STATUS OF THE STARDUST ISPE AND THE ORIGIN OF FOUR INTERSTELLAR DUST CANDIDATES.
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Introduction: Some bulk properties of interstellar dust are known through infrared and X-ray observations of the interstellar medium. However, the properties of individual interstellar dust particles are largely unconstrained, so it is not known whether individual interstellar dust particles can be definitively distinguished from interplanetary dust particles in the Stardust Interstellar Dust Collector (SIDC) based only on chemical, mineralogical or isotopic analyses. It was therefore understood from the beginning of the Stardust Interstellar Preliminary Examination (ISPE) that identification of interstellar dust candidates would rest on three criteria – broad consistency with known extraterrestrial materials, inconsistency with an origin as secondary ejecta from impacts on the spacecraft, and consistency, in a statistical sense, of observed dynamical properties — that is, trajectory and capture speed — with an origin in the interstellar dust stream. Here we quantitatively test four interstellar dust candidates, reported previously [1], against these criteria.

ISPE summary: Stardust returned the first solid samples from a primitive solar system body, comet 81P/Wild2, and the first samples of contemporary interstellar dust. The SIDC was exposed to the interstellar dust stream for a total exposure factor of 20 $m^2 \cdot$day [2]. The ISPE is a consortium-based effort to characterize the collection using non-destructive techniques. The goals and restrictions of the ISPE are described in [3, 4, 5].

More than 30,000 volunteers have collectively conducted more than 80 million searches on slightly over one million fields of view as part of the Stardust@home distributed search. So far 72 tracks have been found using this technique, mostly consisting of secondary ejecta from the aft solar panels. 15 “midnight” tracks, consistent in trajectory with an origin in the interstellar dust stream, have been identified.

42 features have been extracted from the interstellar dust collector and analyzed using synchrotron X-ray and infrared microprobes. Of these, nine are midnight tracks. Of these nine, four impact features appear to be inconsistent with secondary ejecta from the spacecraft [1]. Three have chemistry or mineralogy inconsistent with the expected composition of the Sample Return Capsule (SRC) deck; the fourth was captured at a speed too high to be consistent with secondary ejecta.

Comparison of dynamical observations with IS dust propagation models: In Fig. 1, we show estimates of the observed zenith angles and capture speeds of the four candidates, and compare these with a Monte Carlo simulation of impacts of interstellar dust on the collector, integrated over the two collection periods and taking into account the articulation of the interstellar tray during exposures. The $\pm 15^\circ$ deadband of the spacecraft attitude control is taken into account in the confidence regions of the candidates. The capture speeds were estimated by comparing optical and Scanning Transmission X-ray Microscopy (STXM) imagery of the candidates to calibrations at known speeds done at Heidelberg [6]. The dispersion in zenith angle in the simulations is principally due to the changing orbital geometry during the two exposures. The dispersion in capture speed is principally due to varying values of β — here we assumed a uniform distribution in β from 0 to 1.6. Particles with $\beta > 1.6$ could not penetrate the heliosphere to the spacecraft position. (β is the ratio of light pressure force to gravitational force.) We find the best agreement with an interstellar dust stream radiant at galactic longitude $\sim 270^\circ$. This is consistent with Ulysses and Galileo measurements [7].

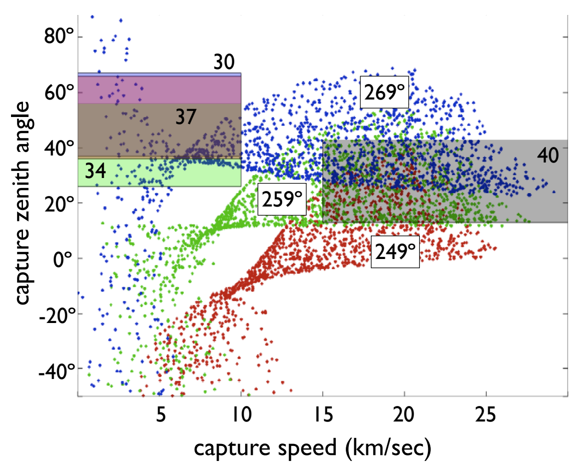

Fig. 1: A comparison of observed dynamical properties of four interstellar dust candidates with those of IS dust in a Monte Carlo simulation. Estimates of the dynamical properties of the four IS dust candidates are labelled 30, 34, 37, and 40. We simulated the trajectories for three ecliptic longitudes of the interstellar dust stream, 249° (red points), 259° (green points), and 269° (blue points).

Origin as secondary ejecta: It is fortunate that the three objects that subtend the largest solid angle in the “sky” of the SIDC — the two aft solar panels and the SRC deck — all contain materials that are readily recognizable in synchrotron X-ray microprobes, and which are rare at best in nature. The aft solar panels were covered with a Ce-rich glass, and the SRC deck consists primarily of Al metal. Al metal is easily recognized by STXM Al K-edge absorption spectral analysis. Nevertheless, secondary ejecta can also contain components of the original projectile [8]. Here we test the hypothesis of a secondary origin of all analyzed low-velocity midnight tracks by computing the statistical likelihood of finding the observed primary/secondary ratio. The ratio of crater diameter to projectile diameter is a measure of the primary/secondary ratio in ejecta. Price *et al.* [9] have measured crater sizes as a function of projectile size at 6 km/sec in aluminum targets. They find that the ratio of crater diameter to projectile diameter, k_d, is ∼4.5 for projectiles $>10\mu$m, but falls to ∼1.6 for projectiles $<3\mu$m, with a smooth transition between the two regimes. Integrating this over the IDP size spectrum [7], we find an average primary/secondary fraction in ejecta of 0.022. While this ratio could be larger for individual impactors, the trajectories of the low-velocity candidates are inconsistent with an origin in a single impactor. The statistical likelihood of finding three or more impactors consisting primarily of projectile material in this ensemble is 9×10^{-4}. Applying a correction for the higher average velocity (Fig. 2) of IDP projectiles gives a probability of 2×10^{-5}.

Track 40 displays a morphology that is most consistent with capture at $\geq$ 15 km/sec. While high-speed secondary ejecta have been observed in impacts of hypervelocity projectiles in the laboratory, they are a very small fraction of the total ejecta. This observation is confirmed by a simple estimate using conservation of energy: the average ejecta velocity for a 15 km/sec impactor, conservatively assuming complete conversion of projectile kinetic energy into ejecta kinetic energy, is ∼2 km/sec. Assuming a log-normal distribution of ejecta velocity, we find $\ll 10^{-4}$ of the ejecta mass emerging at >15 km/sec, over a wide range of widths in $\ln v$. This estimate is independent of projectile velocity in this velocity regime.

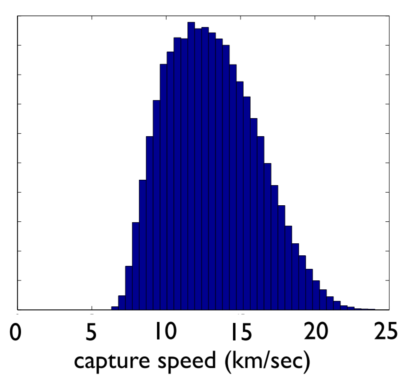

Fig. 2: Distribution of calculated interplanetary dust capture speeds.

Origin as primary interplanetary dust: Here we test the hypothesis of an interplanetary origin of the four candidates. We did a Monte Carlo simulation of the trajectories and capture speeds of interplanetary dust particles in the collector. We used the distributions of eccentricity and inclination derived by Nesvorný *et al.* [10], which fit the observed distribution of zodiacal infrared emission. In the distributions in Figs. 2 and 3, we assumed a uniform distribution of semi-major axes from 1-10 AU, but found that our results are insensitive to the choice of these limits. In Fig. 2, we show the computed distribution of capture speed. The median capture speed is 11 km/sec. In Fig. 3, we show the distribution of trajectories of interplanetary dust on the "sky" of the SIDC, as well as the observed trajectories of the four candidates. The two regions of the sky obscured by the aft solar panels are indicated. We find that 1.1% of the Monte Carlo events are found in the track 40 region, and 0.75% are found in the track 30, 34 and 37 region. The likelihood of all four candidates being primary interplanetary dust particles is thus $< 10^{-6}$.

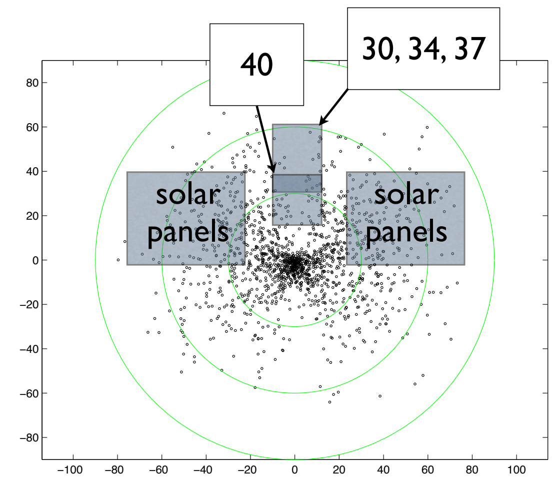

Fig. 3: Distribution of interplanetary dust trajectories, and observed trajectories of the four candidates. In this polar plot, the zenith angle is the radial coordinate, the azimuthal angle is the azimuthal coordinate.

Comparison with SRC deck material: Synchrotron-based X-ray and infrared microscopy of three of the four candidates shows the presence of materials that are unexpected in the SRC deck. (Track 40, discussed above, shows no detectable residue, and is inferred to have an interstellar origin for dynamical reasons only.) Nevertheless, we have been approved to collect samples of the SRC deck, on display at the Smithsonian Air & Space Museum in January 2012. Comparison of this material with the interstellar dust candidates will be reported at LPSC.

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