

Search for the Signature of Interstellar Dust in the COBE Data

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Abstract. Impact data from the ULYSSES dust detector at 5 AU from the Sun have been interpreted as a flux of sub-micron interstellar dust particles (Grün et al, 1994) arriving from 252° ecliptic longitude and 2.5° ecliptic latitude. Following the motions of these particles under the influence of solar gravity, radiation pressure and electromagnetic forces, we present results from the modeling of the thermal emission from the resultant particle cloud, and conclude that the chances for the detection of such an interstellar signature in the COBE data are marginal at best.

1. Introduction

Results from the ULYSSES dust detector have recently been interpreted as a flux of sub-micron interstellar dust particles (Grün et al, 1994). Could the signature of such a source of particles be isolated from the COBE observations? This question can be addressed by knowledge of the distribution of these particles in the solar vicinity and subsequent modeling of the resultant thermal emission.

2. Gravitational focusing of large interstellar dust particles

The contribution of any large particles to the infrared emission is easiest to model; the motions of these particles, with a minimum radius of approximately 10 μm (Leinert & Grün, 1990) are dominated by the solar gravitational force. These particles have not been detected by ULYSSES; their abundance in the local interstellar medium (LISM) is unknown and is a matter for debate. The problem essentially reduces to that of Rutherford scattering. The particle trajectories are hyperbolic, and the gravitational focusing produces maximum density enhancement in the downstream direction, ecliptic longitude 72°. The distribution of particles can be determined by solving for the orbital elements of a given particle from initial position and velocity vectors at 'infinity', seeding this orbit with particles at equal time intervals, and repeating the process until the model provides a good representation of the 'real' cloud. The cloud has a relative speed

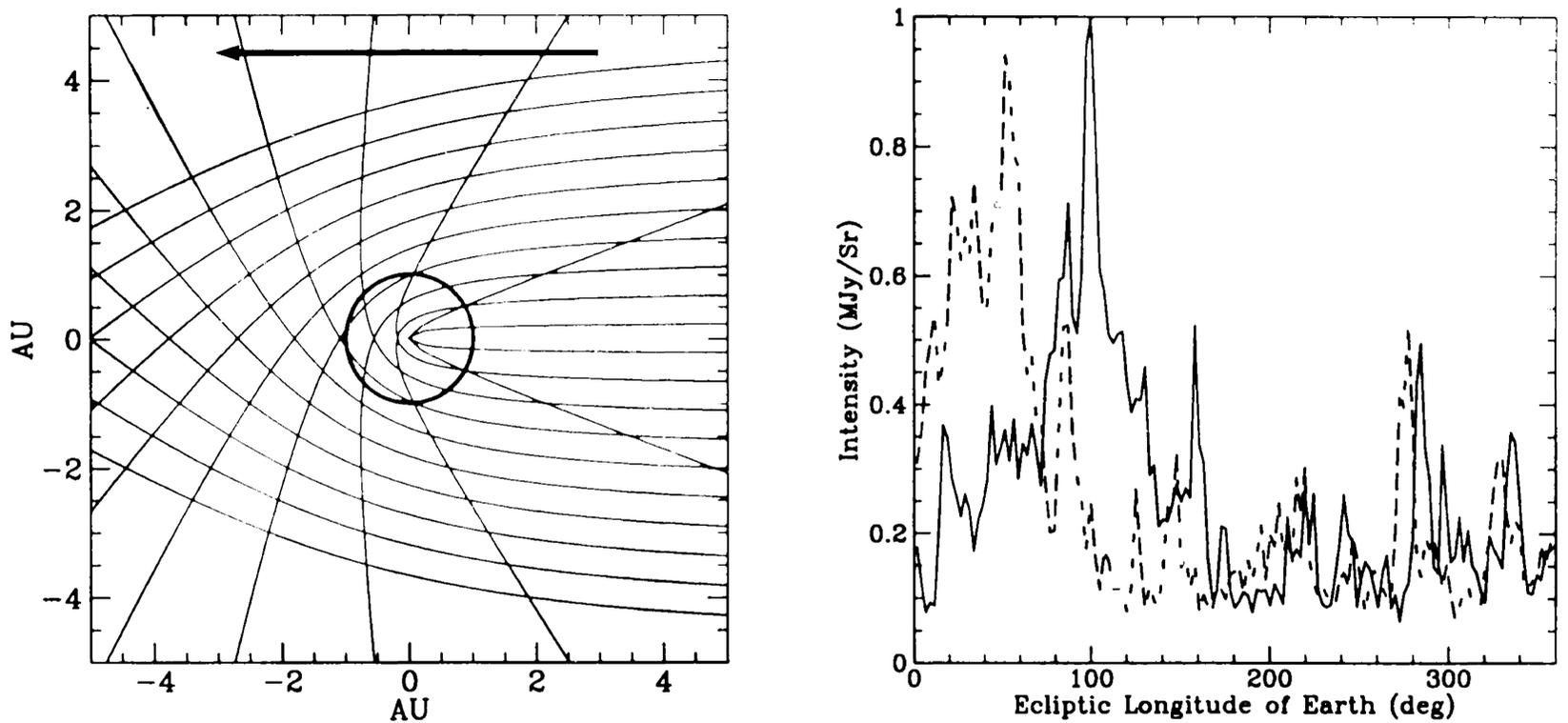


Figure 1. Left: the extent of the solar gravitational focusing assuming an incoming particle speed of 26 km/s. The circle centered on the origin represents the orbit of the Earth. Each curve represents the orbit of an individual particle, and the arrow emphasises that the downstream direction lies to the left. Right: the predicted variation of the 25 μm waveband in-ecliptic thermal emission measured at an elongation of 115° with ecliptic longitude of Earth in both the trailing (solid curve) and leading (dashed curve) directions.

with respect to the Sun of 26 km/s with a speed dispersion of 5 km/s (Grün et al, 1994).

Prediction of the expected signal in the observations can now be made by integration of the brightness along the line of sight in both the trailing/leading telescope pointing directions, corresponding to a telescope pointing direction opposite/along the direction of the Earth's motion around the Sun, assuming that blackbody approximations are reasonable for the particles under consideration. The predicted variation of the thermal emission with ecliptic longitude of Earth is shown in Figure 1. The signal peaks in the downstream direction, the direction of particle number density enhancement. The noise in this diagram arises from the limited number of particles in our model interstellar cloud, and the dispersion imposed on the cloud at infinity. We have no definitive knowledge of the number density of these large particles in the LISM which would lead to a calibration of the intensity scale; our approach has been to set the magnitude of the peak intensity to approximately 1 MJy/Sr assuming that an intensity of around this level is needed for a strong detection. This implies a surface area per unit volume of these large particles at infinity of $1.2 \cdot 10^{-23} \text{ cm}^2/\text{cm}^3$, or approximately 40% that for the small particles detected by ULYSSES. Although the abundance of large material in the LISM is unknown, it is clear that this large particle signature will be present in the observations only if the surface area per unit volume for the large material compares significantly in magnitude to the values generally accepted for sub-micron sized dust.

3. Sub-micron interstellar particles

Obtaining the distribution of the sub-micron particles detected by ULYSSES requires a more complex treatment: the effects of radiation pressure, the solar wind and electromagnetic forces have to be considered. Gustafson & Misconi

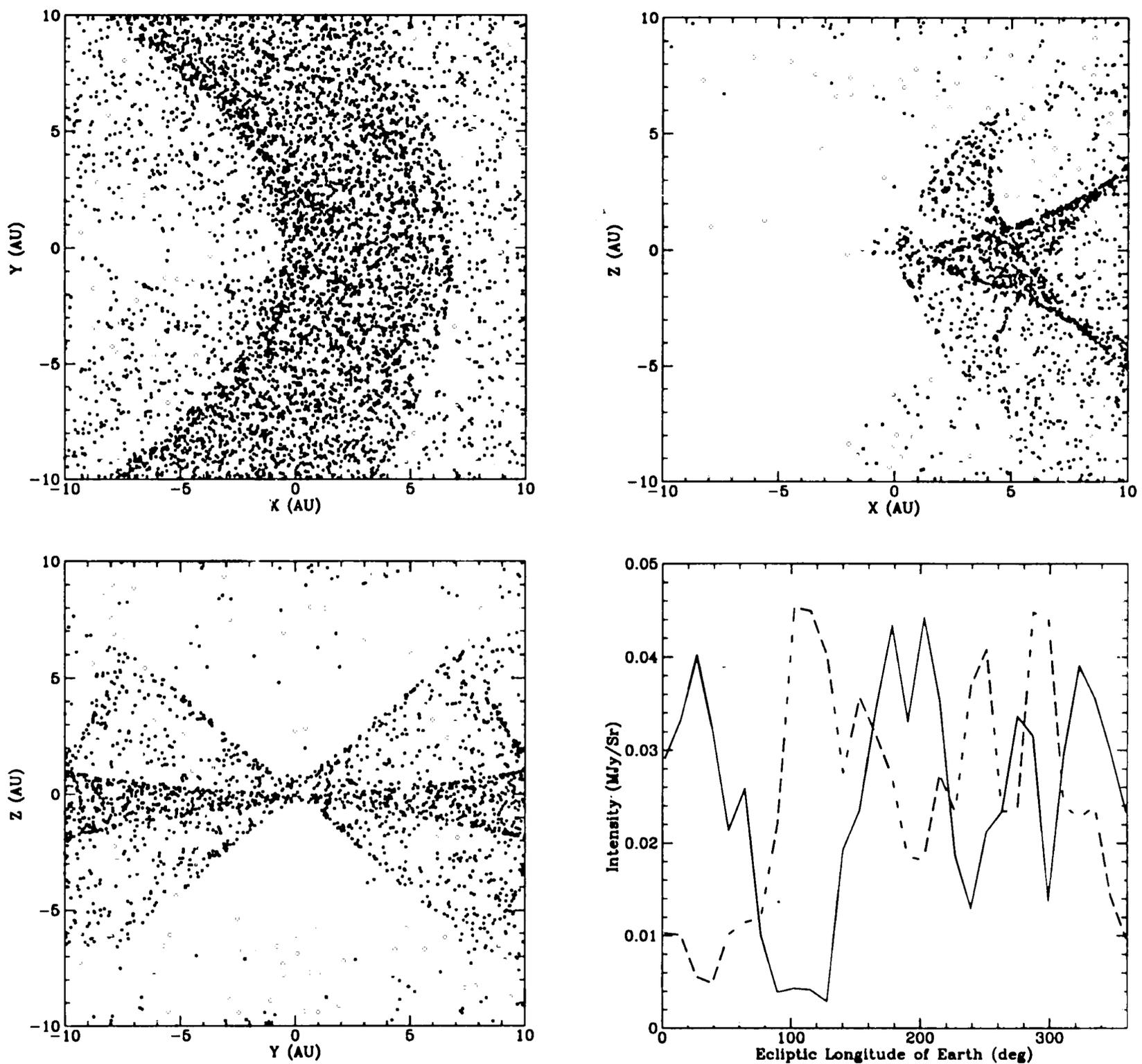


Figure 2. The inner Solar System distribution of $0.12 \mu\text{m}$ radius astronomical silicate particles ($\beta = 1.0$) centred on the Sun. Lower right: the predicted variation of the $12 \mu\text{m}$ waveband in-ecliptic thermal emission if it were measured at an elongation of 90° with ecliptic longitude of Earth in both the trailing (solid curve) and leading (dashed curve) directions.

(1979) address this situation, utilizing the expanding solar corona model of the solar magnetic field (Parker 1958). A clear finding is that even small grains with β (ratio of the radiation pressure force to the gravitational force) > 1 are able to penetrate deep into the Solar System. Three slices through the resultant particle distribution centred on the Sun are shown in Figure 2. The XY-plane is the ecliptic plane, X is positive in the upstream direction, ecliptic longitude

252°. The positive Z axis points north. The distribution of particles will depend on the 22-year solar magnetic field cycle, so that the particle positions will be indicative of a 'snapshot' in time rather than a representation of an equilibrium configuration. The positions in Figure 2 are calculated for the year 1990, corresponding with the time of the COBE observations. A characteristic feature is that particles are decelerated as they approach the Sun, producing a band of enhanced density as seen in the ecliptic, a funnel shape as particles are slowed down at high heliocentric latitudes and a rarefied zone beyond the Sun (as opposed to the enhancement beyond the Sun in the gravitationally dominated distribution discussed in section 2).

The particles have radii of $0.12 \mu\text{m}$, density 2.5 g/cm^3 , $\beta = 1.0$, and the composition and optical constants of 'astronomical silicate' (Draine & Lee, 1984). The particle density at infinity is set to $2 \cdot 10^{-27} \text{ g/cm}^3$ (Holzer 1989); Grün et al. (1994) report a value of $1.7 \cdot 10^{-27} \text{ g/cm}^3$ as measured at 5 AU by ULYSSES. These considerations are important for the purpose of estimating the thermal emission: blackbody approximations will be insufficient. The emissivity of the grains is found from Mie theory, and assuming thermodynamic equilibrium we obtain the variation of temperature of the grains with heliocentric distance. This information leads directly to the thermal emission at a given wavelength. The effects of electromagnetic forces are included as outlined in the above paragraph. COBE made photometric observations in ten wavebands; the thermal emission from our interstellar source will be greatest in the $12 \mu\text{m}$ waveband due to the strong silicate emission bands around 10 and $20 \mu\text{m}$. The predicted variation of the thermal emission in this waveband with ecliptic longitude of Earth, that would be measured at an elongation of 90° , is shown in Figure 2. The magnitude of the emission around the ecliptic plane falls mostly just short of 0.05 MJy/Sr , but drops considerably when the line of sight lies downstream, as expected from the distribution of particles shown in Figure 2. This level is at best borderline to the current techniques of isolating signals from discrete sources; the solar system dustbands are (easily) observable in the data at a level of 1 MJy/Sr above background (Low et al, 1984). These considerations serve to underline the importance of a more realistic model of the smooth zodiacal light background to facilitate detection of these trace signals.

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