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MILLI-ARCSECOND BINARIES

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RESUMEN

Como parte de un programa astrométrico, hemos estado usando el Very Long Baseline Array para medir con muy alta precisión la paralaje trigonométrica de varias estrellas jóvenes en las regiones de formación estelar de Tauro y Ophiuchus. Adicionalmente, hemos obtenido una muestra de imágenes de muy alta resolución ($\sim$ 1 mas) sin precedentes. Estas imágenes revelan que alrededor de un 70% de las estrellas en nuestra muestra son estrellas binarias muy cercanas (con separaciones de unos cuantos milisegundos de arco). Debido a que es altamente improbable que 70% de todas las estrellas sean binarias con separaciones tan pequeñas, en este trabajo discutimos los efectos de selección en el proyecto.

ABSTRACT

As part of an astrometric program, we have used the Very Long Baseline Array to measure with great accuracy the trigonometric parallax of several young stars in the Taurus and Ophiuchus star-forming regions. Additionally, we have obtained an unprecedented sample of high-resolution ($\sim$ 1 mas) images of several young stellar systems. These images revealed that about 70% of the stars in our sample are very tight binary stars (with separations of a few mas). Since it is highly unlikely that 70% of all stars are such tight binaries, we argue that selection effects are at work.

Key Words: astrometry — binaries: general — radiation mechanisms: non-thermal — stars: individual (V773 Tau AB) — stars: pre-main sequence

1. INTRODUCTION

In the last few decades, studies of the solar neighbourhood have led to the conclusion that most stars show a high multiplicity rate: $\sim$ 55% for solar-type stars (Duquennoy & Mayor 1991), and $\sim$ 35 to 42% for M-dwarfs (Reid & Gizis 1997; Fischer & Marcy 1992). Young stars also exhibit a high multiplicity rate: $\sim$ 50% with separations of between 0.02 and 1 arcseconds (Köhler & Leinert 1998; Duchêne et al. 2004; Konopacky et al. 2007). Indeed, several star-forming regions appear to show a multiplicity rate even higher than that of main sequence stars (Prosser et al. 1994; Duchêne, Bouvier, & Simon 1999; Bouvier, Rigaut, & Nadeau 1997). This shows that multiplicity must be already established in the very early phases of star-formation. It is still a matter of debate, however, if different environmental conditions of star formation lead to different degrees of multiplicity.

Observations have shown that non-thermal, high-energy processes often take place in young stellar objects, particularly in weak-line T Tauri stars (WTTS). These phenomena produce compact X-ray and radio emission (Strom & Strom 1994; Feigelson & Montmerle 1999). In this project, we will focus on T Tauri stars known to exhibit such strong non-thermal activity.

2. OBSERVATIONS

We have chosen from the literature a list of 9 young stellar objects: 5 in the Taurus complex, and 4 in the Ophiuchus complex. Those sources are low-mass stars (with the exception of S1 which is a main sequence B star). All 9 sources were previously known to be non-thermal radio emitters, and had been detected with VLBI techniques in the past (see Table 1). We will make use of several series of continuum 3.6 cm (8.42 GHz) Very Long Baseline Array observations of each source. The data were edited and calibrated in standard fashion using the Astronomical Image Processing System (AIPS).

3. RESULTS

In this work we find that $\sim$ 70% of the stars in our sample are multiple stellar systems with separations of a few milli-arcseconds. In the Ophiuchus complex we found a new member in both DoAr 21 and VSSG 14, and two new members in WL 5 (Loinard et al. 2008; see Table 1 and Figure 1). S1 was alredy known to be a binary (Richichi et al. 1994) and

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TABLE 1

OBSERVED STELLAR SYSTEMS CHARACTERISTICS

Region	Source	Phase[a] Evolution	Spectral Type	Members[b] Known	Detected	New	Total
Taurus	T Tauri Sb	CTTS	M0-1	3	1	0	3
	Hubble 4	WTTS	K7	1	1	0	1
	HDE 283572	WTTS	G5	1	1	0	1
	V773 Tau AB	CTTS/WTTS	K2, K7	4	2	0	4
	HP Tau/G2	WTTS	G0	3	1	0	3
Ophiuchus	S1	MS	B5 V	2	2	0	2
	DoAr 21	WTTS	K0	1	2	1	2
	VSSG 14	WTTS	A5-7	2	2	0 or 1	2 or 3
	WL 5	CTTS/WTTS	F7	1	3	2	3

[a]CTTS: classical T Tauri star, WTTS: weak-lined T Tauri star, MS: main sequence star.

[b]From Column 5 to 8 are listed the members known before our observations, the members that we detected in non-thermal radio emission, the new detected members, and the total members for each system after our observations.

we did detect the two members in some of our images. In the case of Taurus, we knew that T Tauri Sb was a member of a triple system, but of these three members we only detect one in non-thermal radio emission (Loinard et al. 2005, 2007; see Table 1). V773 Tau AB was previously known to be a quadruple system, and we detect two of the four members. Hubble 4 and HDE 283572, as well as HP Tau/G2 are apparently single (Torres et al. 2007, 2008). It is interesting that the fraction of tight binaries appears to be larger in Ophiuchus than in Taurus.

Note that 1 milli-arcsecond at the distance of Taurus (137 pc; Torres et al. 2007) and Ophiuchus (120 pc; Loinard et al. 2008) corresponds to ~ 0.137 and ~ 0.120 AU, respectively.

In addition to the high multiplicity rate, we found extended emission in most sources of both complexes (see Figure 1). This might be related to the extent of the magnetospheres. Young stellar objects often contain powerful flares and strong magnetic activity, that might explain the extended emission.

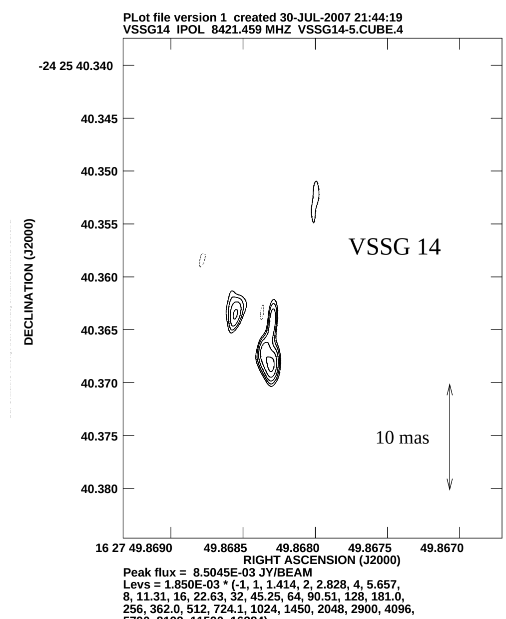

Fig. 1. VSSG 14, multiple stellar system in Ophiuchus complex. Note the extended structure.

4. DISCUSSION

4.1. *Binarity*

It is quite unlikely that 70% of all stellar systems in the Solar neighborhood are tight binaries such as those found in our VLBA observations. The high binary rate found here is, instead, likely the result of a selection effect. The systems considered in this project were selected because they were known to be non-thermal emitters that had been detected with VLBI techniques before. So the high binary rate may indicate that tight binaries are more likely to emit non-thermal radio emission than looser binaries or single stars. This idea is reinforced by the observations of V773 Tau AB (Figures 2 and 3) where we

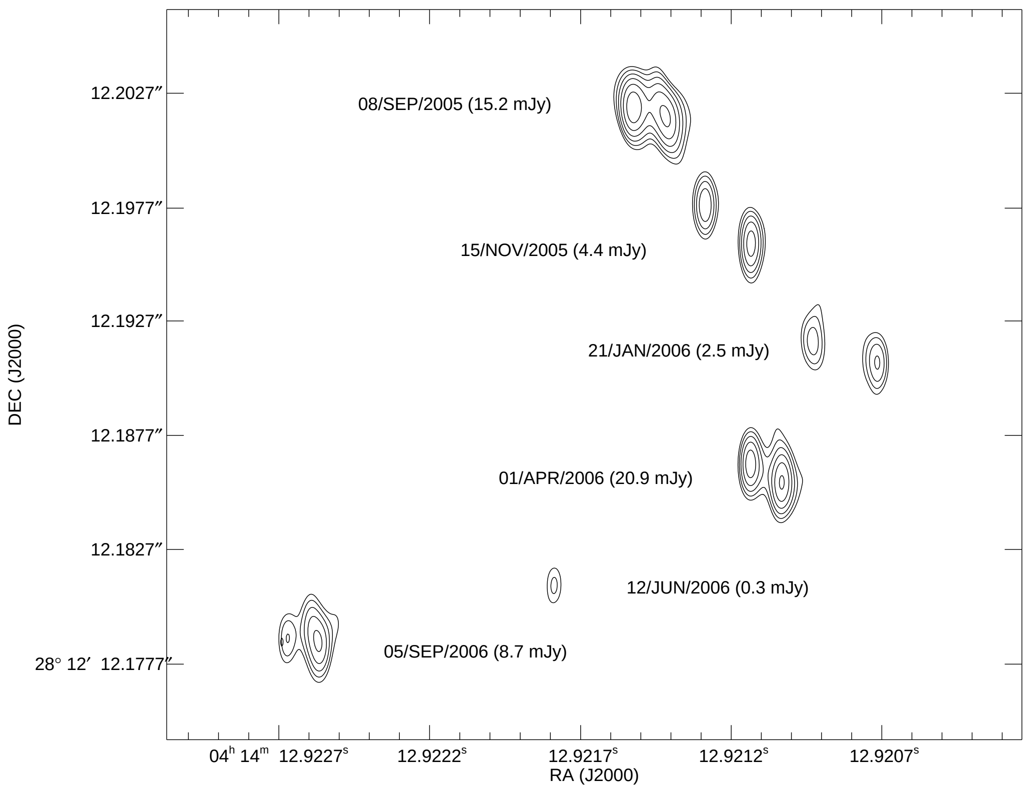

Fig. 2. 3.6 cm VLBA images of V773 Tau AB at six different epochs. The separation between V773 Tau A and V773 Tau B changes from epoch to epoch, and the flux density changes significantly with separation.

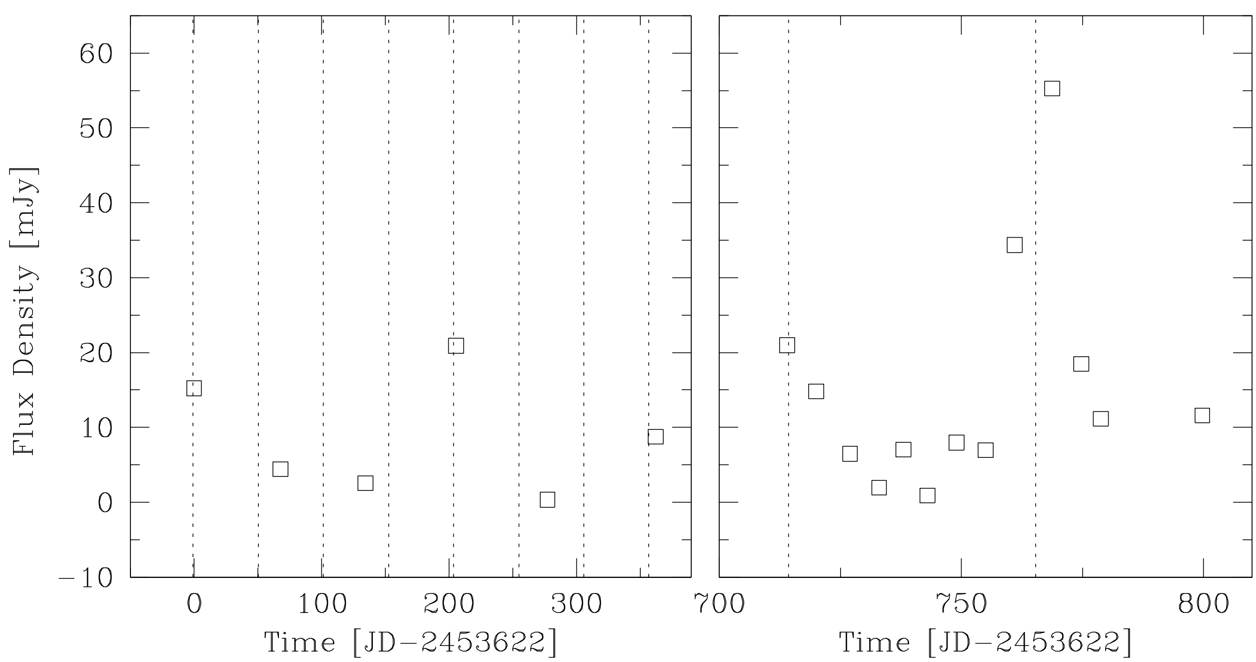

Fig. 3. Flux evolution of V773 Tau AB. The flux is shown as boxes, the sizes of which represent the magnitudes of the errors. The bars in the figure show the periastron passages assuming as initial epoch t_0=2449330.94 JD (Welty 1995).

find that the emitted flux is a clear function of the separation between the two stars (see below).

4.2. *V773 Tau*

V773 Tau (HD 283447) is the strongest stellar radio source in the 5 GHz VLA survey of WTTS in the Taurus-Auriga molecular cloud complex (O'Neal et al. 1990). It was shown to be a triple system when it was almost simultaneously found to be a spectroscopic binary with an orbital period of 51.075 days (Welty 1995), and to have a companion at about 150 mas (Ghez, Neugebauer, & Matthews 1993; Leinert et al. 1993). A fourth stellar source was recently found in the system (Duchêne et al. 2003), so V773 Tau appears to be a young quadruple stellar system, with the spectroscopic binary (V773 Tau A and V773 Tau B) at the center, and the two companions V773 Tau C and V773 Tau D in a wider orbit.

We have been collecting 19 VLBA observations of the compact non-thermal radio source associated with the spectroscopic binary V773 Tau A+B to measure its parallax and proper motion. The system almost always happened to be resolved into two sources. In Figure 2 we show the binaries at the first 6 epochs. Note that as the separation between the sources varies from epoch to epoch, the brightness of the source increases from 0.3 mJy to 21 mJy.

The total flux is shown as a function of time in Figure 3, where the bars indicate successive periastron passages. The brightness of the source increased from 0.3 mJy (fifth epoch) to 55 mJy (epoch 16). The flux density clearly tends to increase when the sources are near periastron. This is consistent with the results reported by Massi, Menten, & Neidhöfer (2002), who also found periodic radio flaring.

While the physical mechanisms leading to this behavior is not entirely clear, it certainly suggests a relation between radio flux and separation.

5. CONCLUSIONS AND PERSPECTIVES

We used the Very Long Baseline Array to obtain an unprecedented sample of high-resolution images of young stellar systems. We found that 70% of the stars in the sample are multiple stellar systems with separations of a few milli-arcseconds. We argue that the high binary rate indicates that tight binaries are more likely to emit non-thermal radio emission than looser binaries or single stars; this ideas are reinforced by the observations of V773 Tau AB, where we find that the flux density tends to increase when the sources are near periastron.

The mass is the most fundamental parameter of a star, because it determines its structure and evolution. For pre-main sequence stars, there are no reliable empirical mass determinations (mass estimates are usually based on comparisons with theoretical evolutionary models). For the binary stars detected here, a direct mass determination will be possible using Kepler's third law and the measured relative motions. We are currently obtaining new observations for those sources that were found to be multiple. These observations followed the sources during complete orbital periods, and will allow the determination of the orbital parameters, and therefore of the masses.

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