A&A manuscript no.
(will be inserted by hand later)

Your thesaurus codes are:
06(02.01.2; 08.02.1; 08.03.4; 08.06.2; 08.09.2 HV Tau; 08.16.5)

ASTRONOMY AND ASTROPHYSICS

Disks in multiple systems: direct imaging of a nearly edge-on circumstellar disk in the young triple system HV Tau ⋆

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Received 3 March 2000 / Accepted 16 March 2000

Abstract. We present high resolution near infrared images of the young triple system HV Tau which clearly reveal a circumstellar disk around HV Tau C. The disk is seen nearly edge-on ($i \approx 84^o$), and has a radius of $\approx 50\,AU$. HV Tau AB, a 74 mas binary (Simon et al. 1996), is resolved as well. If HV Tau C is bound to HV Tau AB, these are the first near-IR images of a circumtertiary disk in a young multiple system.

Key words: Accretion, accretion disks – binaries:close – circumstellar matter – Stars: formation – **Stars: individual:** HV Tau – Stars: pre-main sequence

1. Introduction

It is now well established that circumstellar disks, together with bipolar outflows, are a ubiquitous product of low-mass star formation. Disks have been detected during high angular resolution imaging surveys around isolated young stars (e.g. HH 30, Burrows et al. 1996; DM Tau, Guilloteau & Dutrey, 1998) and since most T Tauri stars actually belong to multiple systems the fate of disks in such an environment has also been investigated. This has led to spectacular images of both circumbinary and circumstellar disks in young binary systems (e.g. GG Tau, Dutrey et al. 1994, Roddier et al. 1996; UY Aur, Duvert al. 1998, Close et al. 1998; HK Tau C, Stappelfeldt et al. 1998).

These structures qualitatively agree with theoretical models of binary formation. For instance, the models of Bonnell et al. (1992) form binaries from the collapse of a rotating elongated cloud. During the collapse, each component of the protobinary is surrounded by a circumstellar flattened structure. Unfortunately, the computations do not cover a long enough time span to follow the fate of the circumstellar matter, from the initial thick flattened structures to the final multiple system and its circumstellar environment, and this makes it still difficult to directly compare model predictions and observations.

Send offprint requests to: J.-L. Monin
⋆ Based on observations made at Canada-France-Hawaii Telescope

In this paper, we present high angular resolution, near infrared images of the young triple system HV Tau. The images clearly resolve an almost edge-on circumstellar disk around HV Tau C, the third component of the system. We briefly describe the observations in Section 2, derive the basic structural parameters of the disk around HV Tau C and the astrometry of the tight HV Tau AB binary in Section 3, and discuss in Section 4 the circumstellar properties of the components of the triple system as well as its overall geometry that provides clues to its formation mechanism.

2. Observations

JHK images of HV Tau were obtained using PUEO adaptive optics system equipped with the near-IR camera MONICA (Nadeau et al. 1994) at CFHT on Sept. 29, 1996. Monica includes a Nicmos 3 256^2 pixel array, with a plate scale of 0.0344″/pixel, yielding a field-of-view of $9''$, thus encompassing the three components of the HV Tau system. Since the primary objective of the observational program was to obtain differential photometry of the components in a sample of young binaries, the integration time was limited to 30 seconds in each filter. For HV Tau, the angular resolution on reduced images ranges from about 0.07″ in J to 0.13 ″ in K.

3. Results

The young triple system HV Tau consists of a tight binary, HV Tau AB, with a projected separation of 0.074″ (Simon et al. 1996, S96), and a third component, HV Tau C, located $\approx 4''$ away from the primary. The JHK photometry of HV Tau AB and HV Tau C measured on our images is listed in Table 1. HV Tau AB has similar JHK magnitudes as those previously reported by Woitas & Leinert (1998), but HV Tau C has dimmed by about 1 mag between their observations and ours. In this section we discuss in turn the high angular resolution images obtained for the various components of the system.

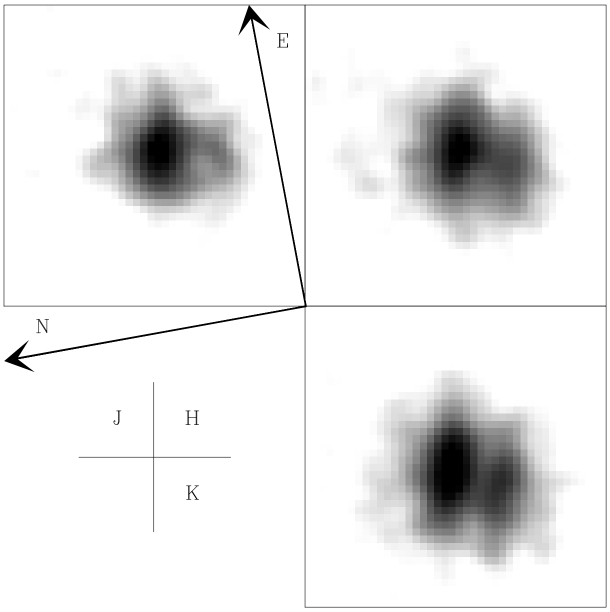

Fig. 1. JHK grey scale images of HV Tau C. The field of view is $1.44 \times 1.44''$; the log scale of the plot goes from 3σ to 0.9 times the peak in every image. Note the dark lane of the disk, clearly seen in the K and H images.

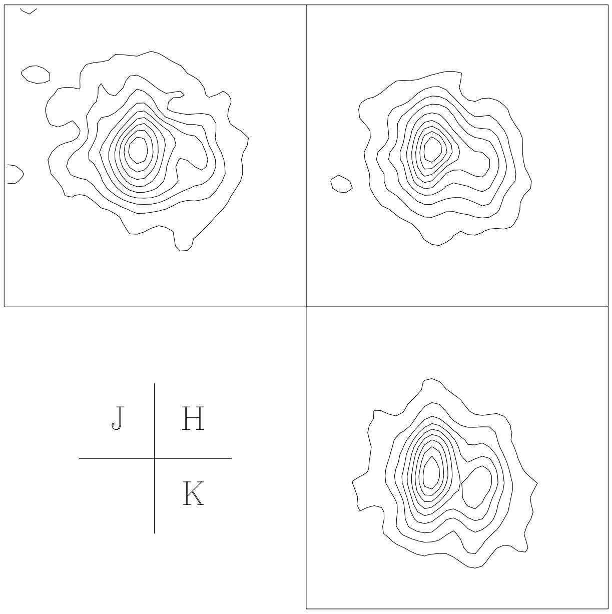

Fig. 2. Contour plots of HV Tau C. Intensity levels are drawn every 10% of peak value in all three images. The orientation and field of view are the same as in figure 1.

Table 1. JHK photometry of the HV Tau system

Filter	HV Tau AB	HV Tau C	Δmag
J	9.20	14.66	5.46
H	8.26	13.69	5.43
K	7.80	12.98	5.18

3.1. HV Tau C: a nearly edge-on disk

The JHK images of HV Tau C are shown in Figure 1. The central dark lane, best seen in the K image and oriented at a P.A. of $\approx 110^o$, delineates the disk's midplane. On each side, bright lobes correspond to photons from the central star scattered back to the observer in the disk's upper layers and in optically thin bipolar cavities. The central star itself is not seen, being heavily extincted by the disk midplane. Comparing these images with synthetic ones computed from a single scattering disk model (Lazareff et al 1990, LPM90), we derive an inclination of $\approx 84^o$ for HV Tau C's circumstellar disk.

Intensity contours shown in figure 2 provide further details on the circumstellar structure around HV Tau C. In all the images, the disk appears to have the same radial extension of ≈ 50 AU. That the disk radius does not depend upon wavelength suggests a sharp outer disk boundary, possibly truncated by the the tidal influence of HV Tau AB. The flux ratio between the northern and southern scattering cavities varies with wavelength. The northern lobe is located on the frontside of the disk and the southern one on the backside so that stellar photons scattered in the latter are obscured by the disk outer regions. Hence, the northern lobe is brighter than the southern one at JHK and the southern one is better seen at longer wavelengths as the disk's optical depth decreases. Finally, the extension of the northern lobe in a direction perpendicular to the disk midplane seems larger at J than at K. This may result from the higher scattering efficiency at shorter wavelengths that allows the observer to detect a more extended part of the scattering medium above the disk midplane at J. All these features and their variations with wavelength are in qualitative agreement with model images of nearly edge-on disks and associated bipolar scattering cavities (LPM90).

3.2. HV Tau AB

Contour plots of HV Tau AB in the JHK bands are shown in figure 3. The contours are clearly elongated in all 3 images with a PA of 310^o. This PA differs by 180^o of $PA = 130^o$ derived by Simon et al. (1996) for this system at visible wavelengths. It might thus be that the eastern component is the brightest one in the near-IR but becomes fainter than the western component at visible wavelengths. However, since the observations were not simultaneous, it may also be that the 180^o flip of the PA between S96's observations and ours is merely the result of instrinsic photometric variability of one of the components or both. HV Tau AB is a weak-line T Tauri star and photometric variations of a few tenths of a magnitude would not be surprising. In fact, S96 found the V-band flux ratio to vary at different epochs, and at least one of their measurement yields a flux ratio of unity.

We have performed a cut along the PA of the binary in the J image and fitted the resulting profile with three gaussian curves (see Figure 3), two of which correspond to the FWHM profiles of HV Tau A and B (FWHM=$0.072''$), and the third one has a much larger FWHM in order to remove the low-intensity pedestal that arises from incomplete adaptive correction. From this fit, we derive a separation of 73 ± 2 mas between HV Tau A and B, fully consistent with the 74 mas V-band measurement of S96. Given that HV Tau AB semi-major axis is ≥ 10 AU, it is not surprising to find the same PA and separation in our 1996 data than in S96's ones obtained in 1994. On a longer time basis, however, HV Tau AB is a good candidate to detect actual orbital motion. We also derive a flux ratio A/B ≈ 2.4 ($\Delta J \approx 0.9$).

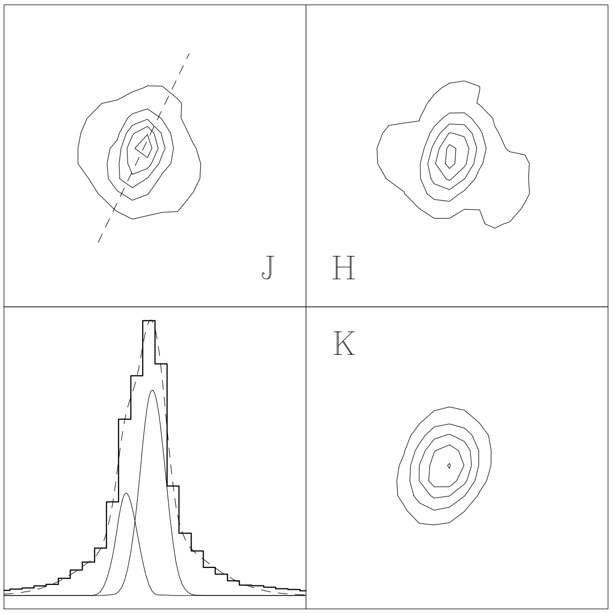

Fig. 3. HV Tau AB images in JHK. The orientation is the same as in figure 1, and the field of view is $0.69''$ on a side. The lower left plot shows a cut along the dashed line drawn along PA = 310^o in the J image above, together with the two gaussian components corresponding to HV Tau A and B. A third gaussian (not shown) has been fitted to the large, low-level pedestal of the profile. The dashed line superimposed on the measured profile illustrates the quality of the fit.

4. Discussion

The nature of HV Tau C has been subject to controversy. On the basis of a low-resolution spectrum that exhibits strong Hα and forbidden lines, Magazzú & Martín (1994, MM94) suggested that HV Tau C is a Herbig-Haro object formed in an outflow emanating from HV Tau AB. This interpretation has been disputed by Woitas & Leinert (1998, WL98) as they failed to measure any significant proper motion of HV Tau C between MM94 observations and theirs, in apparent contradiction to expectations for a fast-moving HH object. Moreover, they noted that the low-resolution spectrum of HV Tau C obtained by MM94 also exhibits a strong continuum ressembling that of a late-type photosphere. They thus concluded that HV Tau C is a low-mass stellar companion to HV Tau AB and further hypothesized that the star is seen through a nearly edge-on circumstellar disk. This peculiar viewing angle would qualitatively account for the much lower apparent luminosity of HV Tau C compared to HV Tau AB in spite of its spectral energy distribution indicative of a hotter black-body temperature.

The images reported here directly confirm Woitas & Leinert's conjecture. HV Tau C thus appears to be a low-mass star of spectral type about M0 (or slightly later if veiling is significant) according to the low-resolution spectrum shown in MM94. The spectrum exhibits strong forbidden emission lines and EW(Hα) $\sim$ 15Å, which indicate that HV Tau C is a classical T Tauri star which actively accretes from its disk. The forbidden line emission most likely arises from a jet originating from HV Tau C itself. As already pointed out by WL98, the small Doppler shift of forbidden line profiles is consistent with a fast outflow moving nearly in the plane of the sky, i.e. perpendicular to the disk. In fact, the [SII] image obtained by MM94 seems to show an elongation of the HV Tau C contours toward the south, which might correspond to a jet emanating from the central object. Higher angular resolution images are required to confirm this possibility.

HV Tau C spectral energy distribution also exhibits a strong excess flux at 10 μm (WL98) and the unresolved HV Tau system has been detected as a mild continuum source at 1.3mm, with a flux density of 40 mJy (Osterloh & Beckwith 1995). The source of continuum emission in the triple system is most probably HV Tau C's disk since HV Tau AB is a weak-line binary with EW(Hα) = 8.5Å (Kenyon et al. 1998).

Assuming HV Tau C and HV Tau AB are coeval, the 3 components of the system appear to have a similar mass of about $0.5 M_\odot$ (similar spectral type for HV Tau A and C and a V-band flux ratio close to unity for HV Tau A and B) and an age of about 1.5 10^6 yr, according to Siess et al. (2000) evolutionary tracks. A major difference, however, is that HV Tau C is still actively accreting from its disk while HV Tau AB shows no sign of active accretion, nor even of a passive disk since its spectral energy distribution is well fitted by a black-body curve (WL98). It is tempting to speculate that tidal interaction between the various components of the system and their circumstellar environments is responsible for this situation.

With a projected separation of 10 AU, primordial circumstellar disks in the HV Tau AB binary have been severely truncated leading to a fast evolution on a short viscous timescale. The lack of IR excess in HV Tau AB further suggests that the system is not surrounded by a circumbinary disk or ring, unlike e.g. GG Tau or UY Aur. While such a disk/ring might have been expected to survive on a longer timescale, it is possible that its absence is due to the tidal influence of HV Tau C, located at a projected distance of 560 AU, i.e., a distance not very different from the radius of the circumbinary disks observed around GG Tau and UY Aur.

Conversely, we argued above that HV Tau C's circumstellar disk might have been tidally truncated by the gravitational influence of HV Tau AB since its 50 AU radius does not seem to strongly depend upon wavelength. However, the ratio of outer disk radius to the projected separation between HV Tau C and AB is about 0.1, which is significantly less than expected for a tidally truncated disk in a system with $q \simeq 0.5$ (Armitage et al. 1999). By comparison, this ratio amounts to 0.3 for the circumsecondary disk of the HK Tau system (Stappelfeldt et al. 1998). Hence, unless the orbit of HV Tau C is highly eccentric, its disk might well have evolved up to an age of $\sim$1.5 10^6 yr without having been much perturbed by the presence of HV Tau AB.

Finally, we note that the position angle of the disk around HV Tau C is nearly the same as the position angle of the tight binary HV Tau AB ($\sim 110°$ and $\sim 130°$, respectively). Although it may be a mere coincidence since HV Tau AB has been observed at only one phase of its orbit, it could also indicate that the orbital plane of HV Tau AB is parallel to the plane of the circumstellar disk of HV Tau C. Coplanarity of HV Tau AB orbit and HV Tau C disk is, however, unlikely since it would then imply an actual separation between AB and C of $560AU/\cos i \sim 5600AU$ given a disk inclination of $i \simeq 84°$. The formation of parallel but non coplanar systems has been predicted to result from the collapse of elongated clouds with rotation about an arbitrary axis (Bonnell et al. 1992). The collapse produces two fragments surrounded by parallel but non coplanar disks, each of which may further fragment to form a close binary system. The appearance of the HV Tau triple system supports this formation mechanism.

5. Conclusion

HV Tau is the second young multiple system in which a circumstellar disk around a component has been resolved at near-IR wavelengths, the first one being HK Tau (Stapelfeldt et al. 1998). If HV Tau C is actually bound to HV Tau AB, this may be the first instance of a circumtertiary disk in a young system. It is likely that circumstellar disks in multiple systems are common, but only nearly edge-on structures are easily seen at optical wavelengths. As soon as the disk inclination decreases below about 80^o, direct light from the central star overwhelms the scattered light from the disk upper layers.

The serendipitous discovery of HV Tau C disk reported here in the course of another program devoted to young binaries needs to be followed up. Deeper images are being obtained at several wavelengths which will allow a full disk model to be developped and confronted with high S/N observations in order to derive more accurate disk properties than the preliminary estimates presented here.

Acknowledgements. We thank C. Clarke for comments on the manuscript and the CFHT staff as well as D. Nadeau for their efficient help during observations.

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