Accretion Disks in the Sub-Stellar Realm: Properties and Evolution

Ray Jayawardhana

University of Toronto

Motivation : Why Study Sub-Stellar Disks?

* Clues to brown dwarf formation
  - truncated disks?

* New (extreme) regime for investigating disk processes such as accretion, grain growth, dust settling, and dissipation

* Prospects for planet formation around VLM primaries

Disk Excess Measurements

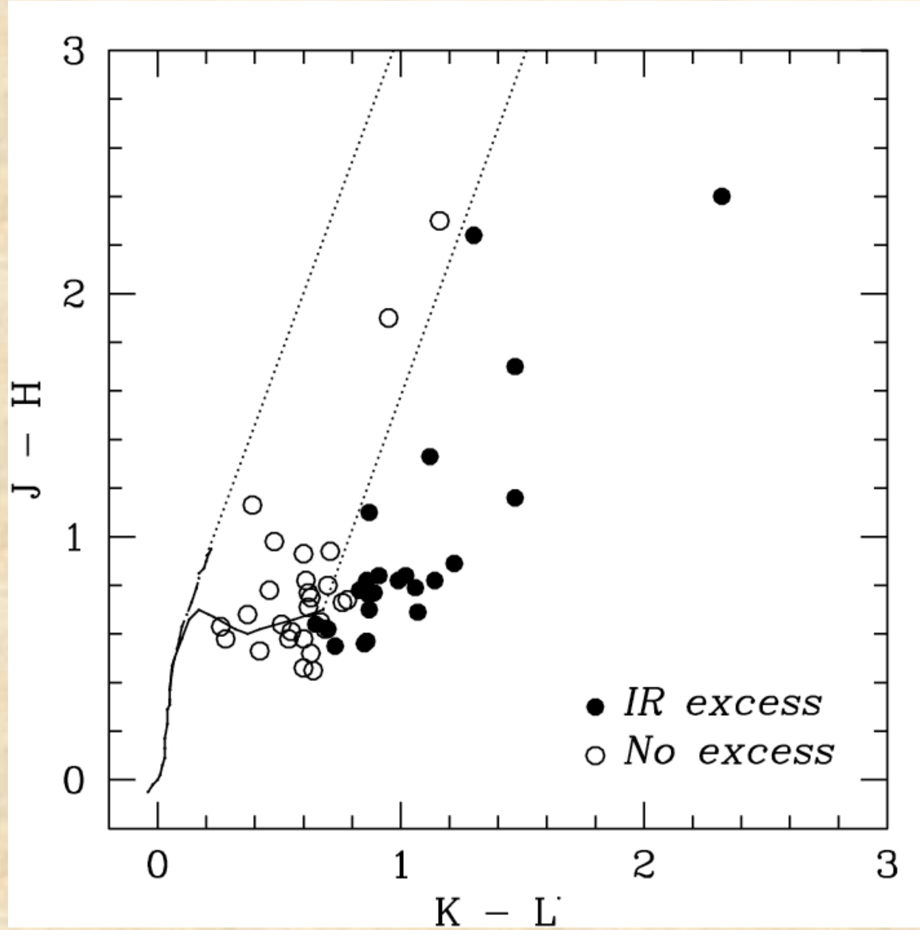
Sample

50+ objects with known spectral types later than M5
in nearby star-forming regions

Observations

JHKL' photometry at VLT, Keck and IRTF, plus 2MASS

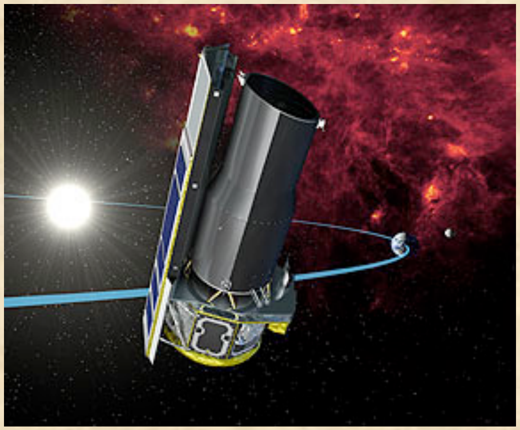
K-L' is a more reliable measure of disk fractions: less susceptible to geometric effects, smaller extinction corrections, easily measurable above photosphere



Jayawardhana, Ardila, Stelzer & Haisch (2003)

also see Comeron et al. (1998); Muench et al. (2001); Natta & Testi (2001); Natta et al. (2002)

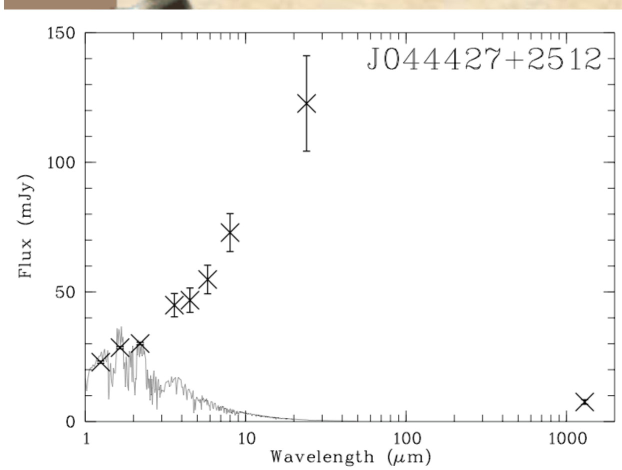
Constraining Disk Geometry and Evolution:
Spitzer Mid-IR Observations

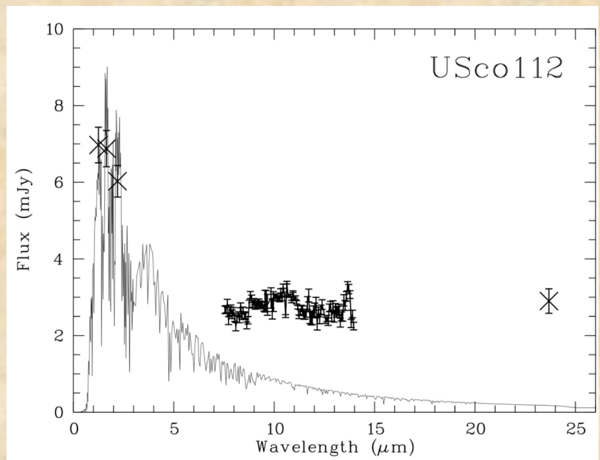


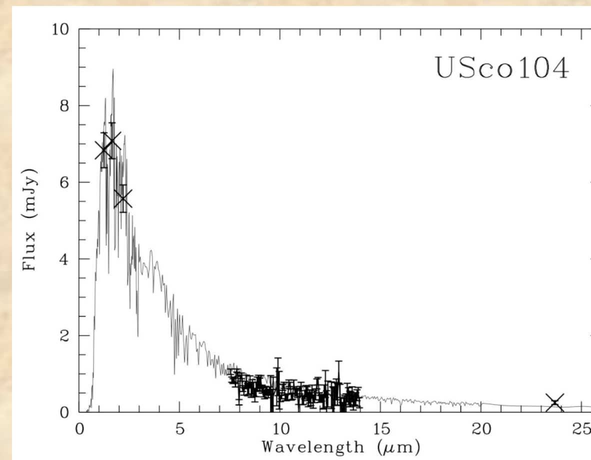
- -disk flaring
- -inner disk clearing
- -grain growth and/or processing

20 BDs in Taurus @ ~2 Myr

35 BDs in Upper Sco @ ~5 Myr



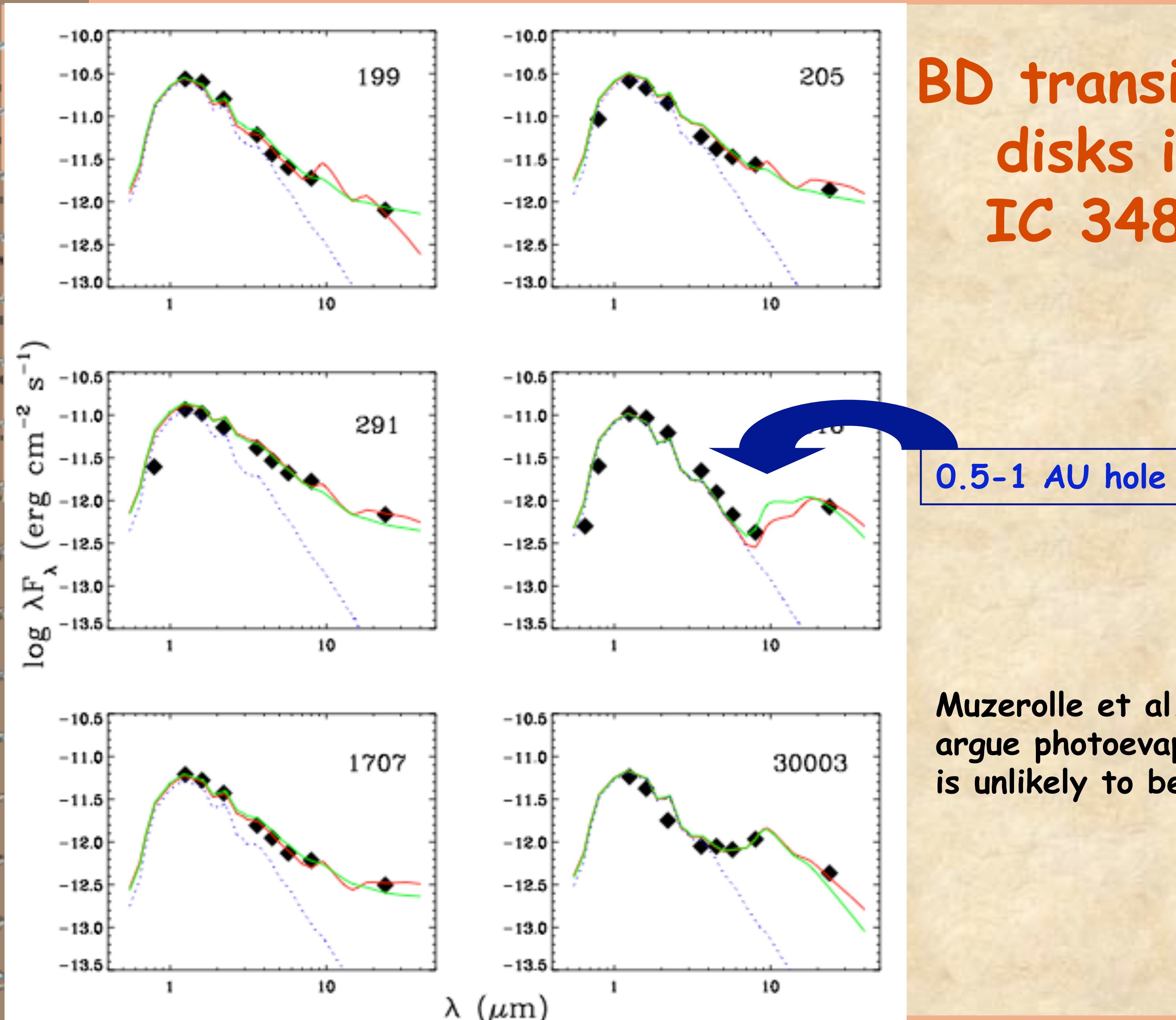




Evidence for dust settling and/or inner holes?

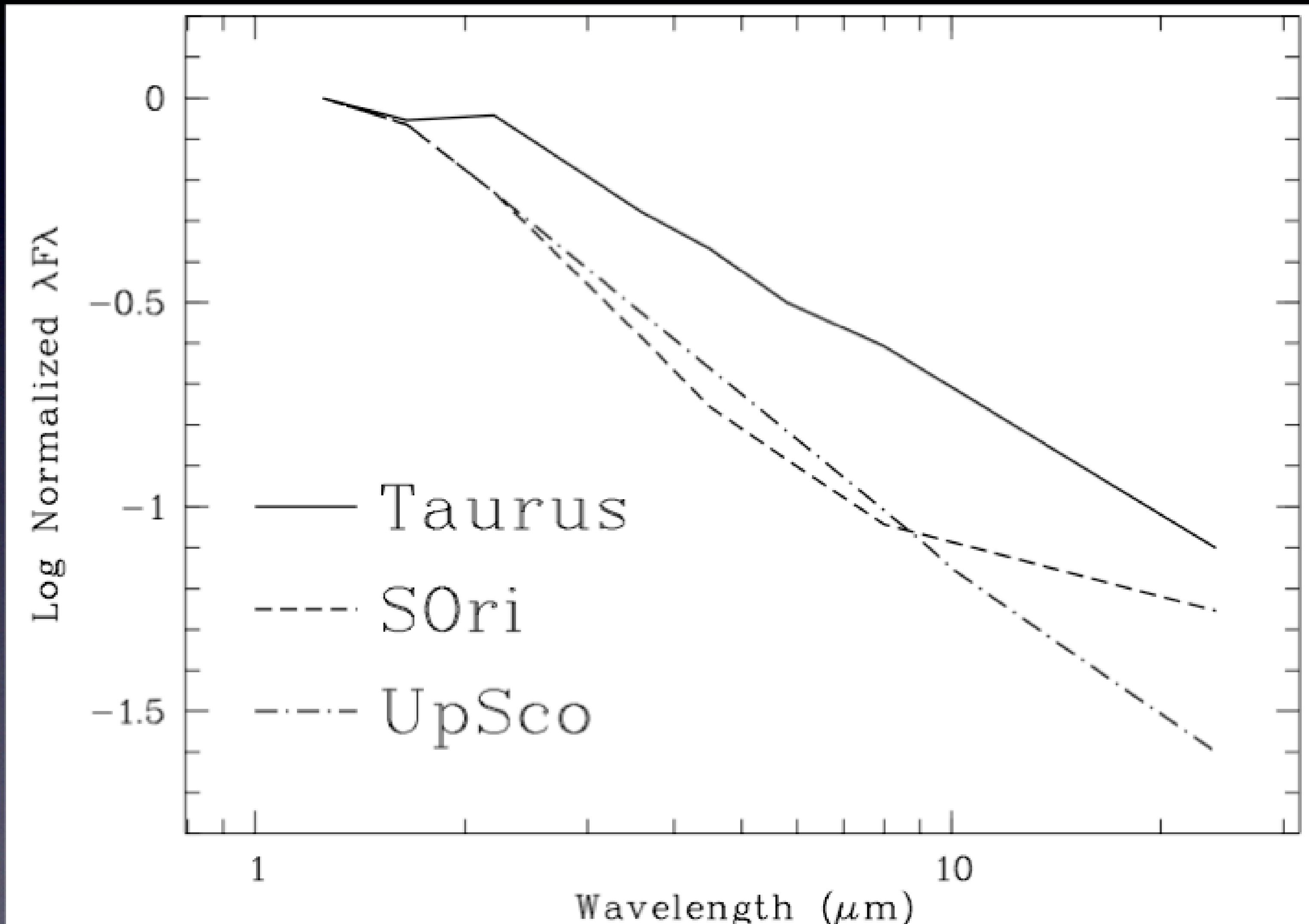
Scholz et al. (2006, 2007); also see Muzerolle et al. (2006)

BD transition disks in IC 348?



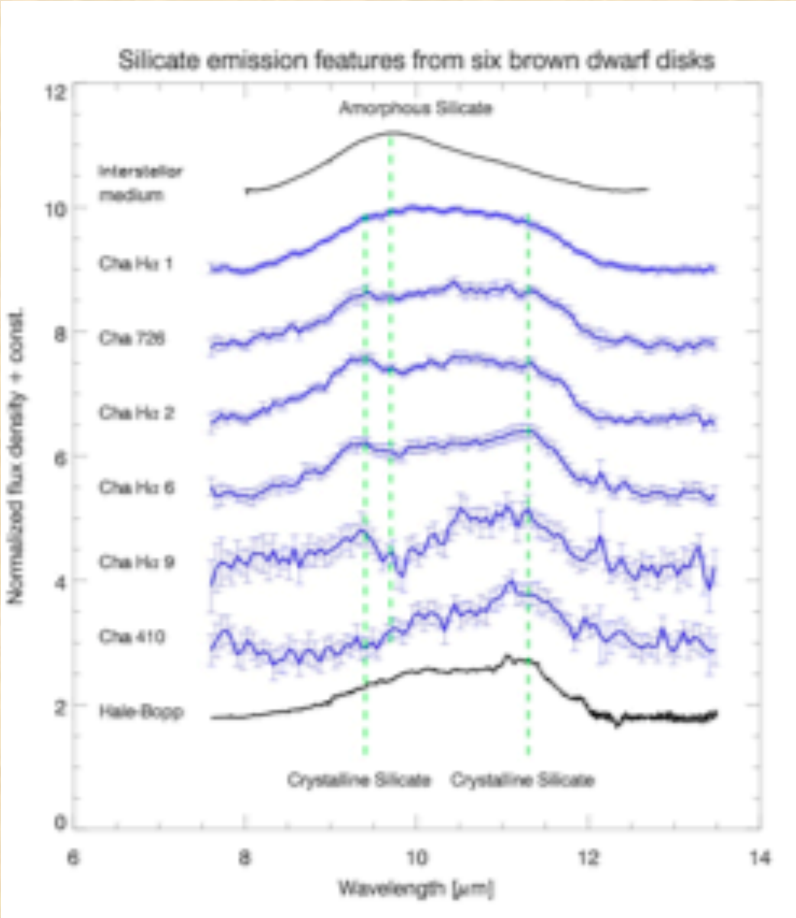
Muzerolle et al. (2006) argue photoevaporation is unlikely to be cause

Evolution of Median SEDs

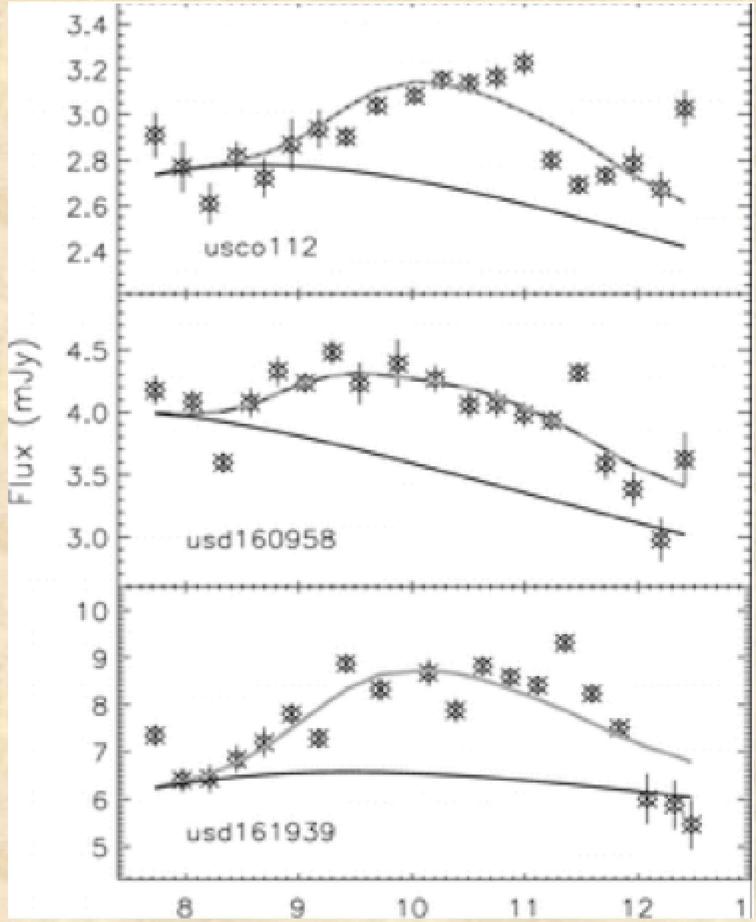


Scholz et al. 2009, including data from Guieu et al. 2007, Hernandez et al. 2006

Grain Processing in Brown Dwarf Disks



Cha I: Apai et al. (2005)



Upper Sco: Scholz et al. (2009)

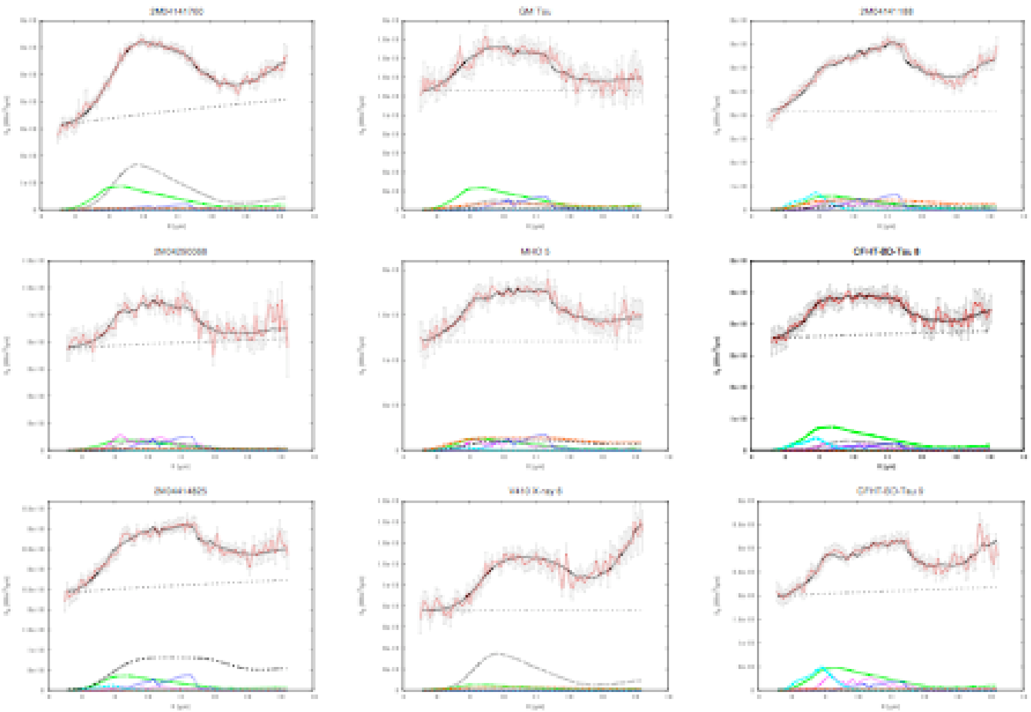


Fig. 4.— Model-fit to the 10μm silicate feature for Taurus brown dwarfs. Colors repre-

Grain Processing in Brown Dwarf Disks

Variety of features

Large grain and crystalline fractions ~equal

Crystalline mass fraction in Taurus BD disks ~2x that of T Tauri stars

Riaz (2009)

also see Pascucci et al. (2008)

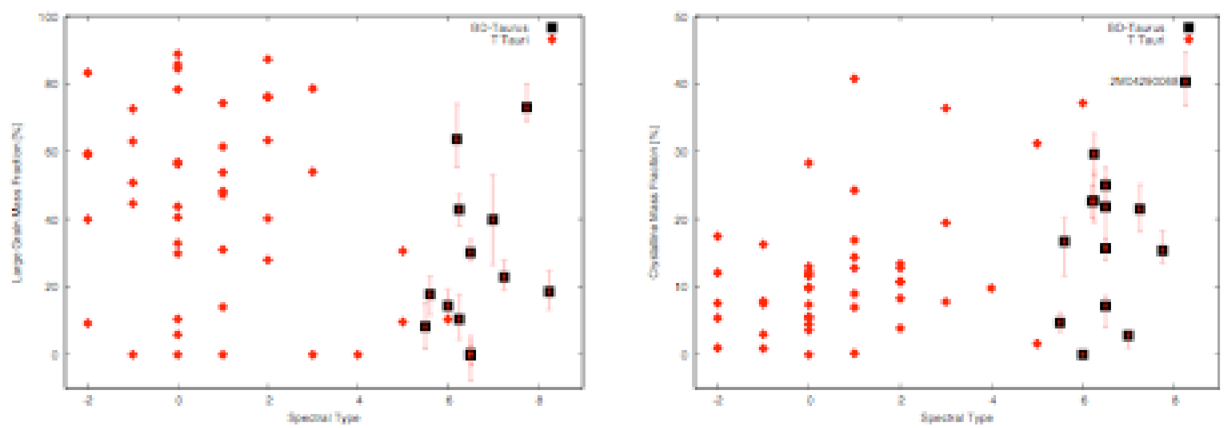
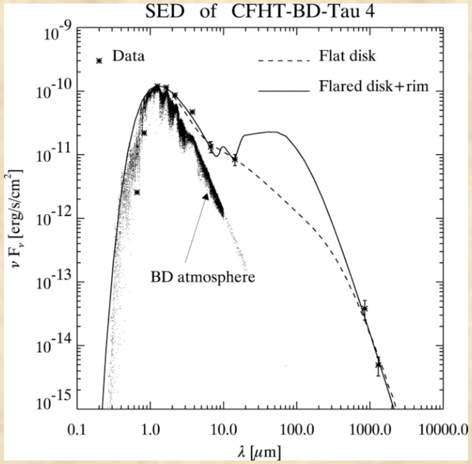


Fig. 8.— *Left*: (a) SpT vs. the large grain mass fractions for T Tauri stars and brown dwarfs in Taurus. The value of -2 indicates a SpT of K7, -1 is K5, while 0-9 are M0-M9. *Right*: (b) SpT vs. the crystalline mass fractions.

Masses of Brown Dwarf Disks



Two BDs detected at mm by Pascucci et al. (2003) & Klein et al. (2003)

IRAM 1.3mm survey of 20 BDs in Taurus

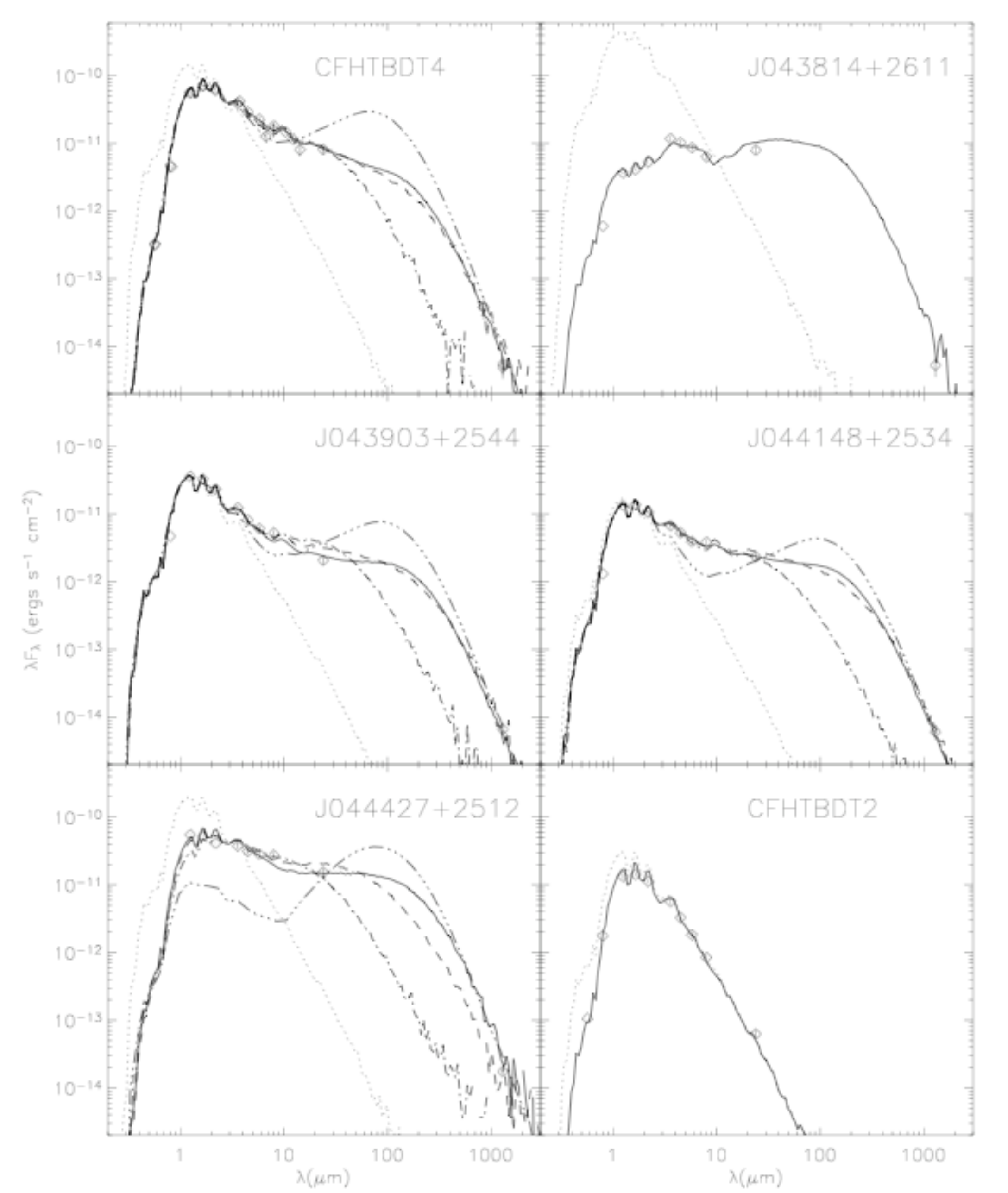
Disk masses range from < ~0.7% -- ~9% of BD mass

Scholz, Jayawardhana & Wood (2006)

Model fits to Taurus BD SEDs

Well modeled as dusty disks with varying degrees of flaring

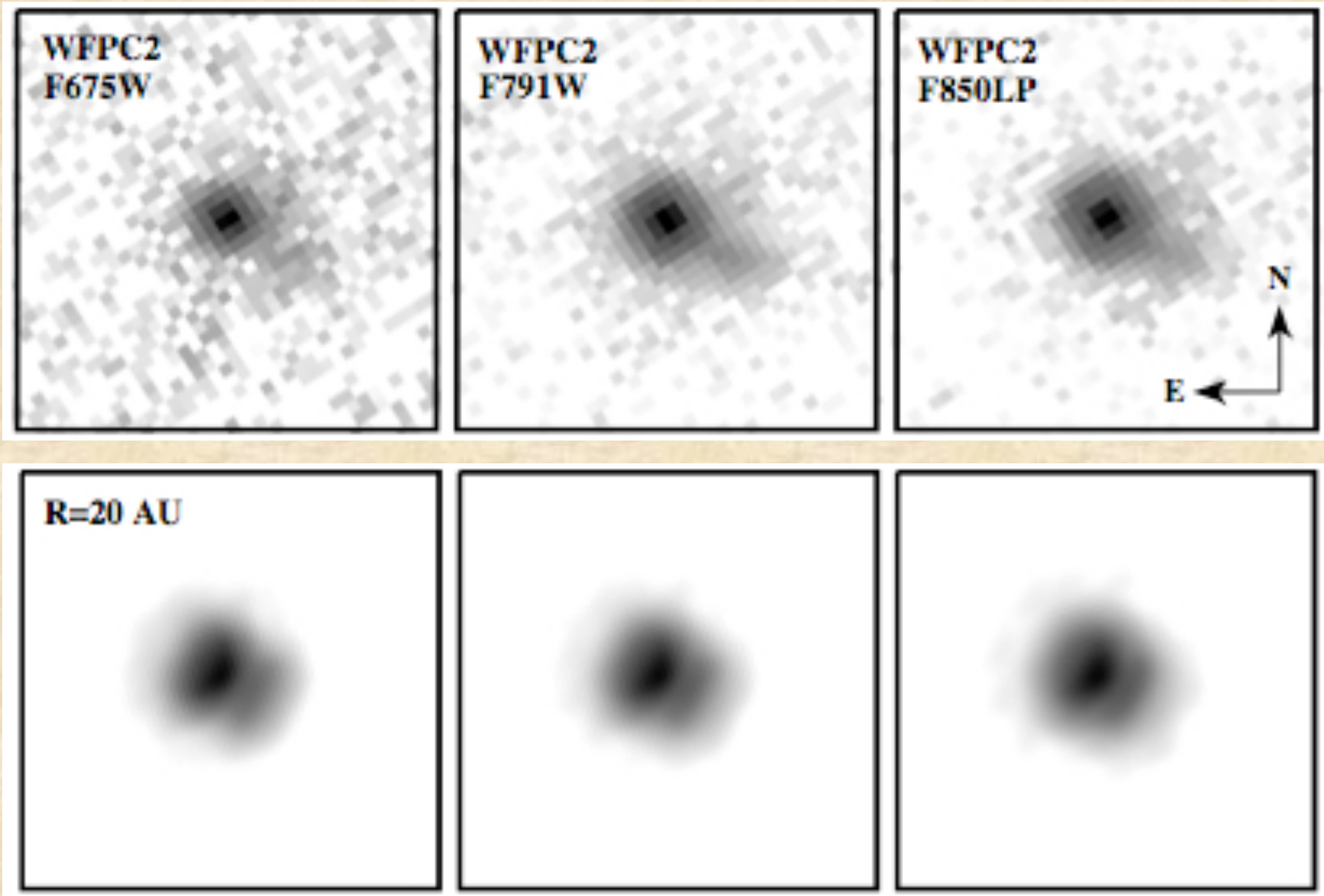
At least 25% have outer disk radii r > 10 AU



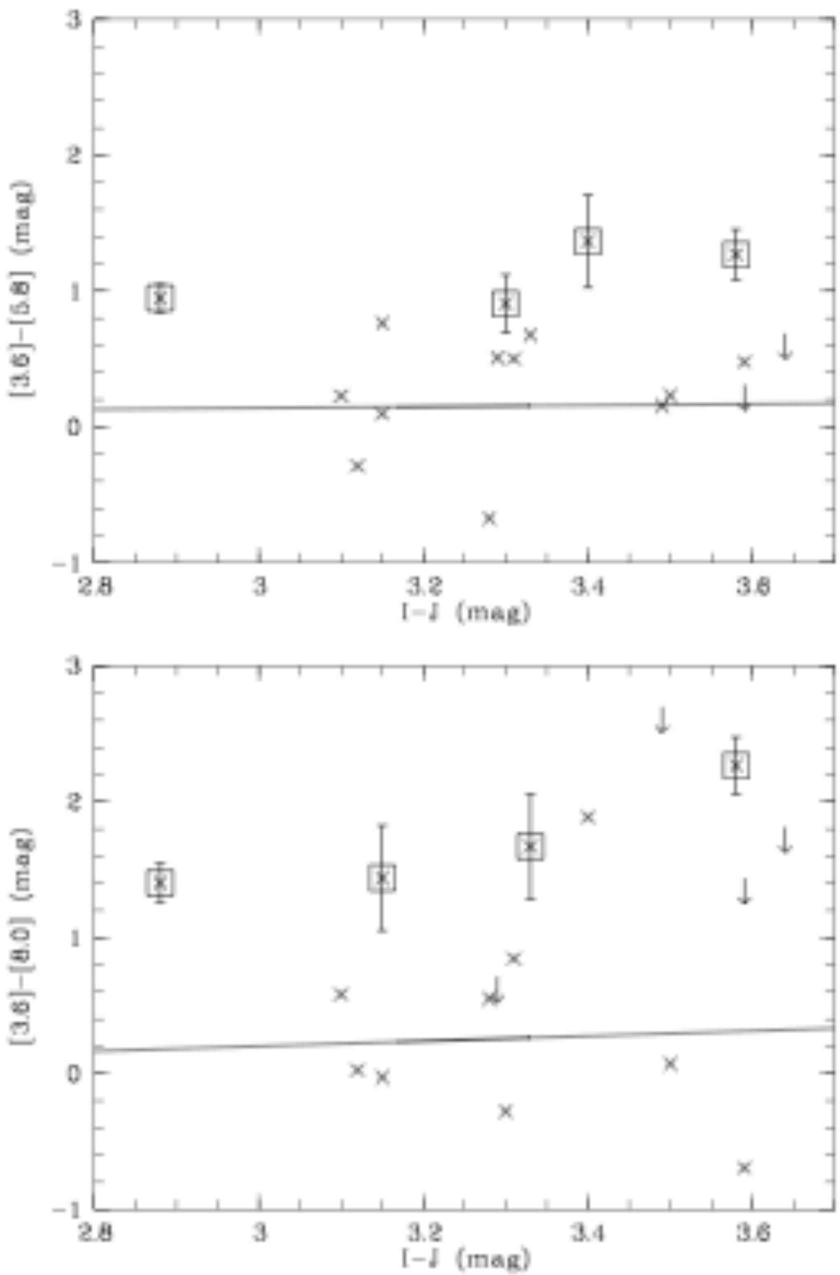
Scholz, Jayawardhana & Wood (2006)

Imaging BD Disks

Easier when seen edge-on



Luhman et al. (2007)



Disks Around Isolated Planetary Mass Objects in σ Orionis

Same disk fraction as for stars and BDs in the cluster

Scholz & Jayawardhana (2008)

Spectroscopic Signatures of Accretion

Sample

Objects with _known spectral types later than M5_ in Upper Scorpius, ρ Ophiuchus, IC 348, Taurus, Chamaeleon I, and TW Hydrae

Total ~ 82, including 55 brown dwarfs (M6 and later)

Observations

High-resolution optical spectra at Keck and Magellan

R~33,000 (HIRES), R~20,000 (MIKE)

Hα line profiles in high-resolution spectra is a good diagnostic of accretion (also OI, HeI, CaII in some cases)

Hα Criterion for Accretion

* Hα EW > 10A are usually categorized as CTTS

* But this threshold value varies with spectral type

•Hα line width at 10% of the peak may be a better indicator

* Nearly free-falling flow between disk inner edge and star

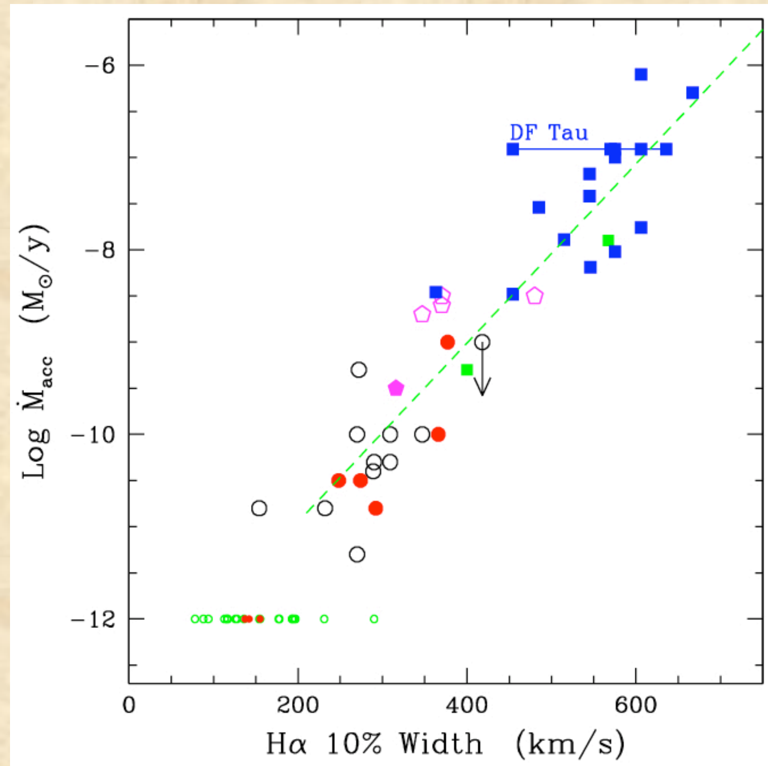
* For brown dwarfs at a few Myr,

adopted accretion threshold: ~200 km/s (+ other diagnostics)

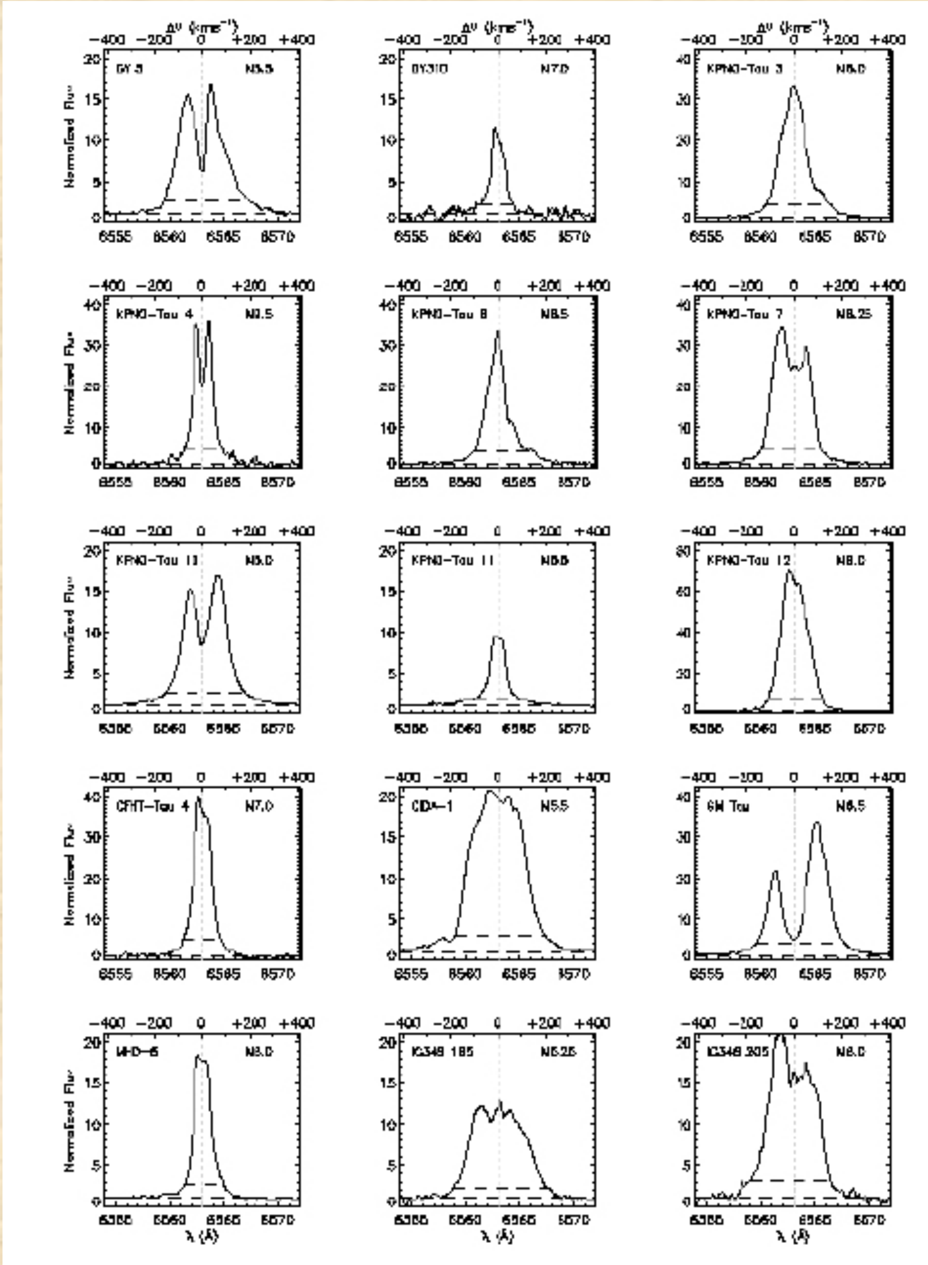
(White & Basri 2003;

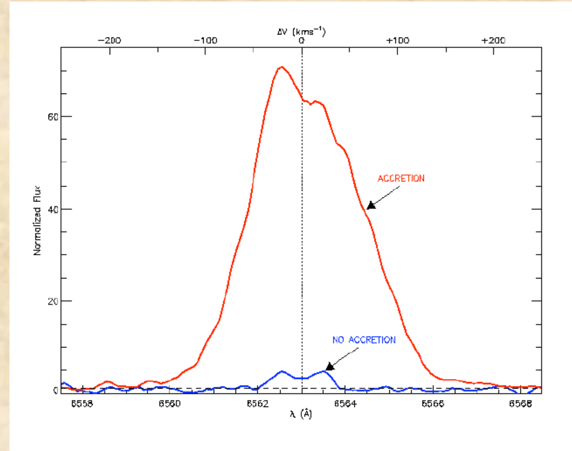
Jayawardhana, Mohanty, & Basri 2003)

Accretion Rate vs. Hα 10% Width



Natta et al. (2004)





Hα line profiles of some accretors in Taurus and IC 348

Jayawardhana, Mohanty & Basri (2002, 2003);

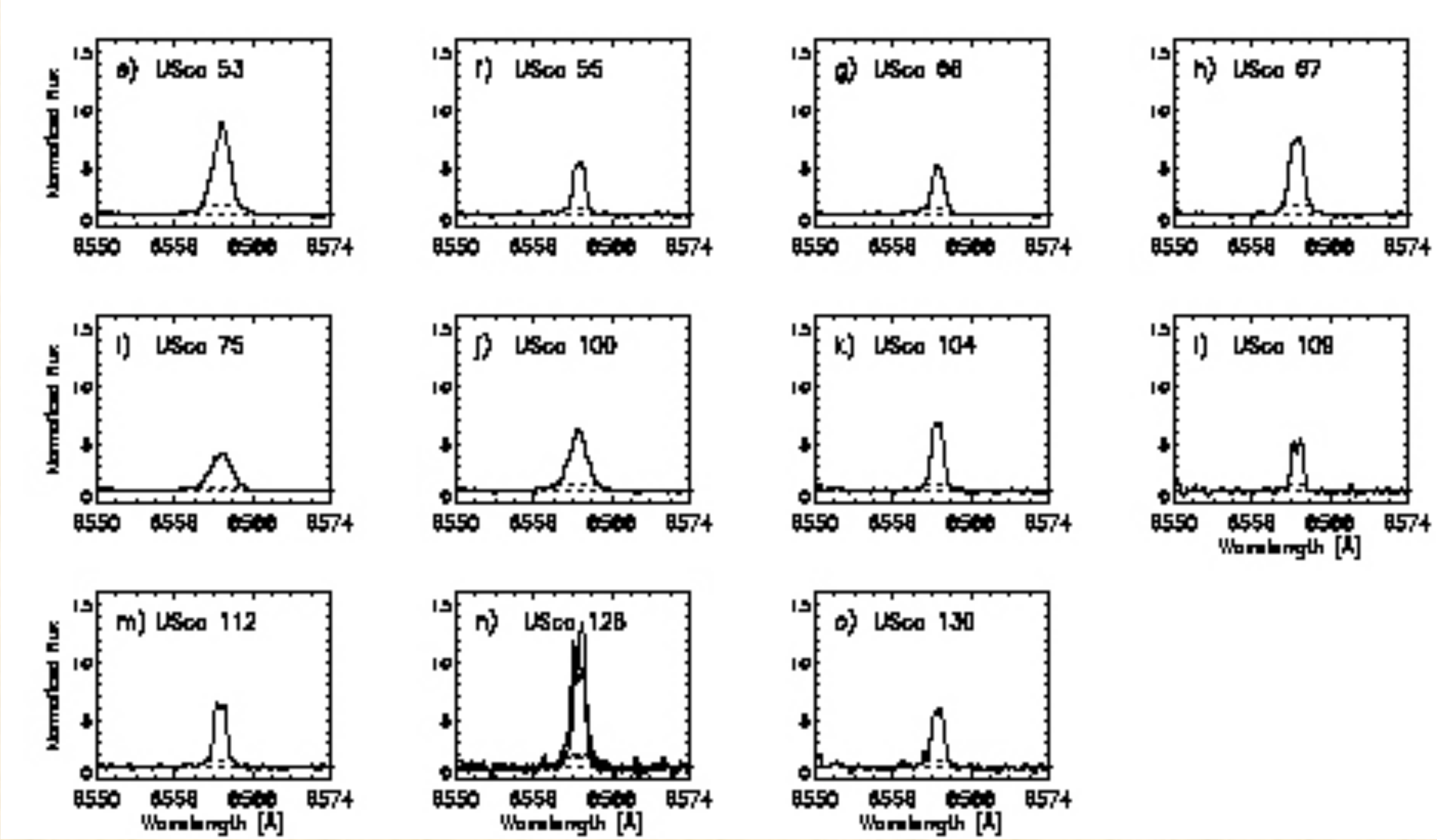
Mohanty, Jayawardhana & Basri (2005);

White & Basri (2003);

Muzerolle et al. (2003, 2005);

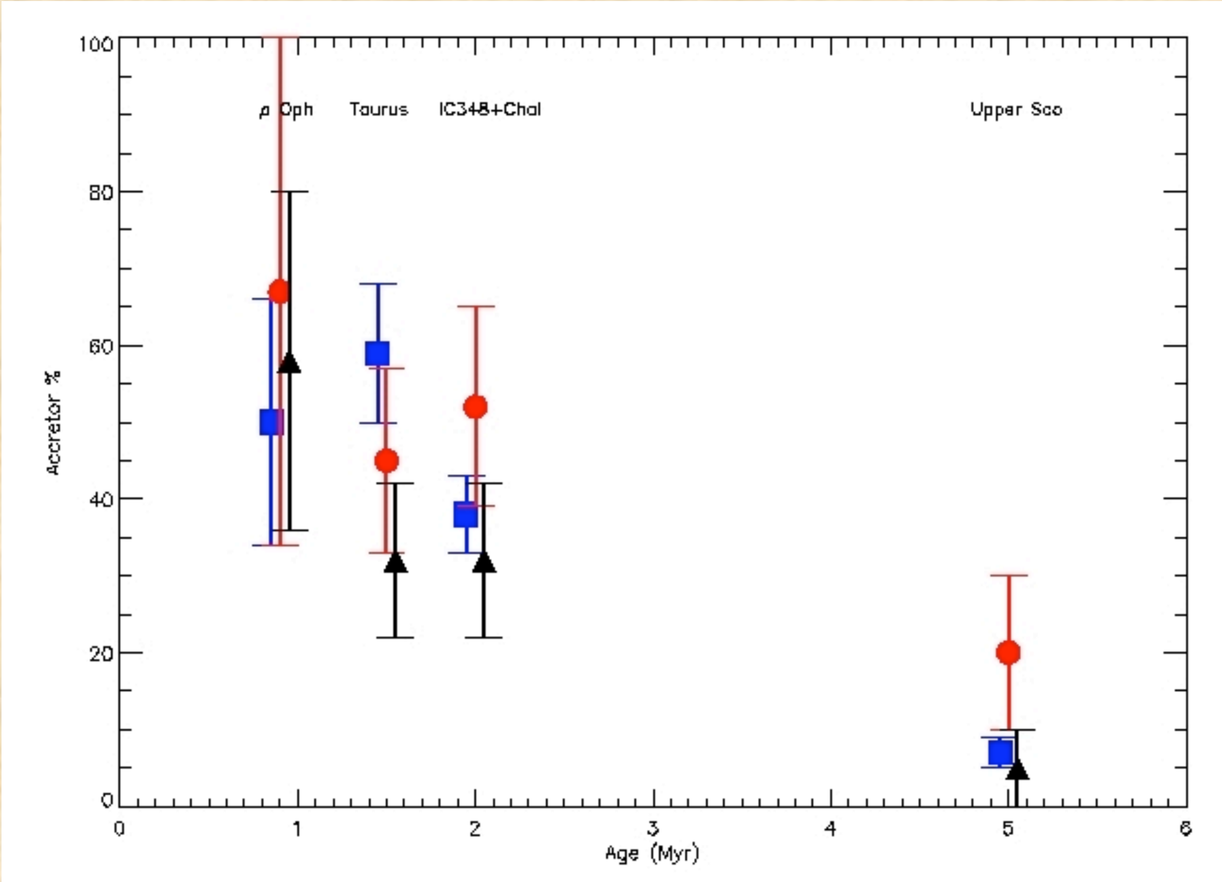
also see Herczeg et al. (2009)

Hα line profiles for Upper Sco (~5 Myr)



Jayawardhana, Mohanty & Basri (2002)

Fraction of Accretors as a Function of Age: Comparison with higher mass stars



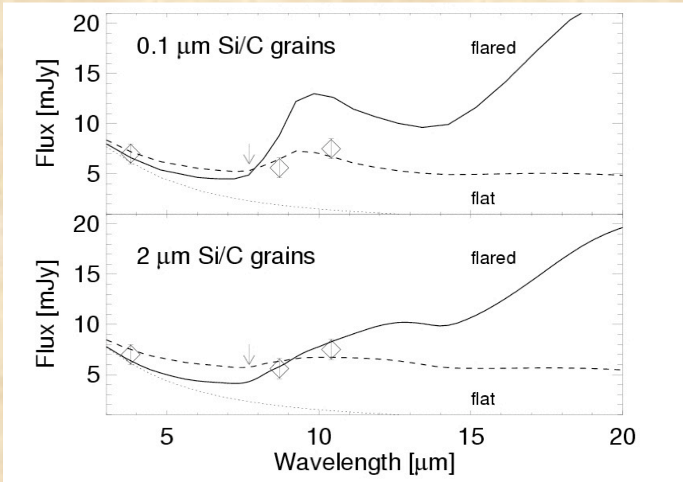
Blue squares: K0-M4 stars using BM03

Red circles: VLM objects using BM03

Black triangles: VLM objects with our high-res. analysis

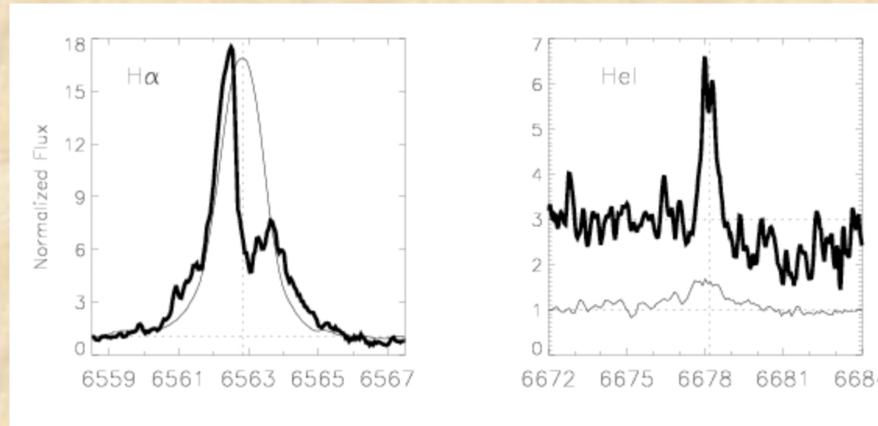
Mohanty, Jayawardhana & Basri (2005)

The Interesting Case of the 8-Myr-old Brown Dwarf 2MASS 1207-3932 in the TW Hydrae Association



inner disk hole

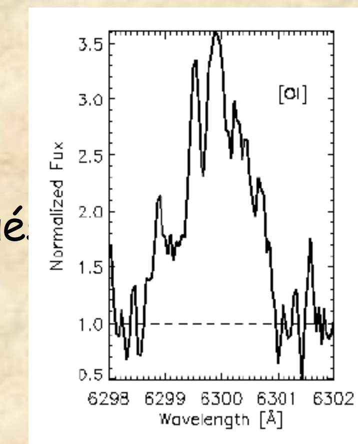
Jayawardhana et al.(2003); Sterzik et al. (2004); Riaz et al. (2006, 2007)



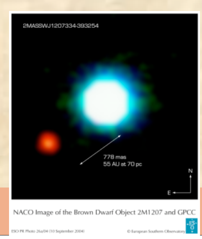
on-going accretion and possible outflow?

Mohanty, Jayawardhana & Barrado y Navascués (2003)

Mohanty, Jayawardhana & Basri (2005)



Accretion and outflow in BDs can persist for up to ~8 Myrs

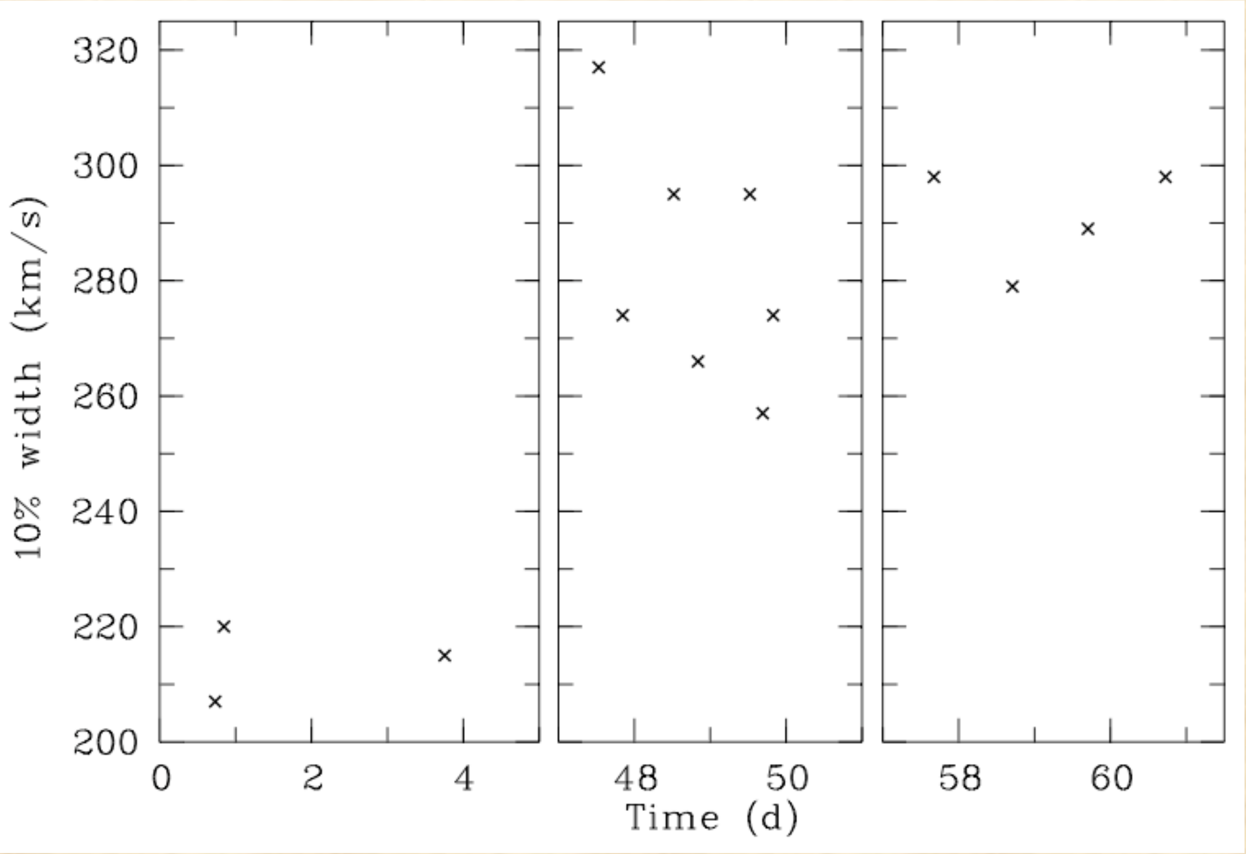


Emission Line Variability in 2MASS 1207-3932: Hα

14 high-resolution optical spectra from Magellan, 2005 Jan-Mar

Variability on timescales of weeks as well as hours

Accretion rate appears to change by 5-10x over ~6 weeks

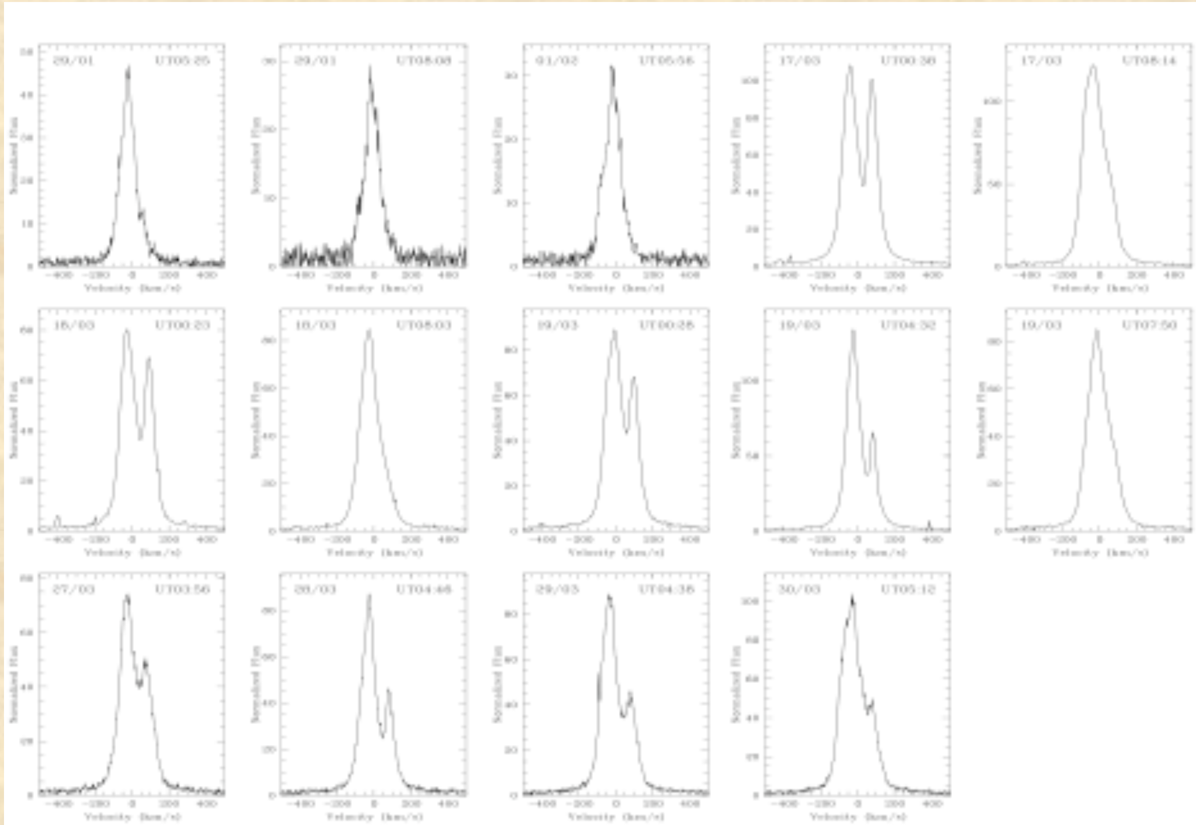


Scholz, Jayawardhana & Brandeker (2005);

Scholz & Jayawardhana (2006)

Stelzer, Scholz & Jayawardhana (2007)

Emission Line Variability in 2MASS 1207-3932: Hα



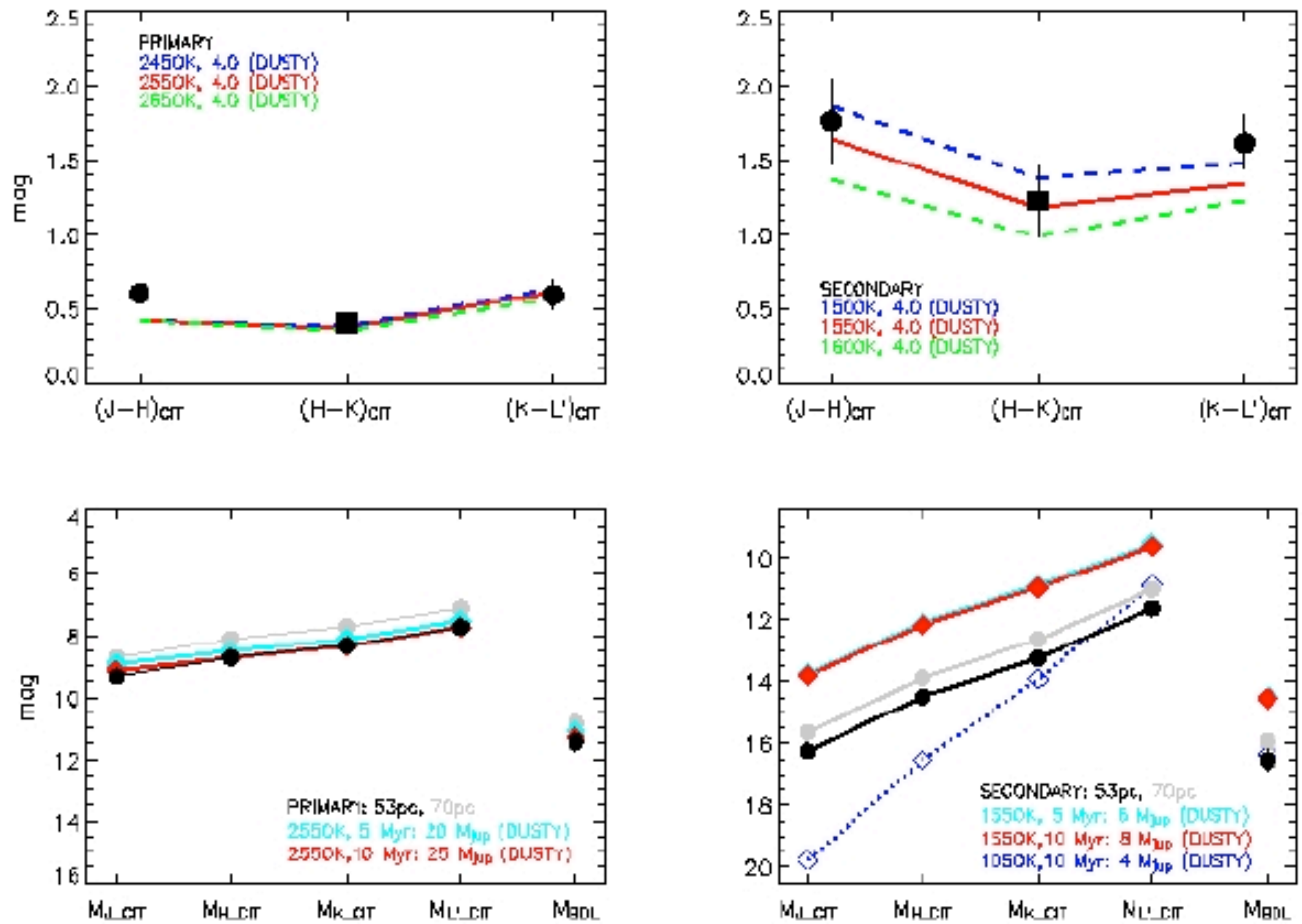
Redshifted absorption coming into and out of view on ~ rotation period

Accretion disk close to edge-on?

Looking into an accretion funnel when line is double-peaked?

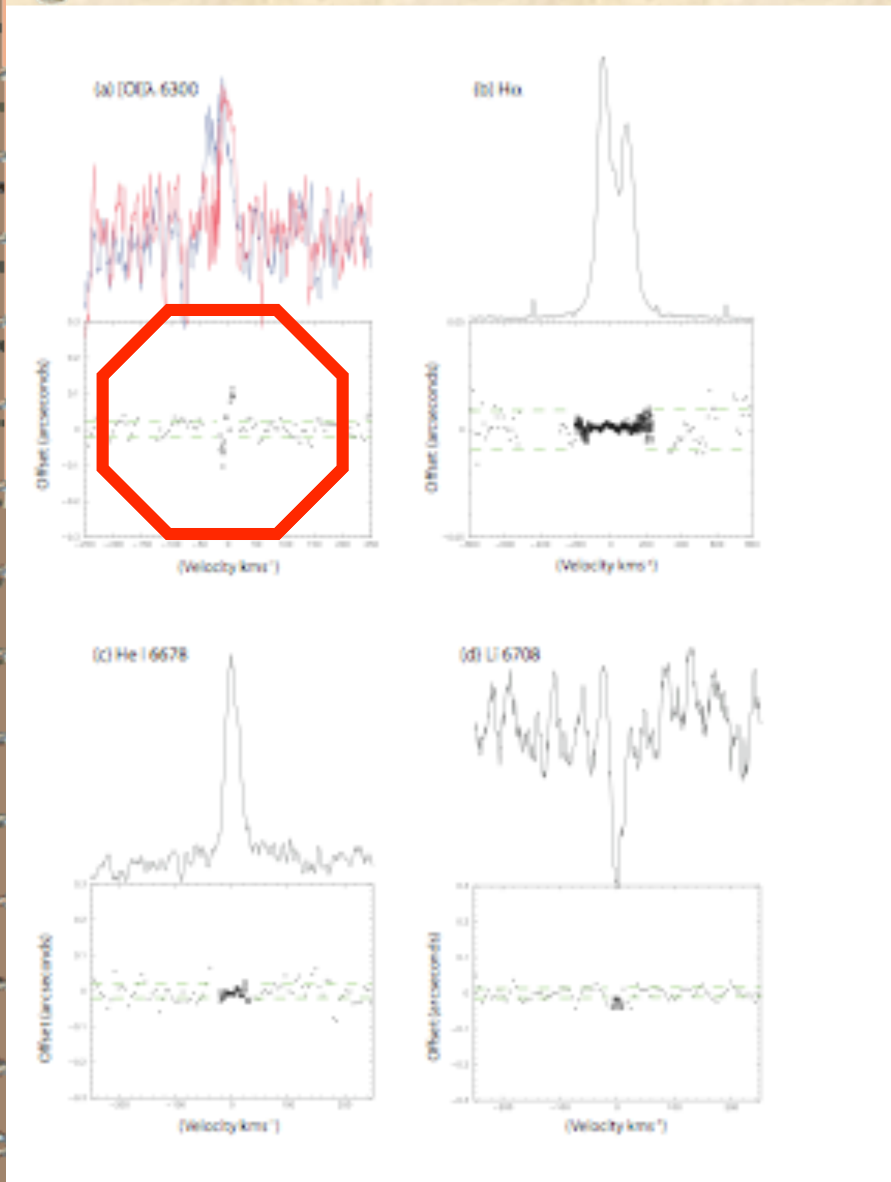
Scholz, Jayawardhana & Brandeker (2005)

A disk around the secondary as well?



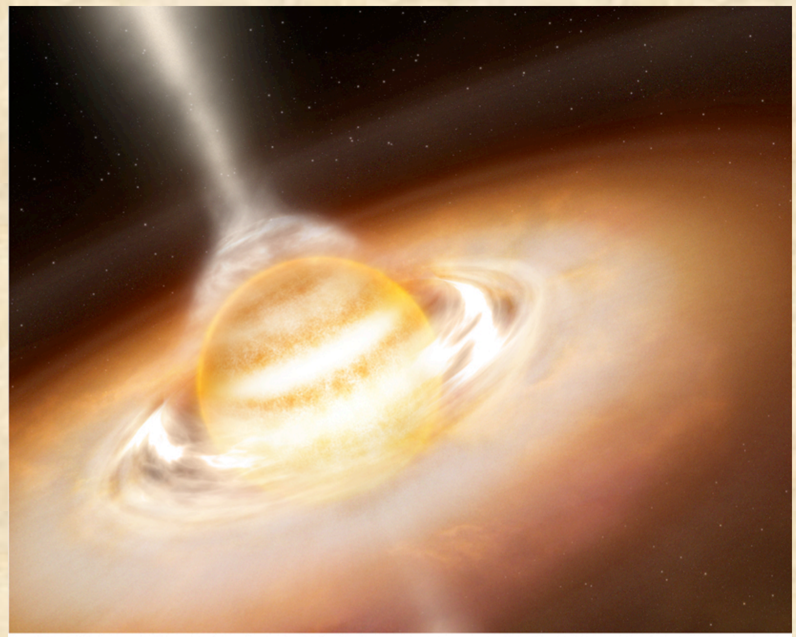
Mohanty, Jayawardhana, Huelamo & Mamajek (2007)

Young brown dwarfs harbor jets too..



2MASS 1207-3932

lowest mass object with a resolved outflow

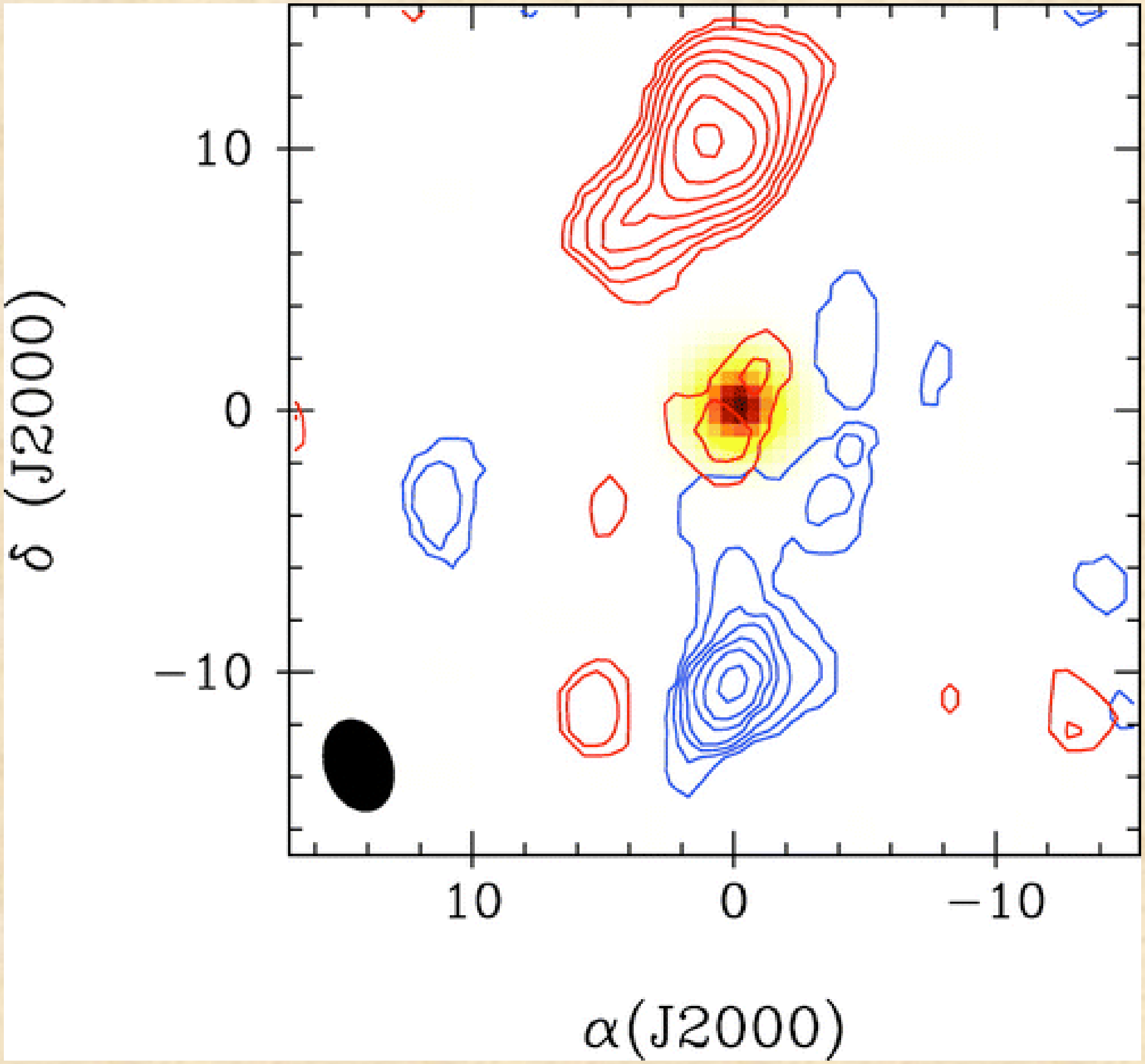


Jets from a Brown Dwarf
(Artist's Impression)

ESO Press Photo 24/07 (23 May2007)

Whelan et al. (2007)

Young brown dwarfs harbor jets too..



ISO-Oph 102

molecular (CO) outflow resolved with SMA

Phan-Bao et al. (2008)

Brown Dwarfs Undergo a T Tauri Phase, Similar to Sun-like Stars

Large, long-lived dusty disks that evolve over 5-10 Myr
Signs of accretion
Evidence of jets/outflows

↓

Objects Just A Few Times More Massive Than Jupiter Can Form With Their Own Disks That May Evolve Into Planetary Systems