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Latest results from the EXOZODI project

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Abstract

High levels of warm dust observed in the inner regions of planetary systems are known as exozodis, reflecting their similarities with the Solar System's zodiacal cloud. Whilst the population of cold, outer debris discs is well characterised observationally and understood theoretically, many mysteries remain regarding the observations of exozodiacal dust. The observed small dust grains have a short lifetime against collisions and radiative forces. Even if they were resupplied from the collisional grinding of a population of larger parent bodies, as commonly suggested to explain cold, outer debris discs, the parent bodies could not sustain the observed dust levels in steady-state for anywhere near the age of the system. Further theoretical investigations, alongside observations of the population of exozodis, are required in order better understand the origin of the exozodiacal dust. Interferometry is perfectly suited to better characterising this population, as the emission from the exozodi can be readily disentangled from the stellar emission. We present results of a statistical survey that aims to characterise the population of exozodis around nearby stars using CHARA/FLUOR and VLTI/PIONIER, alongside theoretical investigations into the manner in which the observed exozodiacal dust may be linked with the dynamical evolution of the planetary system.

1. The CHARA/FLUOR observations (Absil et al. (2013))

We use high-precision K-band visibilities obtained at short baselines (< 30 m) with the FLUOR instrument at the CHARA array in order to search for exozodiacal dust around a sample of 42 nearby main-sequence stars. The calibrated visibilities are compared with the expected visibility of the stellar photosphere to assess the presence of an additional, fully resolved circumstellar emission source. Near-infrared circumstellar emission amounting to about 1% of the stellar flux is detected around 13 of our 42 target stars, most probably associated with circumstellar dust found within the field of view of the telescope (several AU), yielding an overall occurrence rate of $28^{+8}_{-6}\%$ for our (biased) sample. The results find an intriguing absence of a dependence on stellar age of the level of exozodiacal dust, see Fig. 1. We find that exozodiacal dust is significantly more common around A stars ($50 \pm 13\%$) than FGK stars ($18^{+9}_{-5}\%$) and for solar-type stars, correlates with the presence of detectable far-infrared excess emission. An extension to this survey is currently underway using VLTI/PIONIER to observer a sample of 89 fainter stars in the southern hemisphere.

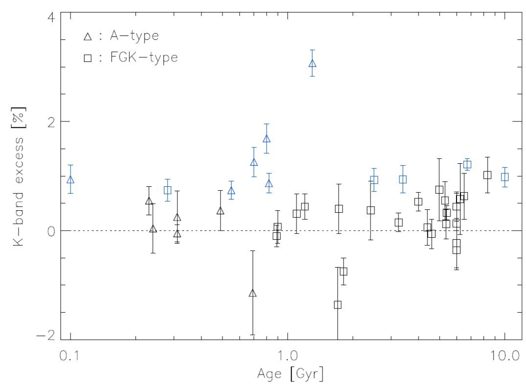

Figure 1: The observed disc to star flux ratio (K-band) as a function of stellar age. Note the omission of the large error bars on the stellar age. Triangles: A stars Squares: FGK stars Blue: stars with K-band excess Black: stars without K-band excess.

2 Scattering by planets (Bonsor et al. (2012))

A potential origin to our Solar System's zodiacal cloud is in Jupiter Family comets, *i.e.* material scattered inwards from the Kuiper belt (Nesvorný et al. 2010). Many planetary systems are known to be orbited by cold, outer debris discs and planets, and even where no outer debris disc is detected, a substantial planetesimal belt could hide below the detection limits. We, therefore, consider the ability of scattering inwards of material from an outer belt to sustain the levels of exozodiacal dust observed, for the age of the system.

We consider stable planetary systems, in which a chain of equal mass planets on circular orbits scatter material from an outer planetesimal belt inwards to sustain an inner exozodi and use N-body simulations to investigate the efficiency of this scattering. We find that chains of tightly packed, low mass planets are the most efficient at scattering material inwards. However, if we take Vega as a typical example of an exozodi, we find that even the most efficient scattering process is at least an order of magnitude too inefficient to sustain the observed exozodi at the required rate of $10^{-9} M_\oplus$/yr (Defrère et al. 2011), after 450Myrs of evolution (Vega's age (Yoon et al. 2010)). Similar analysis can be applied to other systems (see Bonsor et al. (2012) for more details). We, therefore, conclude that scattering is in general to inefficient to sustain the high levels of exozodiacal dust observed in old ($>$ 100Myr) planetary systems.

3 Dynamical instabilities (Bonsor et al. (2013))

A common suggestion to explain the high levels of exozodiacal dust observed is that the dust results from the aftermath of a dynamical instability, an event akin to the Solar System's Late Heavy Bombardment. In this work, we use a database of N-body simulations to investigate the aftermath of dynamical instabilities between giant planets in systems with outer planetesimal belts. We find that, whilst there is a significant increase in the mass of material scattered into the inner regions of the planetary system following an instability, this is a short-lived effect. We determine the maximum lifetime of this material in our simulations (see Fig. 2). From this we determine that even if every star has a planetary system that goes unstable, there is a very low probability that we observe more than a maximum of

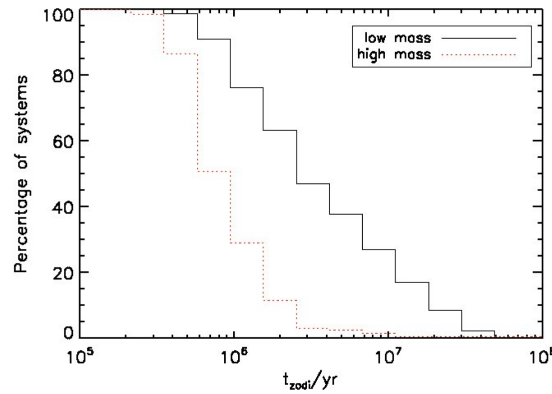

Figure 2: The maximum lifetime of scattered material (t_{zodi}), plotted as a cumulative distribution, for our suite of 424 simulations. The short lifetime of the exozodiacal dust allows us to derive a generous an upper limit of 1% on the fraction of sun-like stars with exozodiacal dust (Bonsor et al. 2013).

1% of sun-like stars in the aftermath of an instability, and that the fraction of planetary systems currently in the aftermath of an instability is more likely to be limited to $\leq\ 0.06\%$. Comparison of this limit with the 18% of systems detected with exozodiacal dust (Absil et al. 2013), we conclude that the production of warm dust in the aftermath of dynamical instabilities is too short-lived to be the dominant source of the abundantly observed exozodiacal dust.

4. Summary and Conclusions

The EXOZODI project aims to characterise and understand the population of exozodi around nearby stars. We present results of a CHARA/FLUOR survey that searches for exozodiacal dust around 42 nearby stars that finds an occurrence rate of $28^{+8}_{-6}\%$. Exozodi are likely to be related to the dynamical evolution of planetary systems, but we are able to rule out the possibility that they are all systems in the aftermath of a dynamical instability. Whilst scattering inwards of material from an outer planetesimal belt may contribute to the observed dust, an additional mechanism that sustains the scattering on long timescales, such as planetesimal driven migration, is required to explain the high levels of dust observed.

Acknowledgements

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