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Submillimetre Images of the Closest Debris Disks

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Abstract. Debris disks are the cold remnant material seen around nearby stars, where dust is thought to be continually regenerated by collisions of asteroids and comets. We discuss some new observations of disks around close sun-like stars. Some have detectable dust up to the late main sequence, although the sun's Kuiper Belt contains much less material. Given the small distance to which we could detect sun-like systems, we discuss whether dusty disks could be the norm — this has implications for searches for other habitable terrestrial planets.

1. Introduction

About 15% of nearby main-sequence stars are known to be surrounded by disks of cool dust grains (e.g. Habing et al. 2001). Radiative and erosive forces would remove these grains on scales less than the stellar lifetimes, so they are thought to be regenerated by collisions of asteroids and comets. However, the analogous zone in the solar system — the Kuiper Belt — has only small quantities of dust (Landgraf et al. 2002), which raises the question of what is typical. Debris disks are difficult to detect as the amounts of dust are less than an Earth mass, and most of our knowledge of these extrasolar dust belts comes from imaging in the far-infared or submillimetre, regimes which are well-matched to the cool thermal spectrum [1]. In this article we discuss observations made at 850 μm with the SCUBA camera (Holland et al. 1999) on the James Clerk Maxwell Telescope, as well as the legacy of ISO 60 μm mapping.

2. New Results

The prototype disk for a sun-like star is that around ϵ Eridani (Greaves et al. 1998), a moderately young K2V star at only 3.2 pc distance. The latest SCUBA image will be presented elsewhere, but the new results (totalling over 20 hours of integration) confirm the presence of a dust ring of $\approx 35 - 75$ AU radius, and containing four brightness peaks. These can only be plausibly explained by planetary resonance, but require a giant planet in a larger orbit than seen in the solar system, most likely at ≈ 60 AU (Ozernoy et al. 2000). A compact dust

[1] An extrasolar analogue to the dust in the asteroid belt, lying at 2–3 AU in our solar system, would emit mainly in the mid-infrared; few stars are known to have such hot dust, and sub-arcsecond resolution would be needed to image this zone around nearby stars.

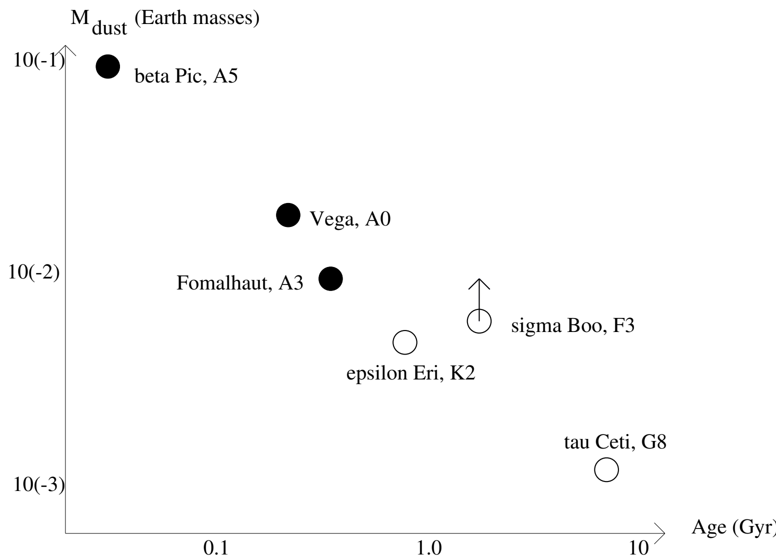

Figure 1. Plot of approximate dust mass versus stellar age, for the resolved disks (σ Boo is not yet fully mapped). Solid symbols indicate A-type stars and unfilled symbols sun-like stars.

clump *interior* to the ring is also confirmed, but at $\sim$ 15 AU is still well outside the orbit of the candidate radial velocity planet (Hatzes et al. 2000).

Very recent observations of τ Ceti (G8V, 3.6 pc) provide an exciting view of an even closer solar analog. There is a clearly resolved disk containing $\sim 10^{-3}$ $M_{\oplus}$ of dust, at least $\sim$ 100 times more than in the Kuiper Belt although τ Ceti is probably *older* than the sun (Lachaume et al. 1999 estimate 7 Gyr, versus 4.5 Gyr for the solar system). This implies diverging evolution, perhaps in the numbers of small bodies remaining after planet formation. However a candidate disk for 55 Cnc, a star with a planetary system (Marcy et al. 2003), turns out to be due to mis-identified background sources (most likely galaxies, Jayawardhana et al. 2002). This emphasizes the importance of high-resolution imaging: not only is it the only way to measure disk sizes and hence infer accurate temperatures and masses, but large-beam photometric observations (such as those of IRAS and ISO) are likely to include other dusty objects such as high-redshift starbursts.

3. Sun-like Stars

The discovery of several disks around moderately old solar-type stars (e.g., the ISO observations of Decin et al. 2000) has changed our picture of a fairly rapid mass decline of debris disks. In fact, there may be an observational bias as the most prominent disks are the warm examples around A-stars (Holland et al. 1998) — and these stars intrinsically have short lifetimes, which tends to skew a mass-age plot. For G-type stars, the occurrence of disks drops by only a factor $\sim$ 2 between objects younger and older than about 0.8 Gyr (Greaves et al., in prep.) where we have used the X-ray activity survey of Gaidos (1998) to

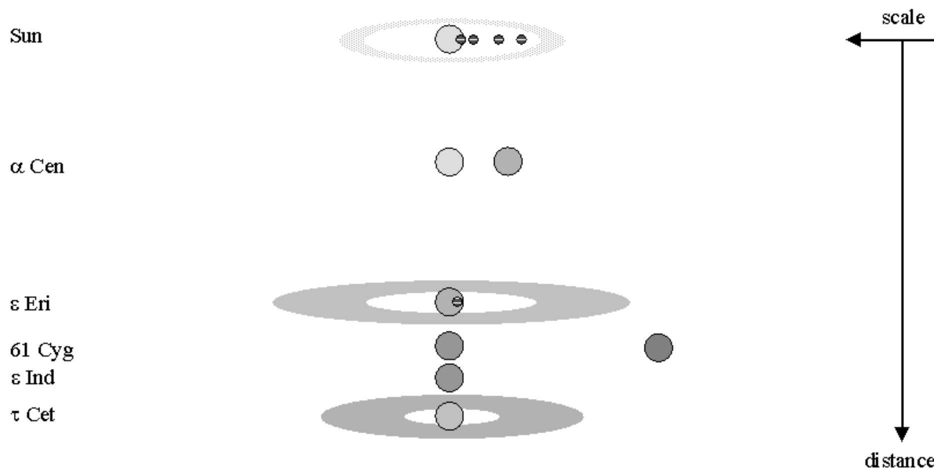

Figure 2. Sketch of disks and giant planets around all local sun-like stars, with distance on the vertical axis and system size on the horizontal axis (0–4 pc and 0–90 AU respectively; for clarity, relative positions are not exact). The next closest similar star is a K7V at just under 5 pc. Grey-intensity indicates spectral type, from light (early-G) to dark (mid-K). Stellar data are from the RECONS project at http://www.chara.gsu.edu/RECONS/.

establish the ages. Moreover, dust masses are only accurate (within the factor $\sim\ 2-4$ given by limited knowledge of grain emissivity) when the disks are resolved. Figure 1 shows the mass-age plot for the stars resolved with SCUBA, and although there is a plausible decline there is also a clear separation of the luminous and sun-like stars. To emphasize our limited knowledge, Figure 2 shows the planets and disks we know about for G to mid-K stars within 5 pc of the sun, a distance which is close to current useful sensitivity and resolution limits. Apart from the binary systems, where disk stability would be poor, nearly all the stars have disks!

4. Implications

The Kuiper Belt most likely has $< 10^{-5}$ $M_{\oplus}$ of dust, with direct detection beyond Saturn's orbit (Landgraf et al. 2002) but considerable uncertainty from modelling of far-infrared data at larger distances (Teplitz et al. 1999). However we can make a rough estimate of whether this upper limit would be detectable in disks around nearby stars. For example, with SIRTF observations at 70 μm (where the background confusion is relatively low) and with $5''$-pixel imaging, a disk the size of the Kuiper Belt would be just resolved (subtending $9''$ at 5 pc). However the flux per pixel of $\sim$ 125 μJy (for $T_{\rm dust} = 40$ K) would be marginally *below* the confusion limit of ≈ 150 μJy. Thus (without higher resolution) we could only detect somewhat dustier systems than our own.

What are the implications? If systems slightly dustier than the Kuiper Belt are the norm, this may have serious implications for potential extrasolar

'Earths'. For example, the Earth suffered massive bombardment for about the first 0.7 Gyr (Zanhle 2001), while the massive impact 65 Myr ago may have caused widespread species-extinction. With a greater population of asteroids and comets (the precursors of dust particles), such impacts could be much more frequent. These effects could be critical for the development of life.

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