Speckle Holographic Imaging of Pre–Main Sequence Visual Binaries in Taurus

Chris D. Koresko

Interferometry Science Center / IPAC / Caltech / JPL

Introduction

The T Tauri stars in the Taurus star–forming region are among the best modern analogs of the Sun during its planet–forming phase at an age between 10^5 and 10^7 yr. They are frequently surrounded by massive dusty disks similar to the Solar Nebula from which the Sun's planets formed.

It is well known that binaries are very common among the low–mass pre–main sequence stars in the Taurus star–forming region. In fact, the formation of isolated stars appears to be unusual.

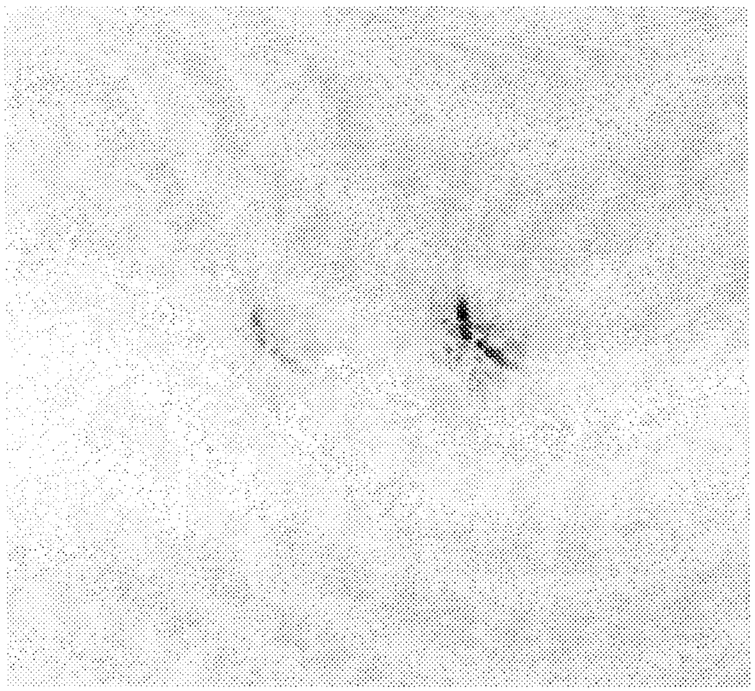
Thus it is of great interest to study the circumstellar environments of stars in these binary systems in detail. For visual binaries, one of the most effective ways to do this is to image them using Speckle Holography. This technique produces diffraction–limited images with high contrast, or, equivalently, very well–calibrated point–spread functions (PSFs) by taking advantage of isoplanatism and the presence of high spatial frequency information in short–exposure frames.

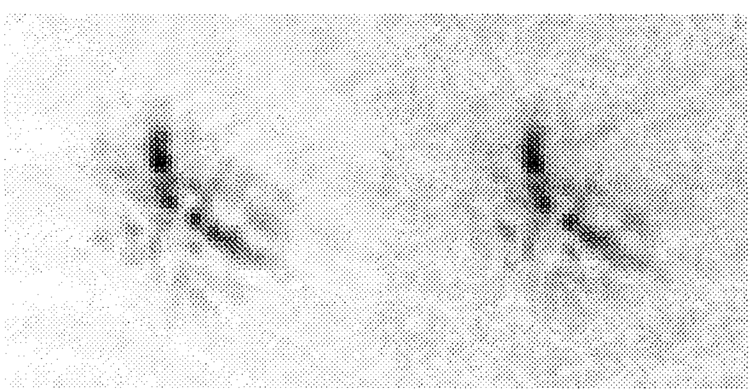
Speckle Holography

Speckle Holography is a close cousin to Speckle Interferometry. It consists of acquiring a large number of frames with exposure times short enough to "freeze" the atmospheric seeing, and with a pixel scale small enough to Nyquist sample the diffraction limit of the telescope.

Unlike Speckle Interferometry, Speckle Holography does not assume that the seeing is statistically stationary and that the number of realizations is large; instead, it relies on the presence of a pointlike star within the isoplanatic field of the science target. The pointlike star provides an instantaneous measurement of the point−spread function in each short−exposure frame. This allows an undistorted, diffraction−limited image of the target to be recovered by Fourier deconvolution. These images (or, equivalently, their Fourier transforms) can be averaged over many frames to accumulate signal−to−noise without losing resolution.

A Single Frame





This is a single 137–msec exposure on the pre–main sequence visual binary star Elias 2–26 in the Ophiuchus SFR. A complete reduction of this dataset, which consists of 857 such frames, indicates that both components are unresolved. Note the detailed similarity of the two stars' images.

The lower picture shows magnified subframes centered on the two stars. The brighter one is used as a PSF estimator to deconvolve the fainter one.

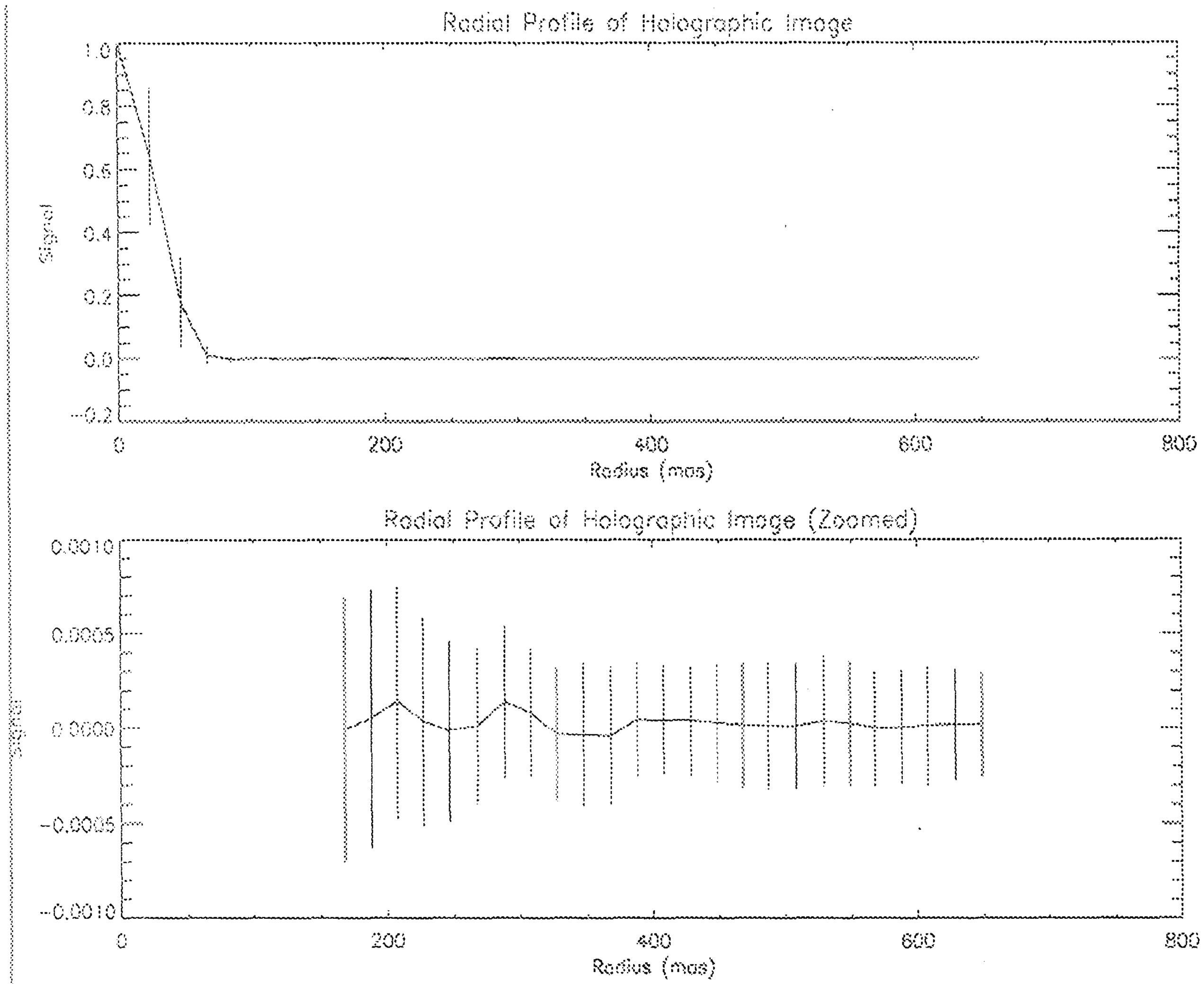
Data Reduction Process

The Fourier amplitude and phase are recovered separately. The amplitude processing is nearly identical to that used for speckle interferometry: The power spectra of the individual subframes are averaged, along with the power spectra of subframes containing blank sky. The average blank–sky power is subtracted from the averages of the target and reference–star power spectra, and the Fourier amplitude is the square root of the ratio of the sky–subtracted target power to the sky–subtracted reference power.

The Fourier phase is estimated for each frame as the difference of the phases of the target and reference–star images. This is simply averaged over the set of frames.

Errorbars are estimated from the scatter among the results derived from subsets of the data.

Radial Brightness Profile

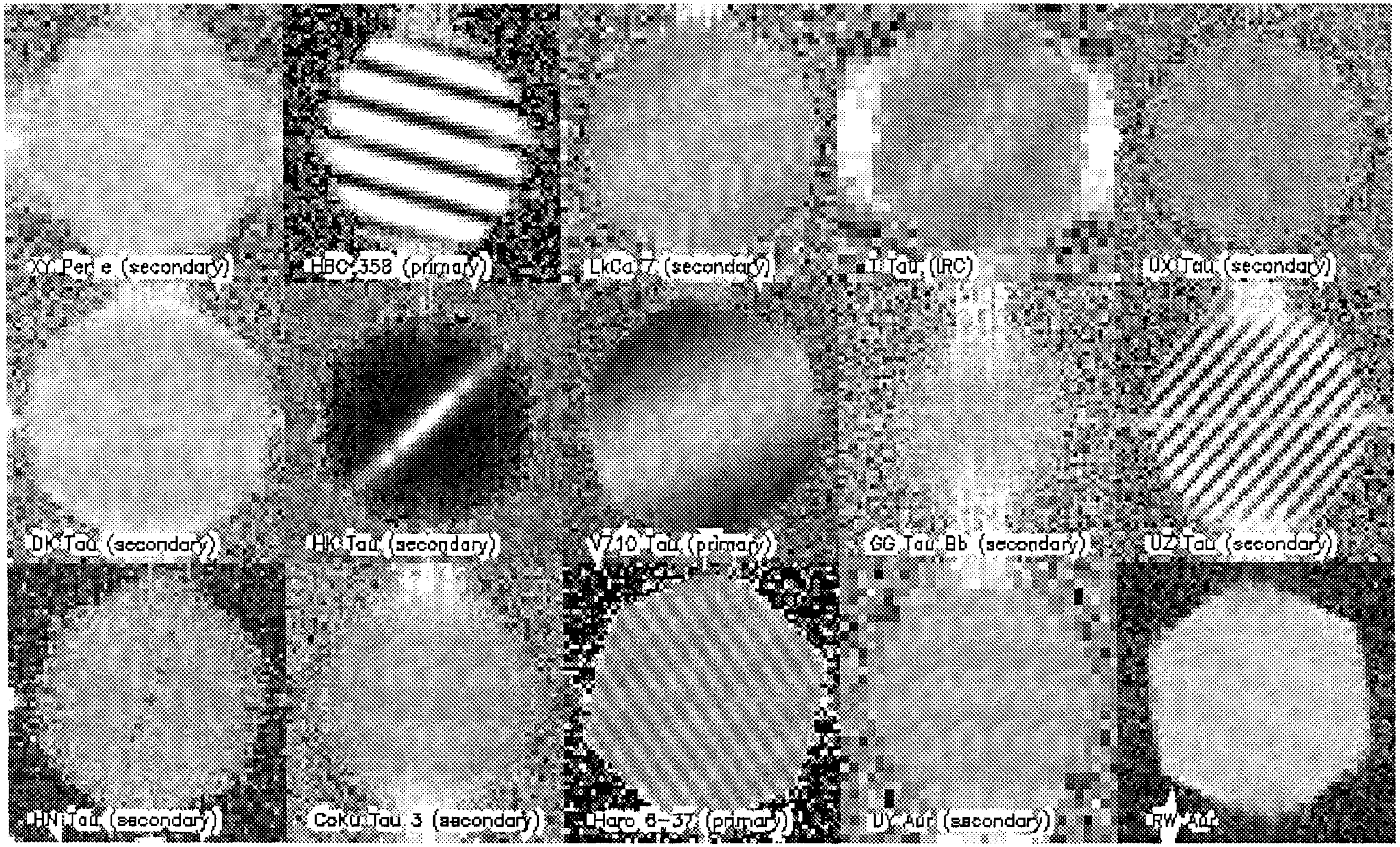


The brightness of a Speckle Holographic image of the unresolved source Elias 2−26, averaged over pixels of equal distance from the star, gives an indication of how well the PSF is controlled. The dynamic range is >2000 at radii beyond 300 mas. The plateau at that distance points to read noise as the limiting factor.

Observations

The observations were made on 14 and15 December, 1997, using the Keck 1 telescope with the Near Infrared Camera (NIRC) and the Image Converter (IC). The data were taken in broadband filters near 2.2 μm, defined either by the standard K filter or by a somewhat narrower one (CH4) for the brightest sources. They typically consisted of several hundred frames with the exposure time set to 137 msec. The image was rotated to place the axis of the binary along the readout direction of the detector to minimize the effect of the time evolution of the PSF during the read.

Results: Two–Dimensional Fourier Amplitudes



These are the Fourier amplitudes for components in the 15 systems in the sample. Zero spatial frequency is in the center of each plot. A striped pattern is characteristic of a double–star image. XY Per e, LkCa 7, and V710 Tau are marginally–resolved but consistent with tertiaries at separations as small as ~10 mas. These data led to the discovery of the edge–on disk in HK Tau and the duplicity of T Tau IRC, which have been published separately.

Discussion and Conclusions

Remarkably, more than half of the visual binary systems studied contain components which were resolved by the holographic observations. Of these, in only one object, the edge–on disk system HK Tau B, is the detected structure clearly not due to the presence of a tertiary companion. The two widest tertiaries, in UZ Tau and Haro 6–37, were already known. The HBC 358 and T Tau systems have fully–resolved tertiary companions, while marginally–resolved structure consistent with tertaries at smaller separations was detected in XY Per e, LkCa 7, and V710 Tau.

The fraction of visual binaries which turn out on closer inspection to be probable hierarchical triples is strikingly large. This may represent a further indication that the star formation process in the Taurus SFR differs significantly from that which produced most of the main sequence stars in the solar neighborhood.

Beyond this, it may be necessary to consider carefully the effect of contamination by unseen tertiaries when placing binary components on the HR diagram to test the predictions of theoretical evolutionary tracks.