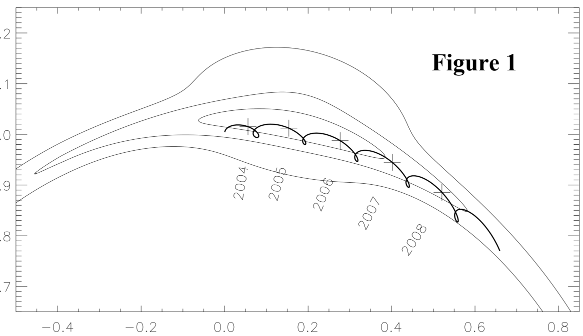
STRUCTURE OF THE ZODIACAL CLOUD ALONG THE EARTH'S ORBIT. W. T. Reach[1], [1]California Institute of Technology (MS 220-6, Pasadena, CA 91125, email:reach@ipac.caltech.edu).

Introduction: The *Spitzer* Space Telescope in its Earth-trailing solar orbit [1] provides a unique and valuable tool to measure the structure of the interplanetary dust cloud. Azimuthal structure was first seen in IRAS data as an "anisotropy of the zodiacal emission [that] followed the Earth during the IRAS mission" [2]. Numerical modeling showed that particles spiraling toward the Sun under the influence of Poynting-Robertson drag can be trapped in external mean motion resonances, and an overdensity develops in a circumsolar ring with a significant enhancement trailing the Earth [3]. The predicted enhancement was confirmed by the *COBE* satellite, whose Diffuse Infrared Background Experiment (DIRBE) provided accurate, stable surface brightness measurements [4,5].

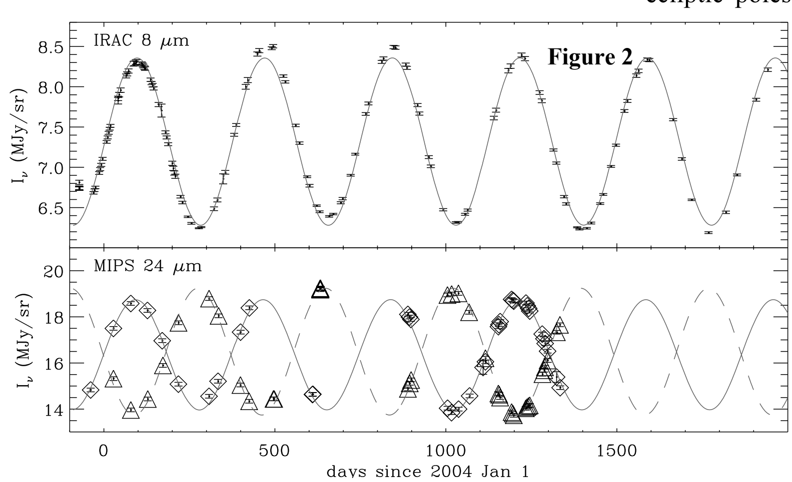
The presence of azumuthal asymmetries in debris disks around other stars is considered strong evidence for planets, and the surface area (and hence detectable brightness) of the dust feature can even exceed that of the planet. By constraining the properties of the Earth's resonant ring, we can provide "ground truth" to models for interactions of planets and debris disks, possibly leading to improved predictions for detectability of life-bearing planets.

Observations: The spacecraft drifts further from Earth, approximately 0.1 AU each year. **Figure 1** shows the trajectory of Spitzer in an Earth-comoving frame. A model for the density of dust in the Earth's circumsolar resonant dust ring is shown for comparison. The model is based on the numerical simulations and fitted to the *COBE*/DIRBE data; it includes a radially Gaussian ring plus an elliptical Gaussian "trailing blob" [6]. *Spitzer* has traveled through the modeled location of the "trailing blob" and should now have emerged from the other side.



Sky brightness observations at 8 μm were made using the Sky Dark calibration sequences during each observing campaign of the Infrared Array Camera (IRAC) [7]. The brightness of a patch near the North ecliptic pole was observed at a range of exposure times [8]; we use the longest (50 sec) exposures at 8 μm. The IRAC arrays are exceptionally stable [9]. Absolute brightness calibration is relative to the cold shutter inside IRAC, which was operated before launch during laboratory testing (but not during the mission). The observations span 2003 Sep 30 to 2009 Apr 25.

Absolute sky brightness measurements at 24 μm were made using the Total Power Mode of the Multiband Infrared Photometer for *Spitzer* (MIPS) [10]. The observing sequences were part of a multiple programs, beginning with the In-Orbit Checkout, then a set of proposals led by S. Jayaraman. The observations span 2003 Nov 23 through 2007 Aug 27. A range of lines of sight through the zodiacal cloud was observed; in this work we analyze only the North and South ecliptic poles. The observations before 2004 Dec 1 used the observing sequence before commissioning, and they yielded brightnesses 43% higher than the later data; we rescaled the pre-commissioned data.



Analysis: **Figure 2** shows the brightness of the ecliptic poles measured *Spitzer*. The annual variation in polar brightness is due to three effects: the tilt of the zodiacal cloud with respect to the Earth's orbit, the eccentricity of *Spitzer's* orbit, and the mean eccentricity of dust particle orbits near 1 AU. To improve upon the zodiacal cloud model, we use empirical methods to search for deviations from annual symmetry. Figure 2 includes a sinusoidal fit to the data. The fits are reasonably good at 24 μm (reduced χ^2=2.9), but there are highly significant deviations at 8 μm (reduced χ^2=36).

Results: Figure 3 shows the residuals from the sinusoidal fits. The scatter in the 24 μm residuals is large, but the pattern at 8 μm is highly significant. To quantify the properties of the overdensity trailing the Earth, we fitted the sinusoidal-fit residuals using Gaussians; Table 1 summarizes the results and the DIRBE model parameters [6].

	DIRBE Model	**MIPS 24μm**	**IRAC 8μm**
Dist. to trailing blob (AU)	0.17	0.14±.03	0.20±.03
Width (AU)	0.21±.06	0.12±.04	0.08±.01

These fits can only give approximate constraints on the properties of the circumsolar ring, since part of the signal has been absorbed into the sinusoidal fit, and the spacecraft travels both vertically and radially with respect to the dust distribution. To validate the sinusoidal fitting approach, we predicted the zodiacal light brightness using the full DIRBE model [8], including a smooth cloud, dust bands, and a circumsolar ring Gaussian in distance from Sun and distance from midplane, with an elliptical Gaussian profile in cylindrical coordinates. All components are inclined from the ecliptic and slightly offset from the Sun. The model parameters were determined from a fit to the temporal variation of the sky observed by DIRBE over 1.25-240 μm wavelength.

The model was analyzed in the same manner as the observations (i.e. evaluated from the location of *Spitzer* and fitted with a sinusoid). The dotted curve in the upper panel of Figure 3 shows the residuals from a sinusoidal fit to the model (divided by 2 for display purposes). The pattern of the residuals is as expected, based on the parameters of the "trailing blob" which is very wide in the model (including Earth within its FWHM, see Figure 1). The oscillations in the model residuals are real; they are the combined effects of inclination and eccentricity of all the model components. The same model, but with the resonant dust removed, was treated the same way, yielding the dashed curve in Figure 3. As expected, the "no ring" model is relatively constant along *Spitzer's* trajectory.

Conclusions: The Earth's circumsolar resonant dust ring is azimuthally asymmetric, as predicted by models for the evolution of dust spiraling inward under the influence of Poynting-Robertson drag. The *Spitzer* results confirm the ring's trailing anisotropy that had been found in *COBE*/DIRBE data, but the unique vantage point of *Spitzer* as it drifted through the trailing anisotropy allows a much-improved constraint on its shape. The width of the trailing anisotropy was poorly constrained by Earth-based observations, which measure the integrated brightness along the line of sight. The new results imply a density enhancement 0.2 AU behind Earth with a width (dispersion) of 0.08 AU.

There may be some substructure in the trailing anisotropy. In particular there is a prominent peak at 0.14±.01 AU behind Earth, with a width of 0.013±.001 AU. The peak could be due to a relatively stable resonance, but modeling 3-dimensional modeling is required to determine whether it could be a radial, vertical, or azimuthal feature.

The ability of spacecraft traveling far from Earth to probe the content and structure of the interplanetary dust cloud makes them of vital importance for understanding and predicting the effects of planets on debris disks. Future observations from a spaceprobe traveling to the outer solar system will be able to search for resonant rings in the orbits of Mars (asteroidal dust) and Jupiter (cometary dust) and Saturn (Kuiper Belt dust).

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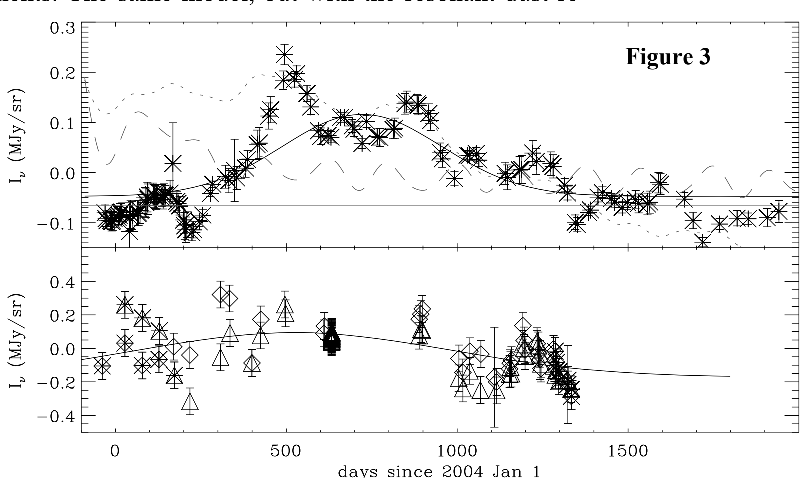

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