Resolved 350 Micron Images of Famous Debris Disks

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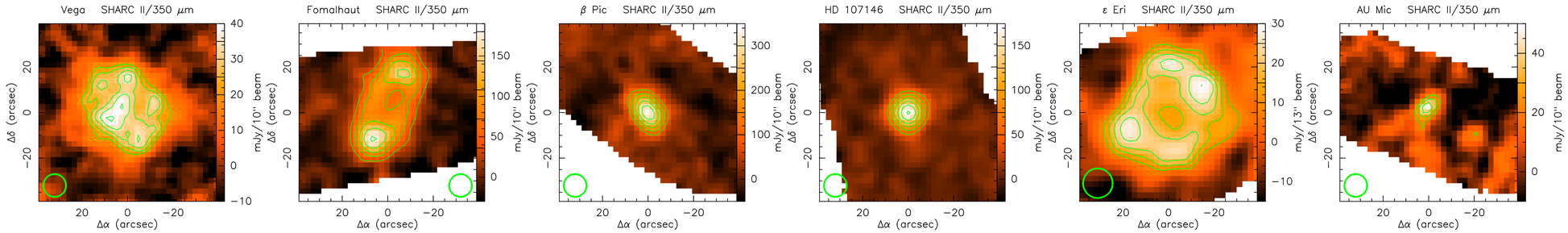

FIGURE 1:SHARC II $\lambda = 350\mu$m images of debris disks. The images are smoothed with a $5''$ FWHM gaussian, resulting in $10''$ FWHM resolution except for ϵ Eri, which is affected by atypical near sidelobes in the beam prior to the commissioning of the telescope surface correction system (DSOS).

Summary

We present resolved 350 μm images of six debris disks obtained using the SHARC II camera[1] on the Caltech Submillimeter Observatory with an angular resolution of $10''$ FWHM.

Source	Integration Time (hr)	Stellar Type	Age (Myr)	Distance (pc)	Detected Radius (AU)
Vega	5.3	A0 V	350	7.8	200
Fomalhaut	3.7	A3 V	200	7.7	150
β Pic	2.8	A5 V	20	19.3	125
HD 107146	3.0	G2 V	100	28.5	110
ϵ Eri	15.8	K2 V	700	3.2	100
AU Mic	1.8	M1 Ve	20	9.9	60

- Disks with central clearing are directly imaged in three sources: Vega, Fomalhaut, and ϵ Eri.

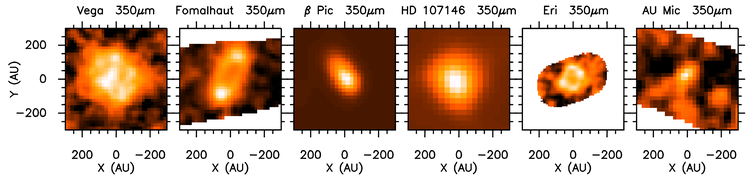

FIGURE 2:SHARC II images displayed at the same physical scale, showing a general decrease in detected dust radius with decreasing stellar mass and luminosity. The images of the most distant sources – β Pic and HD 107146 – are HIRES-enhanced to $5''$ resolution.

Vega

- Vega at 350 μm has a broad ($50''$ detected), low surface brightness (<40 mJy/$10''$ beam) disk with an inner hole or ring (Figures 1 and 4). The noise in our image is 7 mJy/beam rms.

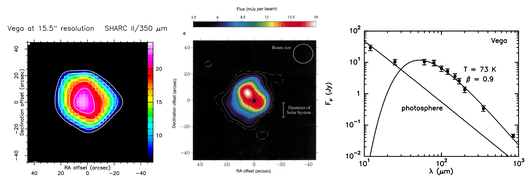

FIGURE 3:Smoothed to the same $15.5''$ resolution, the inner contours of our 350 μm map (left) have the same elongated 'bean' shape and northeast-southwest asymmetry as the SCUBA 850 μm map[2] (middle). The spectral energy distribution (SED) of Vega is shown at right.

- The dust ring aspect ratio (Figure 4) implies an inclination of 40 degrees for the ring (more nearly face-on than edge-on), but with significant uncertainty, and a radius of 110 AU.
- Clumpiness of the ring can not be evaluated at this signal-to-noise.
- The emission extends at least one beam diameter beyond the ring, but we do not have sufficient sensitivity to verify the diffuse debris imaged with Spitzer[3] out to a radius of $100''$ (800 AU).

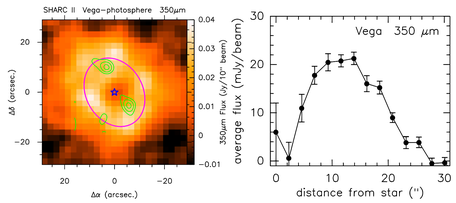

FIGURE 4:Image of Vega (left) and radial profile (right) following subtraction of 30 mJy photospheric emission[3,4], illustrating the detection of the dust ring suspected from prior work[5,3,4]. The purple ellipse is the suggested location of the debris ring. The green contours show the 1.3 mm emission detected at the edge of the Plateau de Bure interferometer primary beam[6], peaking near the ansae of the 350 μm ring where the emission should be concentrated.

Fomalhaut

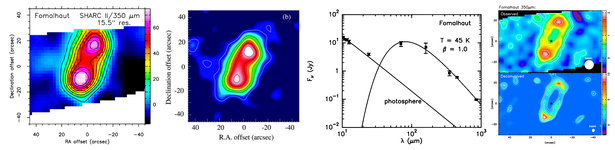

FIGURE 5:The 350 μm (left[7]) and 850 μm (middle-left[8]) images of Fomalhaut, both smoothed to 15.5″ resolution, are remarkably similar, with a slight asymmetry between the eastern and western arcs of the ring. The HIRES deconvolved image of Fomalhaut is shown at right.

- The Spitzer and SHARC II images of Fomalhaut at 24-350 μm have been modeled using DISKFIT[7], which solves for the 2-D map of column density under the assumptions of a power-law dust grain emissivity, radiative energy balance of the grains, and a simple dependence of disk scale height on radius:

Characteristic	Value
inclination of ring to sky	68 degrees
inner, outer radii of ring	110, 180 AU
surface density profile	$r^{1.7}$
vertical thickness of disk	40 AU
eccentricity of ring	0.06
n(apocenter)/n(pericenter)	1.1

β Pictoris

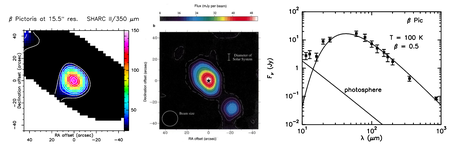

FIGURE 6:Comparison of 350 μm (left) and 850 μm (middle[2]) images of β Pic, both smoothed to 15.5″ resolution. The second peak in the southwest (lower-right) part of the 850 μm image is not detected at 350 μm, placing a 3σ limit of 13(1+z) K on its temperature (β = 1). This is consistent with it being a background submillimeter galaxy[2,5].

- The deconvolved source size of β Pic at 350 μm is $13'' \times < 5''$ FWHM, smaller than $22'' \times < 15''$ FWHM at 850 μm[2]. This is likely a temperature effect which will be explored further in modeling.

HD 107146, ϵ Eridani, and AU Mic

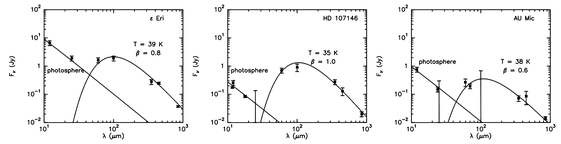

FIGURE 7:SED's of HD 107146, ϵ Eri, and AU Mic, all having cool (T < 40 K) disks.

- HD 107146 is detected in our image with unprecendented submillimeter statistical signal-to-noise of ∼50. Via offset pointing from 3C273 and Callisto in April 2005, we find coincidence of the 350 μm source and star (separation $\lesssim 1.1''$).

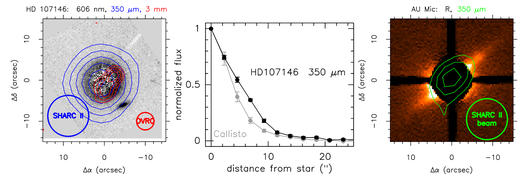

FIGURE 8:We confirm that HD 107146 is resolved in the submillimeter[9,10] (middle). The deconvolved size of $\sim 8''$ FWHM and roundness are in qualitative agreement with the scattered light image[11] (left); both indicate a face-on disk. We tentatively claim that at 350 μm, AU Mic (right) is resolved in the direction of the scattered light disk[12] with a deconvolved extent of $\sim 6''$ FWHM.

Future Plans

- To extract detailed characteristics of the remaining debris disks, we plan to model the 350 μm images with the same DISKFIT approach that was used for Fomalhaut[7], supplementing with SHARC II 450 μm, SCUBA 850 μm, and Spitzer images and eventually SOFIA/HAWC $\lambda \approx 100$ μm data.
- In the era of capable interferometers such as SMA and ALMA, bolometric imaging with single-dish telescopes will continue to play an important role in the study of nearby debris disks due to the broad bandwidth, large field of view, and sensitivity to extended emission.
  - A 25 m Atacama telescope such as the one under study by Cornell and Caltech would be able to make resolved images of >30 debris disks at distances up to 30 pc and, with very large format continuum detector arrays, to efficiently survey nearby star clusters for circumstellar disks.

References

[1]C.D. Dowell, et al. 2003, SPIE, 4855, 73
[2]W.S. Holland, et al. 1998, Nature, 392, 788
[3]K.Y.L. Su, et al. 2005, astro-ph/0504086
[4]I. Sheret, W. R. F. Dent, & M. C. Wyatt 2004, MNRAS, 348, 1282
[5]W.R.F. Dent, H.J. Walker, W.S. Holland, & J.S. Greaves 2000, MNRAS, 314, 702
[6]D.J. Wilner, M.J. Holman, M.J. Kuchner, & P.T.P. Ho 2002, ApJ, 569, L115
[7]K.A. Marsh, T. Velusamy, C.D. Dowell, K. Grogan, & C.A. Beichman 2005, ApJ, 620, L47
[8]W.S. Holland, et al. 2003, ApJ, 582, 1141
[9]J.P. Williams, et al. 2004, ApJ, 604, 414
[10]J.M. Carpenter, S. Wolf, K. Schreyer, R. Laundhardt, & T. Henning 2005, AJ, 129, 1049
[11]D.R. Ardila, et al. 2004, ApJ, 617, L147
[12]P. Kalas, M.C. Liu, & B.C. Matthews 2004, Science, 303, 1990