VLBI Observations of single stars: spatial resolution and astrometry

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VLBI studies can both spatially resolve single dMe stars and measure their positions at submilliarcsecond accuracy. The spatial resolution gives the brightness temperature and allows us to draw conclusions about the nature of the emitting processes. In particular it is possible to distinguish between thermal or non-thermal emission. The position accuracy gives better knowledge about the astrometric properties (like proper motion and parallax) especially for nearby stars. In this contribution recent results of continuum VLBI observations towards two dMe stars (YZ CMi and AD Leo) at 8.4 GHz are presented. For YZ CMi an estimate of the size of the coronal emission is given (0.98 mas in diameter or 0.7 $\pm$0.3 $R_\star$ above the photosphere where $R_\star$ refers to the photospheric radius). For AD Leo an upper limit is given, i.e. the emitting region is shown to be < 0.8 $R_\star$. The position of YZ CMi is found to differ by 32 mas form the Hipparcos catalogue, a discrepancy mostly due to large errors in the listed proper motion (Pestalozzi et al. 2000).

1. Introduction

Young stellar objects show many extreme phenomena e.g. in active dMe stars we see highly time variable enhancements in radio and X-ray emission (Feigelson & Montmerle 1999) both of which arise in the hot corona of those active stars. Hot coronae are the link between the cool convective stars and their environment. It is also believed that the high degree of magnetic activity in those stars makes it possible for some of the hot plasma ($> 10^6$ K) to be driven towards interstellar space through loops of magnetic field lines. The extent of the radio and X-ray emission therefore gives an estimate of the size of these loops.

Thanks to VLBI it has been possible to resolve spatially the emission at 3.6 cm of UV Cet B, allowing us to study the shape and size of its main-sequence corona (Benz et al. 1998). Previous observations of YZ CMi and AD Leo at 18 cm (Benz & Alef 1991, Benz et al. 1995) yielded upper limits in the size of the stellar corona (0.74 $R_\star$ above the photosphere for YZ CMi and 1.0 $R_\star$ for AD Leo). Here we presented new higher resolution 3.6cm wavelength VLBI observations YZ CMi and AD Leo.

2. Observations

All observations were conducted using the VLBA including the phased VLA, between December 1996 and December 1999. The VLA was also used in normal interferometry mode, allowing the monitoring of the total flux density of the targets and their polarisation. Since all targets were known to be weak sources, the phase referencing technique was used (e.g. Beasley & Conway 1995), where observations of the stars were alternated by scans on two bright phase calibrators. The secondary calibrator was used to check the efficiency of the technique after calibrating the data towards the primary calibrator. For YZ CMi and AD Leo the phase solutions found towards the primary calibrator using phase referencing gave maps of the secondary calibrators with a dynamic range of 20:1. The position accuracy of the phase-referenced maps of the secondary calibrator suggested that our positions for YZ CMi and AD Leo are accurate to 0.5 and 0.2 mas respectively.

3. Results

3.1. *YZ CMi*

The most important result of these experiments was the spacial resolution of YZ CMi. The star showed an average flux density of 3.0 mJy, with flares up to almost 6 mJy. The circular polarisation (not shown here) reaches 60%. Fig. 1 illustrates the the spatial resolution of the source. The fall off of the correlated flux with increasing the baseline length was fitted with a circular gaussian (filled line in the plots on the right of Fig. 1). The size of the best fit is 0.98 mas, which corresponds to a coronal extent of 1.77×10^{10} $\pm 8.8 \times 10^9$ cm above the photosphere, or 0.7± 0.3 $R_\star$. The same gaussian was used to fit the star data even during the flare, implying that the star did not change in shape. The derived mean brightness temperature is then $T_b = 7.3 \times 10^7$ K. This value is still consistent with a non-thermal emission but it is not possible to exclude thermal processes. The high degree of polarisation however suggests that the emission arises from a gyrosychrotron mechanism.

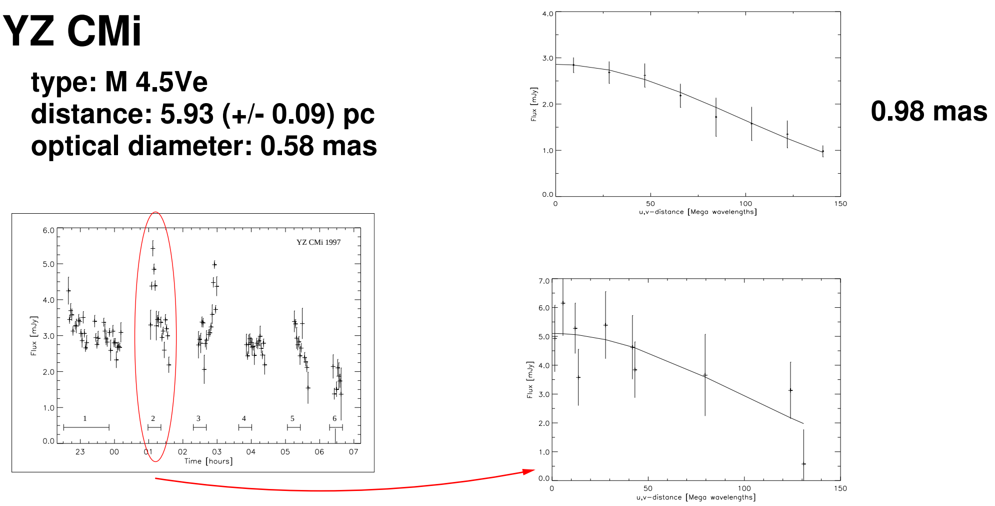

FIGURE 1. Some characteristics of YZ CMi and the plots of the calibrated data showing the resolution. The plot at the bottom left shows the flux monitoring during the whole experiment. Top right: plot of the correlated flux versus u, v-distance with the fit of a circular gaussian. Bottom right: same as above but taken only the data recorded during the flare, as the arrow connecting the left panel shows.

In Fig. 2 an image of YZ CMi with both the optical size at the bottom right side and the synthesised beam at the bottom left is shown. The position was derived using JMFIT in AIPS (RA $7^h 44^m 40^s.22399 \pm 0.00007$, DEC $3^0 33' 10''.1140 \pm 0.0005$). Combining the VLBA position with the one form the Hipparcos catalogue it was then possible to derive an improved value of the proper motion as -348.6±0.6 mas/yr in RA and -446.6±0.3 mas/yr in DEC.

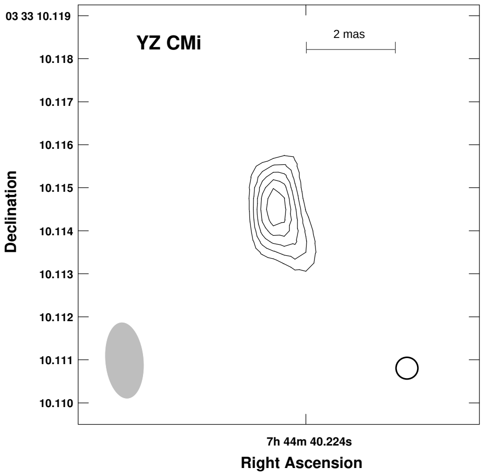

FIGURE 2. Contour plot of YZ CMi. The rms noise is 0.13 mJy/beam, the first contour is at 3 σ, and then at steps of one σ. At the bottom left the beam size, at the bottom right the expected optical size of the star.

3.2. *AD Leo*

AD Leo was not resolved, therefore only an upper limit of the size of the corona is given. In addition, the star in the map (see Fig. 3) shows an elongated shape corresponding to the direction of its proper motion. It is probable that, since the star has a particularly high proper motion, the image has been blurred by its movement during the experiment. Assuming the intrinsic size of the emitting region to be the half of the beam, i.e. 1 mas, a very conservative upper limit is given, fitting an optically thin sphere, what leads to a size for the corona above the photosphere of $< 0.8R_\star$ or $< 2.8 \times 10^{10}$ cm . Here as in YZ Cmi the brightness temperature of $T_b = 4.93 \times 10^7$K does not allow us to exclude thermal emission processes, although such mechanisms are unlikely given the source polarisation.

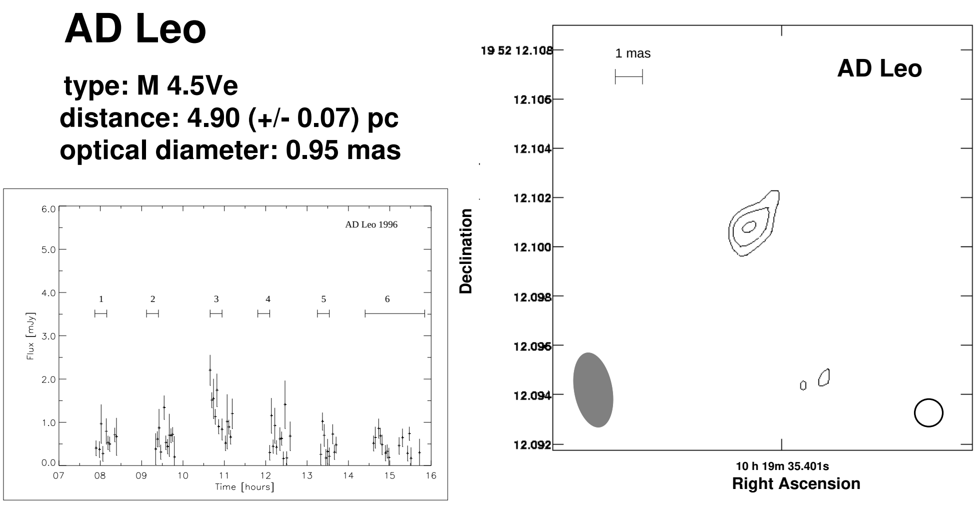

FIGURE 3. Characteristics, flux monitoring and contour plot of AD Leo. Notice the weak average flux intensity (0.6 mJy) and the weak flare (about 2 mJy). The rms noise in this map is 0.18 mJy/beam, the first contour is at 3 σ, and then at steps of one σ. At the bottom left the beam size, at the bottom right he expected optical size.

The position found from the VLBA observations (RA $10^h19^m36^s.40112 \pm 0.00007$, DEC $19^0 52^{'} 12^{''}.1008 \pm 0.0005$) was compared with those contained in the Gliese and Tycho catalogues. Transporting the latter coordinates to the time of the observations one obtains a position inaccuracy which stays inside one standard deviation listed in the Tycho catalogue ($\sigma_\alpha = 176.3$ mas, $\sigma_\delta = 100.0$ mas).

4. Conclusions and future work

These results show that it possible to resolve active single main sequence stars allowing the study of their hot coronae. At the same time high astrometric accuracy allows to measure movements of the order of milliarcsec. The latter capability could be used for searching for massive planets. For instance a Jupiter mass planet at a distance of 5 AU from its star at a distance from the Earth of 5 pc would cause a displacement of the central star of 1 mas in radius. Because of their extreme weakness it is clear that in order to improve our knowledge about single young stars is important to use the largest possible telescopes in future VLBI experiments.

To this end we have recently collected 8.4GHz VLBI data on the T Tauri stars TTau S, HPTau/G2 and Hubble 4. The experiment involves the VLBA, VLA27 and the Effelsberg 100m telescope. A preliminary analysis of the data reveals clear detections of at least two of the targets (TTauS and Hubble 4). The major problems for the data reduction are the faintness of the stars (from a few mJy down to 0.6 mJy) and an inaccuracy of the position of the phase center of the VLA used during correlation. Looking at the phases of the secondary calibrator after applying the phase solutions found towards the primary it was possible to extrapolate the amplitude of the position offset of the VLA. The results of this method are satisfactory but the offset is still not known with high accuracy. Further analysis of the data aims at finding the best method of determining the correct VLA position offset and also correcting other, mainly atmospheric, contributions affecting the phase.

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