# T Tauri S confirmed as a binary Star

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## Abstract

We report on observations of T Tauri with the 3.5 m telescope and the adaptive optics system ALFA on Calar Alto. We used ALFA to separate T Tauri N and S, and speckle interferometry to demonstrate that T Tauri S itself is a binary. This confirms results recently obtained at the 10 m Keck telescope.

## 1. Introduction

The infrared companion of T Tauri, also known as T Tau IRC or T Tau S, was discovered by Dyck et al. (1982), but still no satisfying explanation for its peculiar spectral energy distribution exists. Recently, it was reported that the infrared companion is a binary with a projected separation of only 50 mas (Koresko 2000). Other authors find no sign of binarity, but of an extended envelope around T Tau S (Roddier et al., this volume).

We had the opportunity to observe T Tauri with the adaptive optics system ALFA. Here we report on the first results.

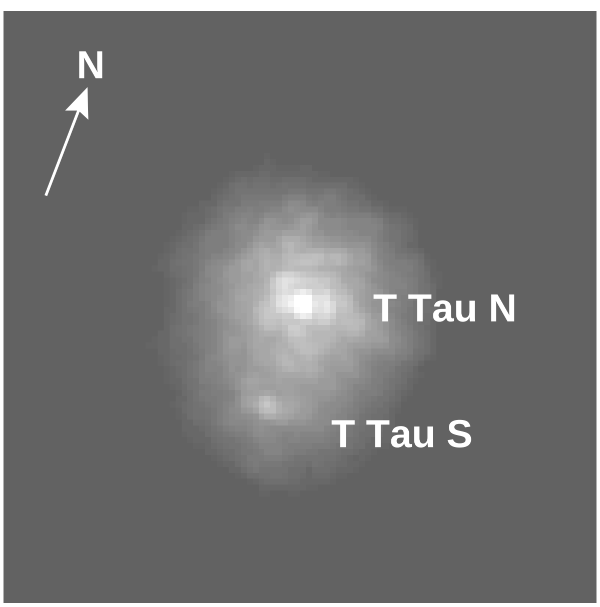


Fig. 1.— Sum of 200 images of our data after sky subtraction and bad pixel correction. A logarithmic scaling was chosen to make T Tauri S visible.

## 2. Observations and Data Reduction

The observations were carried out on 20. February 2000 with the adaptive optics system ALFA at the 3.5 m telescope on Calar Alto. The seeing was about 1.2 arcsec. We observed in the H band to take advantage of the smaller diffraction limit compared to the K band. The camera used was Omega-Cass in its "very high resolution" mode, which has a pixel scale of 0.04 arcsec/pixel. We used the subarray read-out mode to read subarrays of $256 \times 256$ pixels with the shortest integration time possible, i.e. 0.281 seconds. Some 1200 single images were recorded.

These images have been calibrated in the standard way by subtracting mean sky frames and replacing bad pixels by the median of adjacent good pixels. Figure 1 shows an example of the resulting images. Subframes 60 pixels wide and 20 pixels high around the primary and secondary star were extracted. The size of the subframes is a compromise between truncation of the point-spread function (PSF) and contamination of the images of the secondary by light from the primary. The power spectrum analysis of Labeyrie (1970) was applied to the images, using the primary as PSF reference for the secondary.

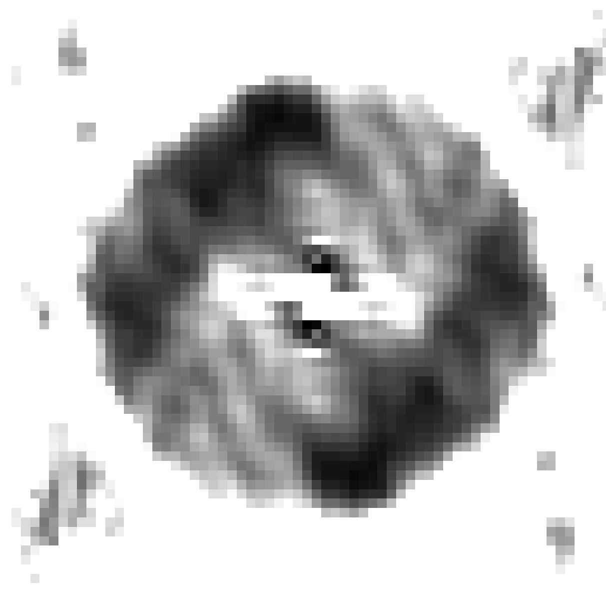

Fig. 2.— Power spectrum of T Tauri S. Although there is a lot of noise caused by the truncation of the PSF and light from the T Tauri N leaking into the image, the characteristic striping pattern of a binary remains visible. Due to the diffraction limit of the telescope, only a circular region contains information about the star. Since the separation of the binary is close to the diffraction limit of the telescope, only a bright stripe through the center of the image and two dark stripes next to it are visible.

## 3. Results

It is not possible to compute the parameters of a binary directly from the data. Therefore, we use a multidimensional least-squares fit using the `amoeba` algorithm (Press et al. 1994). Our program tries to minimize the difference between the power spectrum computed from a model binary and the observational data by varying the separation, position angle, and brightness ratio of the model. Fits to different subsets of the data yield an estimate for the standard deviation of the binary parameters.

The results of this procedure are: position angle $(253 \pm 2)^\circ$, separation $(79 \pm 2)$ mas, and flux ratio in H $0.259 \pm 0.011$. Because of the symmetry of the power spectrum, there is an 180° ambiguity in the position angle, i.e. it can also be 73°. However, we computed the phase of the Fourier-transformed image using the Knox-Thompson algorithm (Knox & Thompson 1974) and find indications that it is in fact 253°.

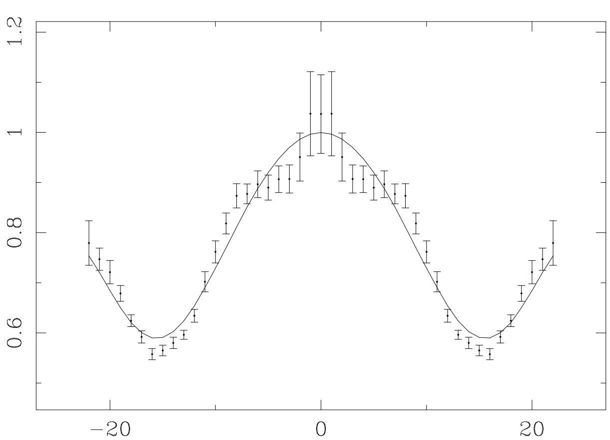


Fig. 3.— One-dimensional power spectrum of T Tauri S, obtained by averaging the two-dimensional power spectrum along lines with position angle 163°. The points and error bars denote the measured data, the line represents the binary model.

## 4. Discussion

Based on our data alone, we would not claim we have evidence that T Tau S is indeed a binary. We see only the first minimum of the stripe pattern in the power spectrum. Translated to "normal" space, this corresponds to two bright pixels next to each other, but without a darker pixel in between.

We can be sure, however, that the source is extended in one direction only. Perpendicular to this direction, it is point-like on the pixel scale of the camera, i.e. 40 mas.

Combined with the results of Koresko (2000), the evidence for a binary star is more convincing. They observed T Tauri on 15 December 1997 and find a position angle of $(225 \pm 8)^\circ$. The position angle has changed by 28° within 2 years, which is about the value one would expect for the orbital motion of a binary of this separation and with a system mass of $1\,M_\odot$.

Furthermore, the better resolution of the 10 m Keck telescope allowed Koresko to reconstruct the second maximum of the stripe pattern of the power spectrum. The power spectrum of an extended source would show only one central maximum.

We thank Mark McCaughrean for helpful comments and proof-reading of the manuscript in the very last minute.

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