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# EXOZODIACAL DUST DISKS

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**Abstract.** The zodiacal cloud has long been suspected to have extrasolar analogs, exozodiacal, debris clouds that remained elusive until very recently. Over the last decade, the presence of exozodiacal dust in the habitable zone around nearby stars, has essentially been discussed as a potential noise source that may compromise the ability of future exo-Earth finding missions to reach their goals. Our pioneering detection of exozodiacal dust around Vega in 2006 using near-IR interferometry shows that exozodiacal disks are by themself very interesting astrophysical objects. In these proceedings, I review the current observations of exozodiacal dust disks around nearby main sequence stars using near-infrared interferometry, and show that, as a rule of thumb, the detected exozodiacal dust disks differ from the zodiacal cloud. I then consider possible dynamical scenarios that may give rise to an abundant production of exozodiacal dust. I emphasize a promising scenario involving the outward migration of a planet toward a planetesimal belt similar to the Kuiper belt, and responsible for a cometary bombardment.

## 1 Introduction

Within about 2 AU, the inner solar system is filled with dust near the ecliptic plane that originates from tails of comets, or produced when asteroids collide. This dust forms the zodiacal cloud that, despites its tiny total mass equivalent to a medium-sized asteroid ($\sim 10^{-8}$M$_\oplus$, vertical optical thickness of $\sim 10^{-7}$ at 1 AU), is the most luminous extended circumsolar component. The zodiacal cloud is furthemore not smooth but structured. Dust bands discovered by IRAS would trace back recent (5–8 Myr ago) breakups of members of known asteroids families (e.g. Nesvorný et al. 2008 and ref. therein), while some dust trails may be associated to short period comets. A noticeable feature of the zodiacal cloud is its resonant 1:1 ring caused by grains migrating inward due to Poynting-Robertson (P-R) and solar wind drag, and trapped in mean motion resonance with the Earth. This leads to a brightness enhancement in the Earth trailing direction, and a dust cavity at the Earth location. All these features make the zodiacal cloud asymmetric and probably variable in time.

To feed the future exo-Earths finders design studies with realistic numbers, and to improve their detection strategy, it appears crucial to better assess the brightness level and structure of exozodiacal clouds around potential targets, namely nearby Main Sequence stars. Our pioneering detection of exozodiacal dust around Vega in 2006 with the CHARA/FLUOR interferometric instrument in the K-band (Absil et al. 2006), soon followed by more detections using the same technique, have shown that exozodiacal disks (henceforth exozodis) are by themself very interesting astrophysical objects that deserve detailled studies. In this paper, I briefly review the current observations of exozodis around nearby main sequence stars using near-IR interferometry, and show that the detected exozodis differ from the zodiacal cloud. I then discuss possible dynamical scenarios that may give rise to an abundant production of exozodiacal dust, with emphasis on a promising scenario involving the outward migration of a planet toward a Kuiper belt and initiating a cometary bombardment.

## 2 Near-IR interferometry of exozodiacal dust disks

Only very recently, hot dust has been unambiguously resolved for the first time around several stars (Vega, $\tau$ Ceti, $\zeta$ Aql, $\beta$ Leo, $\zeta$ Lep, Fomalhaut) using high-precision near-infrared interferometry at the CHARA Array and at the VLTI (Absil et al. 2006, di Folco et al. 2007, Absil et al. 2008, Akeson et al. 2009, Absil et al.

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2009). The detection principle is based on the small decrease of visibility produced by the resolved circumstellar structure with respect to the expected photospheric visibility. This departure from the stellar size can best be detected at short baselines (∼30–50 m), while the long baseline measurements determine the stellar parameters. An example data set on the debris disk system Fomalhaut is shown in Figure 1 (from Absil et al. 2009). The

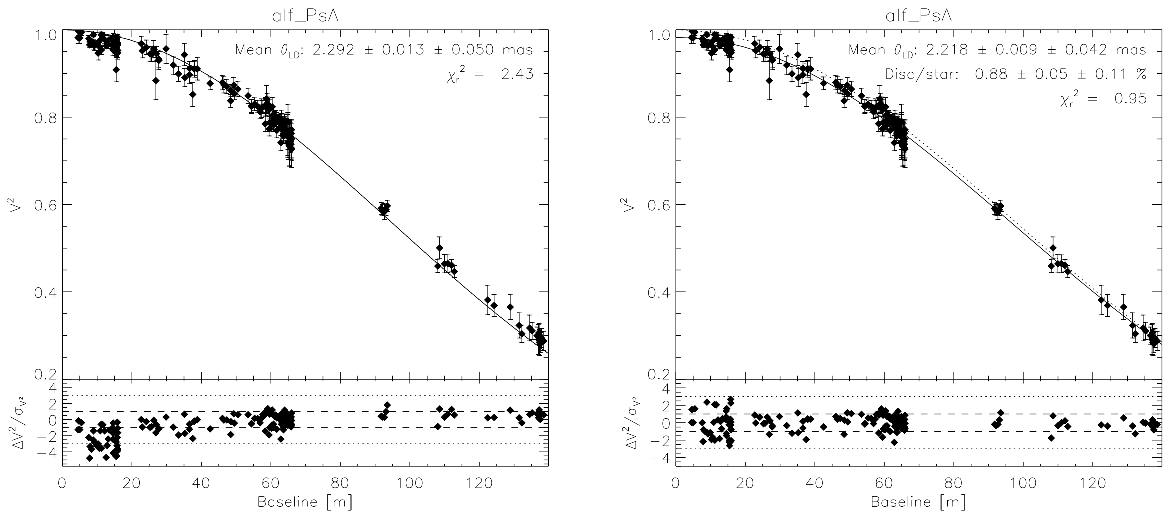


**Fig. 1. Left** : result of the fit of an oblate limb-darkened stellar photosphere to the full VLTI/VINCI data set (top panel). The dashed and dotted lines in the bottom panel represent respectively a $1\sigma$ and a $3\sigma$ deviation with respect to the best-fit model. **Right**: Result of the fit of a star-disk model. The solid line represents the best fit star-disk model, while the dotted line represents the best-fit result with a single star for comparison. From Absil et al. (2009).

VLTI/VINCI measurements are inconsistent with a naked star within the field of view of the interferometer as can be seen in the left panel of Figure 1, while the visibility deficit for Fomalhaut is evidenced when the stellar size is extrapolated to small spatial frequencies (shorter baselines), revealing an extended (over-resolved) emission (right panel). In fact, the restricted field of view of the interferometer ensures that any detected emission comes from much smaller spatial scales than the cooler material, which produces the previously known mid- to far-infrared excess toward these stars. The main outcomes of these observations are therefore a maximum radius where the dust must be confined, and an accurate estimate of the K-band ($2.2\,\mu$m) flux excess, which was not known through broadband spectral modeling, since the interferometrically detected near- infrared excesses are within the photometric uncertainties (e.g. $1.29 \pm 0.19\%$ excess for Vega, $0.98 \pm 0.21$ for $\tau$ Ceti). More and more similar cases are found with the CHARA Array suggesting that about 20% of the stars may have an exozodiacal dust disk, depending on spectral type.

## 3 Nature of the exozodiacal dust

The fit to the $2.2\,\mu$m excess with the solar system zodiacal model (using for example the Zodipic package developped by M. Kuchner), indicates densities a few thousand times larger than the zodiacal density (about 3000 zodis for Vega, 5000 zodis for Fomalhaut). This model nevertheless predicts much too large flux (by about an order of magnitude) in the mid-IR compared to the observations, indicating that the solar system zodiacal spectrum does not match the spectral energy distributions (SEDs) of detected exozodiacal disks. Dust much closer to the star is required to shift the spectrum to shorter wavelengths.

Based on the sole photometric and spatial information derived from the CHARA or VINCI measurements, complemented by (much less accurate) archival photometric data at other infrared wavelengths, it has become possible to put useful constraints on the disk morphology, composition and dynamics by using the radiative transfer code of Augereau et al. (1999) and dust optical constants from laboratory measurements to reproduce the disk SEDs. An example fit to the SED of $\zeta$ Aql is displayed in Figure 2 (top panel), where the derived total mass and fractional luminosity of these exozodiacal grains are documented in the upper right corner (from

Absil et al. 2008). While the case of a binary low-mass companion, or of a background star, can generally be safely excluded to explain the observed near-IR excesses, a 0.6–0.65 $M_\odot$ object at 5.5–8 AU remains compatible with all observational constraints, including direct imaging and astrometric measurements in the case of $\zeta$ Aql (bottom panel of Figure 2).

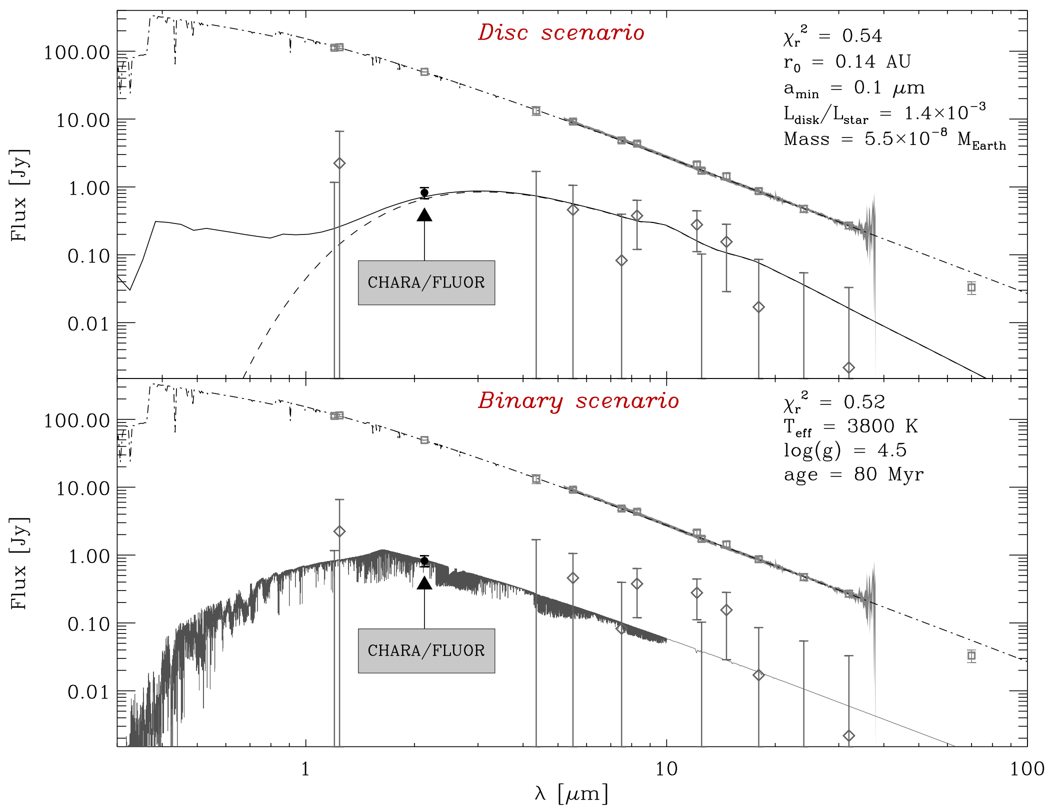


**Fig. 2. Top**: a possible fit of our debris disk model to the photometric and interferometric constraints (excesses represented with diamonds). Dashed line: thermal emission from the disk, solid line: includes the scattered light contribution. **Bottom**: case of a low-mass companion ($T_{\rm eff} = 3800\,$K, $\log(g) = 4.5$). From Absil et al. (2008).

In the case of Vega, the modeling shows that the resolved emission emanates mostly from hot sub-$\mu$m carbonaceous grains located within 1 AU from the photosphere, close to their sublimation limit ($\sim$0.5 AU for the sub $\mu$m-sized grains, $\sim$0.15 AU for the few $>\mu$m-sized grains). The dust mass, $\sim 8\times10^{-8}\mathrm{M}_\oplus$, is equivalent to the mass of a 70 km diameter asteroid. Because of the high temperature of the grains, the luminosity of the exozodiacal dust disk ($L_{\rm exozodi}/L_\star \sim 5\times10^{-4}$) is more than one order of magnitude larger than the luminosity of the outer, Kuiper Belt-like, disk, even though it is almost 105 times less massive than the outer ring. Due to radiation pressure, small grains cannot survive in the Vega exozodiacal disk more than a few years before being ejected toward cooler regions (e.g. Krivov et al. 2006). Larger grains would survive somewhat longer, but not more than a few tens of years due to the high collision rate. This implies a large dust production rate ($\sim 10^{-8}\mathrm{M}_\oplus$) to explain the interferometric observations, a conclusion valid for all systems with detected exozodiacal dust.

## 4 Origin of the exozodiacal dust

In fact, all detected exozodiacal disks have luminosities orders of magnitudes larger than those expected for a steady state collisionally-dominated belt of planetesimals. This suggests that dynamical perturbations are currently ongoing in these systems. As discussed in Absil et al. (2006), a scenario involving the presence of star-grazing comets, injected into the inner planetary system by dynamical perturbations caused by migrating planets, has been proposed, inspired by the most recent models for the Late Heavy Bombardment (LHB) that happened in the early solar system (Gomes et al. 2005). A similar, catastrophic scenario is also proposed by Wyatt et al. (2007) to explain the presence of warm dust ($\sim$300 K) detected by the Spitzer Space Telescope around a few solar-type stars.

The problem of the huge mass of the exozodiacal disks can therefore be mitigated by an assumption that they are fed from outside. While standard dust transport mechanisms such as P-R drag are two slow compared to other dynamical timescales (i.p. collision timescales) to do the job, possible planets in the region between the exozodiacal disk and a Kuiper belt could assist transporting the planetesimals. For Vega, our team is currently building on the planet migrating scenario published in Wyatt (2003) and Reche et al. (2008) to explore the fraction of Kuiper-Belt objects penetrating the inner Vega system to compare with the near-IR observations. Assuming a two planet system composed of a Neptune-mass planet migrating outward from 40 to 60 AU on a low eccentric orbit, and a Jupiter-mass at 20–25 AU, we estimate that this configuration can sustain over 40 Myr the transportation of $10^{-3}$ the mass of the Vega Kuiper Belt within 1 AU every million of year, a rate which is consistent with the $10^{-8}\,M_{\oplus}.yr^{-1}$ derived from the SED modeling (Vandeportal et al., in prep.).

## 5 Conclusion

The mechanisms for the exozodiacal dust production are still largely unclear despites some first attempts to link the exozodiacal disk properties to those of the outer regions of planetary systems. It is in particular not known whether or not the dust production mechanisms are similar to those operating in the solar system. It is not known how different they are in different systems and what is the role of transient events.

To address some of these issues, an ISSI international team (http://www.issibern.ch/teams/exodust) has been assembled. The working group, leads by J.-C. Augereau and A. Krivov, gathers scientists with vast, and mutually complementary expertise in modeling, observations, laboratory experiments, and instrumentation. It includes both specialists in extrasolar dust disks and experts in the Solar System's zodiacal cloud, thus bringing together two communities that use various approaches. Two one-week meetings were held in August 2007 and April 2009, with the concluding meeting planned in 2010. A significant effort is invested into intensive modeling and characterisation of the detected exozodiacal clouds, in an attempt to uncover possible commonalities and diversities between them and the zodiacal cloud in our Solar System. This expertise shall be very beneficial to prepare future space missions, such as the Fourier-Kelvin Stellar Interferometer (FKSI, Danchi et al., these proceedings) that aims at detecting exozodiacal emission levels to that of our solar system around nearby solar-type stars, and characterizing the atmospheres of exoplanets.

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