Observations of the Inner and Outer Disks around Young Stars

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Hot Inner Disks

Introduction

With the exceptional angular resolution of the Keck interferometer we are studying the inner disks of young stars at different evolutionary stages at **spatial scales less than 1AU**. At these scales standard flared disk models (Chiang & Goldreich 1997) predict small sizes unresolvable with the interferometer while more recent models predict a larger inner disk radius (Dullemond *et al.* 2001).

Sample

The observed targets cover a range of evolutionary states and both Solar-type and early-type objects

Type	Targets
CTTS	AS 209, AS 353
WTTS	HBC 634, HBC 380
HAe	HD163296, RR Tau
Submm disk	HD107146

Observations and Initial Results

- Data from Keck interferometer June 2004/Jan 2005
- 2 10m telescopes with an 85m baseline
- K-band target&calibrator visibilities recorded
- **λ/B = 0".005, corresponds to 0.15-0.85 AU**

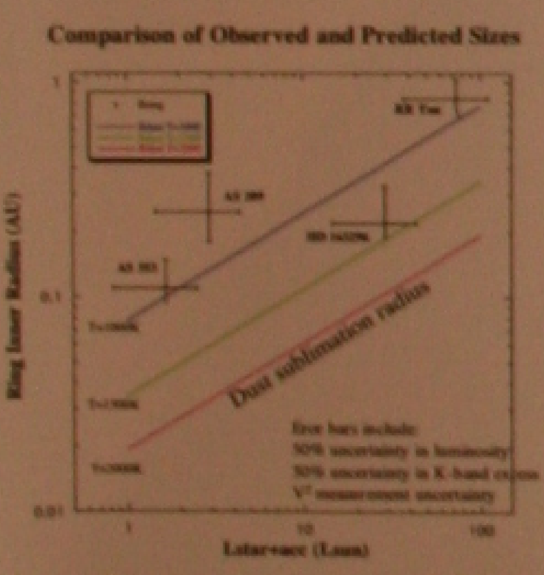
Target	V^2cal	Result	Rring
AS 209	.70-.89	Resolved	
AS 353	.63	Resolved	
HD 163296	.36-.40	Resolved	
RR Tau	.42-.52	Resolved	
HBC 634	.71-.98	Uncertain	
HBC 380	.99	Unresolved	
HD 107146	1.0	Unresolved	

The calibrated squared visibilities (V^2_{cal}) for each target are listed; typical uncertainties are 0.08. **Resolved sources have a value of V^2_{cal} less than 1.0.**

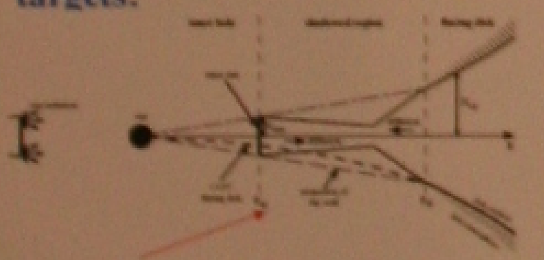
The calibrated squared visibility V^2_{cal} is modelled as arising from an unresolved star and a resolved disk. The stellar and disk fluxes are estimated from photometry or veiling and the disk V^2_{disk} is determined and fit to a ring model.

$$V_{cal} = \frac{F_{star} \times 1.0 + F_{disk} \times V_{disk}}{F_{star} + F_{disk}}$$

Additional components such as scattered light would contribute incoherently and are not included in this model. The interferometer field-of-view is very small -- 0".05 -- which limits the region contributing scattered light.



The inner disk sizes suggested by the ring model are typically larger than the dust destruction radius predicted for stars with the combined stellar and accretion luminosities of the targets.



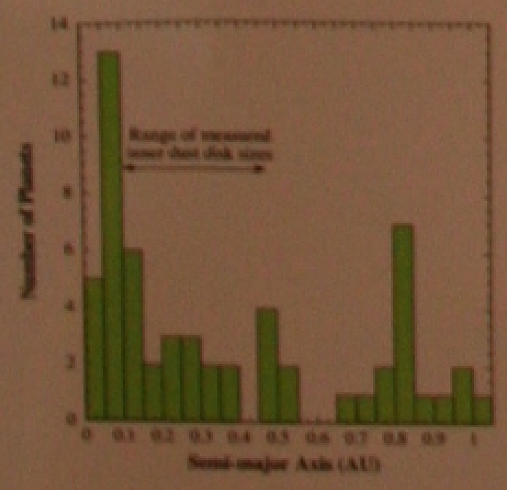
$$R_{dust} = \frac{1}{2}\left[\frac{L}{4\pi\sigma T^4_{dust}}\right]^{1/2}$$

(Dullemond *et al.* 2001)

Implications for Planet Formation

Theoretical models of planet migration require disk material between the star and the planet to provide a mechanism for angular momentum transfer to occur. Since radial velocity detected **extrasolar planets have semi-major axes as small as 0.037 AU**, the inner disk radius is expected to be smaller than this value. Although the **inner disk sizes measured by the interferometer are larger**, there may be interior hot gas that would not be detected in these observations.

(Muzerolle *et al.* 2004)



(California & Carnegie planet search - www.exoplanets.org)

In a modified disk accretion model, the region interior to the dust sublimation radius is not evacuated, but retains gas (light shading) which would allow planets to migrate to closer radii than the edge of the dust disk.

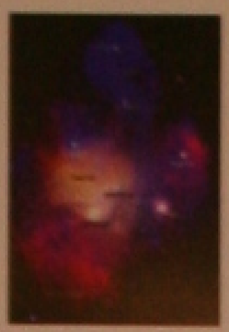
Cool Outer Disks

Introduction

Since the majority of stars in the nearest star-forming regions are members of binary systems, the influence of companion stars is a critical consideration for star and planet formation models. Class 0 binaries are observed to have disks around each component, while Taurus Class II systems preferentially show circumprimary disks. To investigate the circumstellar environments of young multiple systems, we are studying the **distribution of the dust around Class I and Class II binaries** in the Ophiuchus and Taurus star-forming regions, and concentrating on the intermediate Class I stage.

Observations and Sample

- Data from the 6-antenna Owens Valley millimeter-wave array
- Central frequency 112 GHz (3mm), Continuum bandwidth 4 GHz
- Data taken in high and low resolution configurations (baselines 35-240m)
- Beam size sufficient to resolve each pair



Ophiuchus Targets

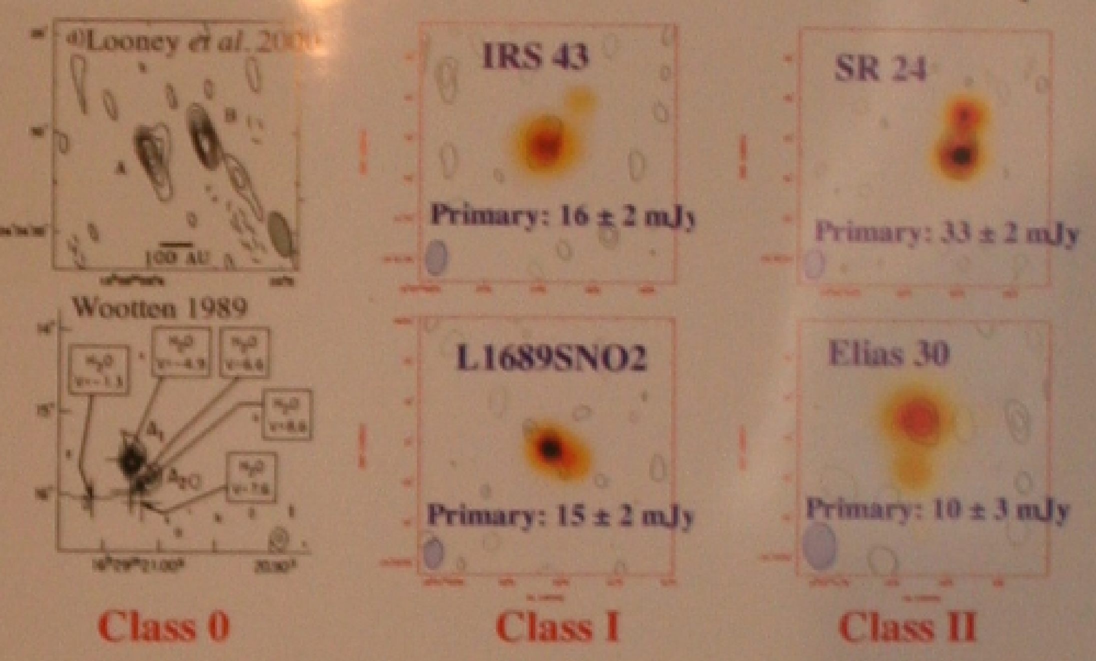
Target	Class	Separation	1.3 mm
IRS 43	I	6".99	75 mJy
L1689SNO2	I	2".92	150 mJy
SR 24	II	6".00	280 mJy
Elias 30	II	6".70	150 mJy

Taurus Targets

Target	Class	Separation	1.3mm
IRAS04113	I	4".03	410 mJy
IRAS04191	I	6".09	110 mJy
IRAS04248	I	4".55	60 mJy
IRAS04325	I	8".15	110 mJy

Evolution of Dust Disks in Ophiuchus Binaries

For each of the four binaries observed, the **mm emission is dominated by the primary disk**, even at the Class I stage. The secondary stars retain inner disks as evidenced by Hα emission and IR excesses, but they lack the massive outer dust disks that are seen around the primary stars and that provide the raw materials for planet formation.



Maps of dust emission from binaries at the Class 0, I, and II evolutionary stages are shown. The Class 0 results are from BIMA and VLA observations. **Massive secondary disks are absent in the later Class I and II stages.**

The OVRO map for each Class I and II source is shown as a contour plot overlay on the 2MASS K_s image, centered on the primary. The contours are -2 (dashed), 2, 3, 4, 5, and 6 times the RMS noise level. The alignment of the 2MASS and OVRO maps is based on the absolute positions.

Implications for Star and Planet Formation

- **Primary Disk Masses:**

  Range from **0.005 Msun - 0.2 Msun**
  Comparable to or grater than the Minimum Mass Solar Nebula
  Planet formation may proceed around primaries

- **Primary Dust Opacity Index:**

  Range from **-1.0 to 2.2**, mostly less than ISM value of 2.0
  Possible explanations: **grain growth, differences in composition or structure of grains**

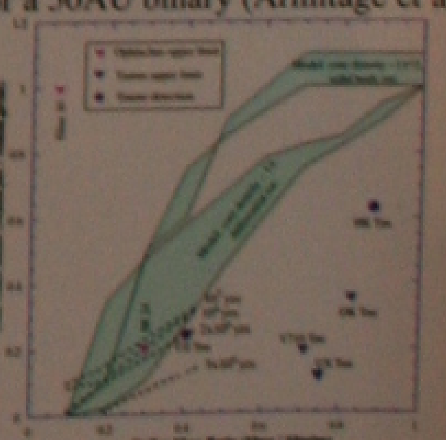
- **Planet Formation vs. Disk Dissipation Timescales:**

Two formation models predict different timescales for planet formation: Gravitational Instability ~0.1Myr Core Instability ~1-10Myr

Ages for Class I systems are uncertain and determined with different methods. **If Class I systems are younger than Class II or if the planet formation timescale exceeds the Class II age, then there may not have been sufficient time to form giant planets around the secondaries** through the gradual accumulation of planetesimals required by the core instability mechanism.

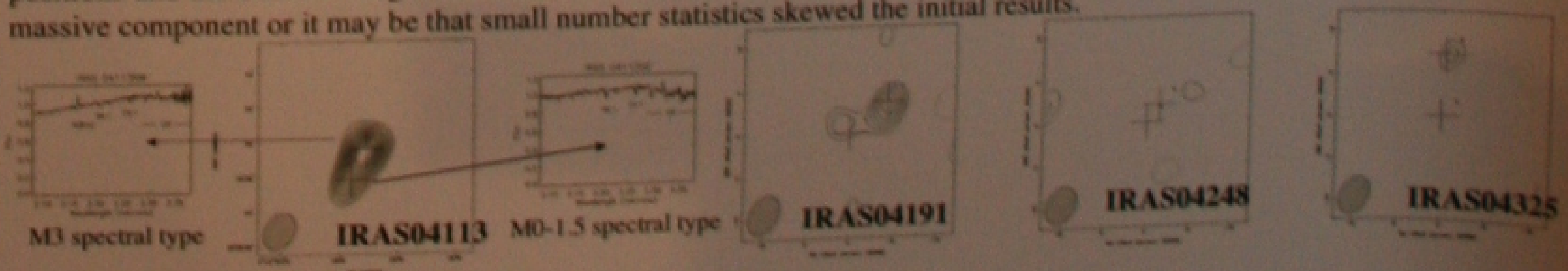
The OVRO data are uniquely suited to test predictions of the ratio of disk masses.

- Fragmentation models (e.g. Clarke 1996) predict the primary disk is more massive as measured
- Simulations of accretion onto protobinaries (Bate 2000) predict a range of disk mass ratios as a function of stellar mass ratio, plotted below. Almost all the measured values and limits are less than expected. The dashed lines are models of the evolution of the disk mass ratio for a 50AU binary (Armitage et al. 1999).



Taurus Results

The Taurus Class I binaries results are different from both the Ophiuchus binaries and the Taurus Class II binaries observed previously. **Taurus class I secondary disks are dominant in three of four pairs.** The maps are all centered on the primary star positions and the contours begin at 3 times the RMS noise level. The difference may result from misidentification of the more massive component or it may be that small number statistics skewed the initial results.

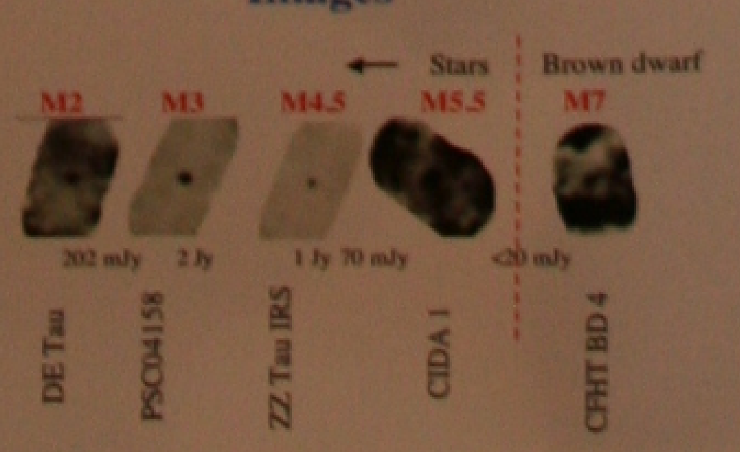


Disks around Low Mass Stars and Brown Dwarfs

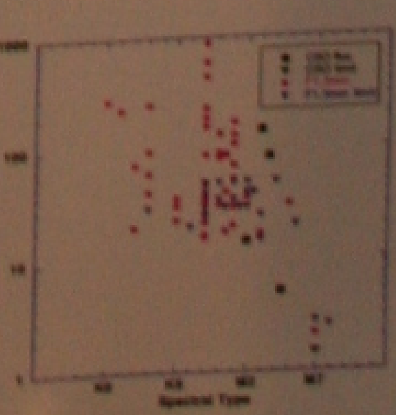
Introduction and Observations

With the 350μm SHARCII camera on the 10.4m Caltech Submillimeter Observatory (CSO), we are surveying low mass stars and brown dwarfs in the Taurus star-forming region to investigate the frequency and properties of disks across the stellar/substellar boundary. The initial sample for a pilot study for this program consists of Taurus members with spectral types from M2-M7 with no known companion and the highest Hα equivalent width of ... spectral type.

Images



Initial Results



On the left plot, the initial data from the CSO are scaled to 1.3mm (assuming $F \sim \nu^2$) and compared with previous results (Beckwith et al. 1990, Klein et al. 2004). On the right plot the brown dwarf 350μm upper limit is combined with detections at other wavelengths.