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Herschel Observations of the HR 8799 Disk

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Abstract. The HR 8799 four-planet host is known to host a multi-component disk from *Spitzer* observations. We have obtained *Herschel*† observations of the disk which provide increased sensitivity and resolution of its outer components: the planetesimal belt and halo. We find that the two components cannot be discerned from the spectral energy distribution alone, but require resolved images to independently identify them. In the resolved images, the halo stands out for its steep radial profile and large radial extent to 2000 AU, a factor of two larger than was estimated from *Spitzer* data.

Keywords. stars: individual (HR 8799), stars: circumstellar matter, planetary systems

1. Background

The excess emission indicating a debris disk was first detected around the A star HR 8799 by IRAS (Moshir *et al.* 1990). The disk was not resolved until after the detection of a directly imaged planetary system around HR 8799 (Marois *et al.* 2008). Using *Spitzer*, Su *et al.* (2009) identified three components present in the disk: a warm inner component and two colder outer components: the planetesimal belt extending from 100-300 AU and the halo extending to 1000 AU. Excepting that very extended halo, the architecture of the HR 8799 system is very similar to that of the Solar System, with a warm inner disk, four gas giants (Marois *et al.* 2010) and then an outer, cold planetesimal disk.

2. Herschel Observations

We have obtained deep maps of HR 8799 with *Herschel* using both PACS (Poglitsch *et al.* 2010) and SPIRE (Griffin *et al.* 2010) and thereby obtain flux measurements for the disk at 70, 100, 160, 250, 350 and 500 μm. The disk is resolved from $70 - 250$ μm (Matthews *et al.* 2013). Figure 1 combines the *Herschel* data with earlier data from Moshir *et al.* (1990), Williams & Andrews (2006), Su *et al.* (2009), Ishihara *et al.* (2010) and Patience *et al.* (2011) to produce a well-sampled SED. We find a best fit model of two temperature components: 153 ± 15 K and 36 ± 1 K. The *Herschel* data are not sensitive to the warmer component, which is traced primarily by *Spitzer* MIPS and IRS data (Su *et al.* 2009).

† Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

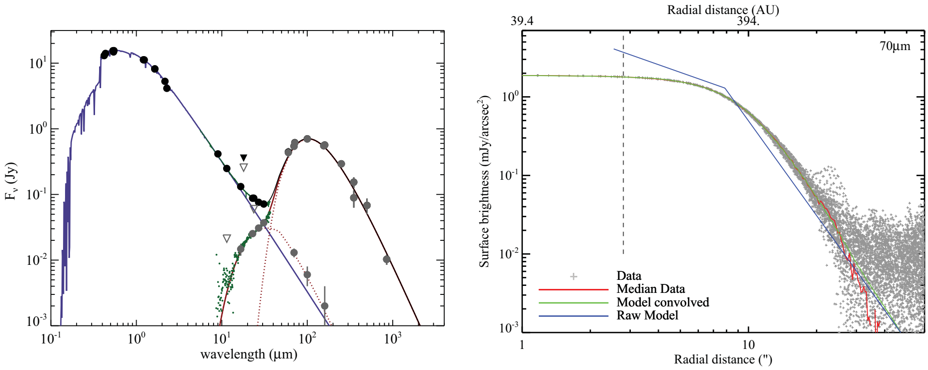

Figure 1. (left) The SED of the HR 8799 disk is shown, with independent curves for the warm blackbody component and the modified cold blackbody component. The stellar emission is fit with a T_{eff} of 7380 K and $L_* = 5.4 L_\odot$, consistent with a late-A or early F-type star. The temperatures of the disk components are 153 ± 15 K (the warm unresolved component not detected by *Herschel*) and 36 ± 1 K (the cold resolved component). There is no temperature distinction between the halo and the planetesimal belt evident in the SED. (right) The radial profile of the disk at 70 μm. The HWHP is indicated by a dashed line. The break in the surface brightness profile around $10''$ is apparent and justifies the interpretation of a two-component model for the outer disk. The data constrain the surface brightness profile very well out to $20 - 30''$ ($800 - 1200$ AU). Figures are from Matthews *et al.* (2013), in preparation.

The *Herschel* images (not shown here) do not exhibit any azimuthal asymmetries. The radial profile produced by azimuthally averaging the data is shown in Figure 1. From this profile, it is clear that the cold component of the disk is comprised of material with two different distributions. The planetesimal belt exhibits a shallow profile from $90 - 310$ AU (the inner radius is constrained to within ± 10 AU) while the halo exhibits a much steeper profile. Separate fits to the resolved images show that the index of the radial profile of the planetesimal belt is ~ -1 (constraint of this parameter is degenerate with the unresolved central flux and the unresolved inner edge of the belt) while the better constrained halo profile index has values of -4.0 ± 0.3 and -3.5 ± 0.5 at 70 and 100 μm respectively. We are able to trace the halo emission to a radius of 2000 AU from the central star. We discuss the non-standard filtering applied to reconstruct the maps to capture the largest scale structures in Matthews *et al.* (2013).

These data illustrate that structural features in disks can be masked by the modeling of SEDs in the absence of resolved imaging. The fact that the halo of HR 8799 matches so closely the temperature of the planetesimal belt suggests that the grains are almost blackbodies. Non-blackbody grains would necessarily emit less efficiently than blackbodies and would therefore exhibit higher temperatures to maintain thermal equilibium.

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