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The Orbit of T Tauri South

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Abstract. We report on previously unpublished diffraction-limited NIR observations of the young binary star T Tauri South. Orbital elements have been estimated by a least–squares fit to the relative positions. Although the parameters are not well constrained by the observations, we can derive a minimum system mass of about 3 $M_\odot$.

With the most recent astrometric measurements by Duchêne *et al.* (2006), hyperbolic (unbound) orbits can be excluded with high confidence. We conclude that T Tauri Sb is *not* in the process of being ejected from the system.

Keywords. techniques: high angular resolution, astrometry, binaries: close, stars: fundamental parameters (masses), stars: individual (T Tau), stars: pre–main-sequence

1. Introduction

T Tauri was once considered to be a prototypical young low-mass star, and its name was used to designate the whole class of stars. However, the more data about the system was collected, the more it became clear that it is not a typical representative. In 1982, an optically invisible, so-called "infrared companion" (IRC) was discovered (Dyck *et al.* 1982). About twenty years later, the companion was found to be a binary itself (Koresko 2000), with a projected separation of only 53 milliarcsec or less than 8 AU at the time. Since then, the separation has more than doubled, and the position angle has changed by about 80°.

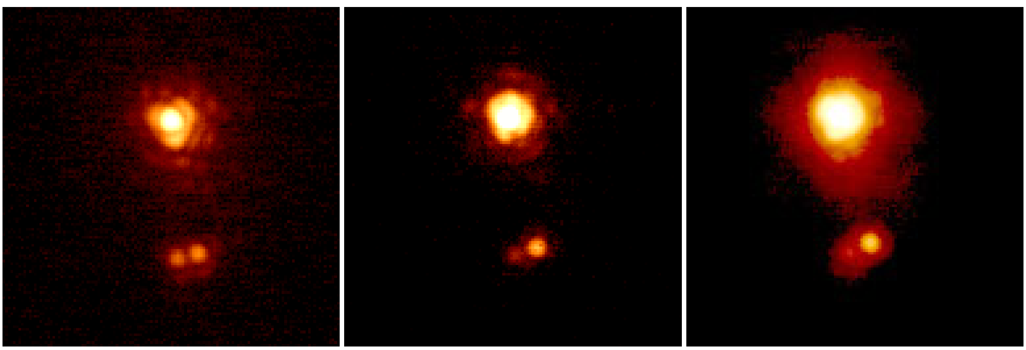

Figure 1. K-band images of T Tauri obtained with NACO at the VLT in December 2002 (left), December 2003 (middle), and December 2004 (right)

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Table 1. Astrometric Measurements of T Tau Sa – Sb

Date (UT)	d [mas]	P.A. [°]	Telescope	Reference
1997 Oct 12	51 ± 9	218 ± 8	Keck	Duchêne *et al.* 2006
1997 Dec 15	53 ± 9	225 ± 8	Keck	Koresko 2000
2000 Feb 20	79 ± 2	253 ± 2	CAHA 3.5-m	Köhler *et al.* 2000
2000 Nov 19	92 ± 3	267.0 ± 1.6	Keck	Duchêne *et al.* 2002
2002 Oct 30	107 ± 4	283.4 ± 2.1	Keck	Beck *et al.* 2004
2002 Nov 20	94.3 ± 3.3	278 ± 1	Subaru	Mayama *et al.* 2006
2002 Dec 13	108 ± 1	284.9 ± 0.9	Keck	Duchêne *et al.* 2005
2002 Dec 15	106.5 ± 1.6	283.8 ± 0.2	VLT	This work
2002 Dec 20	110 ± 4	282.0 ± 2.1	Gemini	Beck *et al.* 2004
2002 Dec 24	108 ± 3.5	287.8 ± 2.6	Mt. Palomar 5-m	Furlan *et al.* 2003
2003 Dec 12	118 ± 2	288.6 ± 1.1	Keck	Duchêne *et al.* 2005
2003 Dec 12	113.3 ± 0.8	288.5 ± 0.8	VLT	This work
2004 Nov 23	100 ± 2	298 ± 1	Subaru	Mayama *et al.* 2006
2004 Dec 09	118.9 ± 1.1	295.9 ± 0.6	VLT	This work
2004 Dec 19	116 ± 4	294.1 ± 1.4	Keck	Duchêne *et al.* 2006
2005 Nov 13	119 ± 1	300.6 ± 1.0	Keck	Duchêne *et al.* 2006

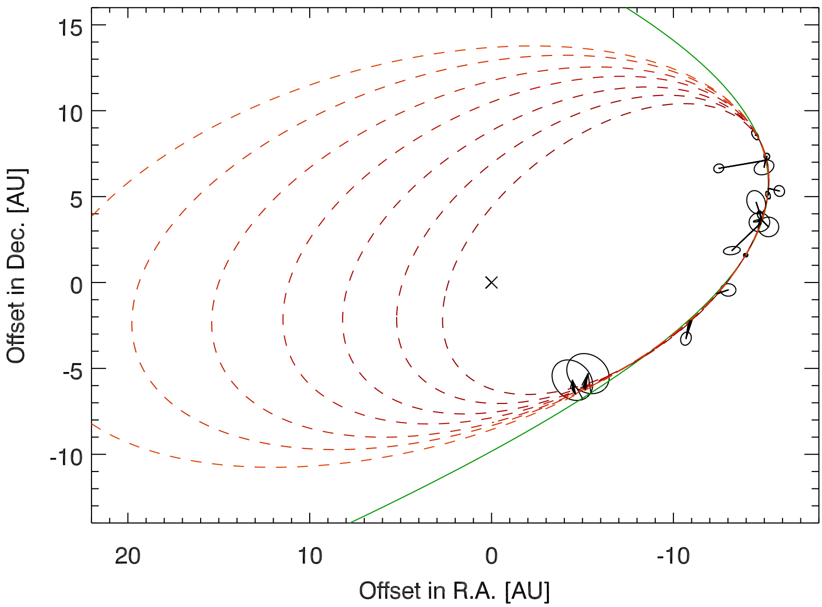

Figure 2. Measurements of the relative positions of T Tauri Sb with their error ellipses, and a few elliptic orbits that fit the measurements (dashed red lines). All these orbits are within $\Delta\chi^2 < 1$ of the "best" orbit. Also shown is the best-fitting hyperbolic orbit (solid green line). The position of T Tau Sa is marked by a cross.

2. Observations

T Tauri has been observed regularly by several authors, using different telescopes and instruments. We used all observations listed in Table 1 with the exception of the results of Mayama *et al.* (2006). Their measurements show a significant systematic offset (see Figure 2) and have been discarded from our analysis. Figure 1 shows the images obtained with the VLT and NACO, an adaptive optics system and infrared camera.

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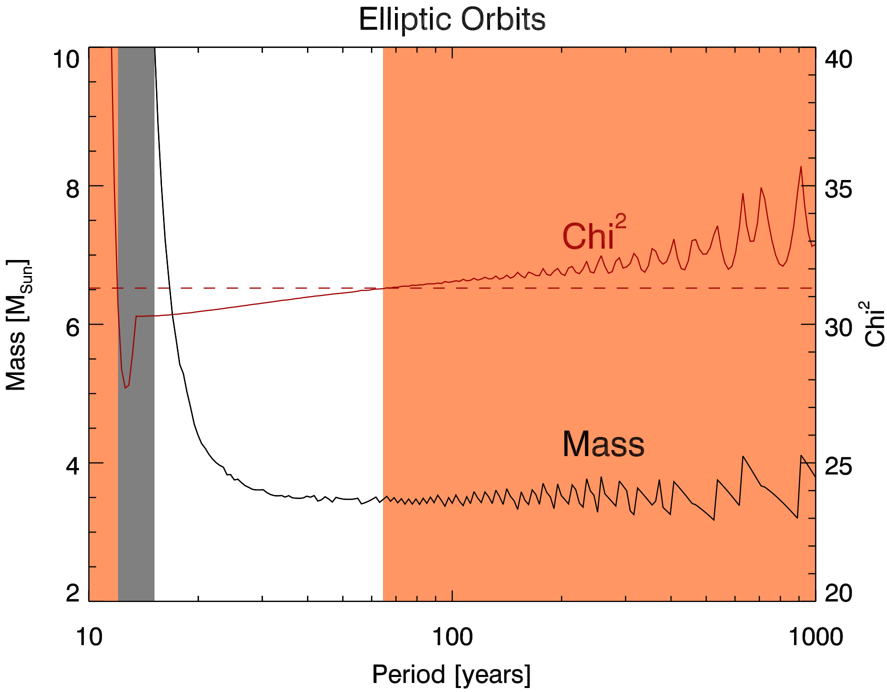

Figure 3. System mass and χ^2 as function of period for elliptic orbits (all other parameters adjusted to minimize χ^2). Orbit fits with periods less than 15 years can be excluded because the system mass is too high (dark gray region). The χ^2 of fits with periods less than 12 years or longer than 65 years (red region) is larger than $\chi^2_{\rm min} + 1$ (marked by dashed line). $\chi^2_{\rm min} + 1$ defines the 1σ confidence limit for the fitted parameters (Press *et al.* 1992, chapter 15.6, p. 693).

3. Orbit Fits

We fitted orbit models to the observations by doing a grid search in the parameter space of period, eccentricity, and time of periastron passage. The remaining 4 parameters are determined by Singular Value Decomposition. The best-fitting orbit has a period of 12.6 years and a system mass of 1211 $M_\odot$ – clearly not compatible with the luminosity of the system, which excludes masses higher than about 10 $M_\odot$. Figure 3 shows system mass and χ^2 as function of the period.

The period of the orbit is still not very well-constrained: For any period between about 15 and 65 years, we are able to find a set of parameters that is within $\Delta\chi^2 = 1$ of the best fit and predicts a reasonable system mass. Figure 2 shows possible orbits with periods in this range. It is clear that all of them fit the observations reasonably well. The corresponding system masses lie between 3.4 and 10$M_\odot$. We also fitted hyperbolic (i.e., unbound) orbits to the observations, the green line shows the one with the smallest χ^2.

Our analysis does not yield good constraints for the system mass: Any mass between about 3.4 $M_\odot$ and more than 1000 $M_\odot$ is within the 1σ confidence limit. This is in surprising contrast to the claim by Duchêne *et al.* (2006) to have determined accurate stellar masses. Whether this can be attributed to their method of estimating confidence intervals for the fitted parameters, or improvements due to the simultaneous fit of the orbits of T Tau N/S and T Tau Sa/Sb deserves further study.

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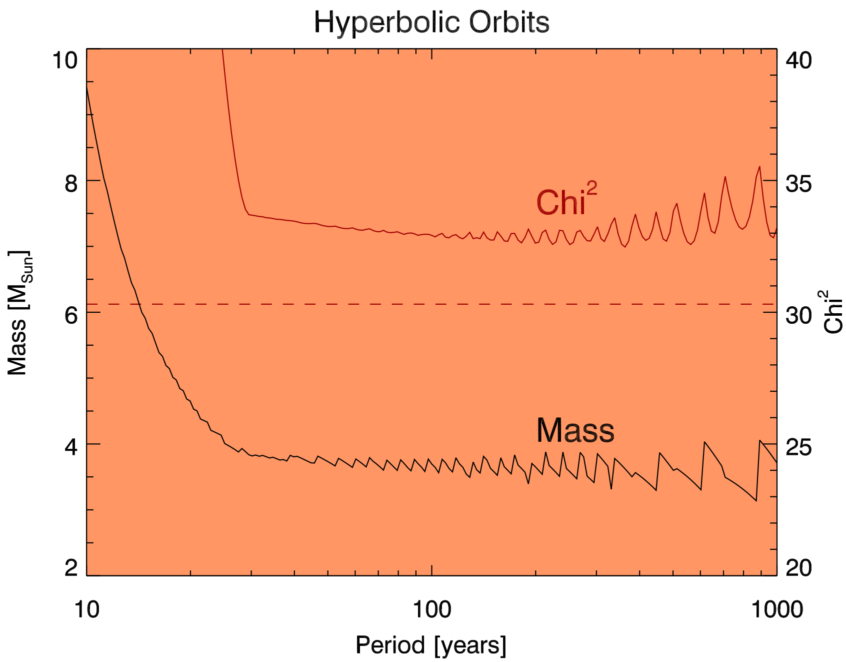

Figure 4. System mass and χ^2 as function of period for hyperbolic orbits (all other parameters adjusted to minimize χ^2). The dashed line marks χ^2 of the best elliptic orbit. The χ^2 of all hyperbolic orbit solutions is significantly higher, these orbits can therefore be excluded with high confidence.

4. Will T Tau Sb be ejected?

If the latest observations by Duchêne *et al.* (2006) are included, hyperbolic orbits can be ruled out with high confidence: The χ^2 of the best hyperbolic orbit is higher by about 2 than the best elliptic orbit with a reasonable system mass (Figure 4).

This indicates that the IR source T Tau Sb is bound to the system, and not ejected like the radio source observed by Loinard *et al.* (2003). The most likely explanation is that the radio and IR radiation are *not* emitted by the same object, in contrast to the result of Loinard *et al.* (2005).

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