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VLBI observations of protostellar coronal radio emission towards YLW 15

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Abstract. Very-Long-Baseline Interferometry (VLBI) of non-thermal centimetric radio emission allows us to study coronal emission at sub-AU resolution in the immediate vicinity of protostars. We present first results of our VLBI observation campaign of nearby protostars, looking for compact non-thermal centimetric radio emission. Compact emission was found towards the protostellar binary YLW 15, at the position of its VLA 2 component.

Key words. Stars: pre-main sequence, Stars: coronae, Stars: magnetic fields, Radio continuum: Stars, Stars: individual: YLW 15

1. Introduction

The high-energy processes which lead to the hard X-ray and gyrosynchrotron radio continuum flares observed towards Young Stellar Objects (YSOs) are thought to be produced in magnetic field geometries in the innermost vicinities of these sources, at scales of less than 1 AU. While scaled-up solar-type activity is a possibility, these processes may also relate to huge magnetic field loops connecting the star to its circumstellar disk (e.g. Feigelson & Montmerle, 1999). In order to observe these structures, milli-arcsecond resolution VLBI radio observations are required.

Starting in the late 1980s, several VLBI observations of YSOs were reported (Felli et al., 1989; André et al., 1991, 1992; Phillips et al., 1991, 1996). Several detections were reported of objects in the T Tauri evolutionary stages, i.e. the later stages of low-mass protostellar evolution at ages of several 10^6 years. One of the youngest sources detected by VLBI techniques certainly is the class I/II source T Tau S (Smith et al., 2003). In order to study the role of the disk in the above-mentioned high-energy processes, we looked for suitable VLBI targets among the earliest evolutionary stages, identified, e.g., by their X-ray and non-thermal radio emission. The main difficulty is that thermal radio emission from the protostellar envelope easily becomes optically thick, effectively concealing any emission from underneath (e.g. André, 1987).

While our VLBI observation campaign will be discussed in detail in an upcoming publication (Forbrich et al., 2007), we present here briefly the results of the observations targeting the binary protostar YLW 15. These observations lead to the detection of an unresolved, compact source while towards the other sources, very low upper flux density levels for compact emission could be determined.

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2. The binary protostar YLW 15

YLW 15, a binary protostar consisting of components in the class 0 and class I stages, is located in the ρ Oph dark cloud at a distance of 130 pc (Rebull et al., 2004). Its binarity was first observed at radio wavelengths (with components named VLA 1 and VLA 2, Girart et al., 2000), and proper motion as well as apparent orbital motion were discovered by Curiel et al. (2003). After an early, unsuccessful VLBI attempt to detect non-thermal radio emission (André et al., 1992), more recent VLBI observations were reported by Girart et al. (2004), achieving a 4σ upper limit of 0.2 mJy at a wavelength of 6 cm. From additional infrared data, they conclude that VLA 1 is more deeply embedded (or less luminous) than VLA 2 while the orbital motion indicates that VLA 1 is the more massive object. VLA 2 was observed to show strong quasi-periodic X-ray emission explained as due to the fast rotation of the star with respect to the disk leading to star-disk shearing of the magnetic field lines (Tsuboi et al., 2000; Montmerle et al., 2000). This, in turn, would lead to magnetic reconnection and the creation of energetic electrons responsible for the quasi-periodic X-ray emission.

3. Observations and data analysis

We observed YLW 15 with the NRAO Very Long Baseline Array (VLBA, ten antennas of 25 m diameter each), combined with the Green Bank (GBT) 100 m radio telescope as well as the phased Very Large Array (VLA, equivalent in collecting area to a 120 m dish). Phase-referencing observations at 256 Mbit/s were carried out on April 30, 2005, in dual polarization mode (RCP & LCP). The accessible field of view which is limited by time-smearing due to the correlator averaging time is estimated to be $\sim 1\farcs8$. The phase reference source J1625-2517 is within $52'$ of the program source. We spent about three minutes on the program source and 1.5 minutes on the reference source in every cycle. All VLA and VLBI data were analyzed in a standard manner with the NRAO Astronomical Image Processing System (AIPS); for details, see Forbrich et al. (2007).

4. Results

The VLA-only data taken of each source as part of the VLBI experiments were analyzed immediately in order to refine the source positions for the correlator, all sources were detected. The two components of YLW 15 with their previously studied proper motion are only marginally resolved in our VLA data. The VLBI data were correlated at the position of the south-western appendix to the main source VLA1, as seen more clearly in an image of our VLA data restored with a circular $0\farcs4$ beam, smaller than the synthesized beam (Fig. 1). It remains unclear at this point whether this emission is due to VLA 2: Given the predictions by Curiel et al. (2003) (positions from their Fig. 2 are plotted onto our VLA map), the position is quite unusual. The observations discussed by Curiel et al. (2003, see also Girart et al., 2004) were carried out in 1990, 2000, and 2002, and the considerable change seen since then in only about three years (if VLA 2 is in the above-mentioned appendix) could possibly be explained by a periastron passage of VLA 2.

In the VLBI data of YLW 15-VLA 2, we find a weak source (see Fig. 1). The detection is persistently reproduced when using different imaging parameters, yielding a significance of $7\ldots9\sigma$. The peak flux density of this unresolved source is 0.145 ± 0.016 mJy compared to an estimated flux density of 0.75 ± 0.05 mJy in the VLA data, thus roughly 20% of the flux density of VLA 2 is due to compact emission of $< 0.4 \times 0.1$ AU (FWHM beam size). No compact emission was detected towards VLA 1.

5. Summary

In an attempt to study the innermost magnetic field structure around protostars at high angular resolution using VLBI techniques, the currently most sensitive observations were obtained towards such sources. While all these sources are detected in VLA-only observations probing larger angular scales, compact emission on milliarcsecond (or sub-AU) scales, as probed by VLBI observations, is only detected towards the putative position of YLW 15-VLA 2 with a significance of $7\ldots9\sigma$ depend-

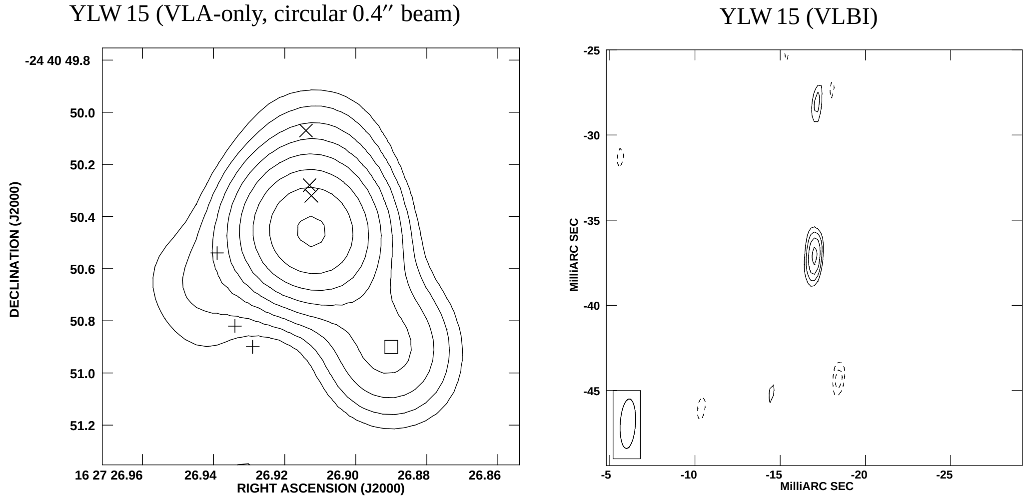

Fig. 1. Left: VLA-only map of YLW 15 (B array data, April 2005), restored with a circular 0.4″ beam. The proper motions of the two components as determined by Curiel et al. (2003) are indicated (years 1990, 2000, and 2002 form north to south for both sources) together with the chosen VLBI correlation position (box). The contour lines delineate multiples of 0.1 mJy ($\sim 4\sigma$), increasing by factors of $\sqrt{2}$. Right: Weak source found in the VLBI data close to the putative position of YLW 15 YLW 2 at RA 16h27m26.88875s DEC $-24°40'50.937''$. The source reaches a significance of $\sim 9\sigma$. The contour lines delineate multiples of 3σ, increasing by factors of $\sqrt{2}$. The 1σ rms noise level is 15.4 μJy. Both figures from Forbrich et al. (2007).

ing on the imaging parameters. For this source, the size of the corona can be constrained to $< 0.4 \times 0.1$ AU. Given the apparently fast orbital motion of YLW15 VLA-2 around VLA-1, more observations will soon enable a much better determination of the orbit. The non-detections of the other sources at VLBI scales is probably due to thermal free-free emission from ionized regions (e.g. due to stellar winds or jets) which are seen in the VLA observations but which are resolved out in the VLBI data.

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