulations for the Stardust mission

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Introduction The Stardust mission was launched in 1996 and brought grains of comet 81P/Wild2 as well as interstellar dust (ISD) back to the Earth in 2006. The cometary grains were collected on one side of a dedicated collector during flyby, whereas the other side was exposed to the nominal ISD flux direction for two periods in 2000 and 2002 [1]. The collector size is 0.12 m^2 [1] and consists for 87% of aerogel tiles and 13% of aluminum foils. Up to now, 4 ISD candidates were found in the aerogel [2] and 4 candidates were found in the foils [3]. In this work, we simulate the ISD flux at Stardust in 2000 and 2002 and derive the impact velocity, flux and material constraints for the period and location of the Stardust sampling. We discuss the role of the interplanetary magnetic field and solar radiation pressure and review the simulation results in the context of the 4 ISD candidates found by Stardust.

Interstellar dust dynamics The motion of interstellar dust through the solar system is governed by solar gravity, solar radiation pressure force and Lorentz forces due to the motion of the charged interstellar grains through the interplanetary magnetic field. The latter depends on the solar wind magnetic field and therefore the flux of grains in the inner solar system is correlated to the solar cycle, with a “focusing” and “defocusing” of their trajectories towards the solar equatorial plane as a main effect. Since solar gravity and radiation pressure force both decrease quadratically with the distance to the Sun, it is common to combine both forces in one term, where the constant $\beta = \mathrm{F_{SRP}}/\mathrm{F_{grav}}$ determines the grains motion. For $\beta > 1$, the net force will be repulsive, and the grain will not be able to penetrate a conical region around the Sun (the β-cone). For $\beta < 1$ the grains will be focused downstream from the Sun by gravitational focusing. Grains with $\beta = 1$ fly in straight trajectories through the solar system. These grains are used as reference for the attitude pointing of Stardust during the capturing periods [1]. β depends mainly on material properties and grain size and is determined experimentally as well as derived from calculations [4]. The relationship between

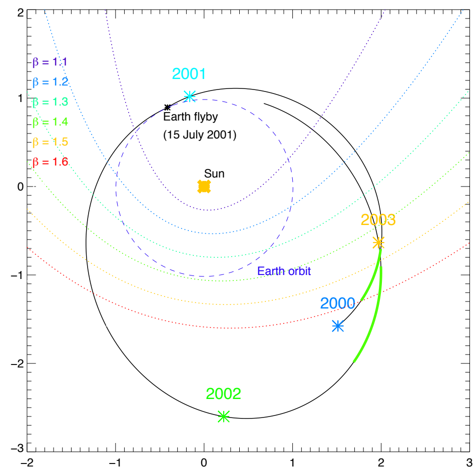

Figure 1: The orbit of Stardust and the two collection periods (in green), with respect to the β-cones.

β and grain size is drawn in a so-called *β-curve*, [5, Fig. 14]. The β-curve assumed in this study is for astronomical silicates [4], adapted to have a maximum of β = 1.6 to comply to the results of [6]. The initial ISD (upstream) direction in the simulations was $+8°$ ecliptic latitude and $259°$ ecliptic longitude and its initial speed was assumed 26 km/s [7].

Stardust collection periods The orbit and ISD collection periods of Stardust are shown in Fig. 1. Stardust was at the edge of the β-cone for $\beta \approx$ 1.5 – 1.6, only allowing the presence of very large carbon grains ($> 5 \cdot 10^{-16}$ kg) or large silicates ($> 10^{-16}$ kg). Besides, the grains with β-values close to the cut-off at β = 1.5 and 1.6, will be deflected in direction and become very slow. The capture period took place during the defocusing phase of the solar cycle, meaning that grains smaller than roughly 0.15 μm radius were filtered out of the solar system by Lorentz forces.

Results Fig. 2 shows the simulated ISD impact speed on Stardust depending on the grain size. Only solar radiation pressure force and gravity were taken into account since grains that are influenced by Lorentz forces are filtered out due to the defocusing phase of the solar cycle (hatched region in Fig. 2). During the capture period, Stardust moved at a speed of 12 – 16 km/s in the same direction of the ISD flow, leading to low capture velocities. This is good for keeping the grains intact during capture with aerogel. However, grains that have $\beta \approx 1.5 - 1.6$ become so slow that Stardust actually "overtakes" them; they may impact on the cometary side of the dust collector instead. This holds for the smallest grains that are not yet filtered by Lorentz forces. Where the velocity curve goes *up* with decreasing grain size in Fig. 2 is where the grains are slower than the spacecraft. As the smaller grains are more abundant than the larger ones, this is an important result for estimating the total number of grains we can expect in the Stardust collector.

Except for the beginning of the second collection period, most grains below 0.3 μm radius would impact on the cometary side of the collector or are filtered out by Lorentz forces. Grains between 0.25 and 0.4 μm radius have impact speeds between 4 and 14 km/s, grains between 0.4 and 0.7 μm have impact speeds between 10 and 20 km/s and grains larger than 0.7 μm have impact speeds between 14 and 25 km/s (assuming the β-curve for astronomical silicates with $\beta_{\max} = 1.6$, and the density of the grain 2 g/cm^3). Preliminary absolute predictions indicate a lower amount of captured grains on the ISD side of the collector than predicted in Landgraf et al. [8]. This corresponds well to the low number of ISD candidates identified so far [2]. Also the low impact velocities are confirmed by calibration measurements of the impacts using a van de Graaff accelerator in Heidelberg, where the relation between track size and morphology with grain velocity and diameter was established [9]. The origin of the four ISD candidates found in the aerogel (interstellar, interplanetary or spacecraft secondaries) is discussed in detail in [10].

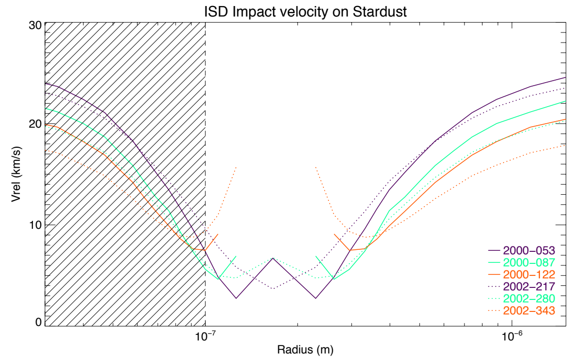

Figure 2: The impact velocity on Stardust as a function of grain size, for gravity and solar radiation pressure only and at 6 different days during the two capturing periods.

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