The study of young substellar objects with ALMA

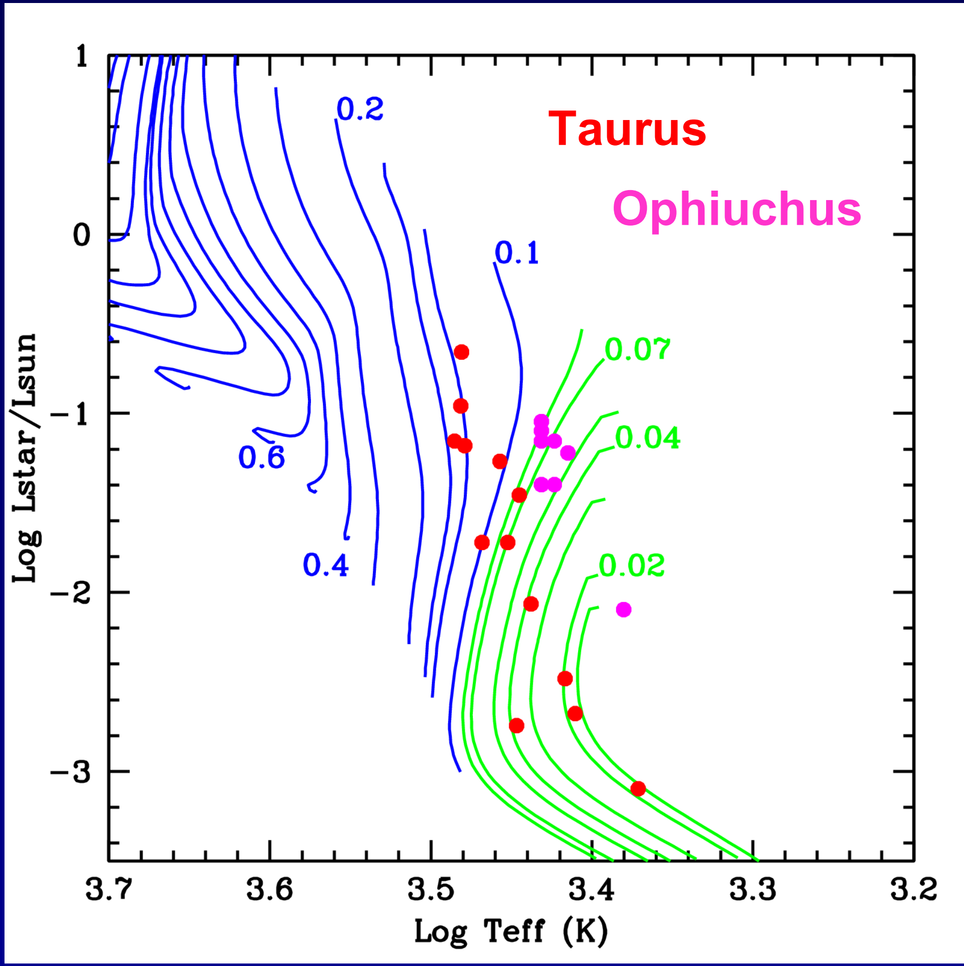
1) How do they form?

2) Can they form planetary systems?

Antonella Natta and Leonardo Testi

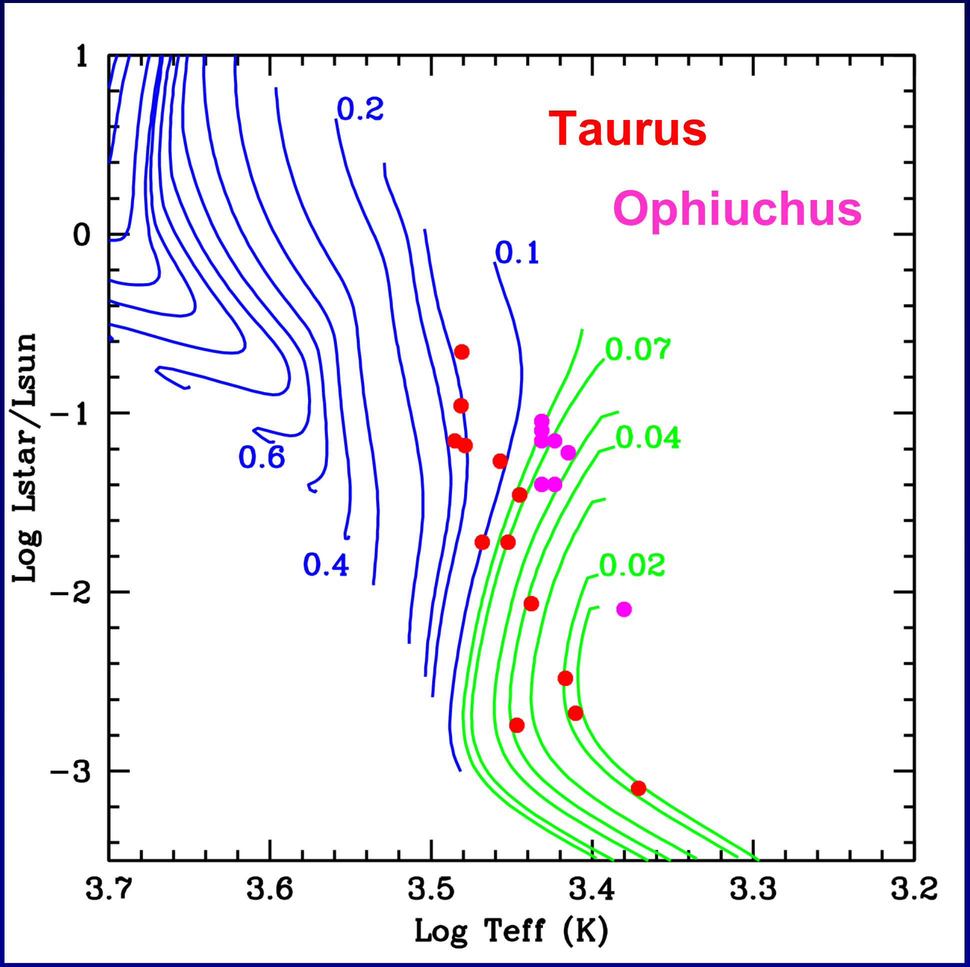
Brown dwarfs: cold and dim

Brown Dwarfs



Brown dwarfs: cold and dim

- Brown dwarfs: below the hydrogen burning limit (<0.075 Msun or 75 M_J)
- Very low mass stars (<0.1 Msun)
- Planetary-mass objects: below the deuterium burning limit (<0.013 Msun or 13 M_J)

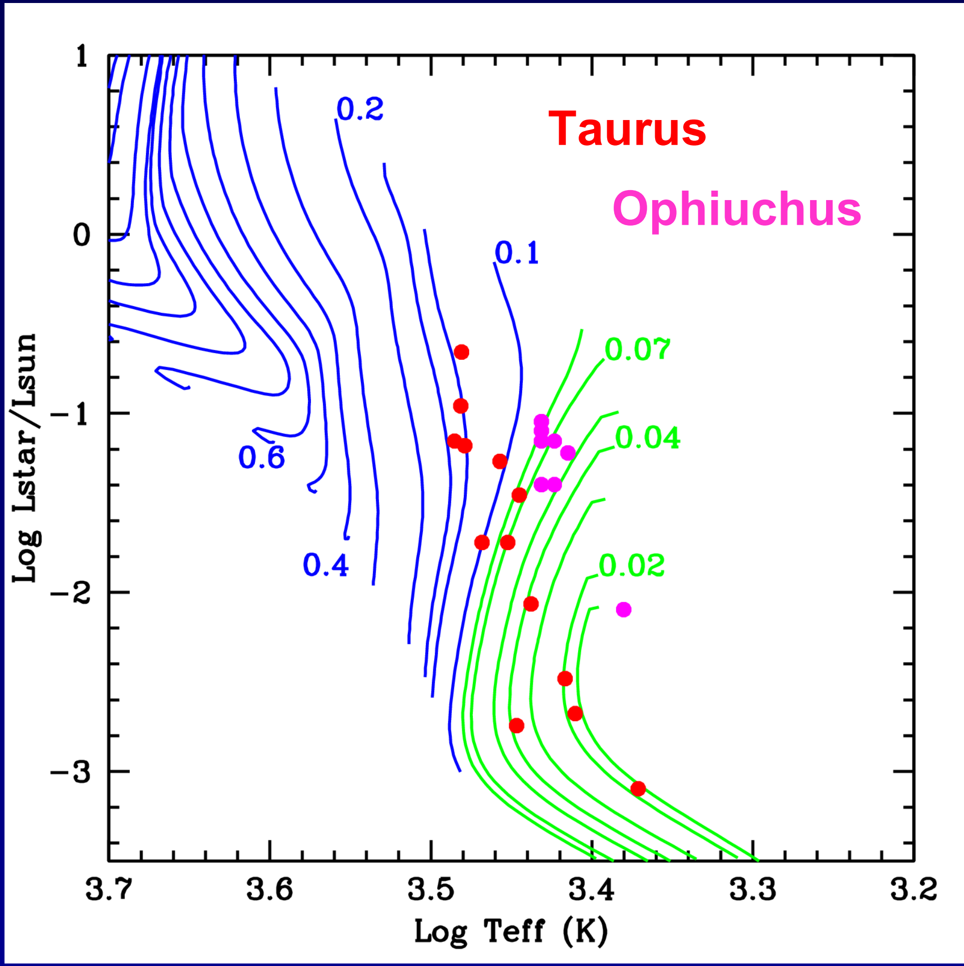


Brown dwarfs: cold and dim

Brown Dwarfs

The first young BD is only 11 years old!
[Teide 1; Rebolo et al., Nature Sept.1995]

Today, many of them in all star-forming regions



How do brown dwarfs form?

- BDs form from core collapse like solar-mass stars
  - Fragmentation of molecular clouds produces gravitationally unstable very low mass prestellar cores
  - Fragmentation of solar-mass collapsing cores
- BDs are failed stars, ejected from the parental core before reaching their final mass
  - Competitive accretion
- BDs form in disks around more massive stars and are then ejected
- BDs form in cores photo-eroded by an expanding HII region

Whitworth et al. 2006, PPV

How to proceed?

- Breaks in BDs vs TTS properties:
  - IMF
  - clustering, binarity, velocity dispersion
  - disks & accretion activity

NONE

"BDs form as H-burning stars, i.e., on a dynamical timescale, by gravitational instability, with initially uniform elemental composition"

- Search for proto-brown dwarfs (Class0/I)
- Search for pre-brown dwarf cores

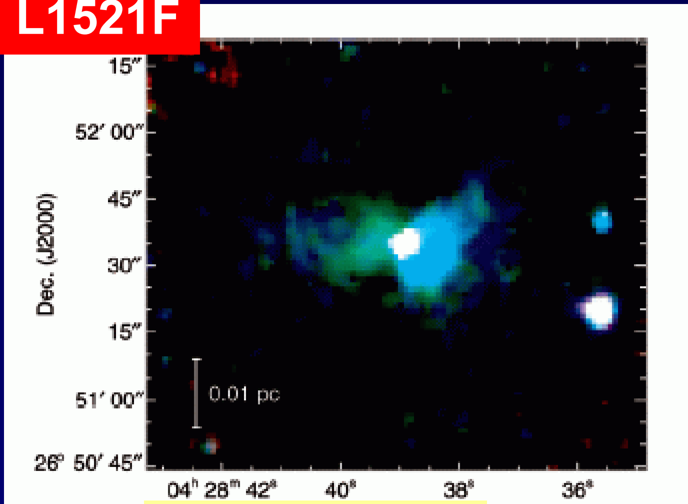
Have we already found Class 0/ BDs?

VeLLO: "starless" cores with a very low luminosity central source (Spitzer, c2d) Lint<0.1 Lsun

L1014
Mcore ~ 1.7 Msun
Lbol ~ 0.3 Lsun
Lint ~ 0.09 Lsun
Weak, compact outflow
[Young et al. 2004]

L1521
Mcore ~ 5 Msun
Lbol ~ 0.36 Lsun
Lint ~ 0.05 Lsun
Weak outflow
[Bourke et al. 2006]

L1521F



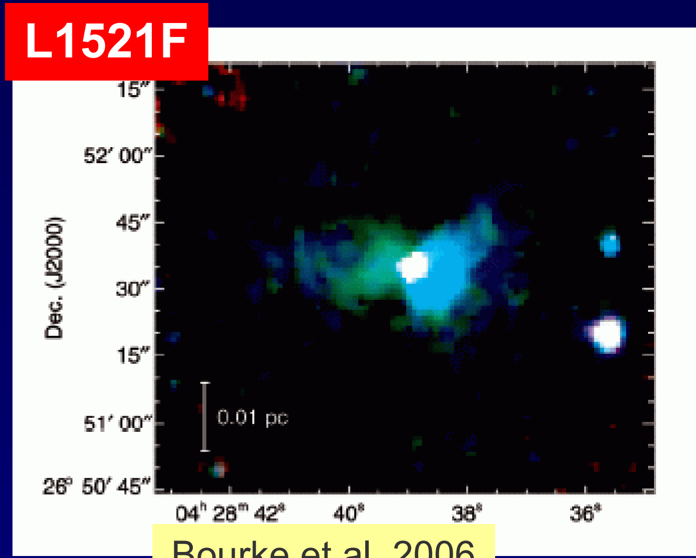
Bourke et al. 2006

IRAM 04191-IRS
Mcore~2 Msun
Lbol~0.3 Lsun
Lint~0.08 Lsun
Outflow → Lint>1Lsun;
Macc~5x10^{-6} Msun/yr
[Andre' et al.1999]
[Dunham et al. 2006]

Have we already found Class 0/ BDs?

VeLLO: "starless" cores with a very low luminosity central source (Spitzer, c2d) Lint<0.1 Lsun

- Very low mass central object (<0.1 Msun)
- consistent with $Macc \sim 10^{-6}$ Msun/yr if Mstar~0.01 Msun
- but Mcore > 1Msun



Bourke et al. 2006

What happens to the core?

Very young, they will end up as hydrogen-burning stars

The IRAM04191 outflow: intermittent accretion ?

Are VeLLO Class 0/I brown dwarfs?

Lint = Lstar+Ldisk < 0.1 Lstar → Mstar<0.1 Msun

$$L_{acc} \propto \frac{M_{star} \times M_{ac}}{R}$$

Lint ~ 0.1 Lsun
If Lint~Lacc and Macc~10^{-6}
↓
Mstar ~ 0.01 Msun

But what happens to the core?

Very young, they will end up as hydrogen-burning stars ??

The IRAM04191 outflow: intermittent accretion ??

Very low mass cores are found in many star-forming regions

Most recent one: NGC 1333

Walsh et al. 2006, BIMA (5arcsec), masses from N_2H^+

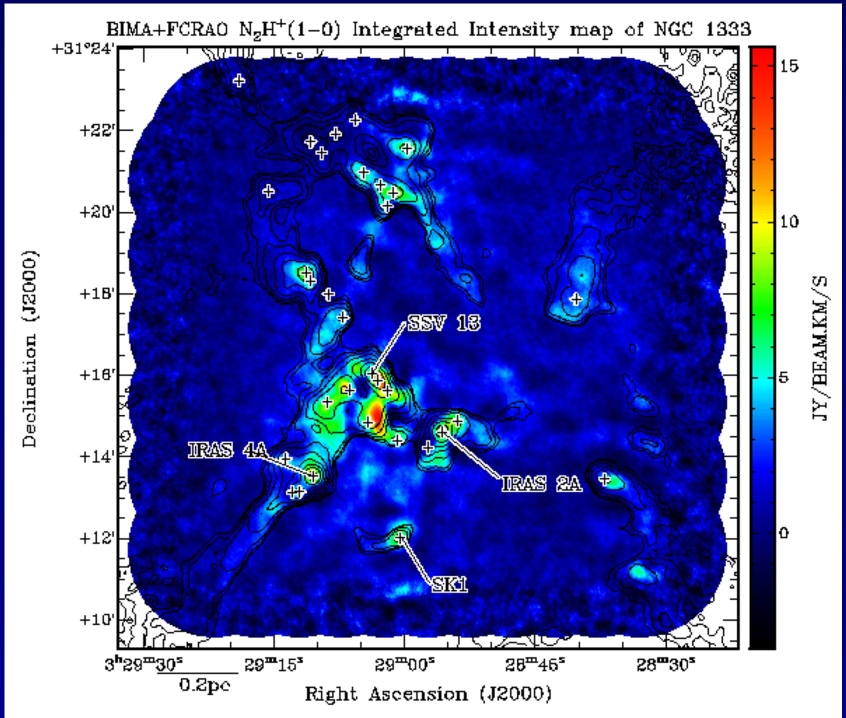
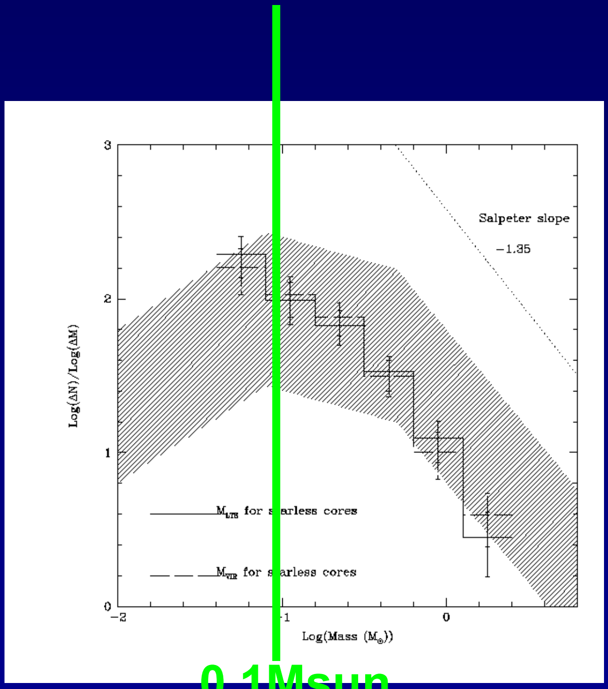


Fig. 3.— N_2H^+(1–0) integrated intensity map of NGC1333. 0.2 Jy/beam km/s = 1σ.



Are these pre-brown dwarf cores?

Maybe

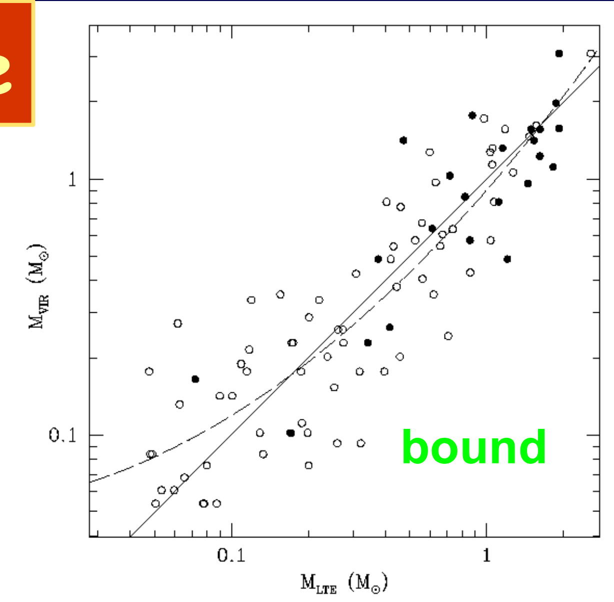


Fig. 9.— Distribution of core LTE and virial masses. Filled circles represent cores associated with stars, as detected by *Spitzer*, and open circles represent cores not associated with stars. The solid diagonal line represents equality between M_{LTE} and M_{VIR}, assuming an N_3H^+ relative abundance of 1.8×10^{-10}. The dashed curve represents a best fit to the data of the form $y = a + bx + cx^3$, where x is $Log(M_{LTE})$, y is $Log(M_{VIR})$, a is 0.071, b is 1.38 and c is 0.26.

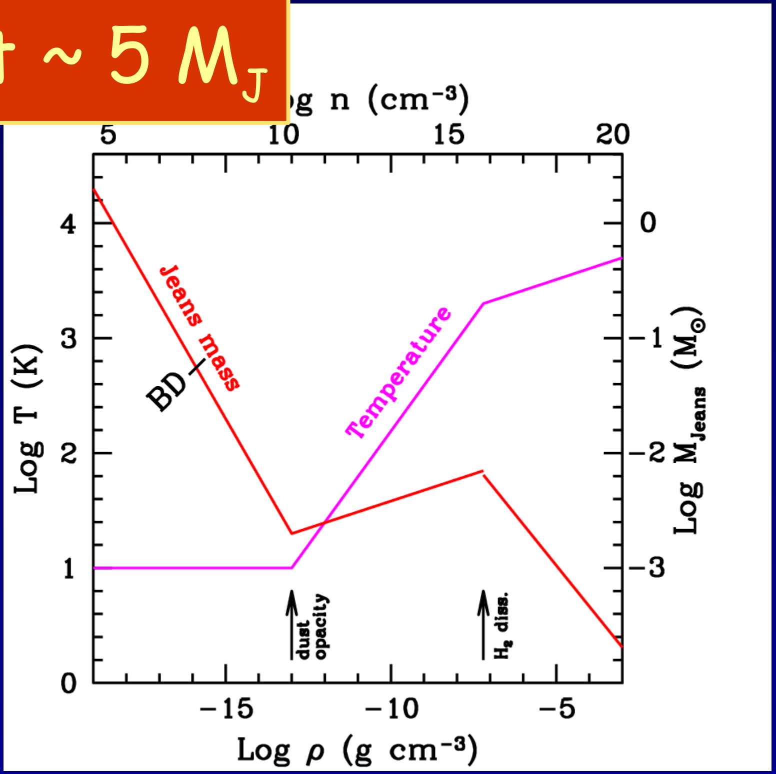
Are these pre-brown dwarf cores?

$M_{Jeans} \sim n^{-1/2}\ T^{3/2}$

Fragmentation opacity limit ~ 5 M_J

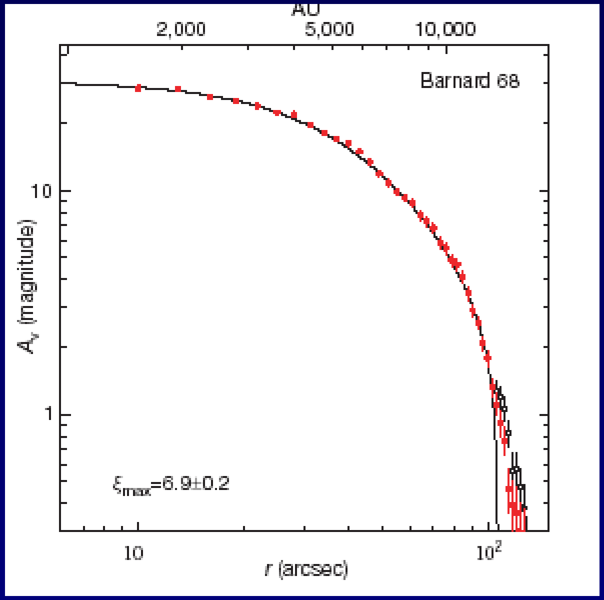
- ✓ $M_{Jeans} \sim 20\ M_J$
- ✓ T ~ 10 K
- ✓ Density ~ $10^9\ cm^{-3}$
- ✓ Radius ~ 100 AU
- ✓ (or ~1" at 140 pc)
- ✓ $F_{1.3mm} \sim 10$ mJy

Very small and dense



ALMA and pre-BD cores

- Pre-BD cores will be easily detectable at all ALMA wavelengths within ~1 kpc
- Core mass function in all nearby star forming regions
- Pre-BD cores in the closest star forming regions will be resolved



kinematic and chemistry

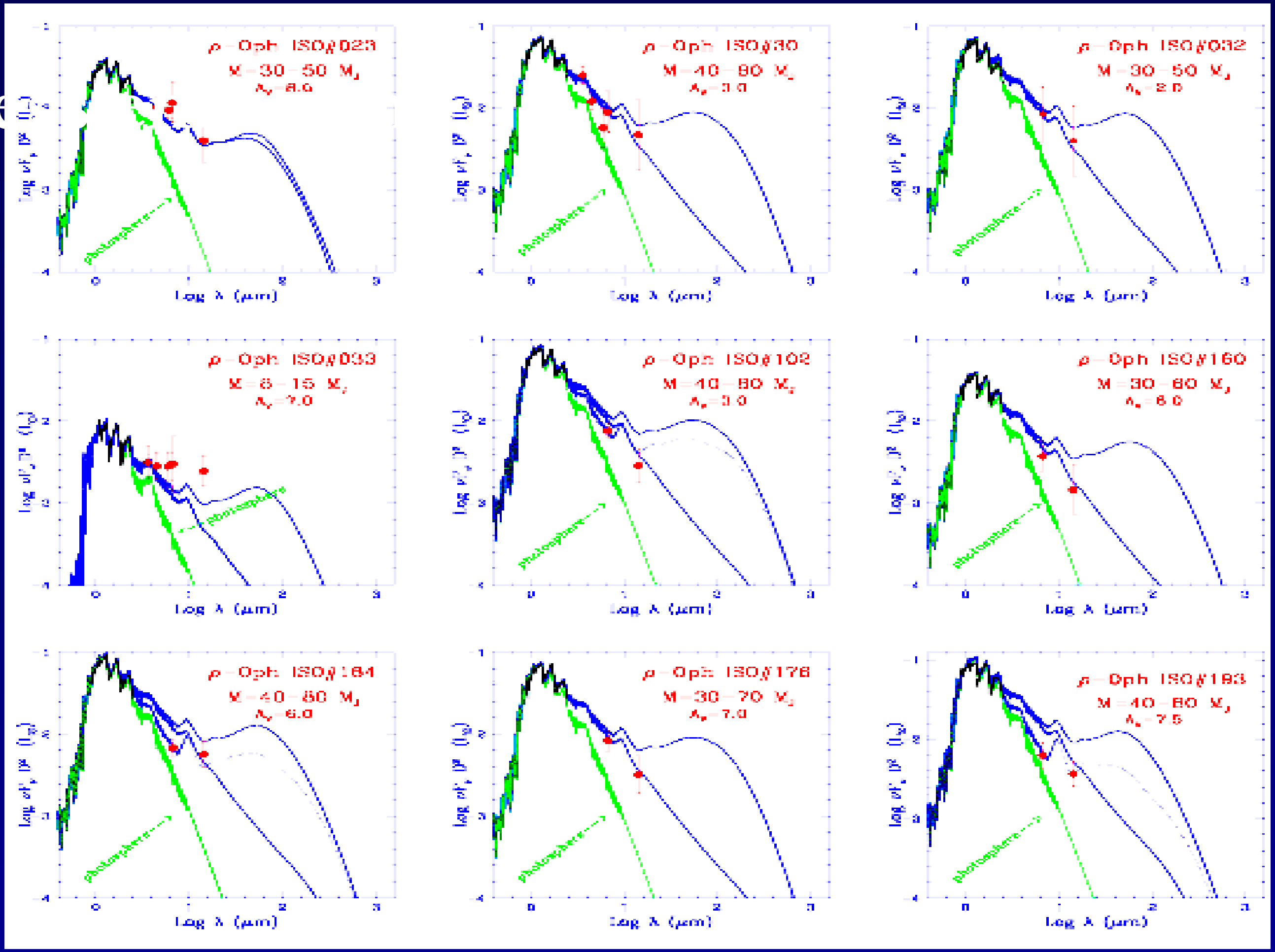
Brown dwarfs have disks

- Mid-IR excess emission

Brown dwarfs have disks

- Mid-IR exce
  - ISO

Ophiuchus: mid-IR excess from ISOCAM

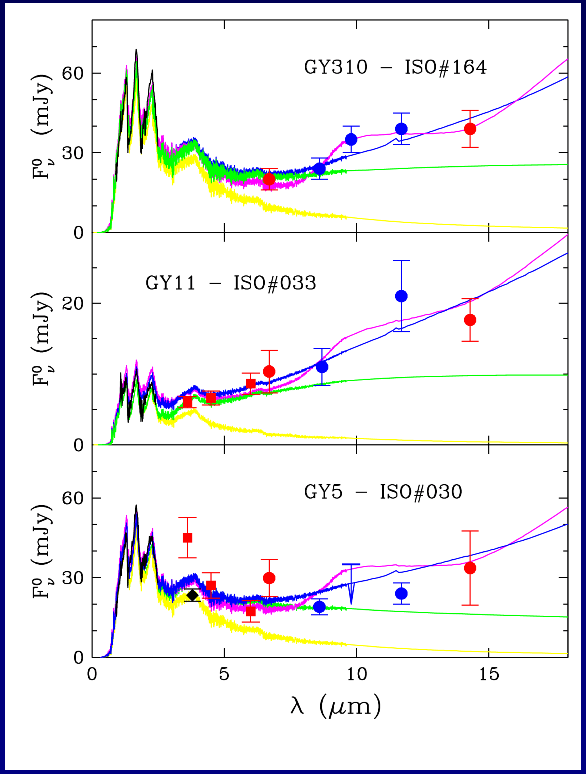


Science with ALMA: a new era for astrophysics

Madrid, 13-17 November 2006

Brown dwarfs have disks

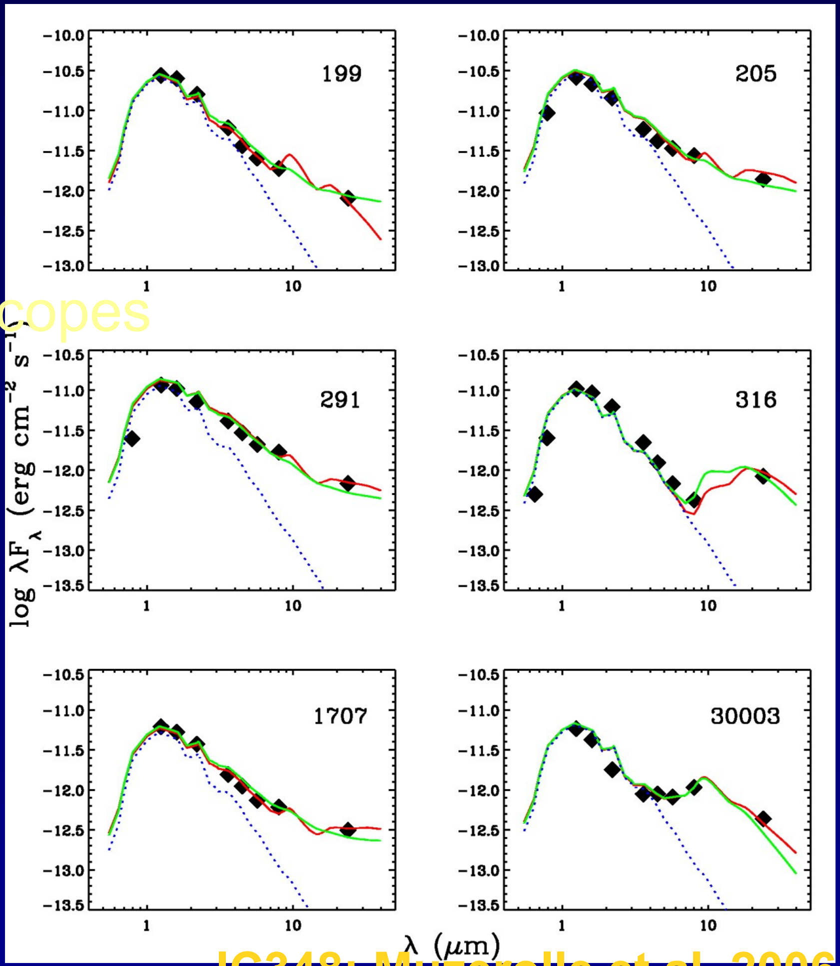
- **Mid-IR excess emission**
  - ISO
  - Ground-based 8m telescopes



Mohanty et al

Brown dwarfs have disks

- Mid-IR excess emission
  - ISO
  - Ground-based 8m telescopes
  - Spitzer !!



IC348: Muzerolle et al. 2006

Brown dwarfs have disks

- **Mid-IR excess emission**
  - ISO
  - Ground-based 8m telescopes
  - Spitzer !!

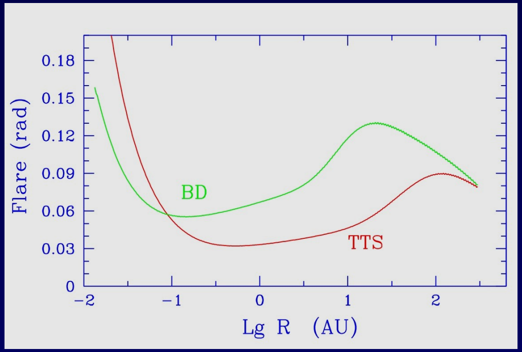
Same fraction of disks in BDs and TTS

Brown dwarf disks

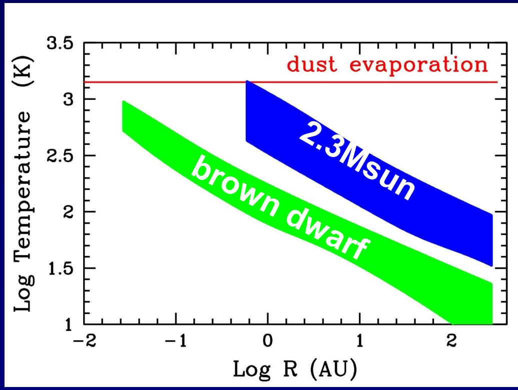
- Irradiated disks in hydrostatic equilibrium, gas and dust uniformly mixed: more flared than TTS disks
- BD disks do not have to be very small (in viscous disks, Rd ∝ t)
- To be gravitationally stable, they cannot be massive
  (~30% Mstar → 15 M_J)

Mdisk = 6% Mstar

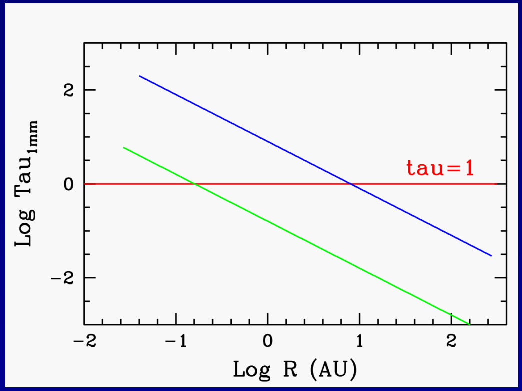
Flaring

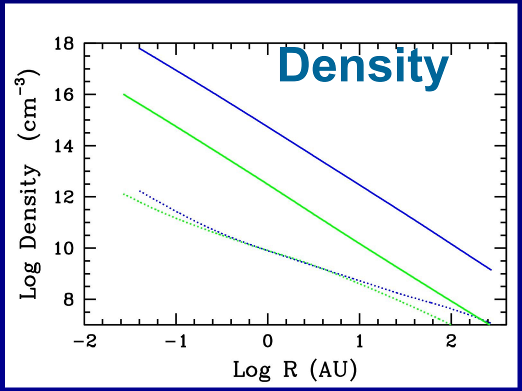


Temperature



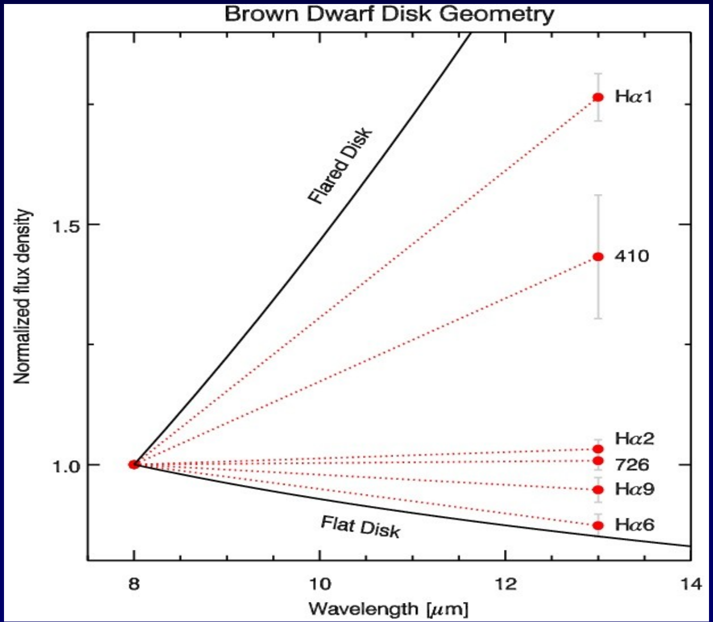
τ1.3mm



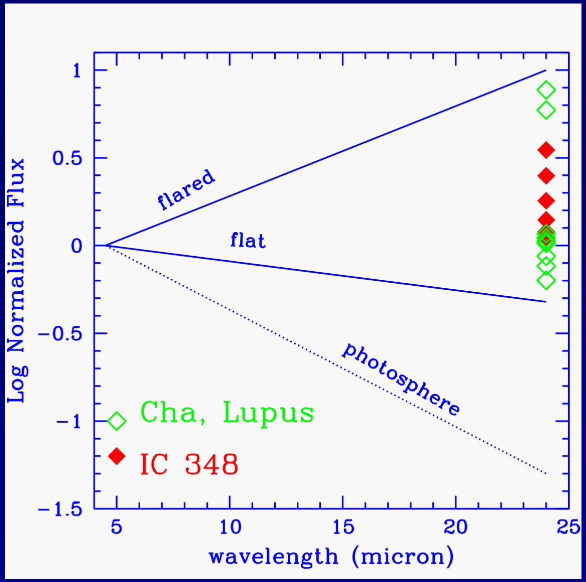


Spitzer

- Spitzer finds a lot of not-fully flared BD disks
  - Grain growth?
  - More than in TTS?
- Evolved silicates
  - Micron-size silicates
  - High cristallinity (!)



Apai et al. 2005; Muzerolle et al. 2006; Allers et al. 2006



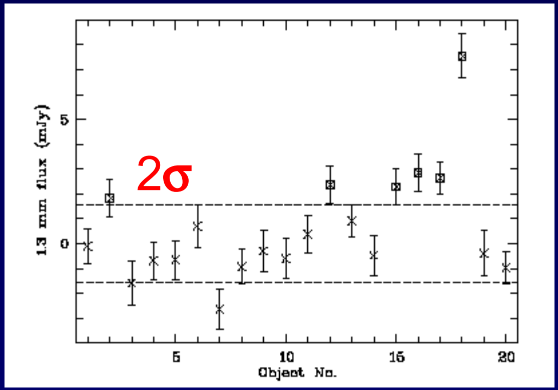
Are these signs of planet formation?

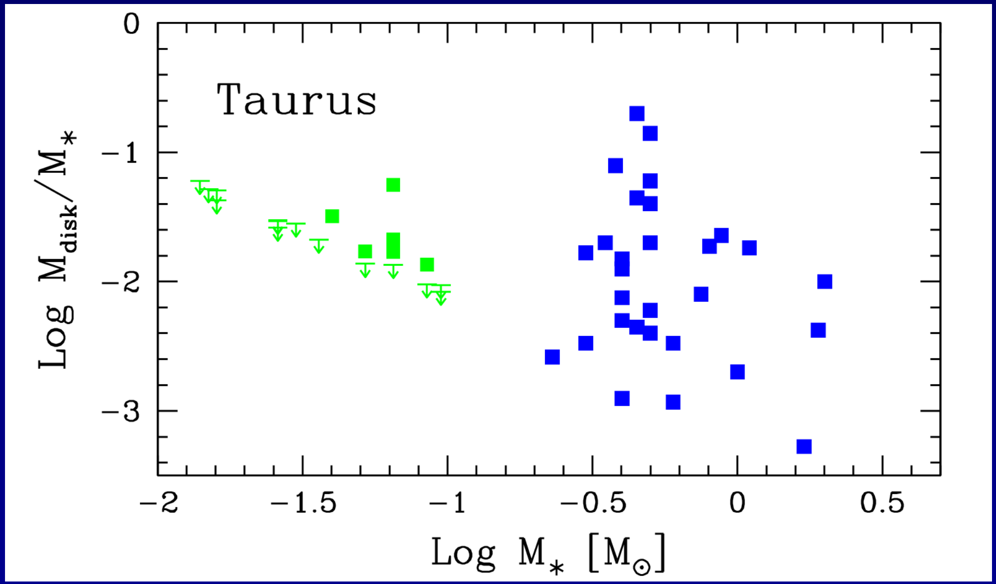
BD disk masses

Taurus BDs

- Few mm detections (6/20) at 2-3σ using MAMBO on the IRAM 30m
- Mdisk~few $M_{Jupiter}$ (Mgas/Mdust=100, k~1cm^2/g)
- Sizes are not constrained (Rd>10-20AU)

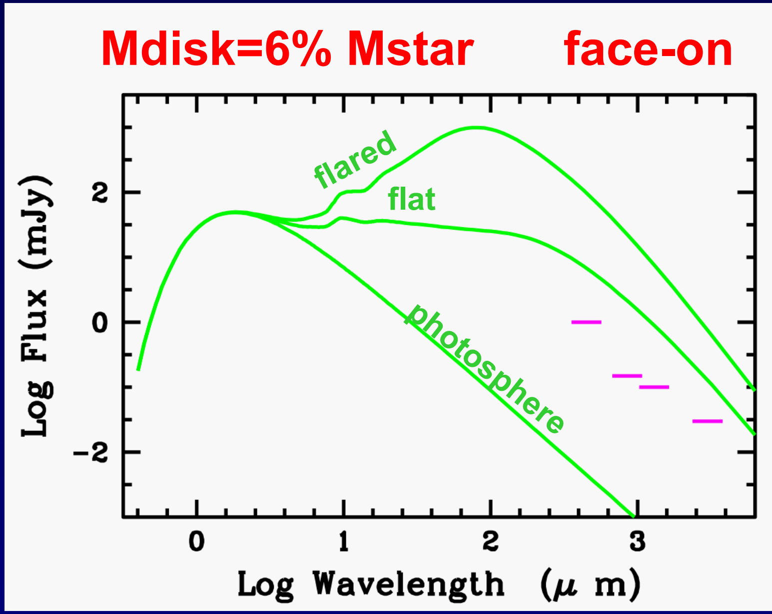
Scholz et al. 2006

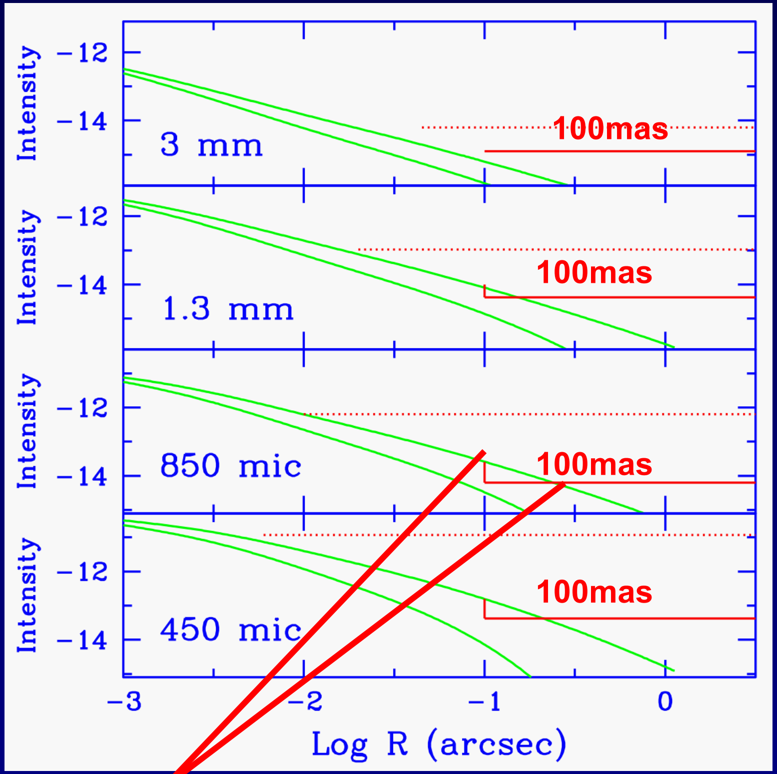




BD disks with ALMA

D=140 pc, 5σ in 1 hour





10-30AU

ALMA will detect BD disks at all wl unless they have very little mass (<1% Mstar)

- **mm opacity**
- **disk masses**

It will be difficult to resolve BD disks

Summary

"BDs form as H-burning stars, i.e., on a dynamical timescale, by gravitational instability, with initially uniform elemental composition"

- Search for very low mass cores in star forming regions
- Mass function of cores down to pre-BD masses
- Study pre-BD cores: density, size, kinematics, chemistry
- Find proto-brown dwarfs (Class0/I)
- <u>Study brown dwarf disks: mass & dust properties</u>