MODELING LARGE INTERSTELLAR DUST GRAIN IMPACTS IN SAMPLE RETURN MISSIONS. G. Domínguez, A. J. Westphal, *Space Sciences Laboratory, University of California at Berkeley, CA USA.*

1. Introduction

Observations by the Galileo and Ulysses missions (1) have established that interstellar dust from the local ISM enters the Solar System and that the largest of these grains penetrate into the inner solar system (2) . These observations provide much of the basis for what we know of the interstellar dust grains in the local Galactic environment.

Observations by the AMOR radar facilities strongly suggest that another source of extrasolar dust exists nearby, apparently in the direction of β-Pictoris (3,4).

Aerogel-based sample return missions, like Stardust, promise to provide new insights into the local population of interstellar dust grains. However, Stardust is expected to collect only a few large (>1μm) interstellar dust grains. Detailed characterization of the local interstellar dust will require that a large area ($\sim 3\mathrm{m}^2$) collector be deployed for an extended period of time. An economical way of achieving this is to deploy such an array in low-Earth orbit (LEO). However, the LEO environment is cluttered with anthropogenic debris, and thus extraterrestrial dust grains captured in aerogel arrays in LEO must be filtered from this background.

So-called "calorimetric" aerogels have been developed to address this issue. These doped aerogels are capable of passively collecting and recording the impact velocities of captured dust grains by means of a fluorescent signal. An added benefit of these aerogels is that the fluorescent spot can be used to identify the point of entry of a dust grain, something that is especially beneficial for small dust grains. The proposed eXtraterrestrial Particle Collector (XPC) mission would consist of a large array of these calorimetric aerogels.

In this Abstract we model the collection statistics of large interstellar dust grains by the XPC collector. An added bonus of this work is that the modeling can be readily applied to a variety of spacecraft, such as Stardust and Genesis. Therefore, we will present results on the number, size, and velocity distributions of large interstellar dust grain impacts into these missions as well.

2. Dust Grain Dynamics

Dust grains in the heliosphere are subject to gravitational, radiative, and magnetic forces from the Sun. Their trajectories, taking these forces into account, is given by the solution to the equation of motion:

$$\ddot{\vec{r}} = -\frac{GM_{\odot}(1-\beta)}{|r|^3}\vec{r} + \frac{Q}{m_g}\left(\dot{\vec{r}} - \vec{v}_{sw}\right) \times \vec{B}_{\odot} \quad (1)$$

Here Q is the charge on the dust grain, m_g is its mass, $\vec{v}_{sw}$ is the velocity of the solar wind, $M_{\odot}$ and $\vec{B}_{\odot}$ are the mass and magnetic fields of the Sun respectively. The parameter β is the ratio of radiation to gravitational force that the grain experiences. In general it is a function of the size and composition of the dust grain.

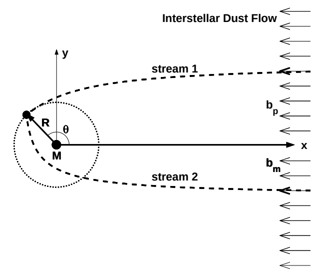

Figure 1: The trajectories of two dust grains with $\beta = 0$. Each point around the massive body can be reached by two distinct trajectories (stream 1 and stream 2).

For a given grain, the relative importance of the Lorentz component of acceleration compared to gravitation one is determined by the ratio $\frac{Q}{m_g}$, which in turn depends sensitively on the dust grain size. Detailed modeling by M. Landgraf (5) concluded that dust grains larger than 0.4 microns, the Lorentz component can be ignored, and that these dust grains follow essentially hyperbolic trajectories across the Solar System.

Analytic solutions to (1) can be found if the Lorentz term is neglected, since the solutions to the equation of motion are Keplerian, and extrasolar dust grains traverse the Solar System on purely hyperbolic trajectories. This simplification allows for the straightforward determination of the density and velocity of hyperbolic dust grains in the Solar System and therefore their collection statistics by sample return missions.

3. Methods

As shown by Landgraf et al. (6), the density of dust grains at the point (R,θ) is given by:

$$n(\mathrm{R}, \theta) = n_\infty \cdot \frac{b^2}{R\sin\theta\,|2b - R\sin\theta|} \quad (2)$$

where n_∞ is the concentration of dust grains far from the mass M and b is the impact parameter of the dust grain stream that intercepts the point (R,θ). The angle θ in this equation is the angle between the position vector of (R,θ) and the direction from which the dust grains come.

The effect of gravitational focusing is further enhanced by the fact that the point (R,θ) can be reached by two separate streams. This is illustrated in Figure 1.

The velocity, in the plane of the dust grain's motion, can be found using conservation of energy and angular momentum. However, unless the direction from which dust grains approach the Solar System is aligned with the ecliptic plane, a set of transformations must be derived in order to specify the dust

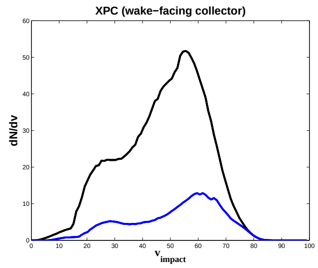

Figure 2: Velocity Distribution of dust grains collected by a wake facing XPC collector. Black=total; Blue=dust grains larger than 1 μm

grain velocities in the heliocentric frame.

These transformations can be represented as the product of three 3×3 matrices, each of which represent a rotation about one of the principal axes. For brevity, we do not present these matrices here, but instead point out that they can be found by specifying the angular momentum unit vector that intercepts the point (R,θ) in the ecliptic, when the initial approach direction was towards the unit vector given by $\hat{x}' = (\cos I \cos \omega)\hat{x} + (\cos I \sin \omega)\hat{y} + \sin I \hat{z}$.

An added benefit of this approach is that it allows us to treat the gravitational focusing of Earth's gravity in just the same way.

The flux of dust grains is given by:

$$\frac{dN(\mathrm{r},\theta)}{dt} = n(\mathrm{r},\theta)\,(\vec{v_{rel}}) \cdot \vec{A} \quad (3)$$

$$\frac{dN(\mathrm{r},\theta)}{dt} = n(\mathrm{r},\theta)\,(\vec{v_d} - \vec{v_s}) \cdot \vec{A} \quad (4)$$

Here n is the number density of dust grains at the collector's position, $\vec{v_d}$ is the velocity of the dust grains and $\vec{v_s}$ is the velocity of the spacecraft carrying the collector. The $\vec{A}$ specifies the collector's orientation. The details of these quantities, depend on the spacecraft's orbit and can therefore be applied to missions such as Stardust and Genesis.

We use the results of Kimura et. al (7) and assume that the cumulative number density of dust grains at infinity is given by:

$$N(\geq m_g) = Am^{-p} \quad (5)$$

where $log(A) \simeq -20.22$ and $p = 0.67$.

We estimated β of the interstellar dust grains using the following:

$$\beta(r_g) \simeq 0.8 \left(\frac{0.4\mu\mathrm{m}}{r_g}\right) \quad (6)$$

where r_g is the radius of the grains.

In our calculations, we assumed that the upstream direction of the IS dust is coincident with that of the interstellar neutral helium and is given by heliocentric longitude of 254.7 (± 1.3) $^\circ$ and a heliocentric latitude of $4.6(\pm 0.7)^\circ$ (6). We assumed that the velocity of these dust grains at infinity, v_{inf}, is equal to 25.6 km s^{-1}.

4. Results

Due to space considerations, we present the results of our XPC modeling (without Earth gravitational focusing) for a wake facing collector in LEO. Note that these results are presented per square meter of collector, flown for 3 years in LEO.

The methods discussed here allowed us to calculate the velocity, impact angle (inclination and azimuth), as well as the inherent biases introduced by the differential focusing of dust grains with differing values of β . To illustrate, we include a velocity distribution of the XPC collector in LEO in Figure 2.

5. Conclusion

Needless to say, detailed analysis of contemporary dust grains captured in aerogel based sample return missions provide us with new insights into the local IS dust cloud. An added benefit of aerogel-based collection is that the trajectory of an impact is recorded, thus providing the potential of studying and constraining the dynamical properties of interstellar dust grains even further, especially if the timing of the impacts can be determined by some other means.

Future work will include modeling predictions of extrasolar dust collection that originates from the β -Pictoris source.

References

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