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# ORIGIN AND EVOLUTION OF THE ZODIACAL DUST CLOUD.

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In recent years, the astrophysical importance of the zodiacal cloud has become more apparent. It has been proved by Brownlee and others that some particles collected in the Earth's upper atmosphere are extraterrestrial in origin. At the same time, progress in laboratory techniques has made chemical and mineralogical analyses of particles less than 10 $\mu$m possible. Thus, particles derived from the zodiacal cloud are now an important, and highly varied, source of extraterrestrial material. Unfortunately, the dominant source of these particles, whether asteroidal or cometary, is not known. It is hoped that the dust collectors (the Cosmic Dust Collection Facility) to be deployed on Space Station Freedom in the next decade will, for the first time, determine the orbits of captured particles and thus place direct constraints on their origins.

At present, the most useful source of information on the structure of the zodiacal cloud is the Infrared Astronomical Satellite (IRAS) observations in the 12, 25, 60, and 100 $\mu$m wavebands. During its all-sky survey in 1983, IRAS discovered three prominent bands of warm emission circling the sky at geocentric ecliptic latitudes of $-10$, 0, and $+10$ degrees. We pointed out (Dermott et al., 1984): (a) that the latitudes of these bands appear to coincide with the known latitudes of the three most prominent Hirayama asteroid families, that is, the Eos, Themis, and Koronis families, and (b) that the expected *equilibrium* number density of particles in the 10 to 100 $\mu$m size range associated with these families could be large enough to account for the IRAS observations.

We have now analysed a substantial fraction of the extensive IRAS data set. We have also developed a numerical model, the SIMUL model, that allows us to calculate the distribution of night-sky brightness that would be produced by any particular distribution of dust particle orbits. This model includes the effects of orbital perturbations by both the planets and solar radiation, it reproduces the exact viewing geometry of the IRAS telescope, and allows for the eccentricity of the Earth's orbit. The result is a model for the variation with ecliptic latitude of the brightness observed in a given waveband as the line of sight of the telescope sweeps through the modeled distribution of orbits at a constant elongation angle. We are now using SIMUL to model not just the solar system dust bands discovered by IRAS but the whole zodiacal cloud. This model is based on (a) the observed distribution of asteroidal orbits, (b) the calculated production rates of asteroidal dust, and (c) the calculated distributions of orbital elements of the dust particles after allowance for the secular perturbation of these orbits by the planets, light pressure, and Poynting-Robertson light drag.

Our main achievement this year has been the development of a new secular perturbation theory that describes the variations of the eccentricities, inclinations and semimajor axes of dust particle orbits and incorporates the effects of gravitational forces due to the planets and those due to solar radiation. In our previous work on the solar system dust bands (Dermott et al., 1984, 1985, 1986, 1988, 1989,), we described how the ecliptic latitudes of the peaks of the dustbands and the ecliptic latitude of the peak of the broad-scale zodiacal background should vary with the longitude of the Earth due to the forced inclinations imposed on the dust particle orbits by the planets. To calculate these forced orbital elements, we used the classical secular perturbation theory of Laplace and Lagrange. This theory is adequate for calculating variations in the orbital elements of the massive planets because the semimajor axes of these bodies are invariant. However, our calculations of the thermal properties of spherical silicate particles (Gustafson, 1991) have shown that particles in the 3 to 4 $\mu$m size range produce most of the thermal flux observed by IRAS in the 25 $\mu$m waveband. The orbits of particles as small as this decay due to Poynting-Robertson light drag on timescales of about 50,000 years and, thus, classical secular perturbation theory cannot be applied.

In our new theory (Gomes and Dermott, 1991), the classical concepts of forced and proper elements still hold good, but the magnitudes of the forced elements no longer depend on the semimajor axes of the dust particle orbits alone, they also depend on the drag rates of the particles and thus on their sizes and orbital histories. With this new theory, we have been able to:

1. Account for the observed inclination of the background zodiacal cloud.

2. Relate the distribution of orbital elements of asteroids in the Hirayama families to the observed shapes of the IRAS solar system dustbands.

3. Show that there is clear ***observational*** evidence in the IRAS data for the transport of dust particles from the asteroid belt to the Earth.

We now intend to determine the contribution of asteroidal collisions to the zodiacal cloud using the dust known to be associated with the Hirayama families as a calibrator. The ratio of the dust production rate associated with the prominent Hirayama families to that associated with the background asteroids will be modeled. By working with ratios, we will avoid the uncertainties inherent in specifying model dependent parameters (such as impact strength and energy partitioning) which strongly affect collisional outcomes. The observed ratio of the area of the dust associated with the families to that of the dust in the zodiacal background will be found by analysis of IRAS data. We will compare this ratio to the modeled ratio of family to background dust production rates and thus determine whether mutual asteroidal collisions alone are sufficient to supply the zodiacal background.