An asymmetry detected in the disk of κ Canis Majoris with AMBER/VLTI


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ABSTRACT

Aims. We study the geometry and kinematics of the circumstellar environment of the Be star κ CMa in the Brγ emission line and its nearby continuum.

Methods. We use the AMBER/VLTI instrument operating in the K band, which provides a spatial resolution of about 6 mas with a spectral resolution of 1500, to study the kinematics within the disk and to infer its rotation law. To obtain more kinematical constraints we also use a high spectral resolution Paβ line profile obtain in December 2005 at the Observatorio do Pico do Diós, Brazil and we compile V/R line profile variations and spectral energy distribution data points from the literate.

Results. Using differential visibilities and differential phases across the Brγ line we detect an asymmetry in the disk. Moreover, we found that κ CMa seems difficult to fit within the classical scenario for Be stars, illustrated recently by α Arae observations, i.e. a fast rotating B star close to its breakup velocity surrounded by a Keplerian circumstellar disk with an enhanced polar wind. We discuss the possibility that κ CMa is a critical rotator with a Keplerian rotating disk and examine whether if the detected asymmetry can be interpreted within the “one-armed” viscous disk framework.

Keywords. techniques: high angular resolution – techniques: interferometric – stars: emission-line, Be – stars: individual: Keplerian rotation – stars: individual: κ CMa – stars: circumstellar matter

1. Introduction

The “Be phenomenon” is related to hot stars that have exhibited Balmer lines at least once in emission, with infrared excess produced by free-free and free-bound processes in an extended circumstellar disk. There is now strong evidence that the disk around the Be star α Arae is Keplerian (Meilland et al. 2007) and that this dense equatorial disk is slowly expanding. However, there is also evidence for a polar enhanced wind. This was predicted for almost critically rotating stars, and thus for a large fraction of Be stars. Recently, Kervella & Domiciano de Souza (2006) showed an enhanced polar wind for the Be star Achernar even though this Be star presents no hydrogen lines in strong emission. Thus, it seems that a significant polar wind may be present even if the star is still in a normal B phase, signifying that this enhanced polar wind is not related to a dense equatorial envelope. However many issues remain unsolved about the structure of the circumstellar envelope in Be stars, which probably depends on the dominant mass ejection mechanisms from the central star and on the way the ejected mass is redistributed in the near circumstellar environment. Meilland et al. (2006) reported theoretical spectral energy distributions (SEDs), Brγ line profiles and visibilities for two likely scenarios of the disk dissipation of active hot stars, and account for the transition from the Be to the B spectroscopic phase.

κ CMa (HD 50013, HR 2538) is one the brightest Be stars in the southern hemisphere (V = 3.8, K = 3.6). It is classified as a B2Ive star, and the distance deduced from the Hipparcos parallax is 230 ± 30 pc. The measured sin i values range from 220 km s⁻¹ (Dachs et al. 1989; Mennekent et al. 2004; Okazaki 1997; Prinja 1989) to 243 km s⁻¹ (Zorec et al. 2005), its radius is 6 R⊙ (Dachs et al. 1989; Prinja 1989) and its mass is 10 M⊙ (Prinja 1989).

The mass and radius determination of a Be star is not an easy task. For instance if we assume values of masses and radii from the Harmanec (1988) compilation, in agreement with Schaller et al. (1992) non-rotating evolutionary models, for the
effective temperatures used by Popper (1980), Prinja (1989) and Fremat (2005), we obtain the Table 1.

Thus, for a main sequence star the stellar radius should be smaller than the $6 R_\odot$ we have adopted, however, our radius estimator based on the parallax and the chosen $V$ magnitude from the correlation between the brightness and emission strength, as proposed by Harmanec (2000), gives the range of radii comparable to the $6 R_\odot$ used in our modeling.

The star exhibits a large IR-excess and strong emission in the hydrogen lines making it a good candidate for the AMBER/VLTI spectro-interferometer (Petrov et al. 2007) using medium spectral resolution (1500). Our aim is to study the geometry and kinematics of the circumstellar environment of this star as a function of wavelength, especially across the Br emission line and to detect any signatures of a possible asymmetry of its circumstellar disk, as already observed through a violet to red peak ratio $V/R \sim 1.3$ (Dachs et al. 1992; Slettebak et al. 1992).

### 2. Observations and data reduction

Dedicated observations of $\kappa$ CMa were carried out during the night of December 26th 2004 with the three VLTI 8m ESO telescopes UT2, UT3 and UT4 (see Table 3 for the baseline configurations). The data were reduced using the amdlib (v1.15)/ammyorick (v0.54) software package developed by the AMBER consortium. It uses a new data processing algorithm adapted to multiaxial recombination instruments called P2VM (Pixel To Visibility Matrix algorithm). The squared visibility estimator is computed from the basic observable coming from this algorithm, the coherent flux (i.e. complex visibilities frame by frame multiplied by the flux) and the estimated fluxes from each telescope. The principles of the general AMBER data reduction are described in more detail by Millour et al. (2004) and Tatulli et al. (2007).

The complex coherent flux allows one to compute differential phase, i.e. the averaged instantaneous phase subtracted from achromatic atmospheric OPD and a wavelength-averaged reference phase. This means that the differential phase is the difference between the phase of the source complex visibility and a mean OPD. This leads to an average differential phase equal to zero on the observed spectral window and the lost of the object’s phase slope over the wavelengths. This technique allows one to retrieve partial information about the object’s phase and is almost equal to the object’s interferometric phase if we have some spectral channels in which we know that the object’s phase is zero.

It also allows one to compute “differential” visibility (as defined in Millour et al. 2007), i.e. the instantaneous modulus of the complex visibility divided by the averaged visibility in all the wavelengths excepted the working one. This leads to an average differential visibility equal to 1 in the continuum. It has the advantage over the “classical” visibility estimator of being almost insensitive to rapid frame-to-frame variations of visibility (due to vibrations or atmospheric jittering for example) and therefore one can expect the differential visibility observed to be more precise than the classical visibility estimator given the current vibrations in the VLTI infrastructure, and even though the continuum visibility information is lost in this observable.

Differential data reduction is described in detail in Millour et al. (2007).

Reducing the $\kappa$ CMa data with good accuracy is difficult to achieve. We encountered specific problems related to this data set. Therefore, in addition to the tools furnished by the default package, some specific processing was added to reach the best precision on the interferometric observables.

- No specific data were available to calibrate the fringe contrast of $\kappa$ CMa. We therefore looked at calibration stars observed during the same night for other stars and corrected their visibilities averaged over the [2.13–2.21] $\mu$m observed spectral range from their estimated diameters (see Table 2) to monitor the instrumental+atmospheric transfer function (see Fig. 1). This transfer function is the visibility of a point source measured by the instrument, allowing us to correct the raw visibilities for the science star for the instrument-specific visibility loss. The scattering over time of the visibilities gives the dispersion due to the instrumental drifts and atmospheric fluctuations during the observing time. This leads to a visibility dispersion estimate of 0.05 for each star, which leads to an error on the calibrated visibilities of 0.07 ($\sqrt{2} \times 0.05^2$).

Then we interpolate the estimated transfer function to the time of the science star observations (as in Perrin et al. 2003). The [2.13–2.21] $\mu$m averaged visibility of $\kappa$ CMa is close to 1.0 with an uncertainty of 0.07 on all the observed base lengths. This would normally be unacceptable for the wavelength-dependence study of the visibilities, but as explained before, we expect to have differential visibility and differential phase estimators that are much more precise than the visibility estimator.

- The lack of dedicated calibration star for $\kappa$ CMa should lead to an inability to spectrally calibrate the differential observables, but fortunately another calibration star (HD 93030) was observed two hours later within almost the same spectral window, which means that the spectograph grating did not move but that the detector window was not exactly the same as for $\kappa$ CMa, allowing us to use the intersecting spectral channels between the two observations without any calibration problems. Detailed data analysis of calibration stars tends to demonstrate that the main pattern on differential observables comes from a fiber-injection pattern (i.e. an AMBER internal instrumental effect) and that it is stable over several minutes in the $10^{-2}$ range for the differential visibilities and $10^{-2}$ radians for the differential phase at medium spectral resolution ($R \approx 1500$, see for instance Vannier et al. 2005).

This allowed us to correctly calibrate the differential visibility and the differential phases (see Fig. 2). In order to ensure our
Fig. 1. Raw absolute visibilities of calibration stars corrected for their angular diameters and averaged over the [2.13−2.21] μm window, allowing us to monitor the instrumental-atmospheric transfer function (points respectively around 1h in red and 7h in blue). For comparison we have overlapped the raw visibilities of κ CMa (around 3h in green). The κ CMa visibilities have the same value as the instrumental-atmospheric transfer function within the error bars, leading to a calibrated visibility of 1, i.e. a non resolved or poorly resolved object on all baselines.

Fig. 2. From top to bottom: Paβ line profile from the Observatorio do Pico dos Dias, Brazil (dotted line) with our best model fit (plain line), Brγ line profile, differential visibilities and differential phases for the three baselines. For each plot, the dots with errors bars are AMBER/VLTI data and the solid line is from our best SIMECA model (see Sect. 4).

3. Envelope extension and flattening

In this section we present the AMBER data to obtain an estimate of κ CMa’s envelope geometry and extension. Assuming that the measured visibility in the continuum, $V_c$, is only due to the central star and its circumstellar envelope and that the envelope is optically thin in the continuum, we can write:

$$V_c = \frac{V_{\infty} F_{\infty} + V_* F_*}{F_c}$$

(1)

1 IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy (AURA), Inc., under cooperative agreement with the National Science Foundation.
The total flux is normalized, i.e. $F_c = F_{cc} + F_* = 1$. Since the star is fully unresolved $\phi_* \sim 0.25$ mas (assuming a $6 R_\odot$ seen at 230 pc) which corresponds to $V_* > 0.99$ for the longest baseline at $2.1\mu m$, we assume in the following that $V_* \approx 1$. In order to estimate $V_{cc}$ we still have to determine the star and the envelope contributions at $2.1\mu m$. Using the fit of the SED given in Fig. 3 we estimate that at this wavelength the stellar emission is similar to the envelope contribution, i.e. $F_* = F_{cc} = 0.5$.

We have the same relation for the visibility in the Br$\gamma$ line:

$$V_t = \frac{V_{cc}F_{cc} + V_cF_c}{F_t}$$

where $V_t$ and $F_t$ are respectively the measured visibility and flux in the Br$\gamma$ line. $V_c$ and $F_c$ are previously defined and $V_{cc}$ and $F_{cc}$ are the visibility and flux only due to the Br$\gamma$ line, i.e. without any stellar contribution and envelope continuum. Using the AMBER Br$\gamma$ emission line profile plotted in Fig. 2 and neglecting the underlying broadened photospheric absorption line, we obtain $F_{cc} \approx 0.5$ and $F_t \approx 1.5$ at the center of the line.

The corresponding visibilities, deduced from Eqs. (1) and (2) and from the measurements shown in Fig. 2, are given in Table 3. Using a uniform disk model for the envelope contribution, for each measurement, we also estimate in Table 3 the corresponding angular diameters in the continuum and in the Br$\gamma$ line. Since the envelope is marginally resolved in the continuum we simply put an upper limit to its angular size.

The envelope extensions in Br$\gamma$ given in Table 3 are strongly dependent on the sky-plane baseline orientation as seen in Fig. 4, where we plotted the $\kappa$ CMa (unresolved star + uniform disk) model diameters as a function of the baseline orientation.

The $\kappa$ CMa circumstellar disk seems to be elongated along B1 but since we only have 3 visibility measurements we cannot accurately determine the angular position of the major axis assuming an elliptical circumstellar disk. The envelope flattening given by the semi-major and semi-minor axis ratio, is about $2 \pm 0.7$. Assuming that the disk is geometrically thin (i.e. its opening angle is only a few degree) we can estimate the range for the inclination angle $i$: $39^\circ < i < 68^\circ$. The lower limit of $39^\circ$ relies on the lack of constraint on the disk opening angle.

## Table 3

<table>
<thead>
<tr>
<th>Base n°</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
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<tr>
<td>Baseline</td>
<td>UT2-3</td>
<td>UT3-4</td>
<td>UT2-4</td>
</tr>
<tr>
<td>Length (m)</td>
<td>42.7</td>
<td>59.3</td>
<td>80.8</td>
</tr>
<tr>
<td>PA (°)</td>
<td>51.6</td>
<td>128</td>
<td>97.1</td>
</tr>
<tr>
<td>$V_t/\phi_*$</td>
<td>&gt;0.95</td>
<td>&gt;0.95</td>
<td>&gt;0.95</td>
</tr>
<tr>
<td>$V_{cc}$</td>
<td>&gt;0.86</td>
<td>&gt;0.86</td>
<td>&gt;0.86</td>
</tr>
<tr>
<td>$V_{cc} (\text{mas})$</td>
<td>&lt;3.6</td>
<td>&lt;2.6</td>
<td>&lt;1.9</td>
</tr>
<tr>
<td>$\phi_{cc} (\text{mas})$</td>
<td>3.7 $\phi_*$</td>
<td>2.0 $\phi_*$</td>
<td>2.6 $\phi_*$</td>
</tr>
<tr>
<td>$\phi_{cc} (D_\odot)$</td>
<td>&lt;15.5</td>
<td>&lt;11.2</td>
<td>&lt;8.2</td>
</tr>
<tr>
<td>$\phi_{cc} (D_\odot)$</td>
<td>15.9 $\phi_*$</td>
<td>23.7</td>
<td>8.6 $\phi_*$</td>
</tr>
</tbody>
</table>

## 4. SIMECA modeling

In order to obtain quantitative fundamental parameters of the central star and its circumstellar disk, we used the SIMECA code developed by Stee (1994) and Stee & Bittar (2001) to model the $\kappa$ CMa circumstellar environment. Since this code was axi-symmetric we made substantial modifications in order to introduce a longitudinal dependence of the envelope density as shown in the AMBER data plotted Fig. 2. To constrain the kinematics within the disk we use a Pa8 line profile obtained in December 2005 at the Observatorio do Pico do Dias, Brazil and plotted in Fig. 5. This profile is strongly asymmetric with a $V/R$ double peak of $\pm 1.3$. This $V/R > 1$ is usually interpreted in terms of a viscous disk similar to accretion disks where the gas and angular momentum are diffused outward by magnetohydrodynamic viscosity (Lee et al. 1991). Considering the time-dependent structure of the isothermal viscous disk, Okazaki (1997) showed that “one-armed” density waves can propagate within the disk and should reproduce the observed
V/R variations from $V/R > 1$ to $V/R < 1$ seen in the line profiles (Hummel & Hanuschik 1997). Such variations were detected for many Be stars, with periods from a few years to over a decade (Hummel & Hanuschik 1995; Telling et al. 1994). But in the case of κ CMa the $V/R$ ratio has remained constant for the last twenty years (Dachs et al. 1992; Slettebak 1992).

In Fig. 5 we over-plotted the supposed “symmetric part” of the Paβ line profile, using an axi-symmetric model, and the asymmetric residual that may be produced within the “one-armed” oscillation over-density. This effect must be compatible with the asymmetric differential phase variation across the Brγ line for the B1 baseline plotted in the bottom part of Fig. 5 since the emitting regions in Paβ and Brγ must be very close each other. The asymmetric contribution to the Brγ emission is about 20 to 30% of the total emission in this line whereas the mean projected velocity of the inhomogeneity is $-130 \pm 20$ km s$^{-1}$. Using a SIMECA model at 230 pc we determined that the projected separation between this over-density photocenter and the central star is about 6.5$\lambda$.

The parameters obtained for our best model are given in Table 4 with the corresponding spectroscopic and interferometric observables of Fig. 2. This best model includes an over-density along the disk major axis at +20°, corresponding to an over-luminosity of 30% of the total flux in the line, and the agreement with the AMBER/VLTI data, the SED (Fig. 3) and the Paβ line profile is very good, as can be seen in Fig. 2. The agreement with the differential visibility and phase across the Brγ line for the three baselines validates the chosen disk geometry and kinematics. The 2.1 $\mu$m continuum visibilities obtained with the 3 baselines, $V_1 = 0.92$, $V_2 = 0.96$ and $V_3 = 0.94$ are also compatible with the 0.93 lower limit measured with AMBER. The corresponding continuum intensity map in the continuum at 2.15 $\mu$m is plotted in Fig. 6. The evaluation of the uncertainties of the parameters of our model is beyond the scope of this work and will be studied in depth when more constraining data is available.

### Table 4. Parameters for the κ CMa central star and its circumstellar environment for the best axi-symmetric model.

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{eff}}$</td>
<td>22 500 K ± 1000</td>
</tr>
<tr>
<td>Radius</td>
<td>6.6 $R_\odot$ ± 1</td>
</tr>
<tr>
<td>Inclination angle $i$</td>
<td>60° ± 10</td>
</tr>
<tr>
<td>Equatorial rotation velocity</td>
<td>240 km s$^{-1}$ ± 20</td>
</tr>
<tr>
<td>Rotation law exponent</td>
<td>$0.32 \pm 0.1$</td>
</tr>
<tr>
<td>Photospheric density ($\rho_{\text{phot}}$)</td>
<td>$4 \times 10^{-11}$ g cm$^{-3}$ ± 2 $\times 10^{-11}$</td>
</tr>
<tr>
<td>Equatorial terminal velocity</td>
<td>1 km s$^{-1}$ ± 10</td>
</tr>
<tr>
<td>Polar terminal velocity</td>
<td>1000 km s$^{-1}$ ± 100</td>
</tr>
<tr>
<td>Polar mass flux</td>
<td>$2 \times 10^{-11}$ $M_\odot$ year$^{-1}$ sr$^{-1}$ ± 0.5 $\times 10^{-11}$ m$^{-1}$</td>
</tr>
<tr>
<td>Envelope outer radius</td>
<td>23 $R_\star$ ± 2</td>
</tr>
<tr>
<td>Major axis position</td>
<td>+28° ± 5</td>
</tr>
<tr>
<td>Over-density position</td>
<td>along the disk major axis</td>
</tr>
</tbody>
</table>

5. Discussion

Following recent AMBER/VLTI and MIDI/VLTI observations of α Arae, Meilland et al. (2007) concluded that this classical Be star fits very well within the classical scenario for the “Be phenomenon”, i.e. a fast rotating B star close to its breakup velocity surrounded by a Keplerian circumstellar disk with an enhanced polar wind. This scenario was also confirmed for the Be star Achernar by Kervella & Domiciano de Souza (2006) using VLTI/VINCI data, even if, for this latter case, the star was not in its active Be phase, i.e. without any strong emission line and no circumstellar disk. Nevertheless, Achernar is still a nearly critical rotator and shows an enhanced polar stellar wind. We will see in the following that κ CMa does not fit very well within this classical scenario.

5.1. Is κ CMa a critical rotator?

If κ CMa was rotating close to its breakup velocity, i.e. $V_c = 463$ km s$^{-1}$, the inclination angle would be around 28° in order to obtain a measured $v \sin i = 220$ km s$^{-1}$. With this inclination angle the maximum flattening corresponding to a geometrically very thin disk is 1.12. Since we measure a flattening of 1.11, κ CMa does not fit very well within the classical scenario.
about $2 \pm 0.7$, this inclination angle can be ruled out. In our best SIMECA model the star is rotating at only 52% of its critical velocity. We may argue that the measured elongation is not the envelope major axis but rather the enhanced polar wind. In this case the projected axis of the Be envelope is not identical to the rotation axis of the star. Nevertheless, in order to obtain an asymmetry in the jet we need an extended optically thick disk, perpendicular to the jets directions, that may screen at least one part of the jet-like structure. Such an extended optically thick disk should have been detected with the AMBER instrument which is not the case in our data.

The value of the projected rotational velocity for an early-B star can be systematically affected by pseudo-photosphere, unrecognized optically thick parts of the Be envelope as shown by Harmanec (2002) for γ Cas. He obtains for this star a $v \sin i$ of 380 km s$^{-1}$ instead of the often quoted value of 230 km s$^{-1}$ from Sletteback (1992). Nevertheless, taking the largest value for κ CMa from the literature from Zorec (2005) who found a $v \sin i = 243$ km s$^{-1}$ we still obtain an inclination angle of 32° which again is not in agreement with our measured flattening.

If the discrepancy between the measured $v \sin i$ and the "real" one is larger it may be possible that κ CMa is still a critical rotator but it requires a factor of 2 between the measured and the true $v \sin i$, which we found unrealistic. Even if Townsend et al. (2004) include the gravity darkening effect on the $v \sin i$ values of rigid early-type rotators, assuming a rotation rate $\Omega/\Omega_c$ of 0.95, they conclude that classic $v \sin i$ determinations for B0 to B9-type stars can be underestimated by 12 to 33%, far from a factor of 2. Moreover, a recent paper by Frémat et al. (2005) studying the effect of the gravitational darkening on the determination of fundamental parameters in fast rotating B-type stars found that on average the rate of angular velocity of Be stars attains only $\Omega/\Omega_c \sim 0.88$.

Frémat et al. (2005) estimate κ CMa’s effective temperature to be $25\,790 \pm 713$ K, a value significantly larger than the 22,500 K used in our modeling. Moreover, Harmanec (2000) found a positive correlation between the emission strength and the brightness in the optical. Therefore we may use the minimum observed $V$ magnitude of about 3.5 to estimate the radius of the central star. Combining with the Hipparcos parallax and its error we obtain a radius between 9 and 14 solar radii. Using the $T_{\text{eff}}$ of 25,790 K and a radius of 14 $R_\odot$ we obtain a stellar luminosity larger by a factor of 8 than our modeling and thus it is not possible to obtain a good agreement with the observed SED plotted Fig. 3. We are more confident in our $6\,R_\odot$ used for our modeling and our finding that κ CMa seems not to be a critical rotator. Nevertheless, regarding the uncertainties and the large errors of all measurements the breakup velocity cannot be totally excluded.

5.2. Is the rotation law within the disk Keplerian?

A Keplerian rotation law would produce a narrower double-peaked separation in the Paβ line profile. Using a simple axisymmetric Keplerian disk model the double-peak separation would be about 90 km s$^{-1}$ whereas we measure an asymmetric double-peak separation of about 160 km s$^{-1}$. Even if we subtract the emission of the over-density producing a larger double-peak separation by contributing to the $V$ peak of the emitting Paβ line, we still obtain a double-peak separation of about 120 km s$^{-1}$ (see Fig. 5). The exponent of the rotation law used for our best SIMECA model is 0.32 whereas it should be 0.5 for a purely Keplerian disk.

We may argue that Be stars vary strongly in time and thus line profile shapes are time dependent. For instance, actual Hα line profiles show a strong emission with a single peak whereas Bahng & Hendry (1975) saw a double-peaked Hα emission line, with the same double-peak separation of 160 km$^{-1}$ we obtained for Paβ with a shell core in their high-dispersion spectra. Nevertheless, these line variations are related to the formation and disappearance of the circumstellar disk around the star as shown by Rivinius et al. (2001) and Meilland et al. (2006). Whatever the model is, a double-peak line profile is a clear signature of an extended rotating disk, at least if the kinematics are not dominated by a strong stellar wind in the equatorial region as shown by Stee & de Araújo (1994). This double-peaked separation is a good indication of the disk extension as shown by Huang (1972), Hirata & Kogure (1984), and Stee & de Araújo (1994). We measure $v_{\text{disk}} \sin i$ at the disk outer radius ($R_{\text{disk}}$) from the peak separation, where $v_{\text{env}}$ is the rotational disk velocity at $R_{\text{disk}}$.

Thus we can write:

$$v_{\text{disk}} \sin(i) = v_\star \sin(i) \left( \frac{R_{\text{disk}}}{R_\star} \right)^{-\beta},$$

where $v_\star$ is the star rotation at its photosphere.

Assuming a Keplerian rotation ($\beta = 0.5$) we obtain, using Eq. (3), $R_{\text{disk}} = 13.5 \, R_\star$, which is about 2σ from the 19.8 $R_\star$ interferometric measurement, assuming that the measured elongation is the envelope major axis and not an enhanced polar wind (see discussion in the previous point). Note that these 19.8 $R_\star$ found are obtained assuming a uniform disk for the envelope and thus is certainly a lower limit to the “true” disk extension in the Paβ line. Thus it seems difficult to maintain a Keplerian rotation within the disk of κ CMa.

5.3. Is the “one-armed” viscous disk model a possible scenario for κ CMa ?

The asymmetry presently detected in the disk of κ CMa seems to be poorly explained within the “one-armed” viscous disk framework. Following the viscous disk models by Okazaki (1997) and the observational detection of “one-armed” oscillations in the disk of ζ Tau by Yakii et al. (1998) and γ Cas by Berio et al. (1999), the precessing period ($P$) of such oscillations should be confined within a few years up to about twenty years for the longer ones. We tried to compile all the observational data available to obtain a “quasi-period” for the V/R variations. The V/R variations occur during the time intervals of observable presence of Be envelopes and that they can show long-term, medium-term as well as rapid changes (Dachs 1981). Moreover, the very strong Hα line profile is not suitable for V/R measurement since it is single-peaked and the illusion of apparent V/R changes can be related to the presence of telluric lines. Compiling the data between 1965 and 2003 for κ CMa from Jaschek (1965), Slettebak (1982), Banerjee (2000) and this work, we were not able to deduce an estimation of a quasi-period (Fig. 7). Several authors suggested a very long V/R variation (i.e. Okazaki $P > 28$ years). An equally plausible possibility is that the star had two episodes of V/R changes with much shorter cycle length separated by a period of quiescence documented by (Dachs et al. 1992; Slettebak 1992). More observations are needed since, if this first possibility could be confirmed, this conflicts with the one-armed model. This “pseudo-period” would be too long compared to theoretical predictions which cannot be longer than two decades for a disk with a radius $\sim 23 \, R_\star$ (Okazaki, private communication). The fact that
this over-density remains confined along the major axis of the disk seems to be only fortuitous...

More observations are needed to confirm these conclusions and to determine whether other physical phenomena occurred within the circumstellar disk of κ CMa.

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References


\(^2\) The structure and members of the AMBER Consortium can be found in the website: http://amber.obs.ujf-grenoble.fr

\(^3\) The JMMC is a center providing software tools for optical interferometry described at the website: http://www.jmmc.fr

\(^4\) http://yorick.sourceforge.net

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