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Estimating the Asteroidal Component of the Zodiacal Cloud using the Earth's Resonant Ring.

Sumita Jayaraman and Stanley F. Dermott

The University of Florida Department of Astronomy, 211 Space Sciences Building, Gainesville, FL 32611-2055

Abstract. The Earth's resonant ring is populated primarily by asteroidal dust particles because cometary particles have higher Poynting-Robertson drag rates and the Earth's resonances are not strong enough to trap them (Gomes, 1995). It has been shown that asteroidal particles in a limited size range from $5 - 30\mu m$ are responsible for the observed trailing/leading flux asymmetry caused by the trailing dust cloud embedded in the ring (Jayaraman and Dermott 1995). The magnitude of the flux asymmetry is a direct function of the area of dust in the ring, which in turn depends upon the number of asteroidal particles in the zodiacal cloud. Using a dynamical model of the ring and the background zodiacal cloud and estimating the surface area of dust needed in the ring to match the observed flux asymmetry in the 25 micron COBE waveband, we have calculated the fraction of asteroidal dust in the zodiacal cloud as a function of p, the slope of the size-frequency distribution of particles.

1. Introduction

A physical model of the zodiacal cloud requires a complete understanding of the various source populations in the cloud. The main problem in achieving this objective arises from the measurements of the integrated flux from the zodiacal cloud along the entire line of sight and can be overcome by studying special features in the zodiacal cloud with known origin.

One such feature of the zodiacal cloud is the Earth's resonant ring that is formed by the trapping of dust particles on low eccentricity orbits into the Earth's outer mean motion resonances (Jackson and Zook, 1989, Dermott et al. 1994). The observational evidence for the ring, discovered in the IRAS data (Dermott *et al.*, 1994) and later confirmed by COBE (Reach *et al.*, Jayarman and Dermott, 1995a), is the flux asymmetry between the trailing (direction opposite to the Earth's orbital motion) and the leading direction. The flux asymmetry is caused by a dust cloud in the ring that corotates with the Earth. A detailed description of the structure of the ring can be found in Jayaraman and Dermott (1995b), henceforth referred to as JD. In this paper we concentrate upon the characteristics of the ring that allow us to estimate the asteroidal dust component of the zodiacal cloud.

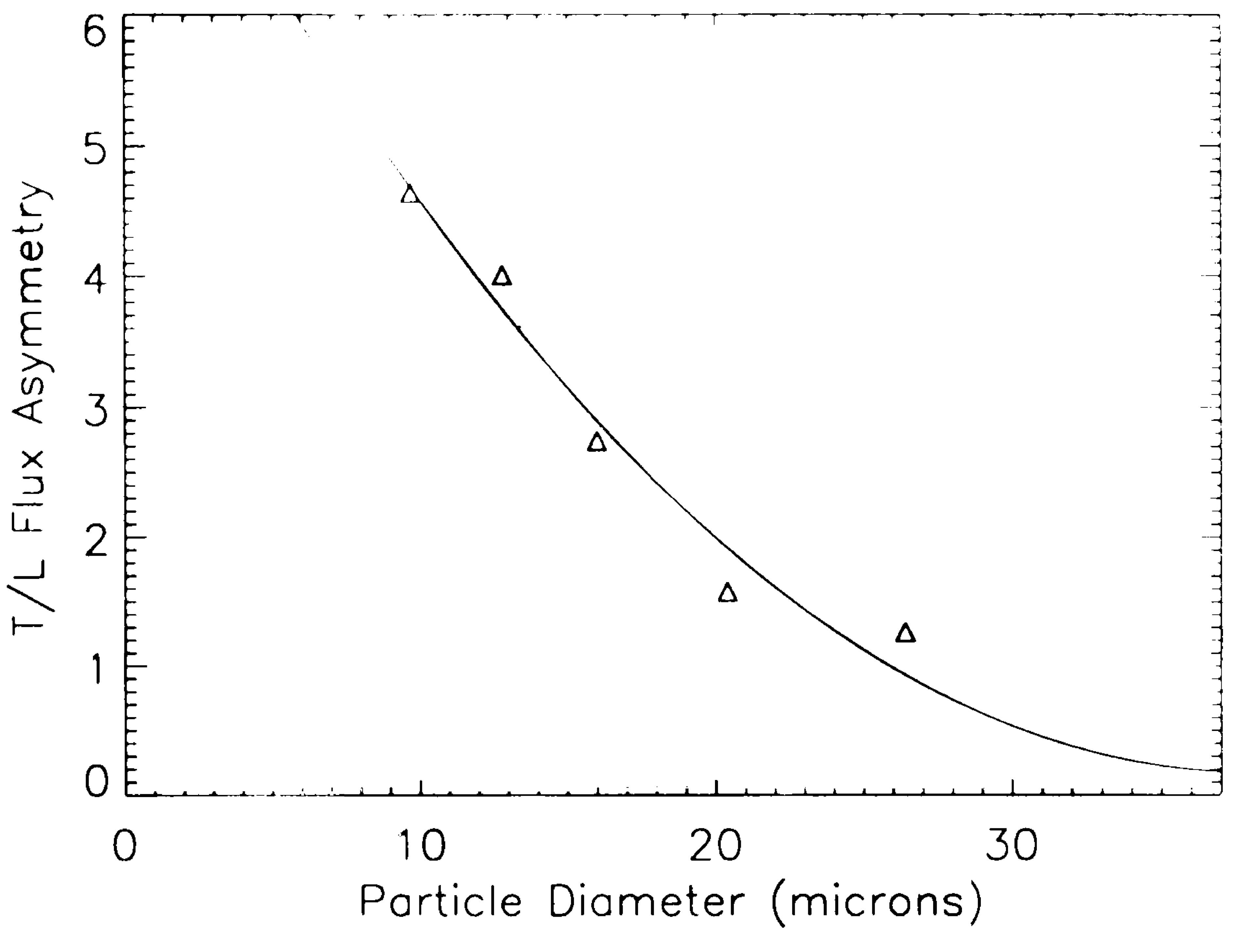

Figure 1. The trailing/leading flux asymmetry per unit surface area of dust in the ring as a function of particle size.

2. Characteristics of the Earth's Resonant Ring.

Micron sized dust particles in the solar system spiral in towards the sun under the influence of solar radiation forces (known as Poynting-Robertson or P-R drag) and solar wind forces and are trapped into the Earth's outer first order mean motion resonances. Resonant trapping causes an increase in the particle number density near 1 AU, forming a ring which extends from 0.8 to 1.4 AU in radius. Resonant trapping is probabilistic and a function of (a) the orbital elements of the particle when it encounters resonance, (b) the rate of orbital decay and (c) the strength of the resonance. For particles greater than $\approx 5\mu m$, the P-R drag is a function of the optical properties of the particle and increases with orbital eccentricity and lower size and density of the particles. For a weak drag force (adiabatic regime), the probability of trapping (Dermott et al., 1988, Malhotra 1988) is 1 for very low orbital eccentricities and falls off steeply for larger values. Gomes (1995) found that small particles ($s < 30\mu m$) have high non-adiabatic drag rates and require a minimum value of eccentricity for capture. In addition, for particles with $e > 0.3$, the trapping probability drops to less than 5% because the resonances are not strong enough to capture them. This favors an asteroidal origin for the trapped particles in the ring as most cometary particles have high eccentricities. It should be noted that cometary particles can also have low eccentricities, for example, if they are released inside a Jovian resonance in the asteroid belt their eccentricities decrease before they escape, (Liou, 1995) but we can assume that this component is negligible (JD).

In this paper, the asteroidal particles are made up of 'astronomical silicates' (Draine and Lee, 1984) with a density of $2.5g/cm^3$ and the corresponding drag rates have been calculated as a function of size (Gustafson, 1994). Numerical

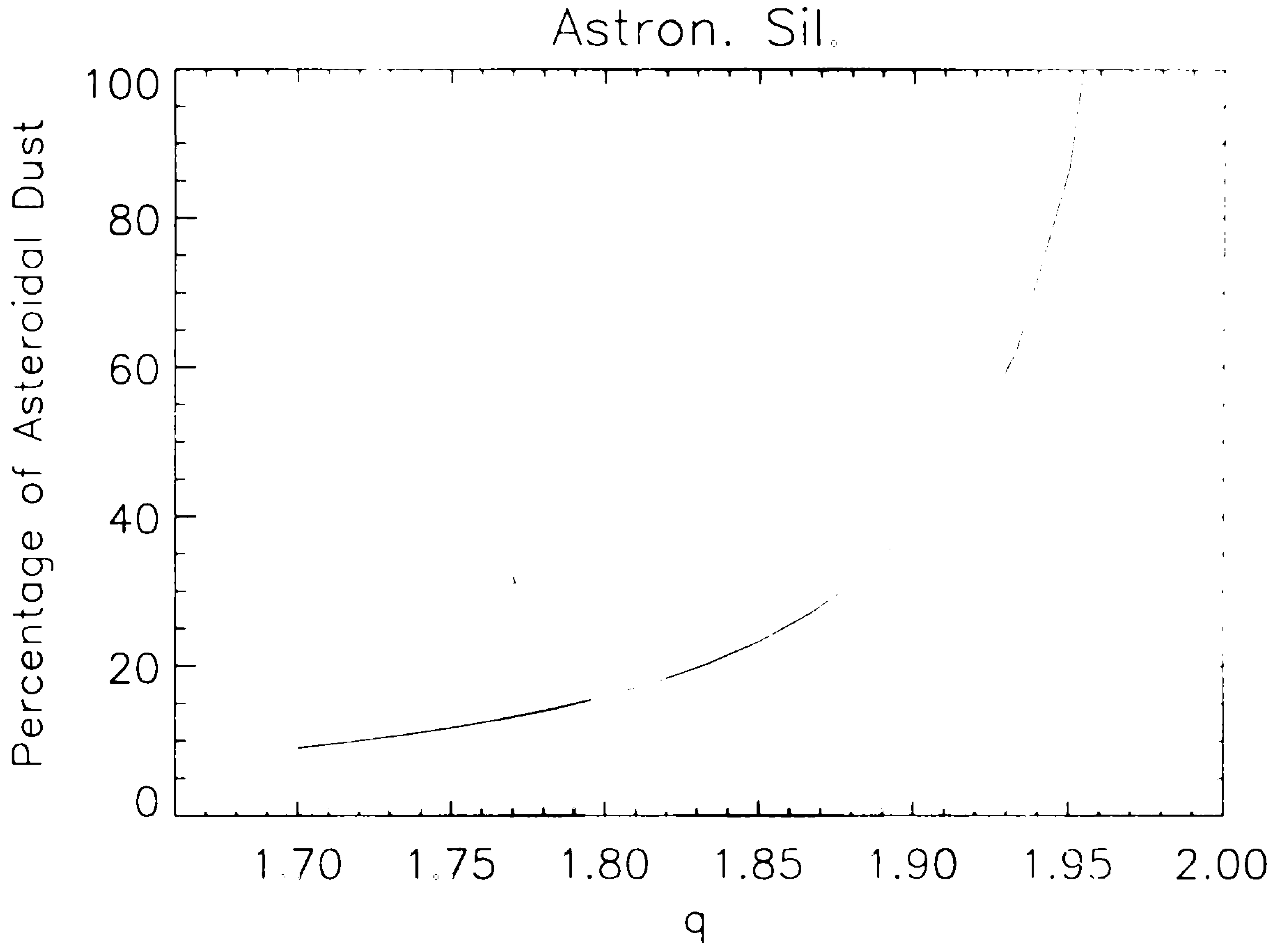

Figure 2. The estimated fraction of asteroidal dust in the zodiacal cloud as a function of q, the slope of the mass-frequency distribution.

integrations of the particle orbits and subsequently modeling has revealed the detailed structure of the ring with an embedded dut cloud that corotates with the Earth (JD). The dust cloud is formed due to orbital asymmetry in particles with high drag rates (small size). We have found that for particles greater than $\approx 30\mu m$ in diameter are trapped in the ring but do not contribute to the T/L flux asymmetry. On the other hand, the drag rate for particles less than $5\mu m$ in diameter is too high for the resonances to trap them. Thus, the particles in the ring, responsible for the observed T/L asymmetry, fall in the narrow size range of $5 - 30\mu m$. Applying all of the above properties of the ring we have developed three dimensional models for six particle sizes - $9, 12, 15, 19, 25$ and $36\mu m$. We have found the flux asymmetry produced per unit area of dust in the ring (F_{TL} in $MJy/Sr/m^2$) as a function of size which can be represented as a second order polynomial in the critical size range of $5 - 30\mu m$.

The total area of dust in the ring is a direct funtion of the asteroidal dust in the background cloud. Let the size-frequency distribution of asteroidal particles in the zodiacal cloud, less than a diameter of $100\mu m$, be given by the following power law.

$$N = CD^{-p}, \tag{1}$$

where N is the cumulative number of particles greater than diameter D and the slope $p = 2.5$ (Durda 1994) (For a mass-frequency distribution the slope denoted as q, such that $p = 3(q - 1)$). The fraction of background particles trapped in the ring as a function of size, (f_R), can then be calculated from the capture probability and trapping lifetime of the particles (JD). Therefore, for an area of dust in background dA between sizes s and $s + ds$, the the asymmetry can be written as,

$$dF = F_{TL} f_R dA(s) \tag{2}$$

The total observed flux asymmetry in any given waveband is

$$F_{obs} = \int_{s_0}^{s_1} F_{TL} f_R dA(s) \tag{3}$$

because F_{TL} is zero for $s > s_0$ and f_R is zero for $s < s_1$, where $s_0 = 5\mu m$ and $s_1 = 30\mu m$. Substituting the measured value of the F_{obs} of $\approx 2MJy/Sr$ from the COBE observations in the $25\mu m$ waveband, we calculate the total surface area associated with asteroidal dust in the zodiacal cloud as predicted by the resonance ring. Now we can determine the peak flux corresponding to this estimated area by using a dynamical model of the zodiacal cloud. The model is made up of asteroidal particles distributed between the the main belt (3AU) and the Sun, with a spatial number density inversely proportional to the distance from the sun. The ratio of the predicted model flux to the observed peak flux from COBE gives an estimate of the asteroidal component of the cloud, shown in Figure 2 as a function of q, slope of the mass-frequency distribution. We find that the calculated fraction of asteroidal dust in the zodaical cloud is very sensitive to the value of 'p' (or 'q') and can range from 10 to 100This result is not as open as it seems because applying additional observational constraints, namely, the model should also match the flux asymmetry in other wavebands and yield the observed flux in the zodiacal dust bands, will narrow the possible fraction of asteroidal dust in the zodiacal cloud.

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