Observations of Young Stellar Objects with Palomar Testbed Interferometer and Keck Interferometer

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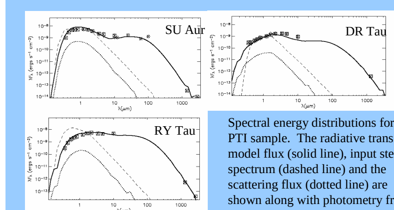
Photo courtesy of National Geographic

- PTI was developed by the Jet Propulsion Laboratory as a testbed for the Keck Interferometer
- The current operations are run by the Michelson Science Center
- PTI has three operational baselines from 85 to 110 meters
- Fringe tracking is done at H and K bands
- PTI T Tauri team: David Ciardi, Josh Eisner, Gerard van Belle, Christina Walker, Kenneth Wood

The PTI Sample

Source	Spectral type	Fractional K excess	Fit ring radius (AU)
SU Aur	G2	0.44 ± 0.09	0.18 ± 0.04
RY Tau	K1	0.71 ± 0.11	0.19 ± 0.06
DR Tau	K7	0.80 ± 0.30	0.07 ± 0.03

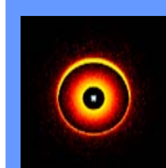


Spectral energy distributions for the PTI sample. The radiative transfer model flux (solid line), input stellar spectrum (dashed line) and the scattering flux (dotted line) are shown along with photometry from Kenyon and Hartmann (1995)

Detailed radiative transfer models

For the PTI sources, we calculated Monte Carlo radiation transfer models to fit both the spectral energy distributions and the measured visibilities. The code includes accretion and shock/boundary layer luminosity and multiple scattering is included in the disk. This technique naturally accounts for the radiation transfer effects and the heating and hydrostatic structure of the inner wall of the dust disk. For more details, see Akeson et al (ApJ, March 2005).

In these models, the gas disk extends to within a few stellar radii and the dust disk starts at the dust sublimation radius. For SU Aur and RY Tau, the gas within the inner disk contributed substantially to the near-infrared emission from the disk (see figure). These models, which reproduced the measured visibilities and the SED, contained only a small (<6%) contribution from emission on scales larger than 12 millarcseconds. This suggests that scattered light in the near-infrared is not a dominant component for these systems.



Example radiative transfer model. The disk is inclined by 30 degrees and the brighter inner dust rim facing the observer is at the top. The inner ring of emission is due to gas within the inner dust radius.

Abstract

Infrared interferometry observations of T Tauri stars are presented from the Palomar Testbed Interferometer and the Keck Interferometer. The objects span a range of both stellar properties (spectral types from K7 to G2) and disk properties (accretion rates from 1 x 10^{-9} to 2 x 10^{-7} solar mass/yr and infrared excesses from 10 to 80%). In most cases, the sources are resolved and we derive characteristic sizes assuming simple source morphologies. Assuming the resolved emission represents in the inner edge of the dust disk, we compare the measured sizes to the predicted dust sublimation radius.

Visibility measurements

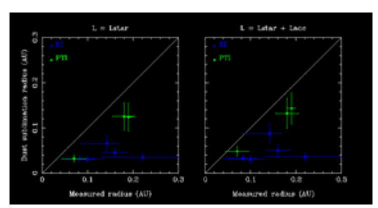
Both KI and PTI are fringe-tracking infrared interferometers and all data presented here are taken at K band (2.2 μm). The PTI data are described in Akeson et al (to appear in ApJ, March 2005). The system visibility is measured using unresolved calibrator stars. The total errors include the scatter in the visibility data, the error in measuring the system visibility, and for KI an estimate of the systematic error (see Colavita et al, 2003 for more details on the KI data reduction).

Model fitting

To characterize the size of the emission region probed by the interferometer, we fit geometric models to the measured visibilities. We adopt a model for these sources comprising of a central (unresolved) star, a partially resolved component (presumably arising from the circumstellar disk) and an incoherent contribution from any extended emssion (size scales larger than 10 milliarcsec). The stellar contributions to the K band emission are quantified by spectral energy distribution (SED) fitting (see side panels) which, for these stars, agreed with infrared veiling estimates derived through spectroscopy by other groups (e.g. Folha and Emerson, 1999; Johns-Krull et al 2001, Muzerolle et al 2003). The infrared excess for each source is listed in the tables. Contributions from extended emission are much harder to assess as observations with sufficient resolution do not exist for most of these sources. The PTI field-of-view is 1 arcsec and the KI field-of-view is 50 mas. For the PTI sources, the radiative transfer models fit the SED and visibility data with extended contribution of less than 6% (see left panel). At KI, we include the scattered light measured through lunar occultations for DG Tau (Leinert et al 1991; Chen et al, 1992) and assume no extended component for the other sources.

Here we present the results from fitting a annular ring of emission to the visibility data. This model approximates a physical model in which the disk emission is dominated by a vertically extended inner wall at the radius where the disk temperature equals the dust sublimation temperature. This model was first proposed to explain the SEDs and aperture masking observations of Herbig Ae/Be stars (Natta et al, 2001; Tuthill et al, 2001; Dullemond et al, 2001). For the PTI sources, data were taken on 3 baselines and inclined ring models were fit to the data, thus constraining the inclination angle. At KI, the hour angle coverage on the single baseline was not adequate to constrain the inclination, and face-on models are used. This assumption will underestimate the true size if the disk is inclined. At both interferometers, acquisition is done at visible wavelengths, biasing the source selection against edge-on sources in which the central star is heavily obscured by the disk In the KI sample, DI Tau and V830 Tau do not have significant infrared excesses using our SED-fitting method and we did not fit the visibilities from these sources, which are marginally resolved in the KI data. The fit ring radii are given in the tables and the errors include the uncertainty in the excess flux.

To compare our measured radii with the expected dust sublimation radius for each star, we use the treatment of Monnier and Millan-Gabet (2002) which does not include backwarming and assumes large grains. We assume the same absorption efficiency and grain size for all stars in this sample and use a dust sublimation temperature of 1500 K. The dust sublimation radius is calculated for both the stellar luminosity and the combined stellar and accretion luminosities (Muzerolle et al 2003).



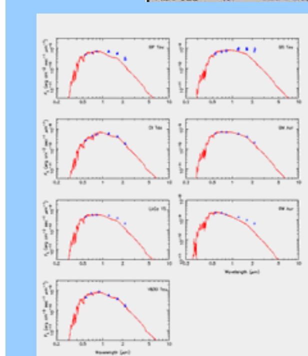
Results

In this figure, the diagonal line is where the measured size and the dist sublimation radius are equal. All the sources fall to the right of this line, indicating that the measured radius is *larger* than the predicted dust sublimation radius (also see Patience et al poster). Although including the accretion luminosity (right panel) does decrease this disagreement, all sources are still larger than predicted from a model in which the disk emission is dominated by dust at the radius where the sublimation temperature is reached. We note that the sources with the largest disagreements (GM Aur and LkCa 15, the right-most blue points) have low accretion rates (6 x 10^{-9} and 1 x 10^{-9} solar mass/yr respectively) compared to sources such as RY Tau, SU Aur and DG Tau (top three points) which have accretion rates of 8 x 10^{-8} to 2 x 10^{-7} solar mass/yr.

- The Keck Interferometer is a NASA-funded project developed jointly by the Jet Propulsion Laboratory (instrument development), the W.M. Keck Observatory (instrument operations and development) and the Michelson Science Center (science operations and support)
- The interferometer combines the two 10-m Keck telescopes and uses both adaptive optics systems
- Angle tracking is done at J and H bands and fringe tracking at H and K bands
- For more information, including proposal support, see http://msc.caltech.edu/KISupport/index.html
- KI T Tauri team: A. Boden, J. Monnier, R. Millan-Gabet, A. Tannirkulam, C. Beichman, J. Beletic, N. Calvet, L. Hartmann, L. Hillenbrand, C. Koresko, and A. Sargent

The KI Sample

Source	Spectral type	Fractional K excess	Fit ring radius (AU)
BP Tau	K7	0.56 ± 0.12	0.08 ± 0.03
DI Tau	K3	0.67 ± 0.19	
DG Tau	M0	0.07 ± 0.10	0.14 ± 0.03
GM Aur	K3	0.12 ± 0.02	0.22 ± 0.08
LkCa 15	K5	0.43 ± 0.04	0.10 ± 0.03
RW Aur	K2	0.64 ± 0.10	0.16 ± 0.02
V830 Tau	K7	0.06 ± 0.12	



Spectral energy distributions for the KI sample. Stellar photosphere templates from Lejeune et al (1997) were fit to the VRI photometry from the literature using fixed effective temperatures (White and Ghez, 2001; White and Hillenbrand, 2004) and treating the extinction as a free parameter.