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Disk structure and stirring mechanism in bright debris disks

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ABSTRACT

In dusty debris disks, dust particles are continuously replenished by destructive collisions between unseen planetesimals, whose orbits are stirred up by some mechanism. While the most commonly invoked mechanism is self-stirring, alternative solutions, such as planetary stirring, are also possible. Here, we present resolved Herschel images of ten bright young debris disks around A-F type stars. We compared the radii of the rings and the ages of the systems to theoretical predictions for the evolution of an outward expanding dust-production zone in the self-stirring model. We found several cases that are too extended to be consistent with this scenario. Should we witness the effect of planetary stirring, some of our disks are prime targets to discover outer giant planets via direct imaging. Our project constitutes a considerable contribution to the list of debris disks successfully resolved at far-infrared wavelengths.

INTRODUCTION

- In debris disks, dust grains of secondary origin orbit the star. This dust is produced by collisions between planetesimals. For destructive collisions, large relative velocities are needed, i.e. the disk must be dynamically stirred. Currently proposed stirring mechanisms are:
- **Self-stirring**: planetesimal growth starts close to the star, then proceeds outwards. When protoplanets of ~1000 km are formed, they de-stabilize their vicinity, increasing dust production (Kenyon & Bromley 2008).
- **Planetary stirring**: giant planets or stellar companions can dynamically excite the motion of planetesimals via their secular perturbations (Mustill & Wyatt, 2009).
- **Close stellar flybys** can also initiate energetic collisions in a planetesimal disk (Kenyon & Bromley, 2002). This possibility is plausible in young clusters during the early phase of debris disk evolution.

MOTIVATION

- The relative contribution of these mechanisms to the stirring of known debris disks is unknown. Self-stirring is usually considered as the default mechanism. But can we identify examples of the other mechanisms?
- The existence of a very large planetesimal belt around a relatively young star cannot be explained within the self-stirring scenario (formation of ~1000 km-size bodies at large radii would require too long time). Prime candidates for alternative stirring mechanism.
- **We selected a sample of relatively young (<800 Myr) systems that harbor large and cold debris disks based on their Spitzer measurements. We observed them with the Herschel Space Observatory to resolve their structure and scrutinize the extension of their debris belt. None of our targets have stellar companions.**

SAMPLE & OBSERVATIONS

ID	Sp.T	Dist. [pc]	T_{eff} [K]	L_* [$L_\odot$]	M_* [$M_\odot$]	Age [Myr]	Membership
HD 9672	A1V	59.4	8900	16.4	2.00	40	Argus
HD 10939	A1V	62.0	9100	30.9	2.25	346	-
HD 17848	A2V	50.5	8450	15.7	1.93	372	-
HD 21997	A3IV/V	71.9	8300	11.2	1.85	30	Columba
HD 50571	F7III-IV	33.6	6550	3.2	1.30	300	-
HD 95086	A8III	90.4	7550	7.0	1.70	17	LCC
HD 161868	A0V	31.5	8950	26.5	2.10	342	-
HD 170773	F5V	37.0	6650	3.5	1.30	200	-
HD 182681	B8/B9V	69.9	9650	24.7	2.18	144	-
HD 195627	F1III	27.8	7300	7.4	1.57	805	-

Herschel program ID: OT1_pabraham_2

We obtained PACS imaging at 70/100/160 μm in mini-scan map mode, and SPIRE photometry at 250/350/500 μm. We detected all our sources at 70 – 350 μm, and some of them even at 500 μm. Five of our targets have never been observed at submillimeter wavelengths before.

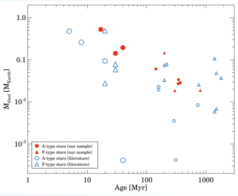
RESULTS

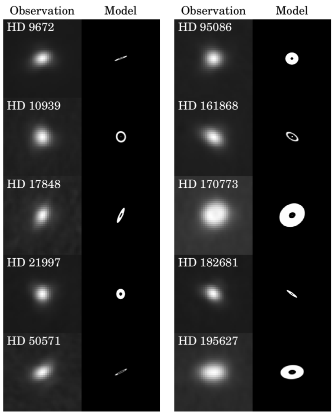
- We complied the spectral energy distribution (SED) of each object. To determine disk parameters, we modeled the SEDs with modified blackbody components.
- Our modeling revealed cold dust belt in each system, with T_{cold} = 44 – 83 K. Moreover, 6-7 of our targets seem to harbor an additional warm belt, with T_{warm} = 127 – 190 K.
- The origin of the warm component might be

(1) sublimation of icy planetesimals crossing the snow line; or

(2) due to collisions in an asteroid belt-like system formed just interior to the snow line (Morales et al. 2011).

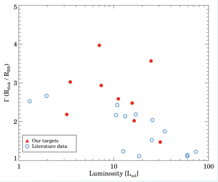
- From submillimeter data we estimated disk masses and plotted them as a function of the age (including literature data). Most of our targets belong to the upper boundary of the distribution, thus represent the most massive debris disk at a specific epoch.





DISK STRUCTURE

- All disks have been successfully resolved at 70 μm, and some at 100 and 160 μm as well. We fitted them with a simple, non-physical disk model with radially constant brightness profile to fit the Herschel images.
- The model is characterized by 4 parameters: position angle, inclination, inner radius, and outer radius. Models were then convolved with the Herschel point-spread-function, and compared to the observed image through Bayesian analysis.
- Except for HD 170773, the inner radius is undetermined from the Herschel image, thus we adopted R_{bb} for it. Disks show a dazzling diversity, with outer radii between 130 and 300 AU.
- These sizes are larger than those inferred from the SED, indicating dust grains with warmer temperature than a blackbody at a given radial distance.
- Gamma factors (R_{disk}/R_{bb}) decrease with increasing stellar luminosity.



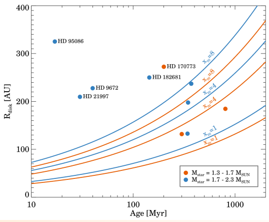
THE STIRRING MECHANISM

- We compared the outer disk radii with the predictions of the self-stirring scenario, using the appropriate age for each target.
- We found that five disks are too extended to be explained with self-stirring. They are the younger systems within our sample.
- Possible alternative explanations:

– Planetary stirring due to yet unseen planets. Indeed, HD 95086 harbors a giant planet detected via diract imaging.

– Stellar flyby is not very likely scenario in our cases (field stars, no companion), although in the case of HD 17848, Deltorn & Kalas (2001) reported the possibility of a recent stellar encounter.

– Faster formation of 1000 km-sized planetesimals at wide separation, e.g., through gravitational collapse (Johansen et al. 2012)



CONCLUSIONS

- By successfully resolving the disks, and comparing the observations with theory, we found that in the five youngest system self-stirring can be excluded with high probability.
- These systems are prime candidates for alternative excitation mechanisms, like planetary stirring. Remarkably, one of them, HD 95086 is a host star of a wide separated giant planet.
- The result that *all* the young disks seem to be inconsistent with self-stirring, might suggest that planetary stirring may have a higher importance in the excitation of debris systems

INDIVIDUAL SOURCES

HD 21997: recently, a giant planet at large orbital radius was directly imaged around this star (Rameau et al., 2013). This object is a prime candidate for planetary stirring (see Moor et al. 2013a; poster of Kóspál et al.). The planetary system resembles the one around HR 8799: both stars harbor a warm inner dust belt and a broad colder outer disk, as well as giant planet(s) inbetween the two dusty regions.

HD 95086: one of the rare debris disks where significant amount of molecular CO gas has been detected (Moór et al. 2011). Our ALMA observations demonstrated that while the dust may have secondary origin, the gas may rather be primordial (Kóspal et al. 2013, Moór et al. 2013b, talk by Á. Kóspál.)

RELATED LITERATURE

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