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Modeling the spatial structure of debris disks

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Abstract

We present high spatial resolution observations and detailed multi-wavelength modeling of the structure and composition of two prominent debris disks and a systematic study on the observability of planet-disk interaction in debris disks with present and future instruments. As the spatial structure of debris disks is, in addition to stellar gravity and radiation, mainly influenced by planet-disk interaction, modeling this structure puts strong constraints on the planetary systems the disks are associated with.

1. Modeling *Herschel* data on the q^1 Eri debris disk

The *Herschel* open time key program DUNES (DUst around NEarby Stars) aims at detecting debris disks with fractional luminosities similar to the Edgeworth-Kuiper Belt (EKB) level around a volume limited sample ($d < 20\,\mathrm{pc}$) of FGK stars including some additional sources. The debris disk around the DUNES science demonstration object q^1 Eri (F8V, $d = 17\,\mathrm{pc}$) has been spatially resolved by *Herschel*/DUNES at $70\,\mu\mathrm{m}$, $100\,\mu\mathrm{m}$, $160\,\mu\mathrm{m}$ using *Herschel*/PACS (Fig. 1) and at $250\,\mu\mathrm{m}$ using *Herschel*/SPIRE. Furthermore, it has been detected at $350\,\mu\mathrm{m}$ and $500\,\mu\mathrm{m}$ using *Herschel*/SPIRE [1, 2]. Simultaneous modeling of images and SED reveals a heavy EKB analog and additional evidence for an inner disk related to an Asteroid Belt analog. A giant planet ($a = 2\,\mathrm{AU}$, [3]) completes the system's similarity to our solar system.

Based on our model, we predict that *ALMA* observations (Fig. 2) will resolve the inner disk and thus put strong constraints on the existence and properties of possible further planets [4]. *ALMA*'s multi-wavelength high resolution maps will strongly constrain the radial dust distribution and allow detailed modeling of its composition.

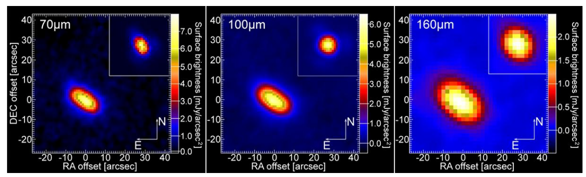

Figure 1: *Herschel*/PACS data of q^1 Eri. The PSF is shown in the upper right corner, respectively.

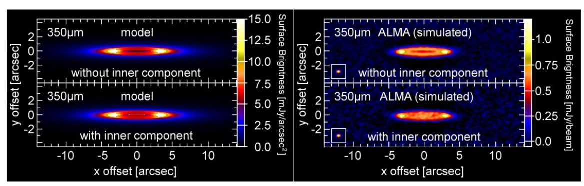

Figure 2: Simulated *ALMA* observations of our best-fit model. Parameters for simulation: $\lambda = 350\,\mu\mathrm{m}$, max. baseline $= 260\,\mathrm{m}$, PWV $= 0.8\,\mathrm{mm}$, time on target $= 8\,\mathrm{h}$. $1\sigma = 0.04\,\mathrm{mJy/beam}$

2. Multi-wavelength modeling of the HD 107146 debris disk

Combined multi-wavelength modeling (Fig. 3, Fig. 4) of high spatial resolution scattered light images, a resolved *CARMA* map at 1.3 mm, and a well sampled SED (star: G2 V, $d = 28.5\,\mathrm{pc}$) reveals a broad ($\sim 90\,\mathrm{AU}$) ring at $R \sim 130\,\mathrm{AU}$ [5]. We find the smallest dust grains present to be significantly (5 times) larger than the radiation blow-out size [5]. Furthermore, from comparison of our detailed model with the *Spitzer*/IRS spectrum we find strong evidence for an additional, inner dust component close to the habitable zone of the star (Fig. 4).

CARMA observations [6] show two peaks, consistent with dust trapped into resonance by a giant planet. If these structures can be confirmed, the HD 107146 disk with its high surface brightness will provide ex-

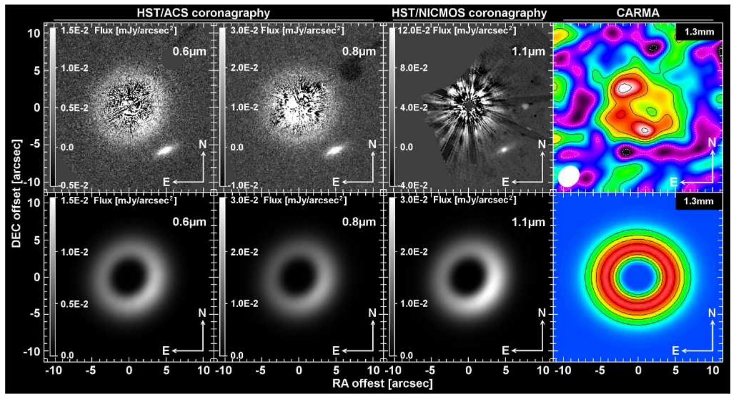

Figure 3: Resolved observations (upper) and modeled images (lower) of HD 107146. Maximum baseline for the CARMA observations: $148\,\mathrm{m}$. Contours in the *CARMA* map start at -1σ (white) and $+1\sigma$ (black), increments: $1\sigma = 0.35\mathrm{mJy/beam}$. White ellipse: beam FWHM. Peak surface brightness in the CARMA map: $\sim 5\sigma$.

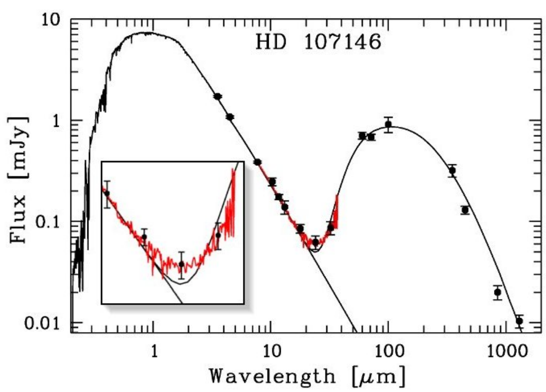

Figure 4: Photometric data along with applied stellar photosphere model and simulated SED from our best-fit model.

cellent conditions to study planet-disk interaction in debris disks with *ALMA* [4]. High resolution multi-wavelength images by *ALMA* will strongly constrain the dust composition and lower dust grain size.

3. *ALMA* observations of planet-disk interaction in debris disks

We perform dynamical simulations to study the observability of structures induced in debris disks by planet-disk interaction with present and future instruments [4, 7]. *ALMA* provides unique opportunities for such observations, but is limited by its sensitivity, not its resolution, due to the low surface brightness of debris disks (Fig. 5).

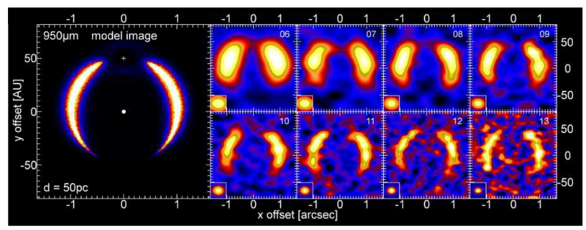

Figure 5: Simulated *ALMA* observations of planet-disk interaction. Parameters for simulation: $PWV = 0.8\,\mathrm{mm}$, time on target $= 8\,\mathrm{h}$. The numbers represent the predefined array configurations (CASA[1] [8]). The color scales have been adjusted to fit the dynamic ranges. A ring of debris at $50\,\mathrm{AU}$ (e.g., EKB or HD 105) with a planet ($M_\mathrm{p} = 1\,\mathrm{M_J}$) at the same distance has been considered. The total flux has been scaled to the level of the HD 105 debris disk. Assumed distance of the system: 50 pc.

4. Summary and Conclusions

We modeled the spatial structure of two debris disks around solar type stars (q[1] Eri and HD 107146). We put strong constraints on the dust spatial distribution as well as on it's composition. For both systems we found evidence for a multi-ring system similar to our solar system with a heavy Kuiper Belt analog and an additional, inner Asteroid Belt analog. Our simulated *ALMA* observations of planet-disk interaction in debris disks show that such observations are possible and able to put strong constraints on the planetary system.

[1] http://www.cv.nrao.edu/naasc/alma_simulations.shtml

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