The potential of exozodiacal disk clumps to confound the search for terrestrial planets

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Introduction

Most, if not all, of the debris disks that have been imaged to date, including our own zodiacal cloud, exhibit clumps in the structure of their dust disks. It is important to try to quantify the number and brightness of clumps expected in an exozodiacal disk, since their emission could be misconstrued as that of a terrestrial planet. This paper briefly describes two of the mechanisms that cause the zodiacal cloud to be clumpy — collisions in the asteroid belt and the trapping of dust into resonances with the Earth — and discusses the effect this clumpiness would have on the ability of a TPF/DARWIN-like mission to detect an Earth-like planet if looking at a solar system analogue from 10 pc. We consider for reference the mission design of Mennesson & Mariotti (1997, Icarus, 128, 202; MM97) which showed how interferometry at 10 μm with a beam size of 0.06 arcsec could be used to null the emission from both the Sun as well as that of a smooth zodiacal cloud component, thus revealing the much lower level (0.3 μJy at 10 pc) point-like emission from the Earth.

Collisional Clumps

When two large asteroids collide, a significant amount of dust is released. This dust starts off in a small clump which then slowly disperses into the background cloud by spreading along the orbit of the parent asteroid. As collisions are always happening in the asteroid belt at some level, then at any one time we expect the region 2–3.5 AU from the Sun to exhibit clumps with a distribution of both fluxes and spatial sizes. Using a model of the outcome of collisions (Wyatt & Dent, in prep.), it can be shown that a clump with the same 10 μm flux as the Earth is most likely to be produced by the break-up of a 9 km diameter asteroid when impacted by one 900 m in size. Since it would take such a clump $\sim$ 600 years to spread 360° around the orbit of the parent asteroid, and this magnitude of collision occurs every 2,000 years in the asteroid belt, the chance of observing an Earth-like clump which is $< 10°$ in azimuthal extent (i.e., unresolved from 10 pc in a 0.06 arcsec beam) is 1:100.

Fig. 1a shows the magnitude of the brightest unresolved collisional clump we would expect to see in the asteroid belt with a given beam size from 10 pc; e.g., the brightest clump we expect to see that is unresolved in a 0.06 arcsec beam would be some ten times fainter than the Earth. However Fig. 1a also shows that the same clump in an extra-solar asteroid belt that is ten times more massive than our own would be expected to have a flux equal to that of the Earth. Such collisional clumps would provide confusion in a search for terrestrial planets, since they would be indistinguishable from planets without further study of their emission spectrum. To ascertain the extent of this confusion in real extra-solar systems we would need to know the locations and masses of their asteroid belts. Information about these should become available in the coming years through studying the systems' exozodiacal emission using both ground based nulling interferometry (e.g., VLTI and Keck) and space based coronography (e.g., NGST).

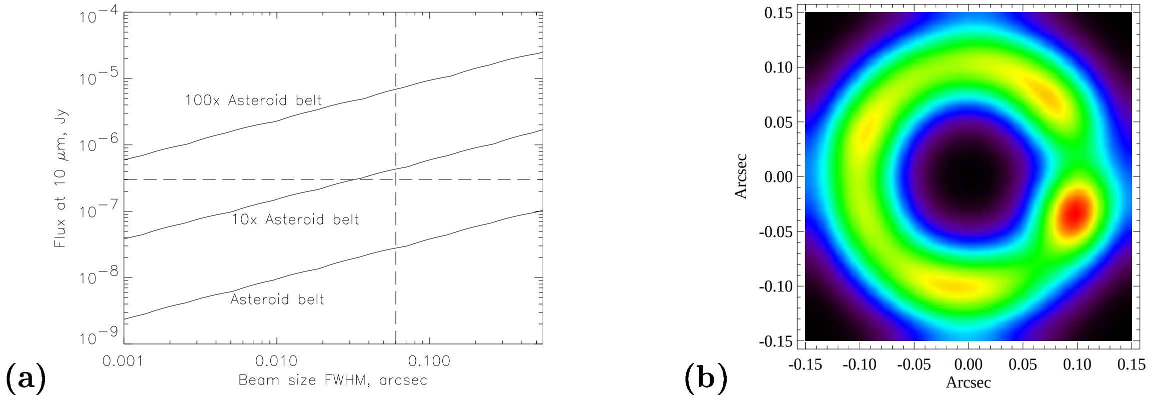

Figure 1: Dust clumps in the zodiacal cloud when viewed from 10 pc: **(a)** Model showing the brightest unresolved clump we expect to see from collisions between asteroids in the asteroid belt. The horizontal dashed line indicates the flux of the Earth, and the vertical dashed line indicates the MM97 beam size. **(b)** Model of the Earth's resonant ring (Dermott et al. 1994, Nature, 369, 719) viewed face-on with a 0.06 arcsec beam. The Earth's emission, not shown on this image, would be at [+0.1,0] arcsec, and would be 10–20 times brighter than that of the trailing cloud just below it.

Resonant Ring Clumps

Once dust created in collisions in the asteroid belt is small enough, < 1 cm, it spirals in toward the Sun due to Poynting-Robertson (P-R) drag. As this dust approaches the Earth it encounters the Earth's numerous mean motion resonances. These are locations where the orbital period of the dust in years is a ratio of two integers. This means that the dust receives periodic kicks from the gravitational perturbations of the Earth, which can halt the migration of the dust causing it to become trapped in the resonance. This results in an enhanced density of material at 1 AU — the *Earth's resonant ring* (Dermott et al. 1994, Nature, 369, 719). When plotted in a frame co-rotating with the Earth these resonant orbits are not axisymmetric but show loops, causing the ring to be clumpy. In addition, P-R drag introduces an asymmetry which means that all resonances have a loop located just behind the Earth. This means that the most prominent feature of the ring is a large clump that follows in the Earth's wake — the *trailing cloud*.

Fig. 1b shows a model of the resonant ring as viewed from 10 pc with a 0.06 arcsec beam. The Earth's resonant ring would not have any impact on our ability to detect the Earth, since the trailing cloud emits a flux just 5–10% that of the Earth. However, this may not be the case for extra-solar asteroid belt/planet combinations, the resonant rings of which may be quite different to that of the Earth. For example, a system with an asteroid belt ten times more massive than our own would have an Earth ring trailing cloud with a flux almost equivalent to that of the Earth. In such a case, the MM97 image of the Earth would appear extended with enhanced flux. The other fainter clumps in the ring may also be apparent in the image. The relative strengths of the trailing clouds to the other clumps in these rings, as well as their strength relative to the emission from the perturbing planet, depends on the detailed dynamics of the systems. However, note that if brighter trailing clouds are the norm, then the effect of resonant rings would be to aid, rather than hinder, the detection of terrestrial planets by enhancing their brightness.