Resolved Debris Disk Around η Tel: A Young Solar System or Ongoing Planet Formation?

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Abstract

Over half of the A star members of the 12Myr-old [1] Beta Pictoris moving group (BPMG) show significant excess emission in the mid-infrared, several million years after the proto-planetary disk is thought to have dispersed. Theoretical models suggest this peak may coincide with the formation of Pluto-sized planetesimals in the disk, stirring smaller bodies into collisional destruction. Here we present resolved mid-infrared imaging with TReCS of the disk of η Tel (A0V in the BPMG) and consider its implications for the state of planet formation in this system.

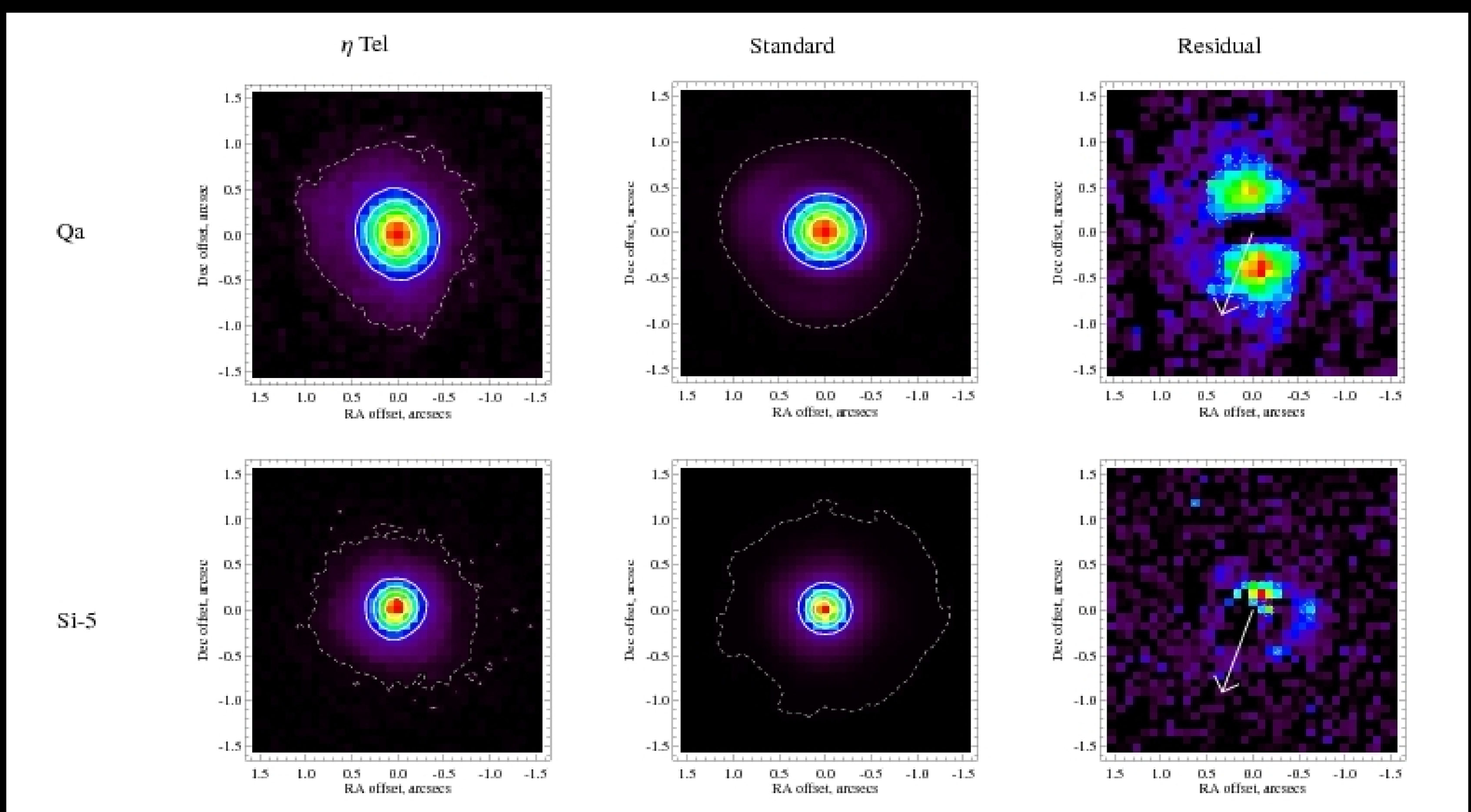

Fig. 1. This shows the observations of η Tel taken with TReCs on Gemini South. Observations taken with filters Qa (λ=18.3μm) (top row) and the Si-5 (λ=11.7μm) (bottom) are shown after co-adding all exposures. Orientation of the images is North up, East left.

Left: The total co-added images of η Tel. Solid line contours are at the 20%, 40%, 60%, and 80% of the peak levels for all images. Note the distinct ellipticity with major axis in the North-South direction seen in the Qa image of η Tel is not seen in Si-5 or in the standard star images. This is indicative of the extended emission at a PA of 8.º (seen on two nights at same PA), which the residual image (Right) shows

Middle: The co-added images of the standard star forming our reference PSF. Note the lack of ellipticity. Analysis of the PSF variations to check that the extension wasn't due to changes in PSF shape during the observations show the Qa image of η Tel is significantly extended with FWHM=0.117$\pm$0.07, compared to FWHM=0.084$\pm$0.005 for the standard.

Right: The residual emission after subtraction of the total standard star image scaled to the peak of the image of η Tel. This shows in peaks at ~0.43" (21AU) from the star, indicating a near edge on ring. The dashed contour indicates the 3σ per pixel level. The arrow indicates the direction of the M7/8V binary which lies at 4″, PA 160°. Note that the emission seen in the N band residual image is not significant when the variation in the PSF is considered.

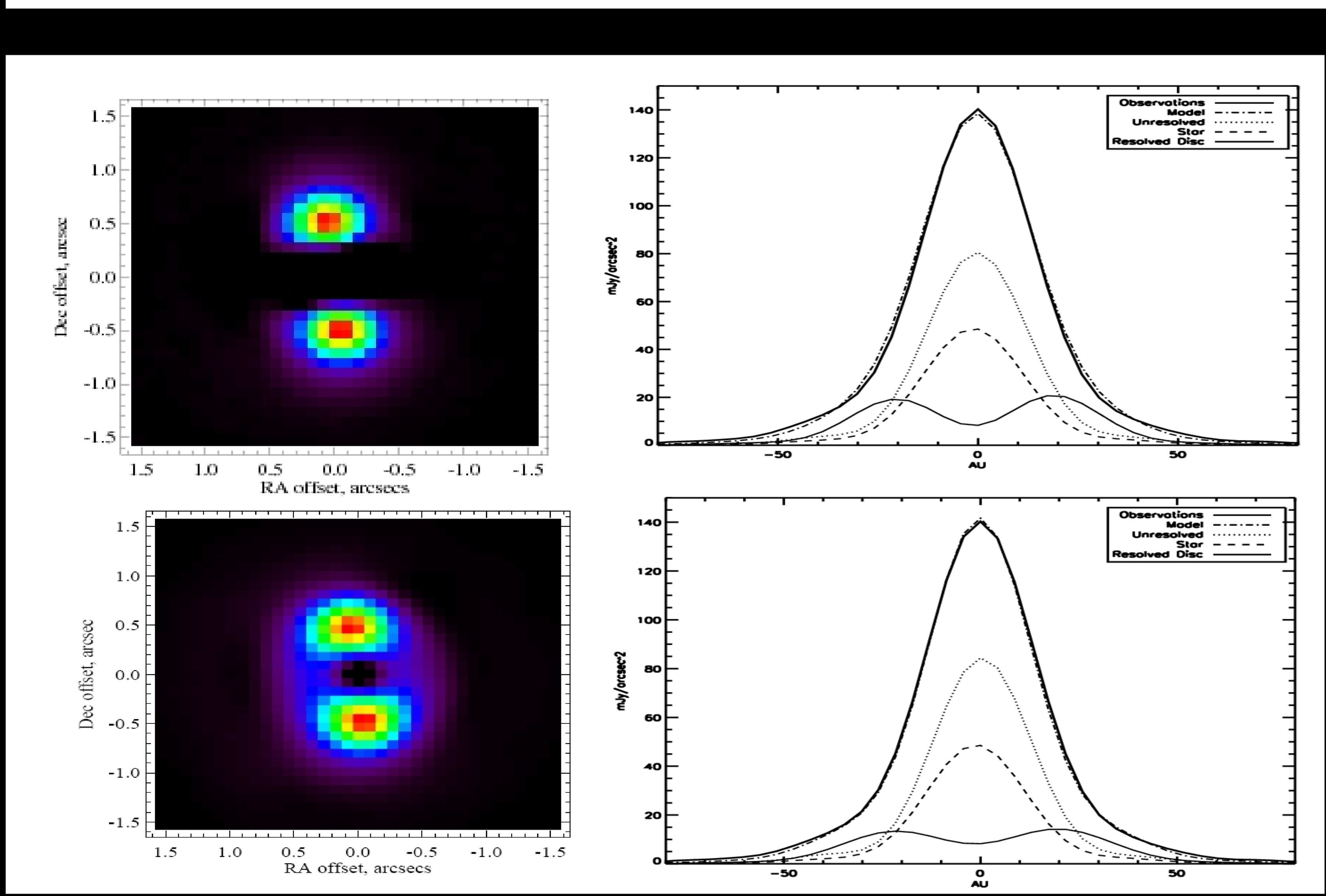

Fig. 2: In order to determine the constraints on the radial distribution of emission provided by the resolved Qa imaging, we considered models for disk structure of increasing complexity. For both models it is assumed that the images are comprised of unresolved stellar flux (114mJy), an additional unresolved disk component, F_{unres}, and an additional resolved component, F_{unres}. The total flux was constrained to $F_{unres}+F_{res}$=257mJy from the IRS flux [5]. The best fitting models were determined by minimisation of χ^2 between the model and observed linecuts taken at a PA of 8°, the direction of extension. Two models were found to provide a good fit to the data.

Top Panel: Young solar system model. This model is a two parameter model that includes stellar flux, an unresolved flux component at 205mJy and an edge-on resolved disk component between 21–26AU, that is a narrow ring. Models with just an unresolved component cannot simultaneously fit the central peak and extended wings of the linecut. Left: The model "residual" image. The model was convolved with the PSF and subjected to the same subtraction (standard star PSF reference image scaled to peak) as the η Tel image. This figure can therefore be compared directly to Figure 1 top right. The colour scale is the same as that image. Right: The line cut through the η Tel Qa image at 8° and the best fitting model at the same position angle. The reduced χ^2 for the model fit to observed line cut was 1.13, and the χ^2 for the fit of the model residual image (left) and the observed model residuals (Fig. 1 top right) was 1.3.

Bottom Panel: Ongoing planet formation model. The self stirred model [3] of the resolved disk component, which is a self-stirred planetisimal belt, and linecut as above. The reduced χ^2 for the linecut fit was 1.21 and for the residual image fit was 1.15. The structure of the disk is therefore consistent with an extended planetesimal belt of surface density 0.7xMMSN undergoing planet formation, with an additional component at small AU, possibly from collisions associated with the final stages of terrestrial planet formation.

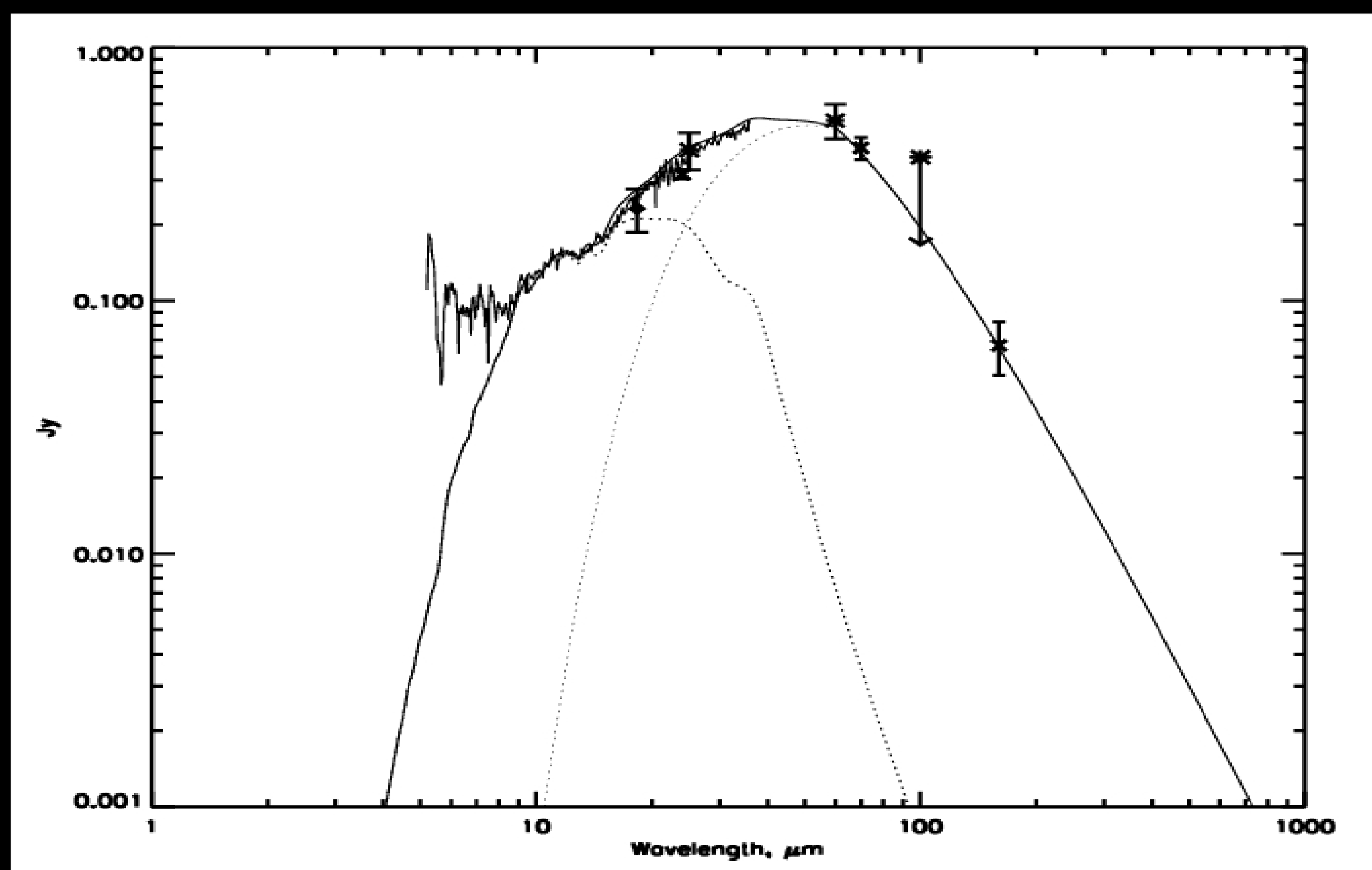

Fig. 3 shows the SED modelling of η Tel with a two component model (unresolved component at ~4AU, and a resolved component at ~24AU (105K)). This confirms the hot and cold component from the modelling (Fig. 2) and sets constraints on the hot component. The two component fit to the SED is fitted to the 18μm flux, with the unresolved component dominating at <18μm, and the resolved component dominating at >18μm. The two component fit to the excess spectrum is shown with a dotted line (unresolved component at 3.9AU) and a dashed line (resolved component at 24AU, 105K). The unresolved component was best-fit by dust grains with a size distribution $n(D)\alpha D^{-3.5}$ [6], with grain sizes 10.8μm-1000μm (below this minimum size grains are removed by radiation pressure). The silicate feature at ~10μm was fitted using a silicate fraction of 30% by volume (with the remaining volume composed of organic refractory material) and a porosity of 0.2. The hot dust population is consistent with it being unresolved as predicted by the modelling (see Fig. 2) . The cold component is consistent with dust located between 21 and 26AU as constrained by modelling the resolved Qa emission and provides a good fit to the Spitzer IRS spectrum. Observations are shown after the subtraction of photospheric contributions: the IRS spectrum [5] (solid line between ~5–30μm), MIPS fluxes (crosses) [7],IRAS colour corrected excess (asterisks) and the contribution to the 18μm fluxes from the unresolved (open triangle) and resolved (open diamond) components, as inferred from the modelling.

Conclusion

Modelling of the resolved images (Fig. 2) and the SED (Fig. 3) indicates that the extension arises from an edge-on disk of radius ~24AU, but that >50% of the 18um emission comes from an unresolved dust component at ~4AU. The radial structure of the η Tel debris disk is reminiscent of the asteroid and Kuiper belts in the Solar System, suggesting that this is a young Solar System analogue [2], as shown in the top panel of Fig. 2. However, for an age of 12Myr, both the radius and dust level of the extended cooler component is also consistent with self-stirring models (in which the collisional cascade in the planetisimal belt is ignited by the formation of a Pluto-sized (~2000km) object [3]) in which case the hot dust component may arise in massive collisions due to ongoing terrestrial planet formation, as shown in the bottom panel of Fig. 2.

References: [1] Zuckerman et al 2001 ApJ 562 L87, [2] Smith et al 2008, Submitted, [3] Kenyon & Bromley, 2004 AJ 127 513, [4] Currie et al 2008 ApJ 672 558, [4] Hauschildt et al 1999 ApJ 512 377 [5] Chen et al 2006 ApJS 166 351 [6]Dohnanyi 1969 J. Geophys. Res. 74 2531 [7]Rebull et al 2008 ApJ 681 1484

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