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DETAILED MODELS OF A SAMPLE OF DEBRIS DISKS: FROM HERSCHEL, KIN AND SPITZER TO THE JWST

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Abstract. Dusty debris disks surrounding main sequence stars are extrasolar equivalents to the Solar System populations of asteroids, icy bodies and dust grains. Many were observed in thermal emission by Herschel with unprecedented wavelength coverage and spatial resolution, complementing available scattered light images, mid-infrared spectra and interferometric measurements. We present detailed models of the HD 181327 and HD 32297 disks obtained with the GRaTer radiative transfer code and made possible thanks to Herschel. We then focus on the intriguing case of the nearby F2V star η Corvi that shows strong infrared excess despite an estimated age of 1.4 Gyr. We establish a detailed model of its disk from the sub-AU scale to its outermost regions based on observations from the Keck Interferometer Nuller, Herschel and Spitzer. These bright and extended disks will be of prime interest for future observations with the JWST. We finally discuss new debris disks science that will be addressed with the NIRCam and MIRI instruments.

Keywords: Debris disks, radiative transfer, Herschel, JWST, HD 181327, HD 32297, η Crv

1 Introduction

Debris disks are the dusty component of planetary systems. The grains are the by-product of collisions occurring between large planetesimals (comets, asteroids, Kuiper Belt objects). They are distinct from protoplanetary disks because they have no (or little) gas and they are optically thin: their evolution is driven by photo-gravitational forces and collisions. In favorable cases in which the disks can be imaged, structures such as belts, clumps or, asymmetries, and measurements of the dust density profile are precious clues of the dynamical activity of the global planetary system. Famous examples of structured debris disks include β Pictoris (Golimowski et al. 1993), Fomalhaut (Kalas et al. 2005) and AU microscopii (Augereau & Beust 2006).

There are only few cases of disks that harbor unambiguous spectral features (*e.g.* Beichman et al. 2005). Yet details on the properties of debris disks can be retrieved using radiative transfer models such as the one implemented in the GRaTer code (Augereau et al. 1999; Lebreton et al. 2012, 2013). In cases where both high-resolution images (e.g. Herschel, HST) and detailed Spectral Energy Distributions (SED) are available, it becomes possible to infer the properties of the dust and to constrain the collisional and dynamical activity of a planetary systems.

2 HD 181327: A very young, 90 AU-wide debris disk

In Lebreton et al. (2012), we performed a detailed study of the HD181327 debris disk based on observations from Herschel. The star is an F5/6V member of the β Pictoris moving group located at 51.8 pc. It has thus a well determined age ($\sim$ 20Myr) that corresponds to the earliest stages of a debris disk life. Its disk is very bright and it is extended enough to be resolved by Herschel/PACS at 70μm (Figure 1). Higher-resolution images were obtained with the HST, the latest of which were shown by (Schneider et al. 2014, with STIS). We inverted the HST/NICMOS surface brightness images in order to construct radial density profiles. The

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dust is distributed in a narrow belt at 89.5 AU, slightly inclined with respect to the plane of the sky. SED measurements are available for a wide-range of wavelengths from the mid-infrared to the millimeter domain, including extensive coverage from Herschel/PACS and SPIRE and Spitzer/MIPS, MIPS-SED and IRS. Having a well-defined radial density profile is a prerequisite to study the dust properties in details. We used it has an input in the GRaTer code, we parameterized the size distribution and composition, solved the radiative transfer and computed optical efficiencies to generate synthetic SEDs. We found that simple icy grain models (silicate or carbonaceous material) fail at reproducing the overall SED and we rather proposed a self-consistent model (Figure 2) consisting of porous grains ($63 \pm 21\%$ "empty"), made of carbon and silicate, mixed with water ice ($67 \pm 7\%$ in volume fraction). The size distribution consistent with a collisional equilibrium and the radiation pressure blowout of small grains. The disk has a total mass of $0.05 \pm 0.02\, M_{\oplus}$ in grains smaller than 1 mm and we can extrapolate that there are as much as $50\, M_{\oplus}$ of planetesimals smaller than 1 AU in the belt. Our conclusion on the composition of the grains is strongly attested by the statistical Bayesian inference method we developped. We also note that there is no need for a secondary belt located closer to the star and that if one was detected, in would not impact our conclusions on the dust properties.

3 HD 32297: Icy dust in a bright edge-on disk

In a second paper (Donaldson et al. 2013), we applied the same methodology to another young debris disk. HD 32297 is a 30 Myr star and unlike HD 181327, it is edge-on. This makes it a favorable case for high-resolution coronagraphic imaging from the ground. In this case, the disk surface density profile is based on images obtained with the VLT/NaCo instrument (Boccaletti et al. 2012). We find that the disk is composed of a dust belt at 110 AU and that it requires an additional dust component around near the habitable zone to explain the mid-infrared SED. Based on a this two-component model of the SED from Herschel, Spitzer and ancillary measurements, we find that the HD 32297 dust is very similar to the one of HD 181327. It includes 50% of ice and is is 90% porous. Overall, we conclude that these dust models including silicates, carbonaceous material, water ice and porosity and reminiscent of comet-like compositions should be used to properly interpret the properties of debris disks. We proved that the presence of ice can be inferred depsite the absence of strong solid-state features.

Recently, we obtain new images of the disk with the Palomar/P1640 coronagraph that suggest one side of the disk is brighter and/or more extended than the other side. Future scattered light studies could allow us to measure the dependence of the size distribution to distance, bringing more constraints on the dynamics and collisions.

4 η Corvi: A cold and a warm debris rings around a Gyr old star

η Crv is a nearby (18.2 pc) F2V star surrounded by a massive debris disk despite an estimated age of 1.4 Gyr. The peculiarity of this object is its strong and structured mid-infrared excess that provides information on the properties of its warm dust component. We revised the Spitzer/IRS spectra of the disk (Chen et al. 2006) and carefully proceeded to the photosphere subtraction. The relative excesses below 18μm are small and are very sensitive to assumptions on the stellar spectrum. The disk has two spatially separated components as it clearly appears in the Herschel/PACS images at 70, 100 and 160μm (Figure 1). The outer one reaches the maximum of its surface brightness at 6 to 7.5" along the major axis. There is marginal evidence for side-to-side asymmetry or offset but at smaller scale that the PACS resolution. The inner component (exozodi) is unresolved by Herschel. We used interferometric nulls from the Keck Interferometer Nuller to spatially constrain the exozodi location and correct it with respect to what is inferred from simple SED fitting. We modeled in details the two-component debris disk from the sub-AU scale to its outermost regions by fitting simultaneously the interferometric nulls, the Herschel images and the spectro-photometric data against a large parameter space. We found that the cold material resides at an orbital distance of 133 AU and is consistent with a collisional cascade occurring in a parent reservoir of ice-free planetesimals. The warm component is located between 0.2 and 1 AU and its surface density decreases slowly. The exozodiacal dust has a very high albedo produced by forsterite-rich grains with an overabundance of small grains. Our analysis provides accurate estimates of the fundamental parameters of the disk: its surface density profile, grain size distribution composition and mass. The overall architecture of the system is very similar to that of the Fomalhaut debris disk. Given its age we support previous claims that the system is likely encountering a violent Late Heavy Bombardment (Lisse et al. 2012). Our study is presented in Lebreton J. et al. (2015) (submitted).

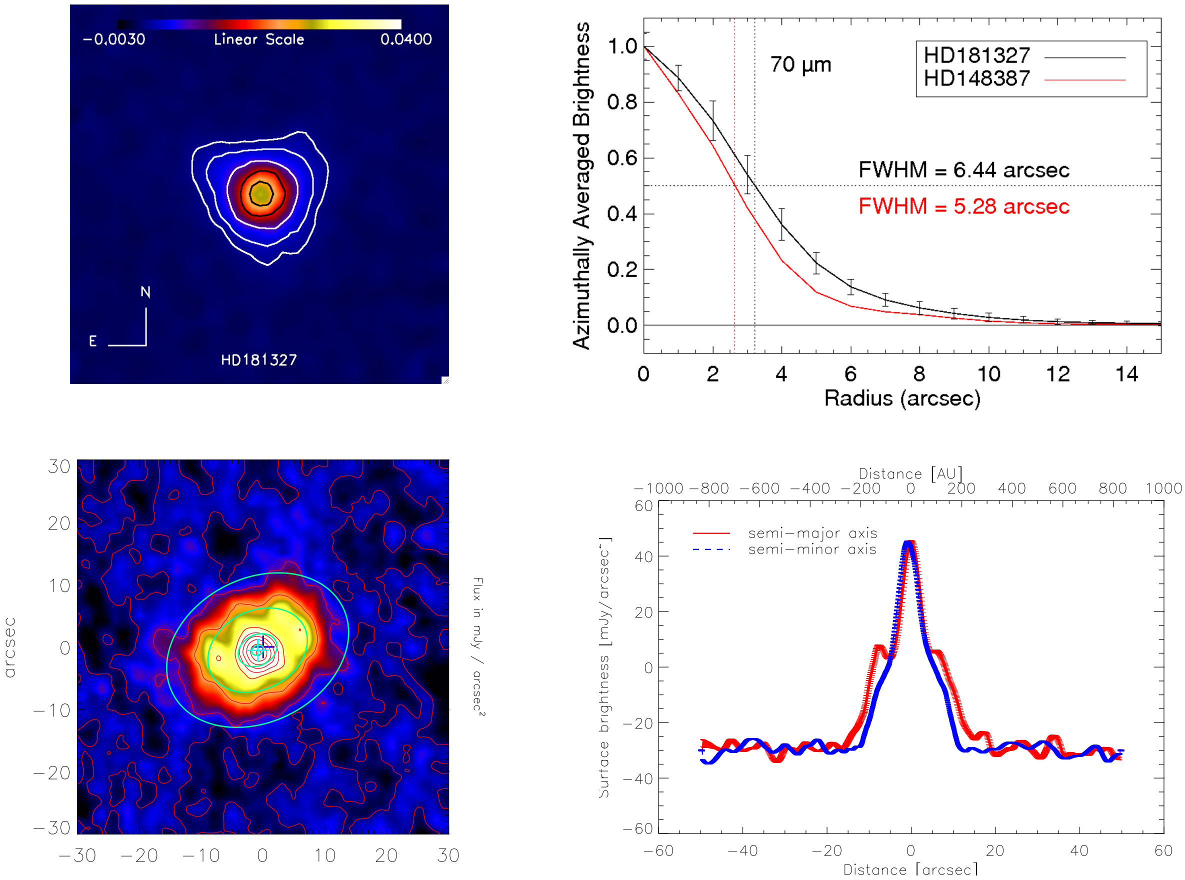

Fig. 1. Herschel/PACS 70μm images (**Left**) and radial brightness profiles (**Right**) of **Top:** HD 181327 and **Bottom:** η Crv. The HD 181327 profile is compared with the PSF reference HD 148387 to show that the disk is resolved. The η Crv profile is resolved along both axis of the inclined disk; along the major axis, the outer belt is clearly distinguishable. The HD 32297 data are not shown because the disk is spatially unresolved.

5 JWST perspectives

The James Webb Space Telescope is scheduled for launch in 2018. Two instruments will be particularly interesting for debris disk studies. NIRCam is a near-infrared imager operating in the 1 to 5 μm range. MIRI has a camera and a spectrograph, it operates between and 5 and 23 μm. Both instruments are equipped with coronagraphs and will offer an inner working angle and resolution comparable to the HST, but in a whole new wavelength range.

Debris disks are faint in scattered light and they rarely have strong spectral features. Yet icy debris disks detected by Herschel have a detectable ice features at 3 microns. Imaging the disks within several NIRCam filters will make it possible to detect dips in the spectrum providing the first unambiguous detections of debris disk ices. The ice-line is of prime importance in the formation and evolution of planetary systems and we may also be able to locate ices other than H_2O, such as CO_2, CO or NH_3, either by looking for features in the 4 to 5 μm range or by measuring color gradients within the medium-band filters. The colors and spectra of minor bodies in the Solar System provide a lot of constraints on its formation history and JWST will make it possible to conduct these studies for extrasolar planetary systems.

MIRI will permit to observe the mid-infrared silicate absorption bands. A more complete coverage of the SED at the transition between scattered- and thermal light-dominated regimes will further constrain the grain optical properties and help understand discrepancies between scattered light images and far-infrared models. Finally in terms of imaging, NIRCam and MIRI will teach us a lot about debris disk structures such as asymmetries, clumps, gaps or spiral structures providing further constraints on the systems dynamics. In Lebreton et al.

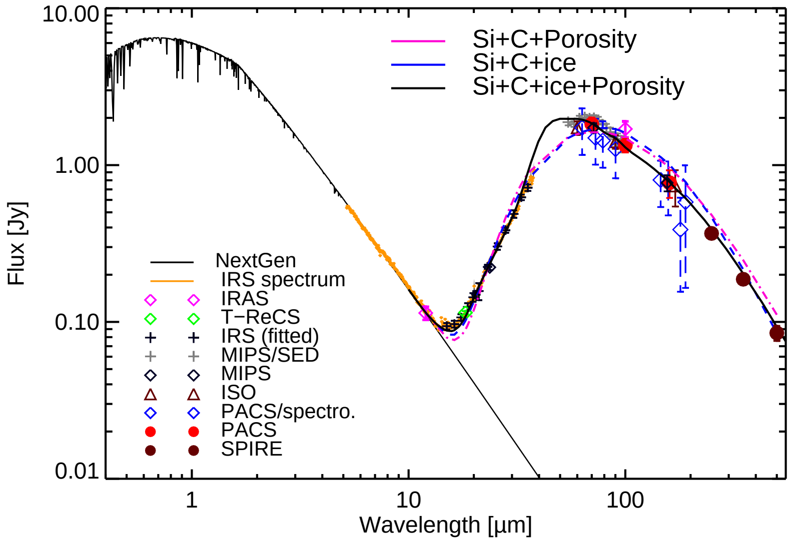

Fig. 2. Spectral Energy Distribution and models of the HD 181327 debris disk. The figure is an update since Lebreton et al. (2012) incorporating new data from Herschel/SPIRE. Three of the best models are shown with reduced $\chi^2 =$ 6.1, 4.5, 1.6 respectively (44 or 43 degrees of freedom).

2015b (in preparation) we will present simulations of the performances of NIRCam and develop concepts for debris disks studies.

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