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Close Companions to T Tauri Stars: Abundant and Perturbing

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Abstract. The results of a speckle imaging survey of T Tauri stars suggest that most, if not all, young low mass stars have companions. Furthermore, this survey reveals a distinction between the classical T Tauri stars (CTTS) and the weak-lined T Tauri stars (WTTS) based on the binary star frequency as a function of separation: the WTTS binary star distribution is enhanced at the closer separations. This suggests that close companions interact with the circumstellar disk material to effectively shorten the accretion time scale in multiple star systems. Recent follow up work has revealed orbital motion in the closest pairs ($\leq$ 0.″3), providing (1) evidence that these systems are indeed gravitationally bound and not the result of chance superpositions and (2) the basis for mass estimates that are necessary to distinguish between the various binary star formation mechanisms that have been proposed to date.

1. Introduction

T Tauri stars are a class of low mass pre-main sequence stars that are expected to evolve down to the main sequence to be very much like the Sun. Our current paradigm for how these stars form is based on the production of a single star that is surrounded by a disk of gas and dust, roughly a few hundred AU in extent, from which a planetary system may form. However, recent surveys suggest that T Tauri stars are primarily members of multiple star systems (Ghez et al. 1993; Leinert et al. 1993; Zinnecker & Reipurth 1993; Simon et al. 1992).

The abundance of companions at such an early stage of evolution, roughly $2 - 3 \times 10^6$ years (Simon et al. 1993), suggests that multiple star systems, as opposed to single stars, are the main product of star formation. Furthermore the presence of companion stars with separations less than the size typically assumed for a circumstellar disk suggests that they must have a significant, but so far virtually unrecognized, effect on the evolution of the circumstellar disk material.

This contribution focuses on the study reported by Ghez et al. (1993) that revealed both an abundance of T Tauri companion stars and the possible role these companions play in distinguishing the two observationally defined T Tauri subclasses. In addition, a discussion of subsequent follow up work aimed at detecting orbital motion in these T Tauri binary star systems, which has provided evidence that these systems are indeed gravitationally bound, is included.

2. Abundance of Close Companions

Ghez et al. (1993) carried out a magnitude limited (K $\leq$ 8.5 mag) speckle imaging survey of T Tauri stars in the nearby star forming regions Taurus-Auriga and Ophiuchus-Scorpius (D=150pc). Each of the 69 stars in the sample was observed over the period 1990 July to 1991 November at the f/415 Cassegrain focus of the Hale 5-m Telescope of Palomar Observatory using a 58 $\times$ 62 InSb array camera. Thirty-three companion stars were found with separations ranging from 0.″07 to 2.″5.

All the observed companion stars were assumed to be physically related to the primary stars on the following statistical argument. The probability that any of the detected double stars are merely chance alignments with a field star is negligibly small, given the density of field stars in the direction of both Taurus-Auriga and Ophiuchus-Scorpius. To be precise, of the 45 targets in Taurus-Auriga, 0.04 are expected to show a field star within a radius of 2.″5 (the maximum detectable separation for this survey). Likewise, for the 24 targets observed in Ophiuchus-Scorpius, only 0.14 are expected to appear as doubles as a result of a chance projection with a field star.

The results of this survey, shown in Figure 1, indicate that the binary star frequency in the projected linear separation range 16 to 252 AU for T Tauri stars (60[$\pm$17]%) is a factor of 4 greater than that of the solar-type main sequence stars (16[$\pm$3]%). Given the limited separation range of this survey, the rate at which binaries are detected suggests that *most, if not all, T Tauri stars have companions.*

3. Effect of Companions on Accretion Time Scales

The evolutionary relationship between the two observationally defined subclasses of the T Tauri stars, the classical T Tauri stars (CTTS) and the weak-lined T Tauri stars (WTTS) has remained a mystery to date. The subclasses are distinguished on the basis of their Hα emission, which is believed to reflect the presence or absence of an inner accretion disk: the CTTS, which have strong Hα emission, are thought to have an inner accretion disk, whereas the WTTS, which have weak Hα emission, are believed to lack an inner accretion disk.

The survey of Ghez et al. (1993), however, provides evidence for a distinction based on the binary star frequency as a function of separation between the two T Tauri star subclasses (see Fig. 2). The WTTS dominate the binary star distribution at the separations $\leq$ 35 AU, less than the size typically assumed for a circumstellar disk, and the CTTS populate the wider separations. This result suggests the exciting possibility that the close companion stars play a significant role in the differentiation of these two T Tauri star subclasses.

A close secondary star can create a gap in the circumstellar disk (e.g., Artymowicz & Lubow 1993), truncating the amount of material available for accretion. We propose that by reducing the amount of material that can be

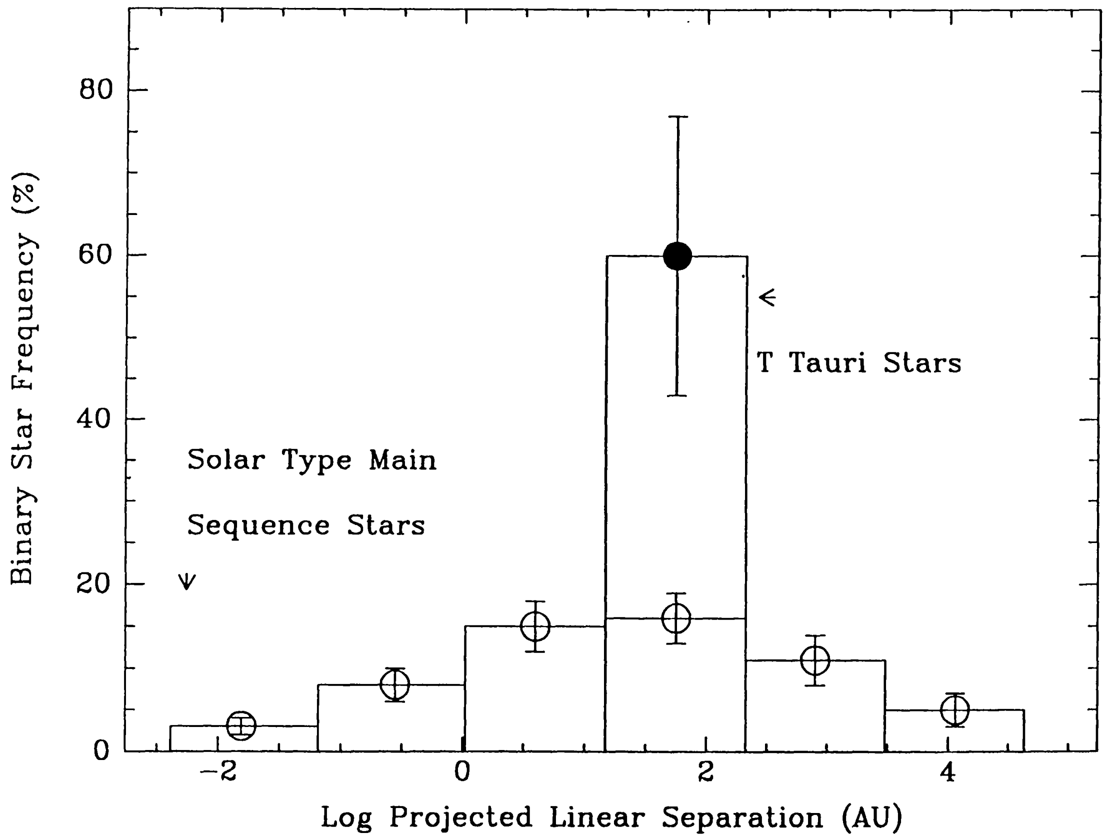

Figure 1. A comparison of the binary star frequency of T Tauri stars between the separations 16 and 252 AU from Ghez et al. (1993) to that of solar type main sequence stars measured by Duquennoy & Mayor (1991)

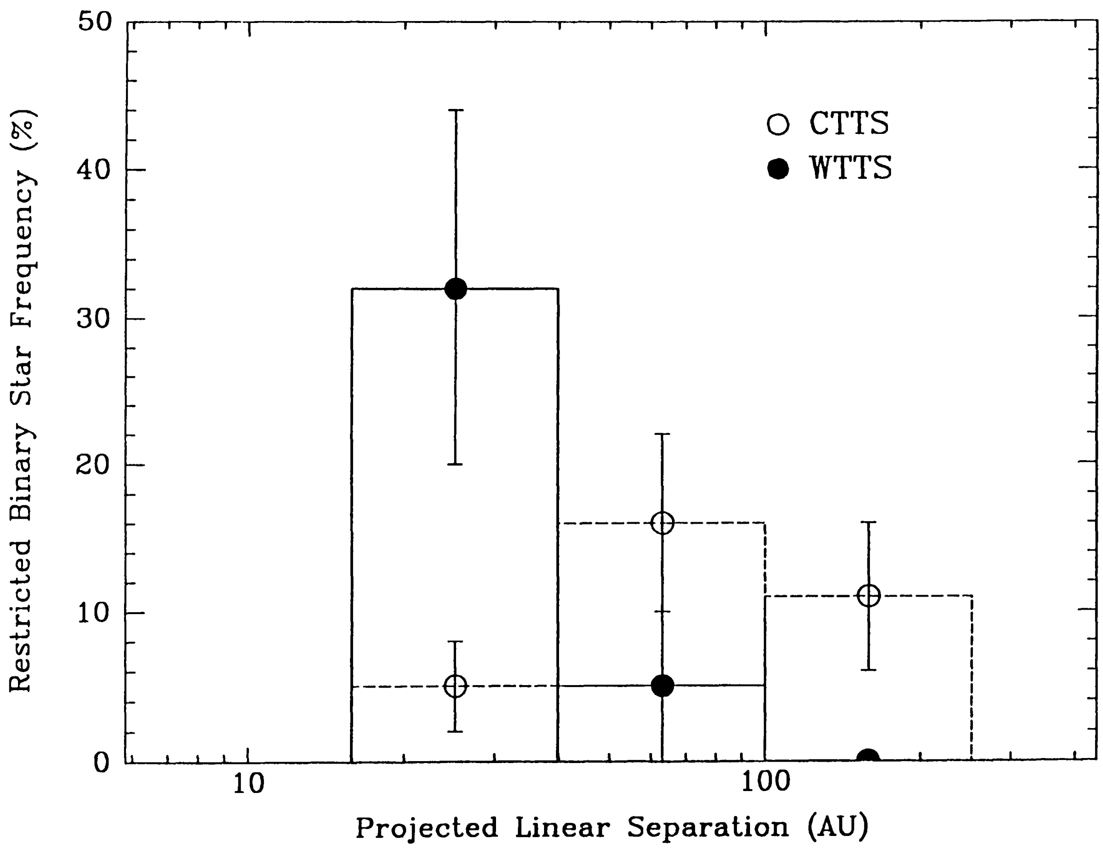

Figure 2. The binary star frequency as a function of projected linear separation for the WTTS (filled circles) and the CTTS (unfilled circles). The binary star frequency of the WTTS is enhanced at shorter separations compared to that of the CTTS.

accreted, the effect of a close secondary star is to shorten the accretion time scale in close binary T Tauri stars. In this way those T Tauri stars with close companions would quickly deplete their accretion disks and appear as WTTS at a fairly early age. Thus it is possible that *all T Tauri stars begin as CTTS and become WTTS when accretion has ceased, with the nearby companion stars acting to shorten the accretion time scale in multiple star systems.*

4. Evidence of Orbital Motion

To follow up on the discovery of such a wealth of T Tauri binary stars, we have begun a monitoring program using infrared speckle imaging to detect motions of the binary star systems with small angular separations. The ultimate goal of this project is two-fold. The first objective is to demonstrate that all the systems are indeed gravitationally bound, which would definitively prove that the observed overabundance of T Tauri stars does *not* result from chance superpositions. Furthermore, if these systems are bound and separated by less than 100 AU, the estimated size of the circumstellar disks, then the secondary stars much play an important role in the evolution of the circumstellar disk material, as already suggested both by the observed difference in the distribution of companions stars in WTTS and CTTS (Fig. 2) and numerical simulations carried out by Artymowicz & Lubow (1993). The second objective is the determination of masses, which would constrain the possible binary star formation mechanisms.

The first objective requires only orbital motion to be detected. With speckle imaging the two-dimensional separation of these binary star systems can be measured with high precision (2% uncertainties). Thus, assuming the systems are composed of two one solar mass stars in a face on orbit at a distance of 150 pc, we expect to detect orbital motion in systems separated by less than 0.″15, 0.″25, 0.″32, over time baselines of 1, 2, and 3 years, respectively. The second objective, that of mass determinations, is more ambitious and requires that more, approximately one-forth, of the orbit be observed such that the parameters of orbital motion can be measured.

Repeated speckle imaging measurements were carried out over the period 1992 February to 1993 July at the Hale 5-m telescope with the same camera used for the survey initially with the f/415 Gregorian secondary and later on (after 1993 May) with a new reimaging systems designed to go with the standard f/70 Cassegrain secondary. Additional observations were made at the Steward Observatory 90 in with a similar two-dimensional speckle imaging camera described by McCarthy et al. (1990). The initial measurements are taken from Ghez et al (1993) for all the systems except two, SR 24 N, SR 12, and DoAr 51, which were not included in this survey and whose initial two-dimensional separation measurements are given in Table 1.

Table 1. Initial Separation Measurements not in Ghez et al. (1993)

Object	Date	Separation	Position Angle
SR 24 N[a]	1992 May 12	0.197±0.004	84±1
SR 12[b]	1992 May 12	0.262±0.006	84±1
DoAr 51[c]	1992 Feb 18	0.77±0.02	76±1

[a]Simon et al. (1992) used lunar occultation to obtain a one-dimensional measurement of this system

[b]Also measured by Chen et al. (1990) with lunar occultation and by Zinnecker & Perrier (1988) with one-dimensional speckle interferometry

[c]A newly discoved binary star

For the binary stars that were remeasured, the majority of systems with separations less than 0.″3, which corresponds to 45 AU at a distance of 150 pc, show significant motion, whereas those with larger separations appear to be stationary (see Fig. 3). This implies that the motion is the result of orbital motion as opposed to proper motion, which would move the system independent of their average separation. *This is the first demonstration that these systems are indeed physically bound.*

With additional observations over the next few years these separation measurements will provide mass estimates. Estimates of the masses and ages (which are also being derived, but will be discussed elsewhere) of the components in multiple star systems, can be used to distinguish between the two proposed bi-

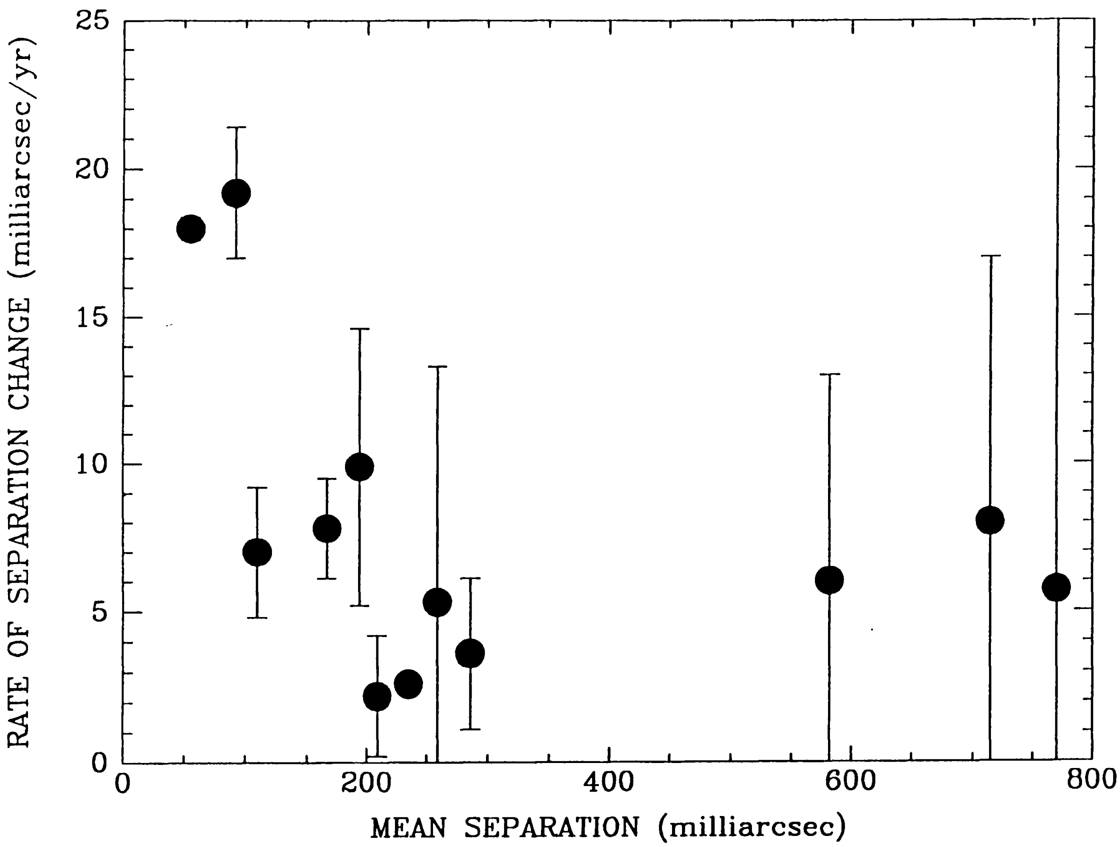

Figure 3. A plot of the rate of change in the separation versus the mean separation of the binary systems. As expected for orbital motion, closer systems show a higher rate of change, and very wide systems show no significant change

nary star formation mechanisms mentioned above, core and disk fragmentation (e.g., Boss 1993; Bonnell & Bastien 1993; Adams, Ruden, & Shu 1989). Core fragmentation, in which the components are formed during the collapse of a rotating molecular cloud core, would produce components of the same age and a wide range of masses. Whereas disk fragmentation, in which the companions are formed from the growth of instabilities in the primary star's circumstellar disk, would result in companions that are younger than the primary star and not very massive given the apparent absence of massive disks (Tereby et al. 1993).

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