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A LARGE FLARING DISK AROUND HD97048

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Abstract. Circumstellar disks are ubiquitous around young stars with intermediate ages around a few million years. They are a natural outcome of the star formation process. The pre-main sequence stars of intermediate-mass, the Herbig Ae (HAe) stars, represent a particularly interesting laboratory for studying disks evolution. Although great progress has been made in modelling the disk struture with radiative transfer models able to reproduce the SEDs of Herbig Ae stars, the structure of the disks is not uniquely constrained. Spatially resolved observations are needed to better constrain the geometry of the disks. Transiently-heated polycyclic aromatic hydrocarbons (PAHs) are good tracers of the disk geometry. If the disk is flaring, the PAHs located at the surface of the disk are in direct view of the central star and their emission allows to access the disk structure up to large distances from the star. We present high resolution imaging observations of HD 97048, a young Herbig Ae star, observed with VISIR, a mid-infrared instrument installed at the VLT. VISIR images reveal a flaring disk inclined to the line of sight, extended up to at least 370 AU. The geometry of the disk is in agreement with predictions based on existing models of passive centrally irradiated hydrostatic disks made to fit the SEDs of the Herbig Ae stars.

1 HD97048

We have started a program of imaging nearby HAe stars with VISIR, the new mid-infrared instrument attached to the third 8-m unit of ESO's Very Large Telescopes located at Cerro Paranal, Chile. One of the first targets was HD 97048 which has a strong IR excess and strong PAH features. HD 97048 is a Herbig Ae/Be star, member of the Chamaeleon I association, situated at 180 pc (Van den Ancker et al. 1997; Whittet et al. 1997). The Spectral Energy Distribution (SED) is rising in the far infrared, so that HD 97048 has been classified as a HAe star of group 1, which is characteristic of a flared disk (Meeus et al. 2001). Spectroscopic observations of the near- and mid-IR excess have revealed the presence of strong PAH features at 3.3, 6.2, 7.7, 8.6, 11.3 microns (Siebenmorgen et al. 2000, Van Kerckhoven et al. 2002). The very extended part of the emission in the mid-IR (Prusti et al. 1994; Siebenmorgen et al. 2000) is most likely due to an extended envelope surrounding the star and the disk of transiently heated very small grains and PAHs. Mid-IR long slit spectroscopic observations with TIMMI2 show that the aromatic emission features at long wavelength (i.e., 8.6 and 11.3 μm) are spatially extended and comes mostly from a region of 200-300 AU, likely a disk (Van Boekel et al. 2004).

2 Observations

The object was observed in the PAH band at 8.6 and 11.3 μm, and in the adjacent continuum (Tab. 1) with an imaging-mode of the ESO mid-infrared instrument VISIR installed on the VLT called the BURST mode. This mode allows diffraction-limited image in the N band. The principle is to take short enough exposure images ($\lesssim$ 50 ms) to freeze the turbulence (Doucet et al. 2006). To correct from the turbulent effect, the data are stored every 1000 elementary images in one nodding position for a chopping frequency of 0.25 Hz in the direction north/south. The nodding direction is perpendicular to the chopping direction with an amplitude of 8". The object and the reference star are observed at an airmass around 1.6.

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Table 1. Comparaison of the FWHM for the object and the reference star (PSF) in the different filters. We also mentionned the theorical value of the FWHM in order to show that the diffraction-limit is obtained with the BURST mode. In order to see the spatial extension, we give in the third and fourth columns the distance from the star at 10 σ above the noise in the east/west direction.

		HD97048					PSF		
Filter	Central— wavelength— (μm) —	Flux measured (Jy)	East (10 σ) (arcsec)	West (10 σ) (arcsec) —	FWHM (E/W) (mas)	FWHM — (N/S)— (mas)	FWHM (E/W) (mas)	FWHM — (N/S)— (mas) —	FWHM (diffraction) (mas)
PAH1	8.59	5.5 $\pm$ 0.1	1.27	0.75	330 $\pm$ 15	330 $\pm$ 15	240 $\pm$ 15	225 $\pm$ 15	225
ArIII	8.99	3.7 $\pm$ 0.1	0.75	0.52	300 $\pm$ 15	330 $\pm$ 15	240 $\pm$ 15	232 $\pm$ 15	217
SIV	10.49	4.2 $\pm$ 0.1	0.67	0.60	322 $\pm$ 15	337 $\pm$ 15	277 $\pm$ 15	262 $\pm$ 15	262
PAH2	11.26	7.7 $\pm$ 0.1	1.60	0.90	337 $\pm$ 15	360 $\pm$ 15	300 $\pm$ 15	285 $\pm$ 15	285
NeII	12.27	6.7 $\pm$ 0.2	0.67	0.60	390 $\pm$ 15	412 $\pm$ 15	300 $\pm$ 15	307 $\pm$ 15	307

3 Results

Figure 1 presents the images of HD 97048 obtained in the PAH emission filters, as well as in the adjacent continuum emission. HD 97048 is quite extended (up to 2 arcsec) compared to the reference star. Furthermore, comparing the emission in the PAH band and in the adjacent continuum, the emission in PAH is much more extended than in the continuum. In the PAH2 filter, the disk is extended to 330 AU (surface brightness of 112 mJy/"2) whereas the extension in the continuum at 10.5 μm goes to 135 AU (surface brightnesss of 410 mJy/"2). These results are in agreement with those found by Van Boekel et al. (2004): 270 $\pm$ 70 AU at 11.3 μm and 110 $\pm$ 40 AU at 10.5 μm. Furthemore, the full-width at half-maximum (FWHM) of HD 97048 is 1.2 times those of the standard star, close the diffraction-limit, for almost all filters (Tab. 1).
The images in PAH band reveal a large extended emission with a strong east-west asymmetry. The brightness isophotal contours are elliptical in shape. The centre of the ellipse is displaced eastwards from the peak of emission which corresponds to the star location. The decentering increases when lowering isophote contours up to a mean isophote radius of 370 AU. Such features are characteristic of a flaring disk, vertically optically thick at the wavelength of the observations and inclined to the line of sight (Lagage et al. 2006). To retrieve quantitative information about the disk flaring in these regions, we have fitted the east and west brightness profiles with a simplified model. In this model (Lagage et al. 2006), the PAH-emitting region is only located at the surface of the disk whose height, Hs, varies according to the astrocentric distance following a power law: $\mathrm{Hs(r)=H_0.(r/r0)^{\alpha}}$. We further assume that the spatial variation of the flux intensity, I, follows a power law: $\mathrm{I(r)=I_0.(r/r0)^{\beta}}$, where I_0 is the intensity at the astrocentric distance r0 and β the power law index. This hypothesis is only valid once the continuum emission contribution in the PAH filter has been removed, which we have done by extrapolating the continuum emission observed. The power law index β for the intensity is found to be $-2.3^{+0.2}_{-0.0}$, close to the expectation of an index -2 for PAH emission and the disk is inclined by $42.8^{+0.8}_{-2.5}$ degrees.The flaring index α is found to be 1.26 $\pm$0.05 in agreement with the value expected from hydrostatic, radiative equilibrium models of passive flared disks (Chiang & Goldreich 1997).

4 Modelisation

The disk is heated by irradiation from the central star, in hydrostatic equilibrium in the vertical direction, with dust and gas well mixed. We used the model of Dullemond et al. (2001, 2004) which could already account for the SED of a quite high number of Herbig Ae stars. Here, the model includes PAHs stochastically heated in addition to large grains in thermal equilibrium. We wonder if a sophisticated model of disk could explain the SED of HD97048 and at the same time, the spatial distribution of the circumstellar material in the PAH band. The disk is heated by a typical Ae star with effective temperature $T_{eff} = 10500K$, luminosity $L_\star = 32L_\odot$ and mass $M_\star = 2.5M_\odot$, which are suitable for HD 97048 (Van den Ancker 1998). The surface density of the disk is $\Sigma = \Sigma_0\ (r/R_{in})^{-q}$ with q the power law index equal to 3/2 inferred for the solar nebula (Weidenschilling 1977) and $\Sigma_0 = 444\ g.cm^{-2}$. This implies a total disk mass of 0.01 $M_\odot$. The grains are composed of graphite

and silicate as in Dullemond et al. (2001, 2003). For simplicity, we take one size of PAH, i.e. $N_C = 100$. The hydrogen to carbon ratio is H/C=0.1. We assume that PAH are neutral and they have the same properties along the disk.
Here, the model could roughly reproduce the observed SED of HD97048 which is characterised by a near-IR bump, a quite high ratio between 30 and 10 μm and strong PAH emission features (Fig 2). This aspect is showing that the disk intercepts a large fraction of energy in the outer part and this is indeed evidence of a flared disk geometry. The model predicts a spatial distribution of PAH emission very similar to those observed (Fig 2). The disk model predicts, as in the observations, an asymetry east/west, which only results from the inclination of a flared disk optically thick at the observed wavelength. The emission at 11.3 μm (band + continuum) is, in the central part, dominated by the thermal grains emission whereas in the outer part, it is dominated by the PAH emission feature.

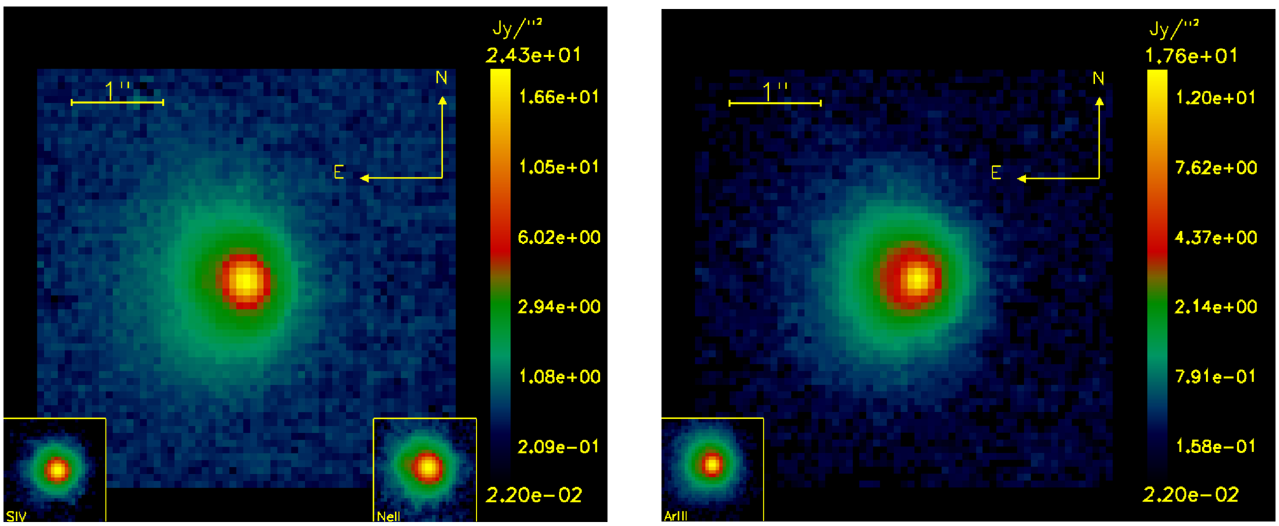

Fig. 1. *On the left*, HD 97048 in the PAH2 filter (*image in the middle*), and in the adjacent continuum (SIV *on the left*, NeII *on the right*). The images have the same signal-to-noise so that it is possible to compare the extension. *On the right*, HD 97048 in the PAH1 filter (*in the center*) and in the adjacent continuum (ArIII, *in the left corner*).

5 Conclusion

We have observed with VISIR HD97048 in the PAH band. It is surrounded by a large flaring disk optically thick at the observed wavelength inclined to the line of sight. The PAH emission can probe the external region of the disk of HAe stars and allows to see the disk extended up to 350 AU. The existing models of passive centrally irradiated hydrostatic disks made to fit the SEDs of the Herbig Ae stars could explain the SED and, at the same time, the spatial distribution of PAH emission around HD97048. These observations are a strong support to the existing disk's physics in these systems.

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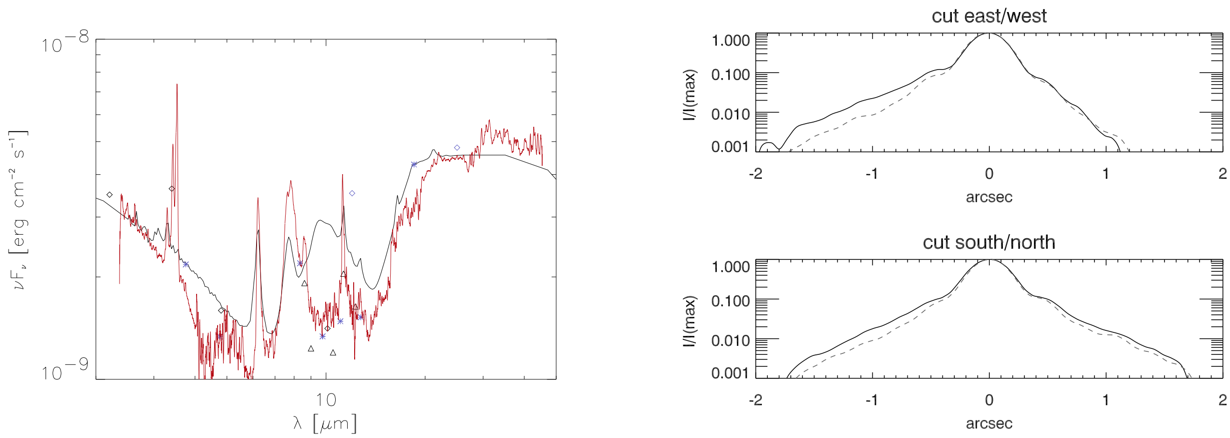

Fig. 2. *On the left*, SED observed and calculated with the model. Full red line shows ISO SWS spectrum of HD 97048. Points of photometry are taken from Hillenbrand et al. 1992 (open diamond black), IRAS (open diamond blue), Prusti et al. 2004 (blue crosses) and VISIR measurement (black triangle). *On the right*, cut in north/south and east/west (up panel) for the model in the PAH band at 11.3 μm convolved with VISIR PSF (dashed line) compared to the observation (full line). The disk is inclined by 43 degree and is situated at a distance of 180 pc. It is heated by a typical Ae star with effective temperature $T_{eff} = 10500K$, luminosity $L_\star = 32L_\odot$ and mass $M_\star = 2.5M_\odot$. The disk is flared with a total mass of 0.01 $M_\odot$, R_{in}=0.41 AU and R_{out}=370 AU.(Doucet et al. 2006b, in preparation)

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