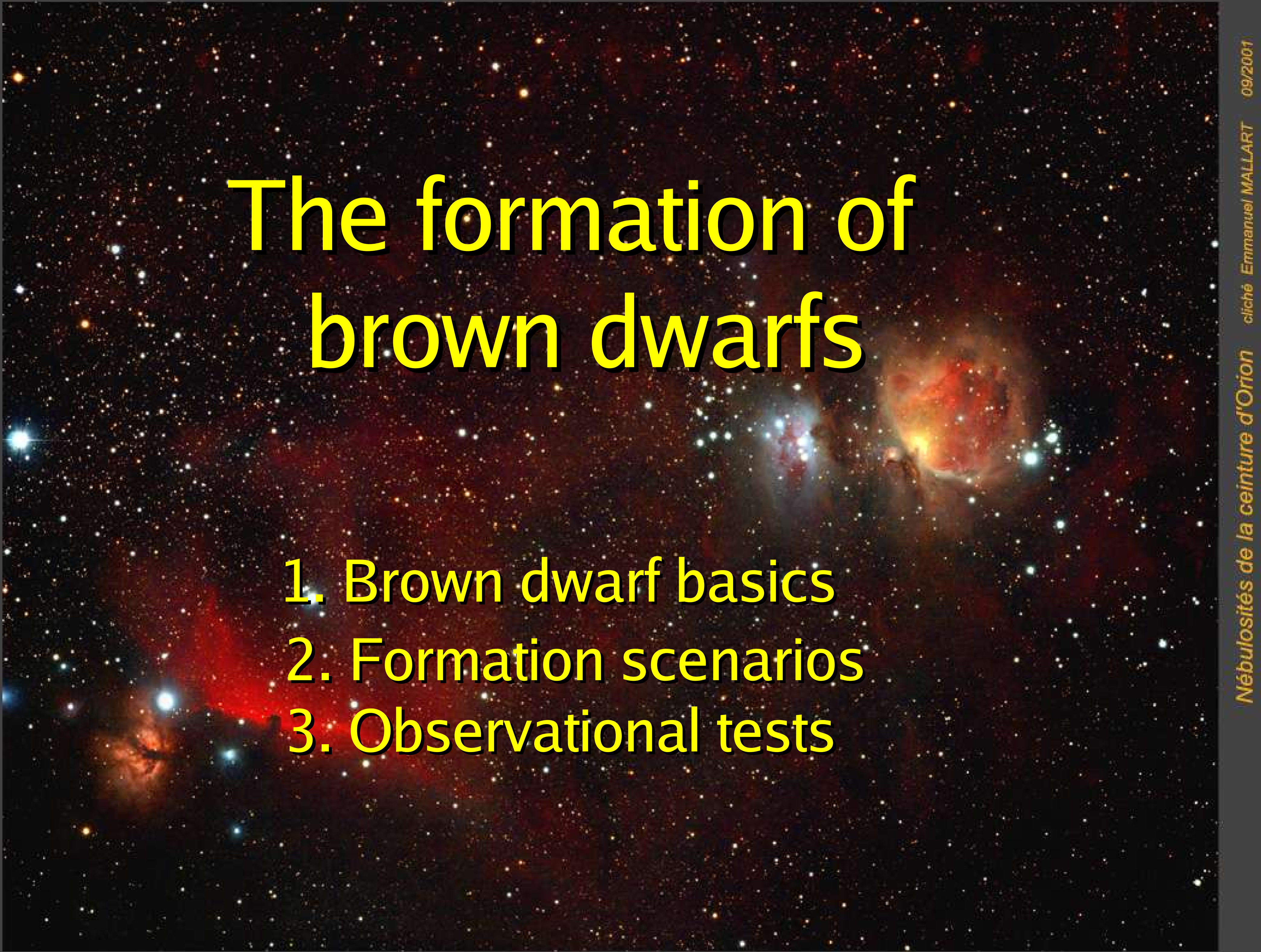
The formation of brown dwarfs

1. Brown dwarf basics
2. Formation scenarios
3. Observational tests



What are brown dwarfs?

'A main sequence star is to a candle as a brown dwarf is to a hot poker recently removed from the fire.' (Oppenheimer 2000)

THE STRUCTURE OF STARS OF VERY LOW MASS

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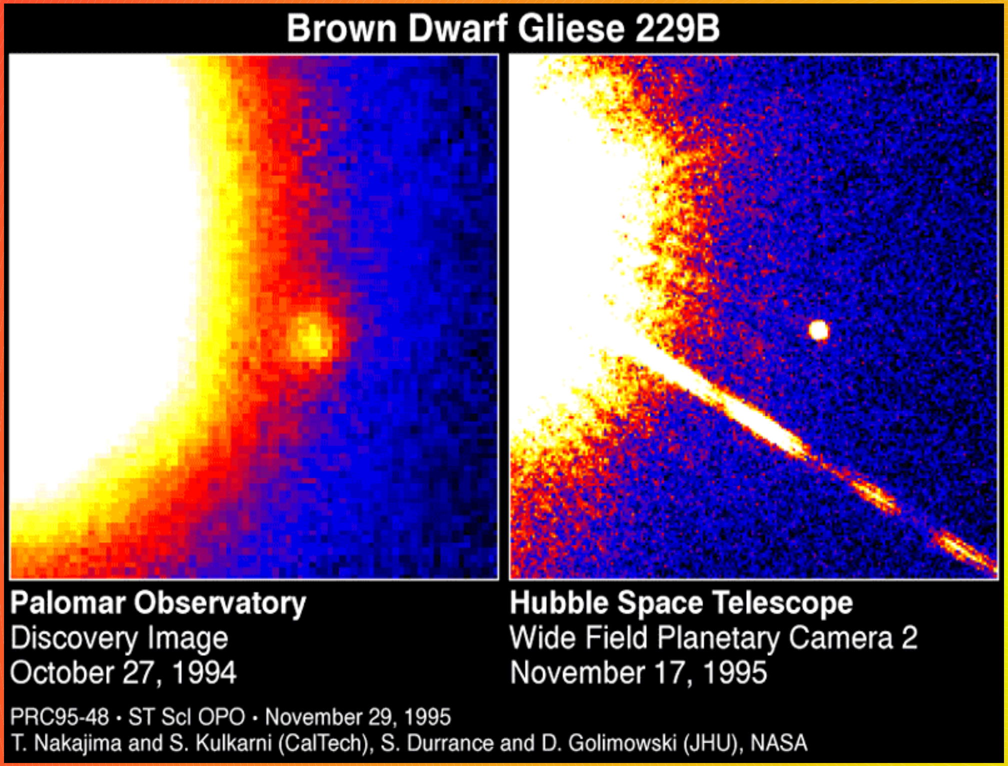
ABSTRACT

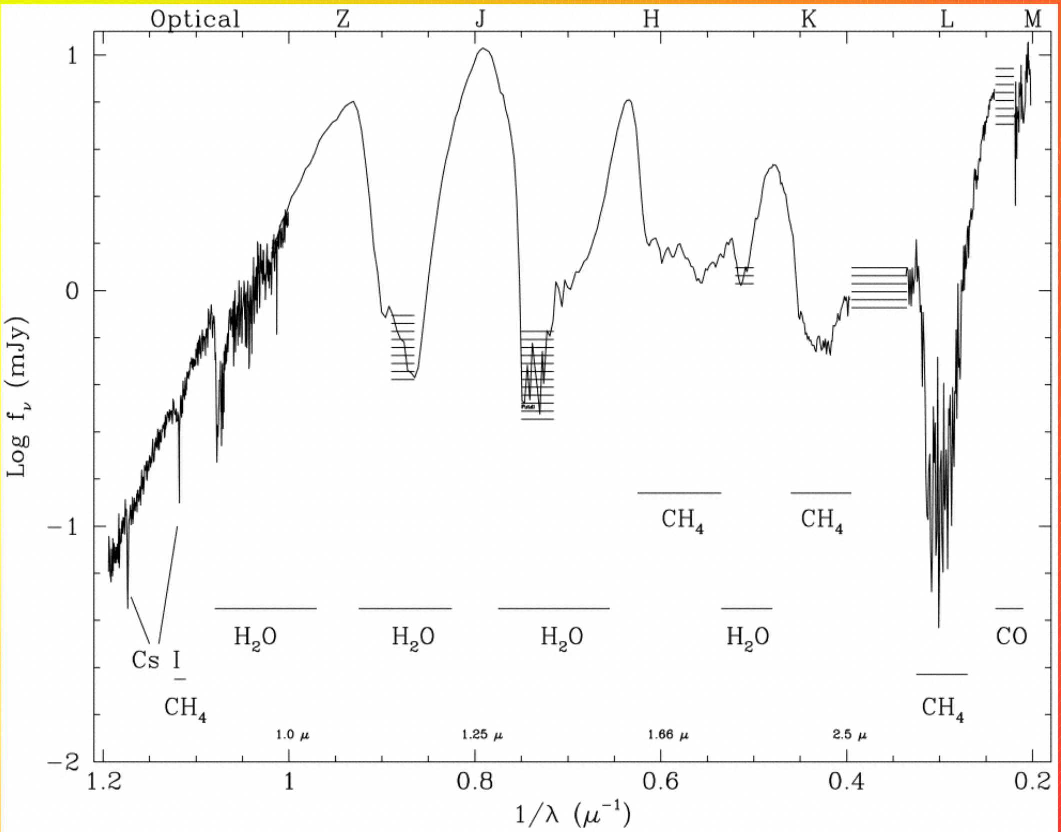
Completely convective models have been constructed for stars of masses 0.09, 0.08, 0.07, 0.06, 0.05, and 0.04 (solar units), taking into account the non-relativistic degeneracy of the stellar material. It is shown that there is a lower limit to the mass of a main-sequence star. The stars with mass less than this limit become completely degenerate stars or "black" dwarfs as a consequence of gravitational contraction, and, therefore, they never go through the normal stellar evolution.

Compact object with a core temperature insufficient to support sustained nuclear fusion reactions

Hydrogen Burning Mass Limit: 0.07-0.08 M_S

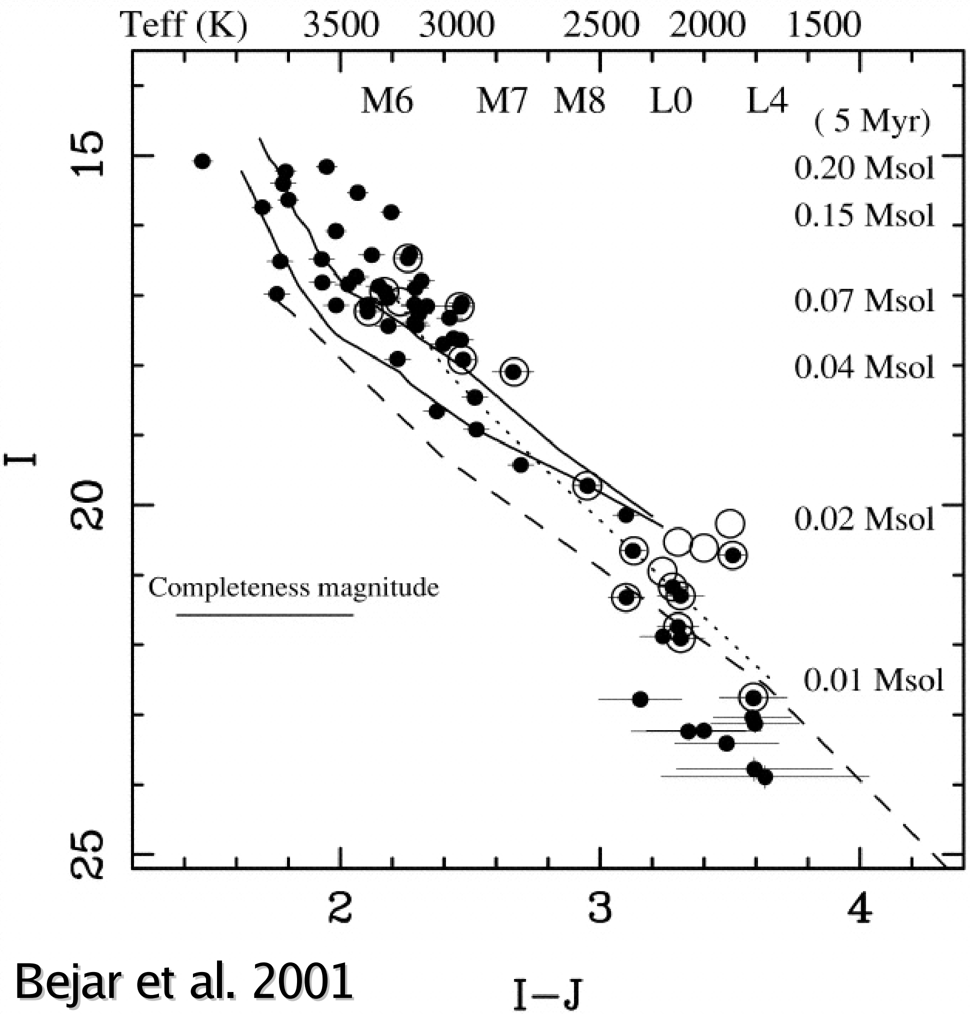
First detection: Gliese 229B



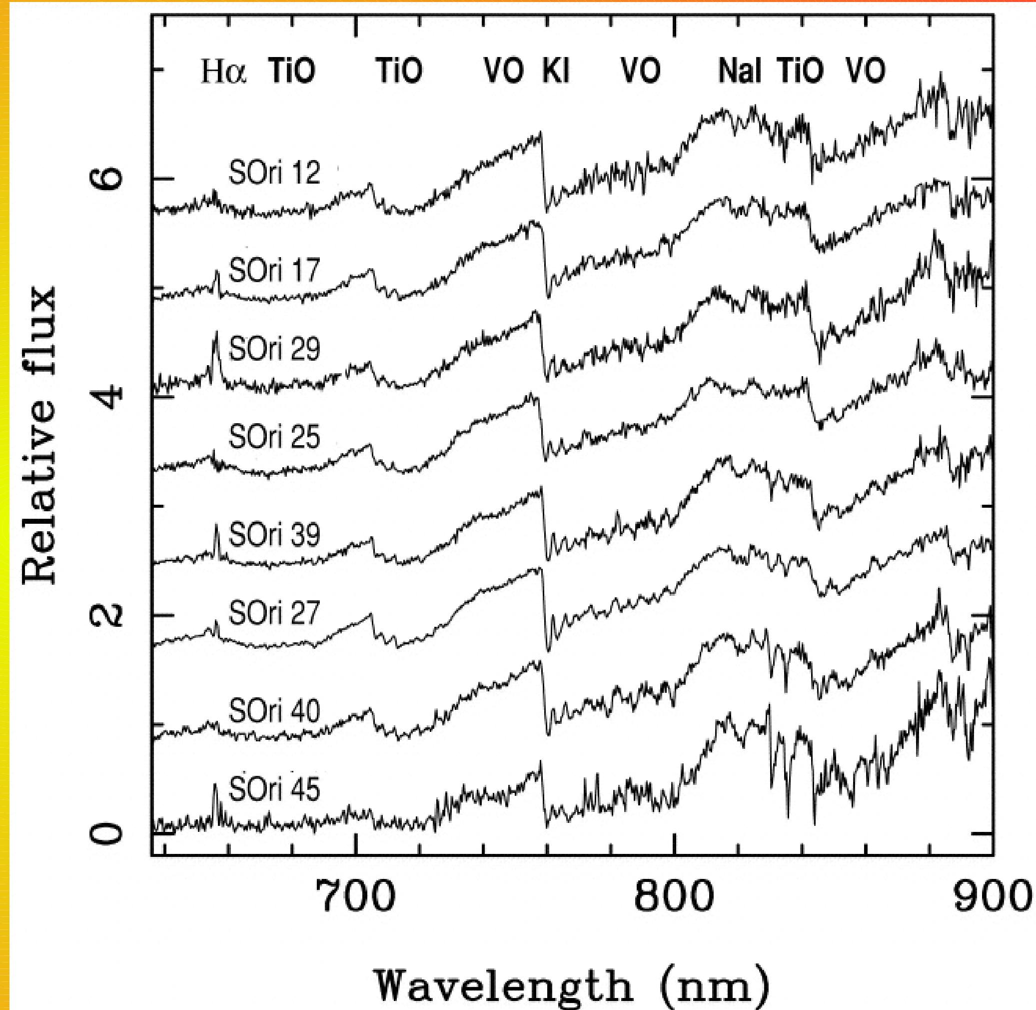


Oppenheimer et al. 1998

Brown dwarf surveys

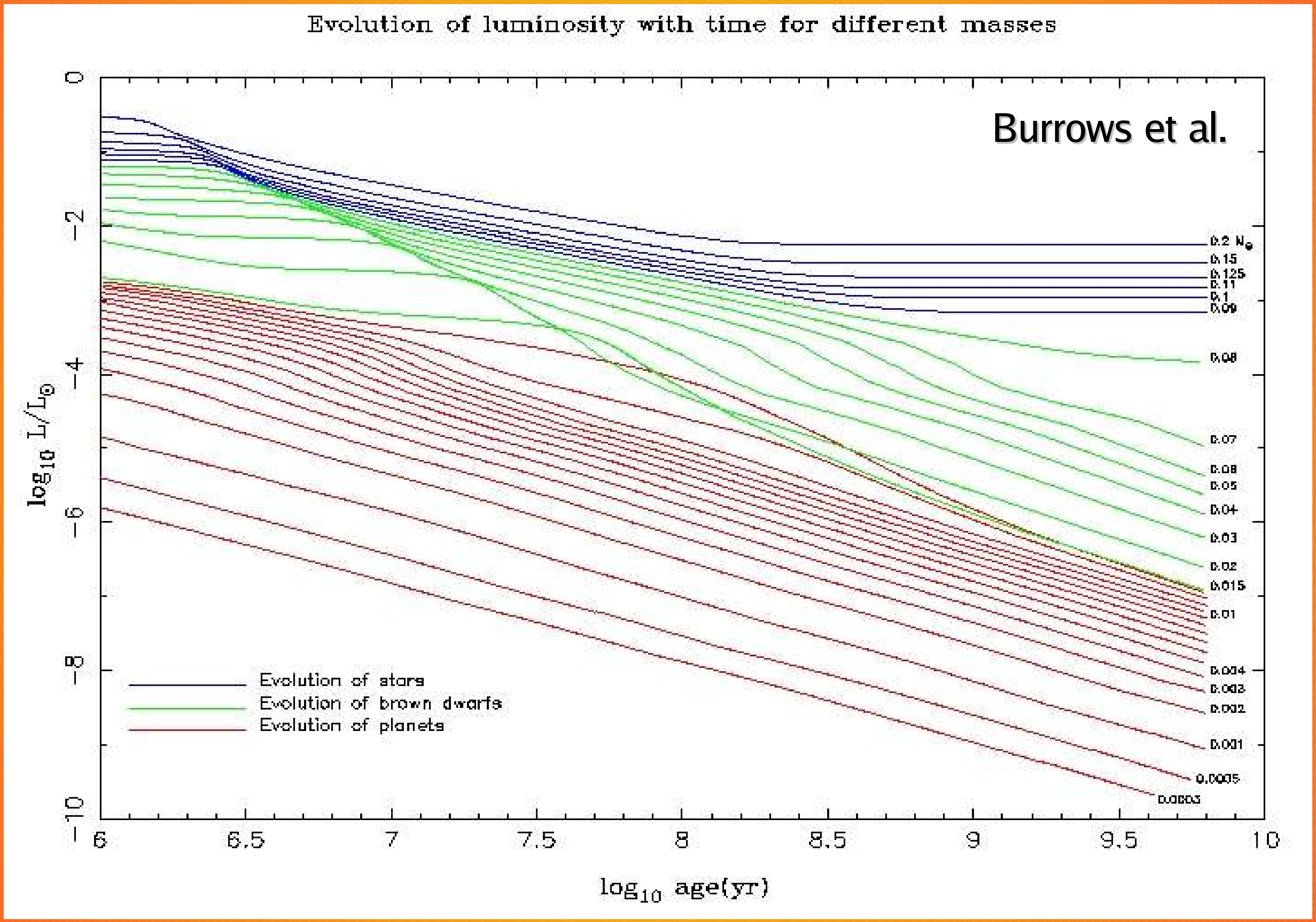


Bejar et al. 2001



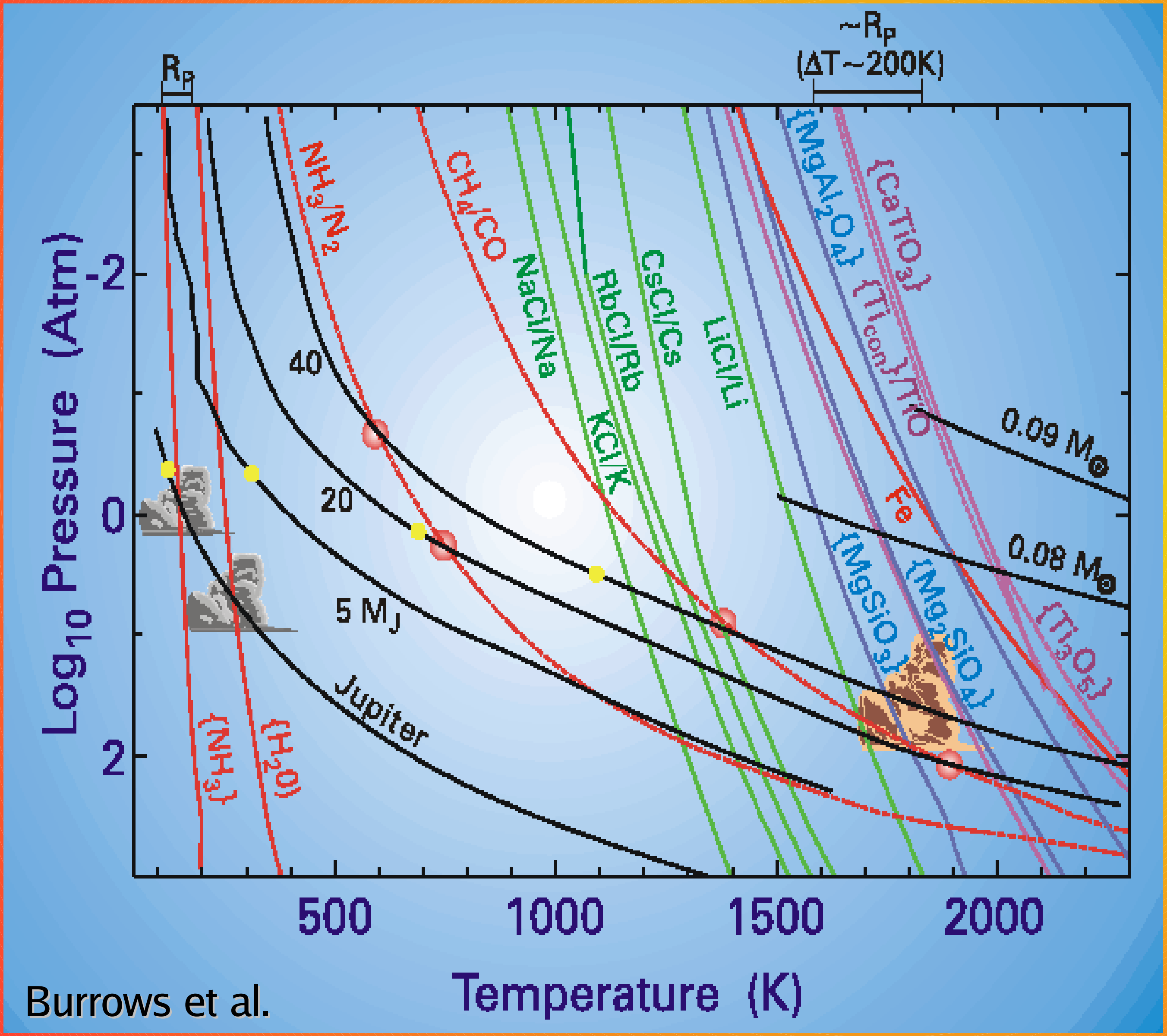
Today: hundreds of brown dwarfs identified

Luminosity

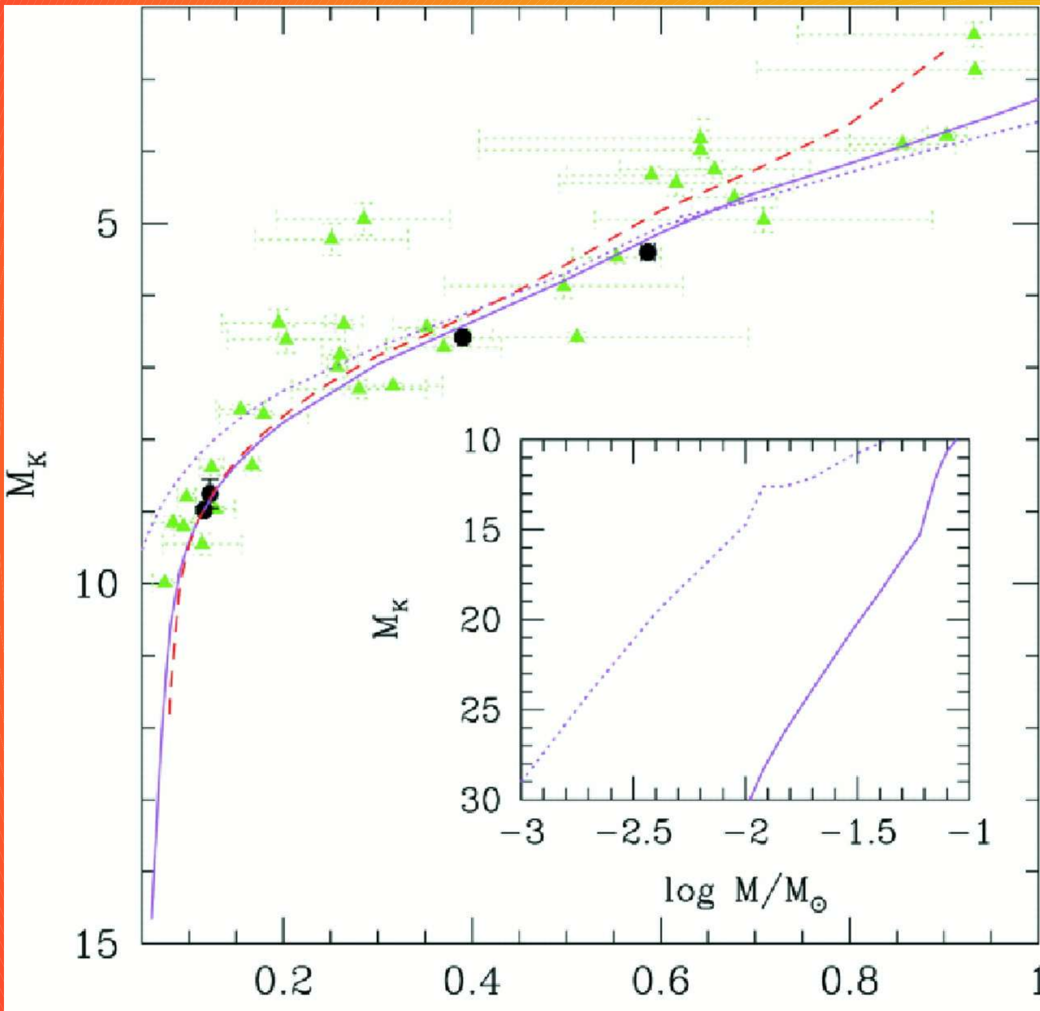


Brown dwarfs cool as they get older

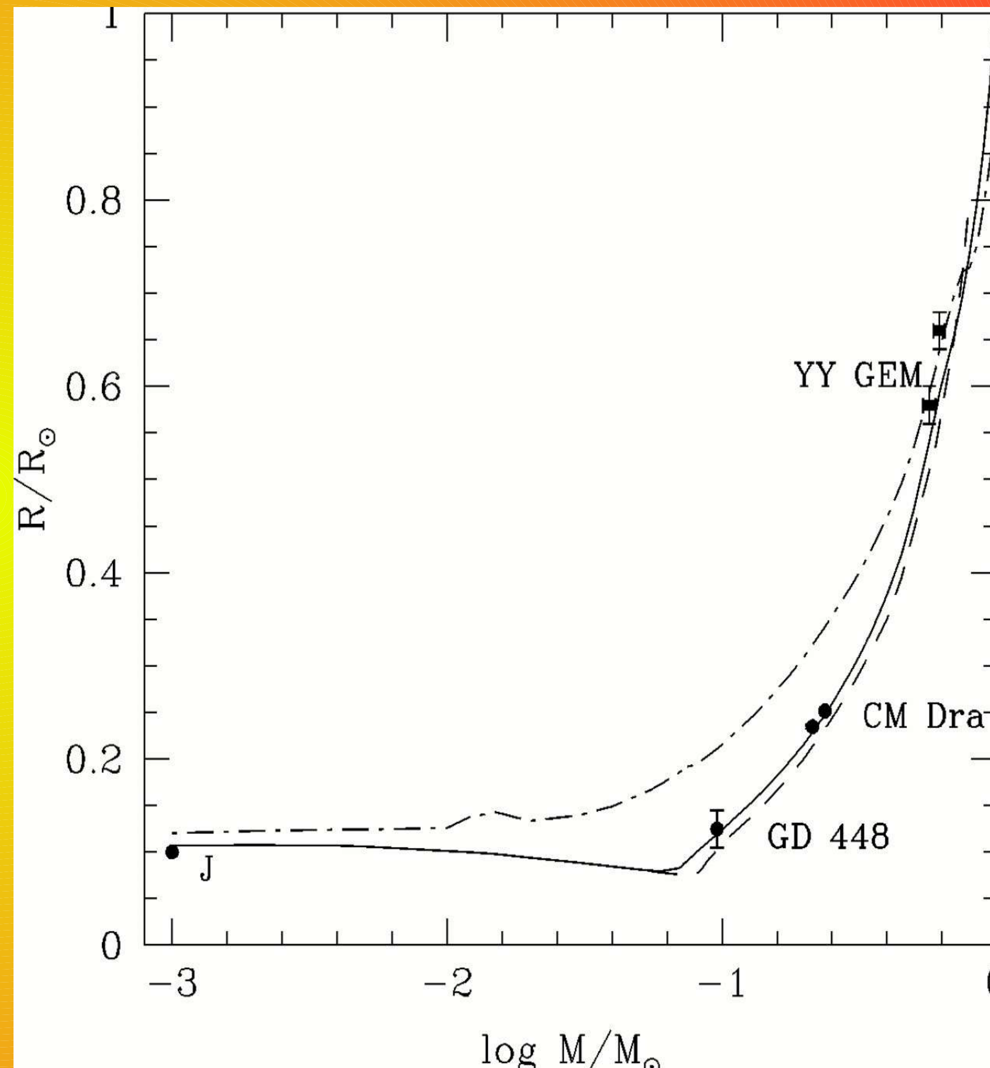
Dust formation



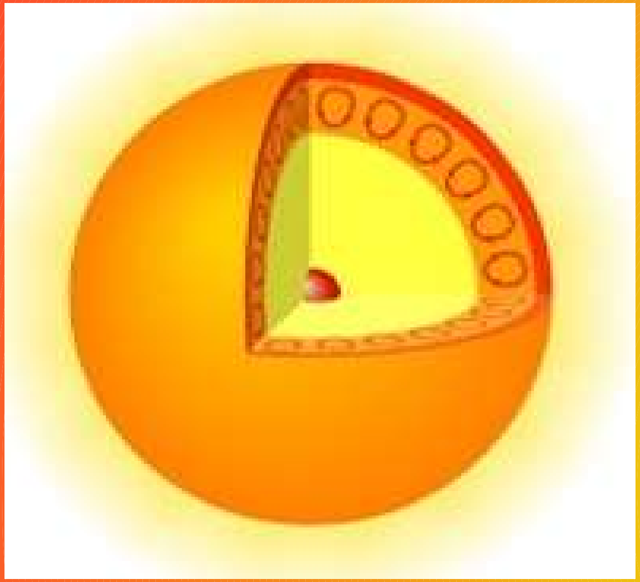
Mass vs. Magnitude/Radius



Chabrier 2000



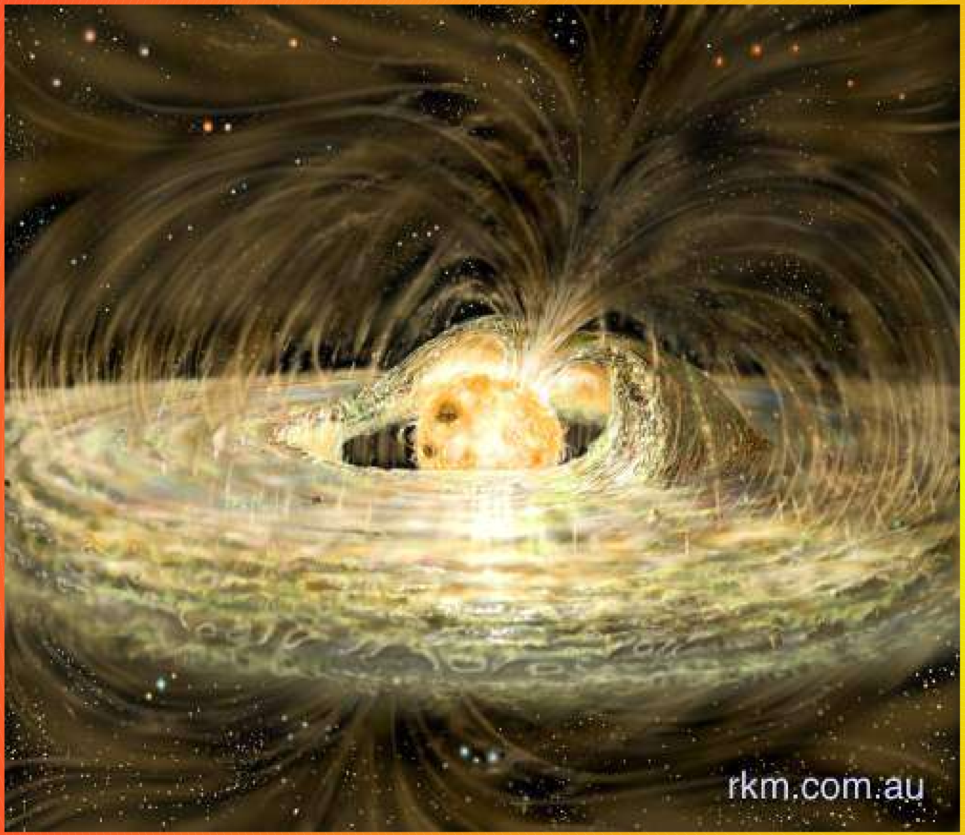
Convection



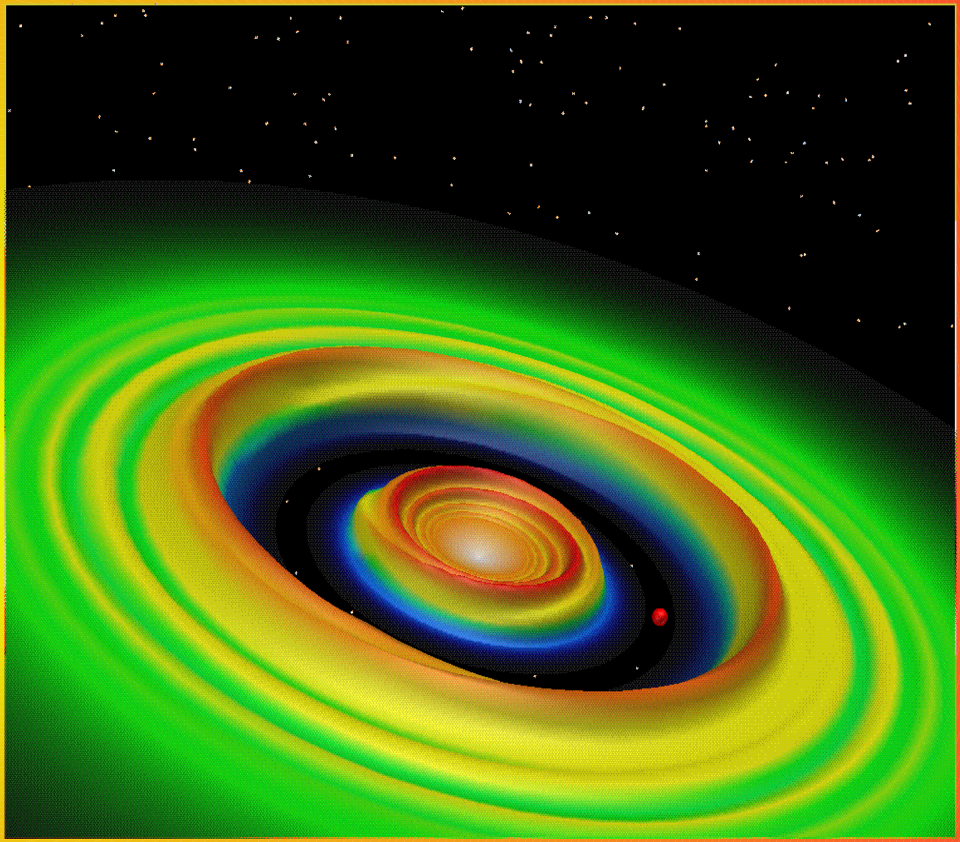
Sun: radiation zone + convection zone
large-scale magnetic field is produced in transition layer

Brown dwarf: fully convective
no large-scale magnetic field?

Formation of brown dwarfs



collapse + fragmentation



disk instability

Star-like? Planet-like? Or something else?

Fragmentation

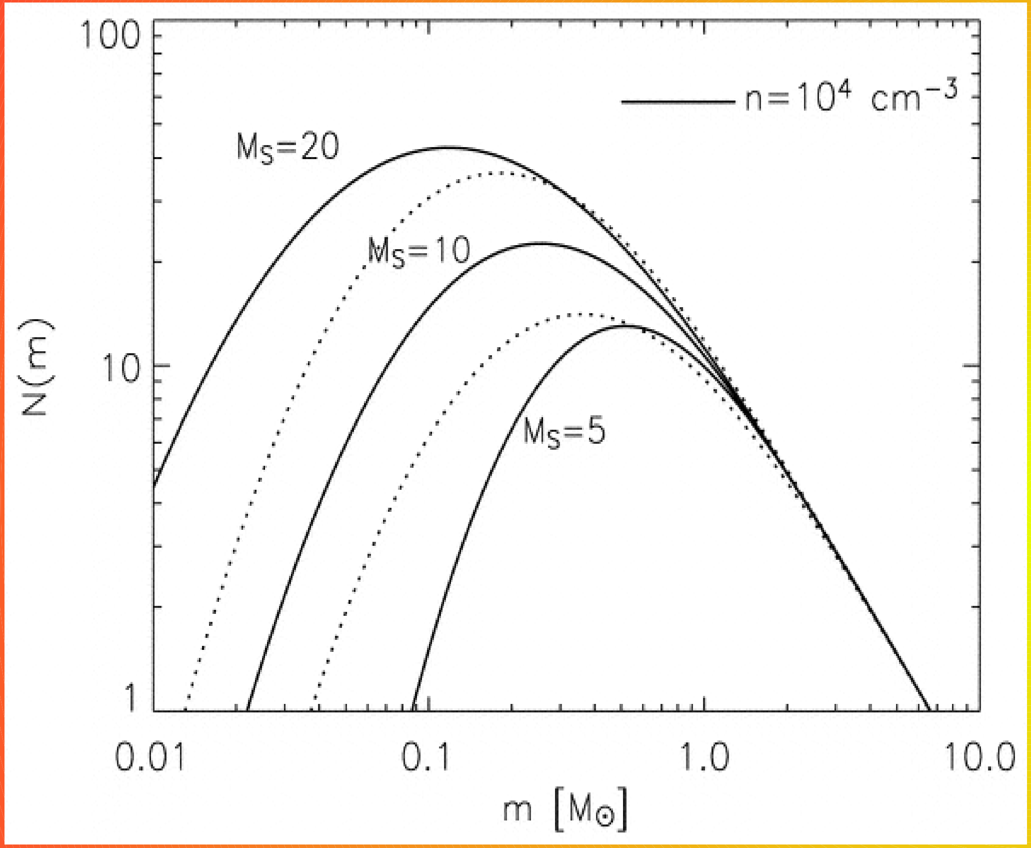
What is the minimum Jeans mass?
At which masses must fragmentation cease?
Can brown dwarfs form via fragmentation?

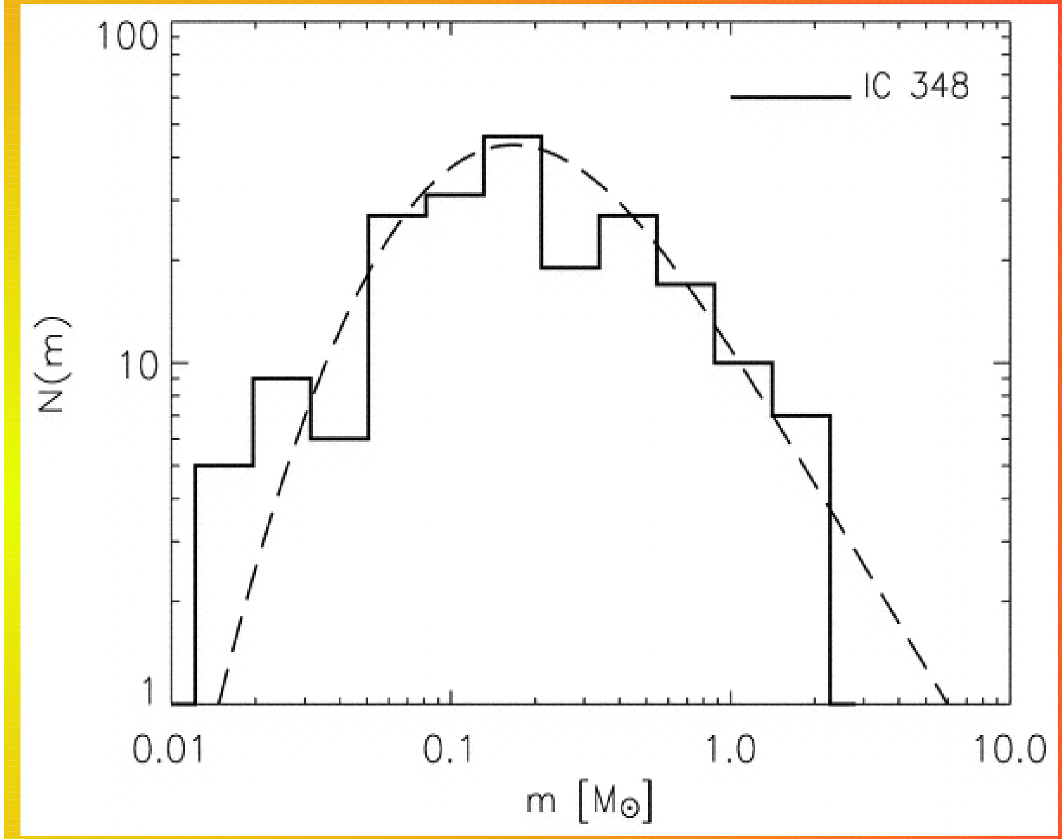
Analytical estimates: 0.003-0.007 Ms
(Low & Lynden-Bell 1976, Rees 1976, Silk 1977)

Numerical estimates: 0.003-0.010 Ms
(Boss 1988, 1993, Boyd & Whitworth 2004)

neglected: magnetic fields, rotation, hot dust
tend to increase the minimum

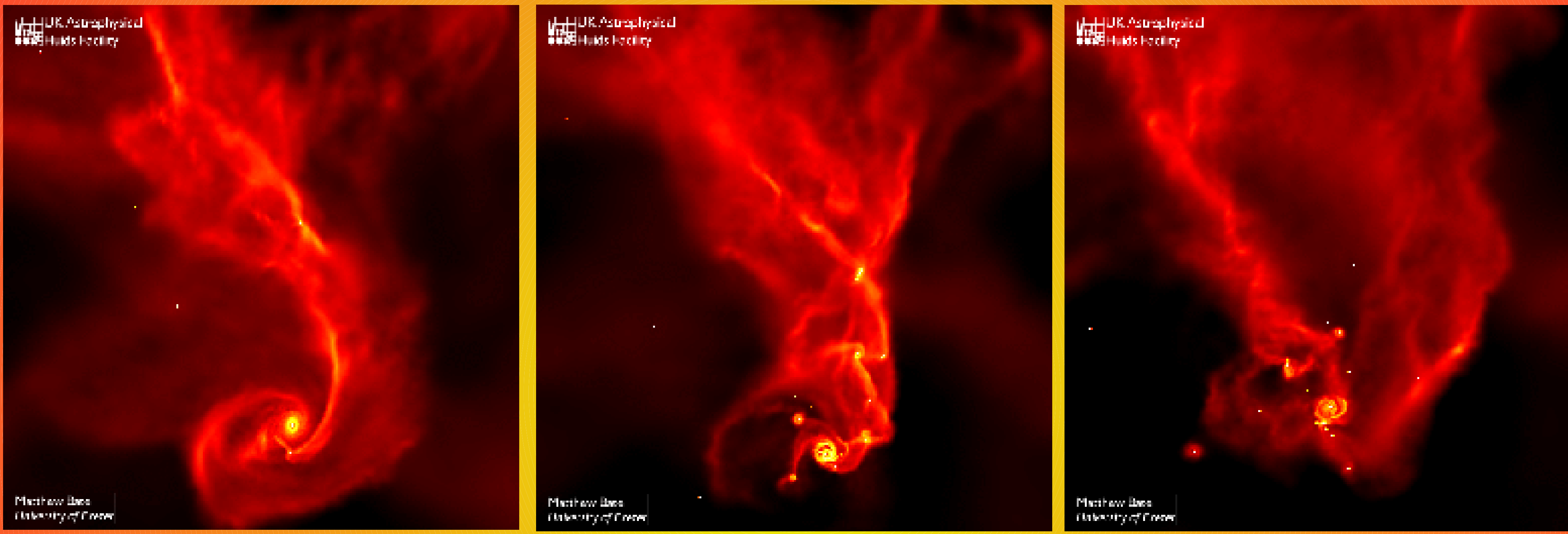
Fragmentation





Most recent simulation: Padoan & Nordlund (2004)
Substellar masses by turbulent fragmentation

Ejection



Basic idea: brown dwarfs are stellar embyos ejected from multiple systems during formation and thus cut-off from their accretion reservoir (Reipurth & Clarke 2001)

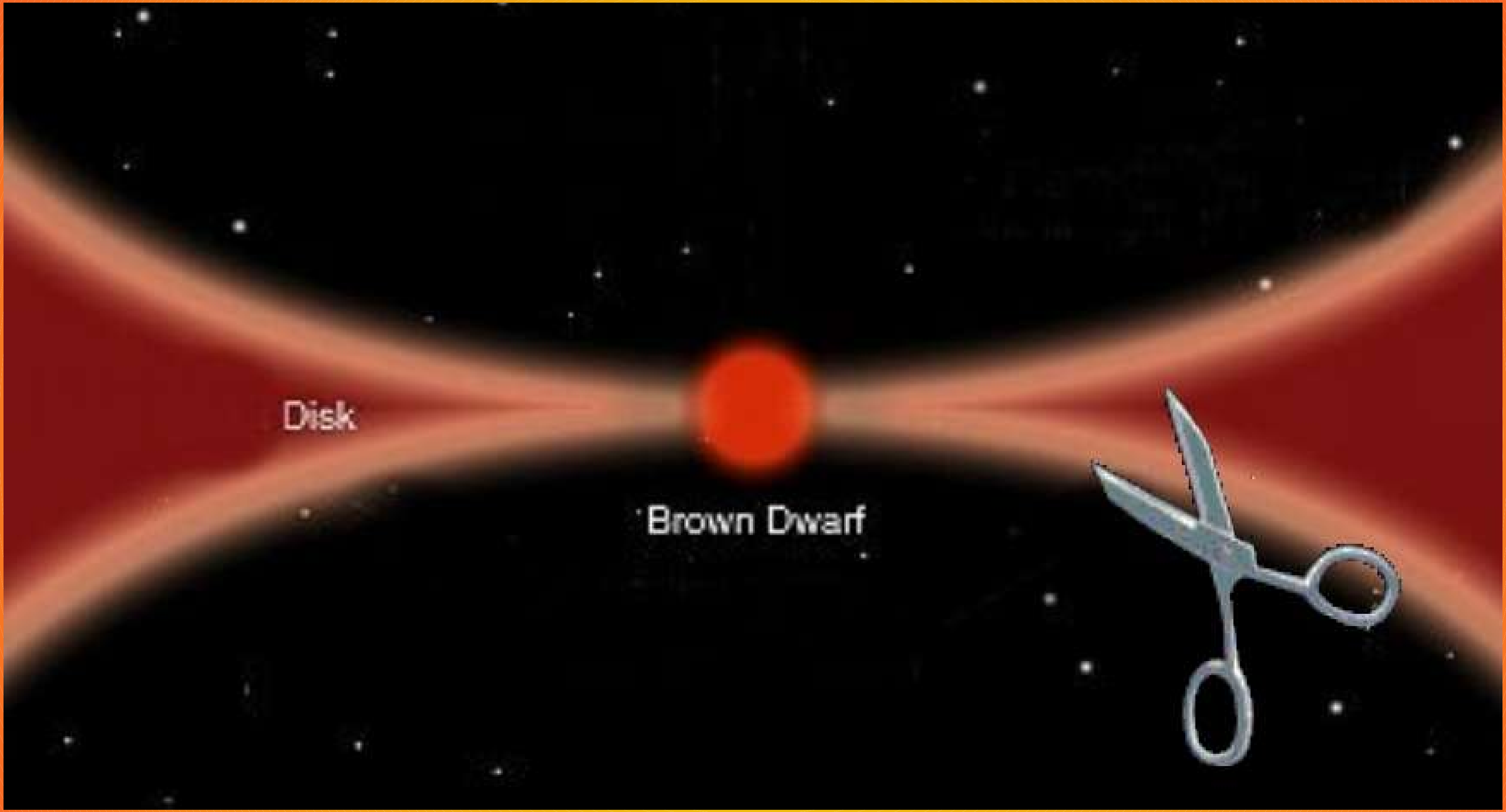
Simulations by Bate et al. (2002, 2003)

Alternative scenarios

- Disk instabilities: may form companion BDs similar to planets
  Pickett et al. 2000, Boss 2001, Rice et al. 2003

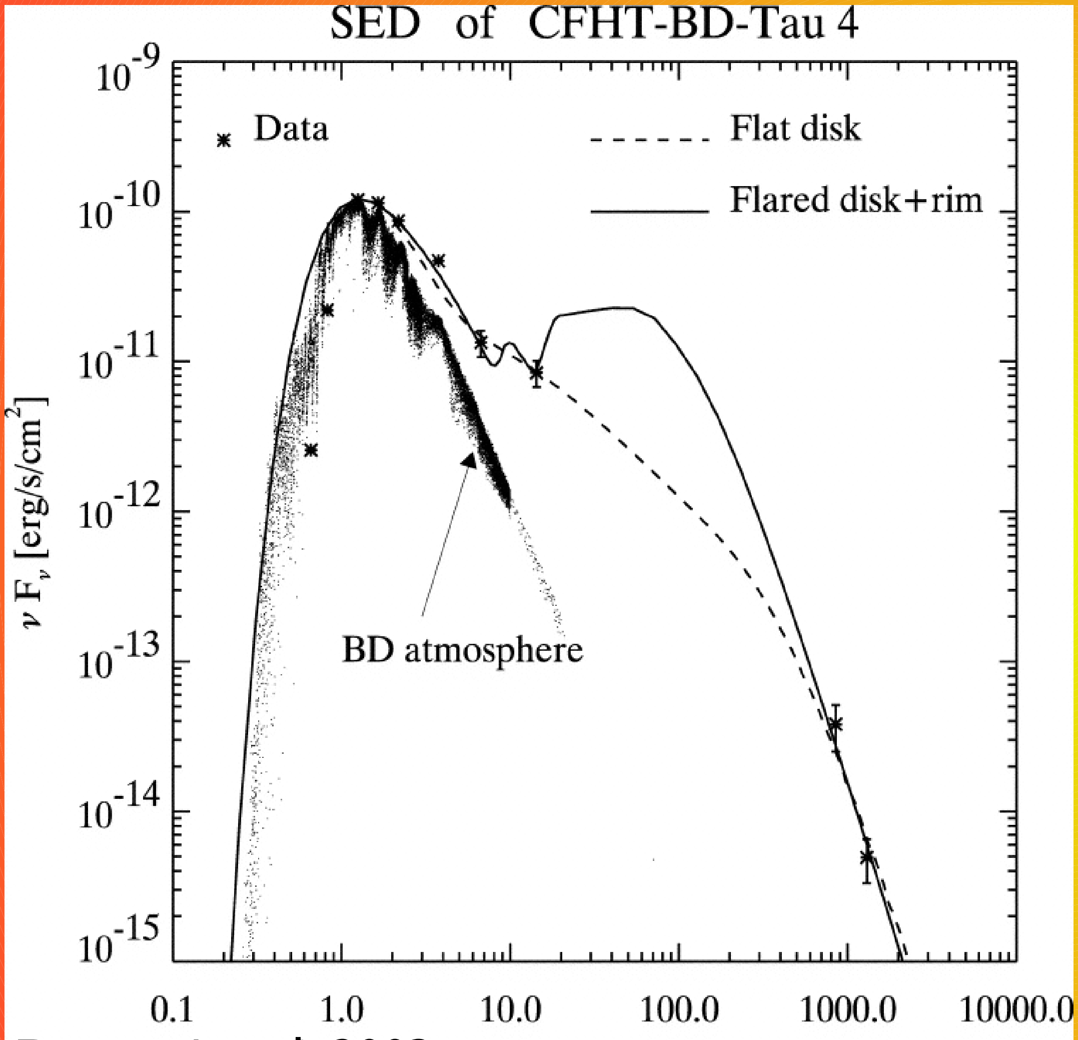
- Photo-erosion of protostellar cores: only with OB star nearby, needs massive initial core
  Whitworth & Zinnecker 2004

Signatures of ejection

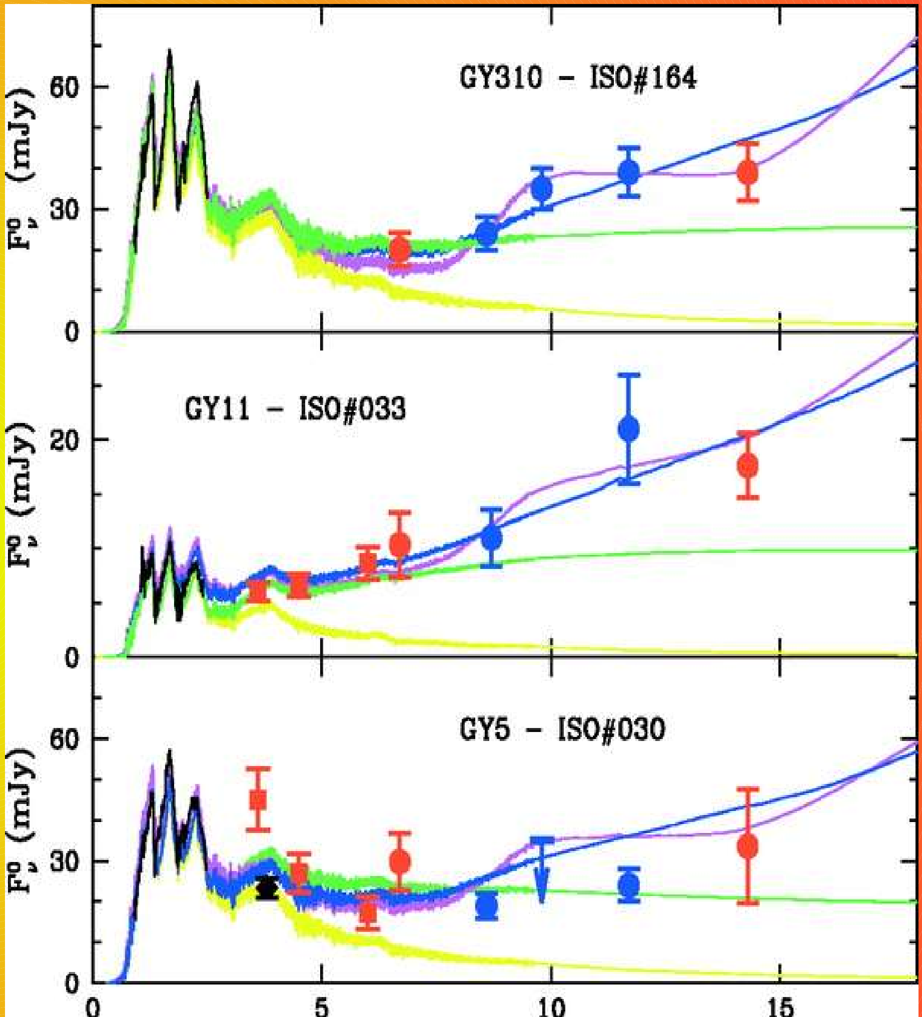


1. Truncated disks
2. Very few binaries
3. High spatial velocity

Accretion disks



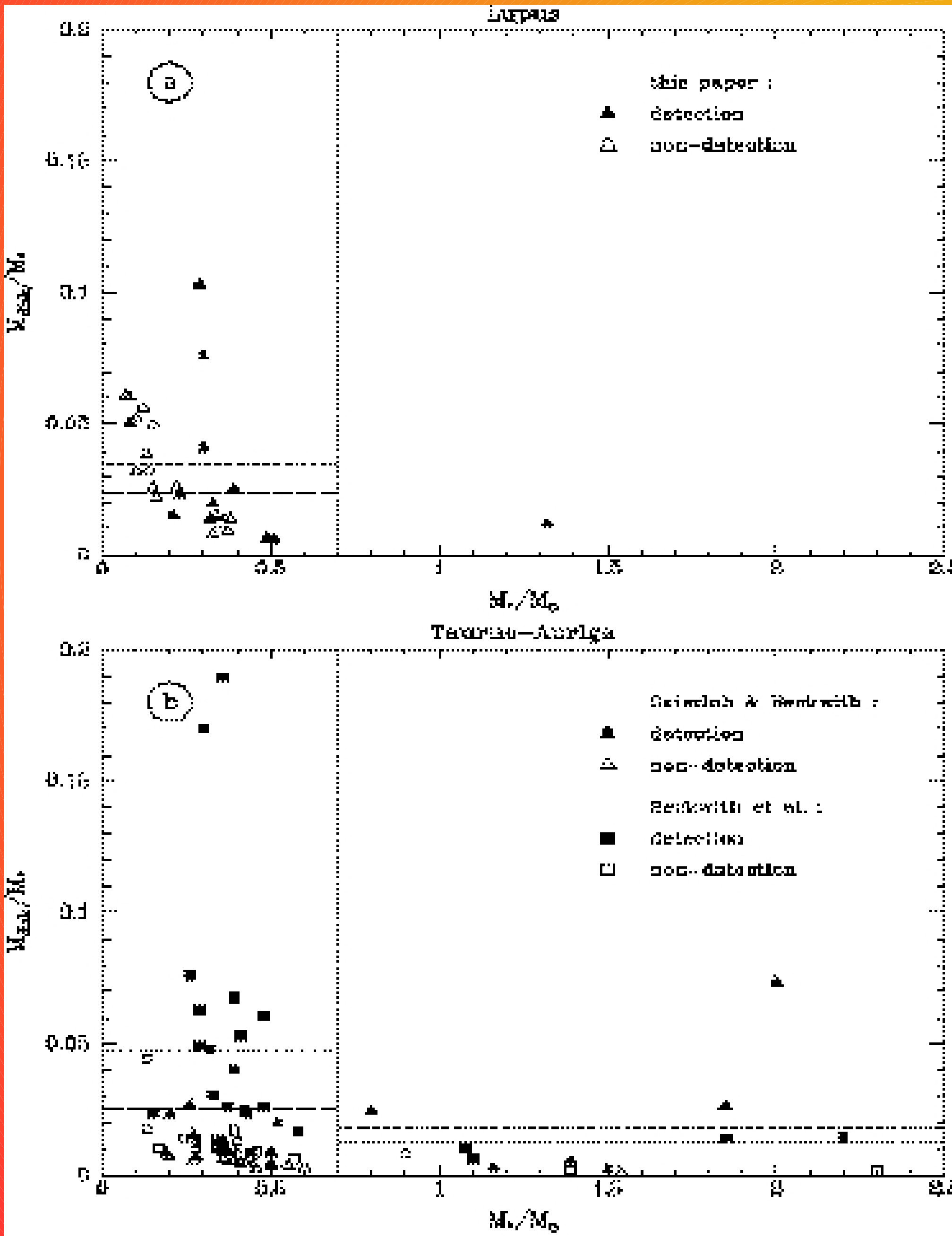
Pascucci et al. 2003



Mohanty et al. 2004

Mid-IR + submm: Disks around brown dwarfs

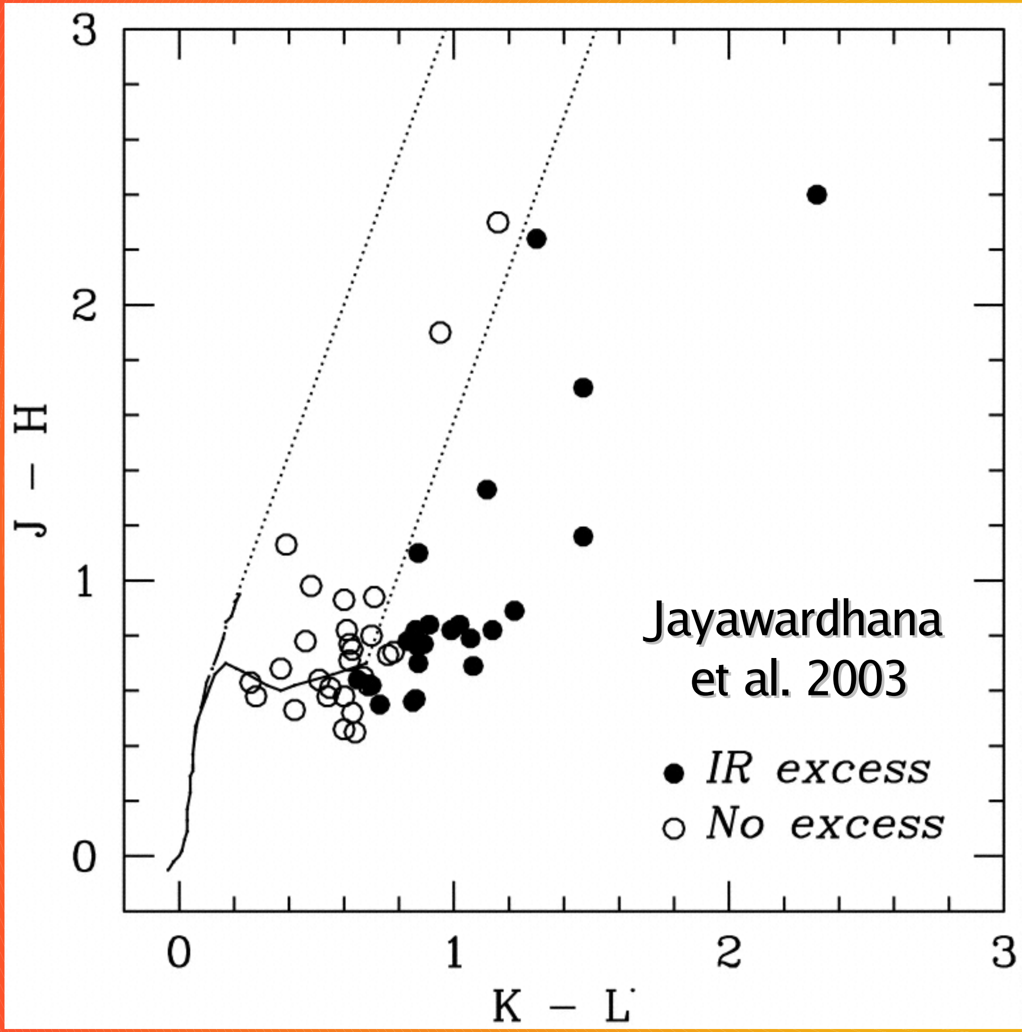
Disk mass vs. stellar mass

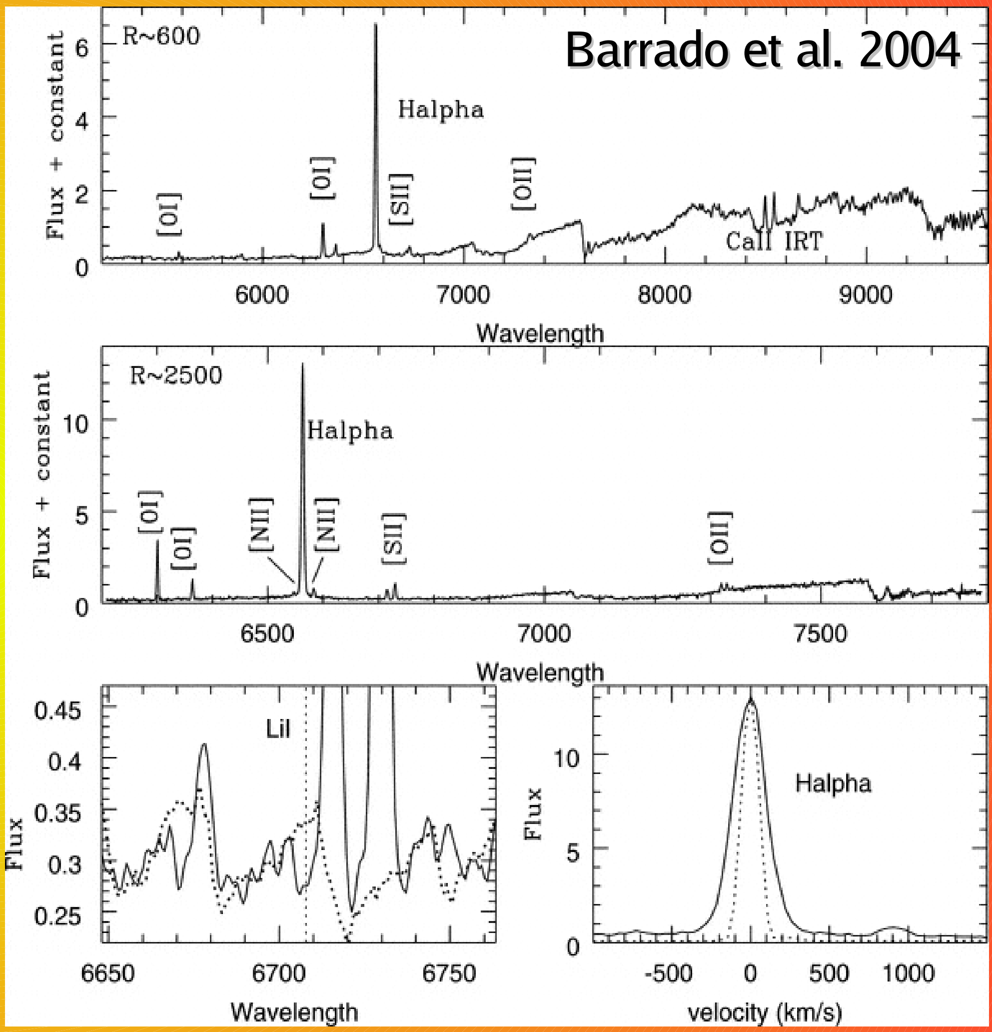


Expected disk mass 2-5% of stellar mass

Nuernberger et al. 1998

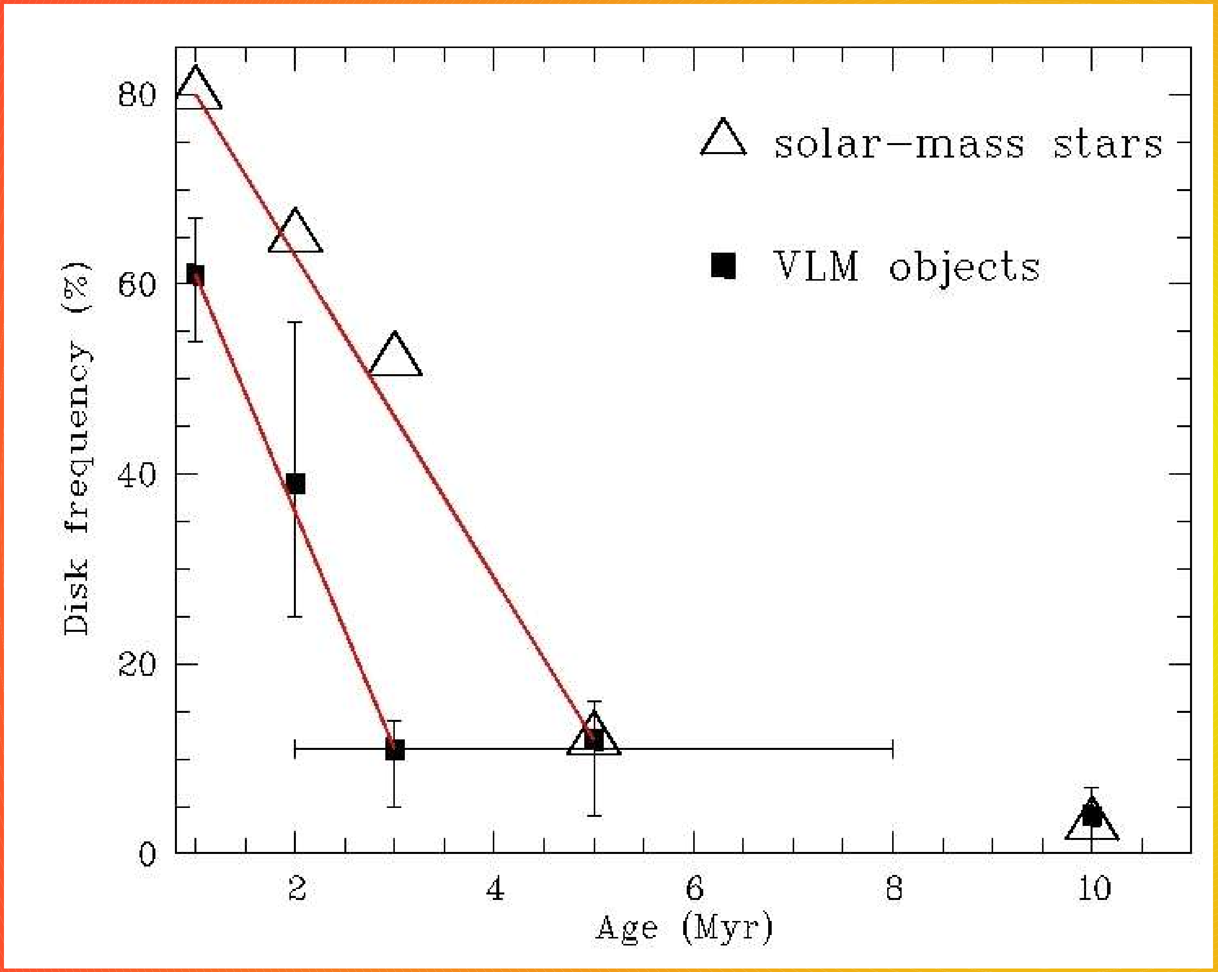
Accretion disks





NIR colour excess + emission lines:
signatures of disks and accretion

Accretion disks

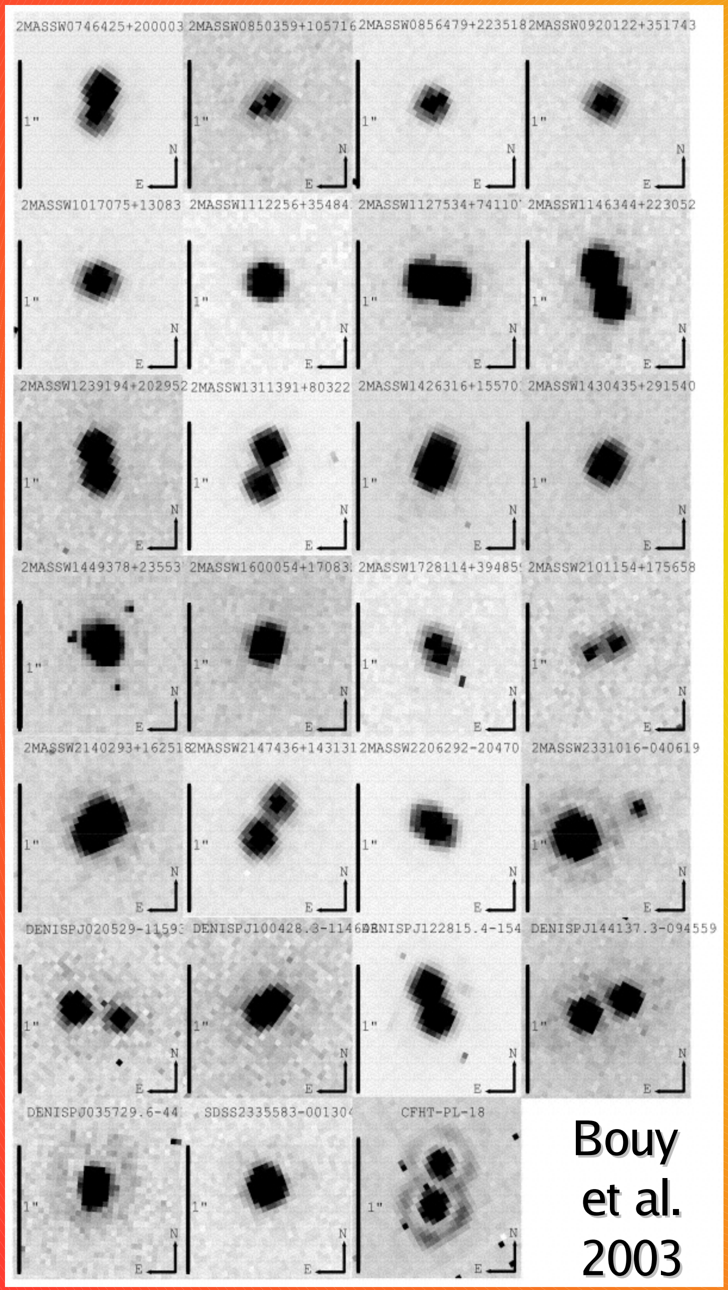


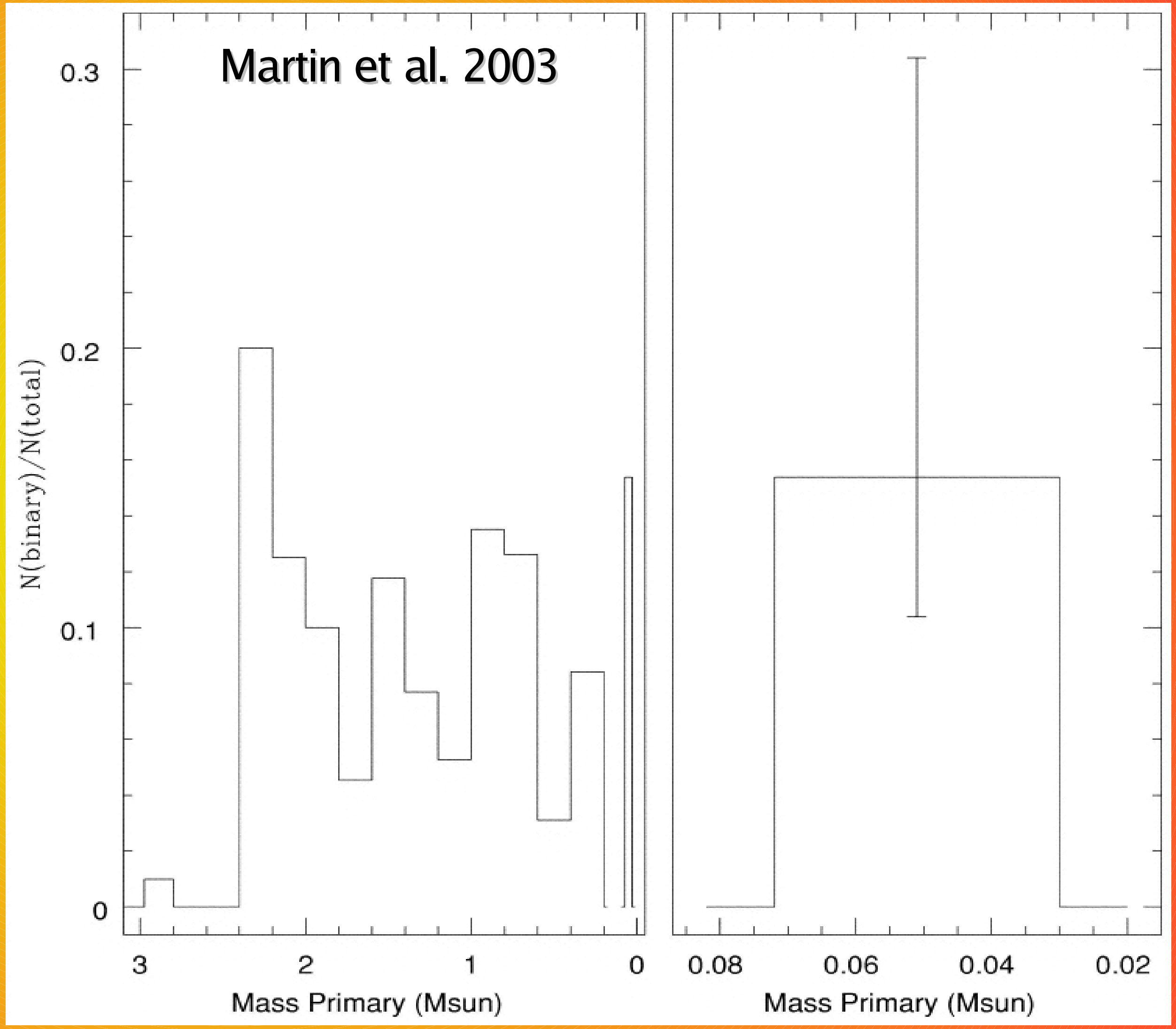
Disk frequencies
for stars and Bds

-> Disk lifetimes appear to
be similar for BDs

Problems: age uncertainty, inconsistent disk indicators, small samples
Required: MIR/mm observations of large BD samples

Binarity

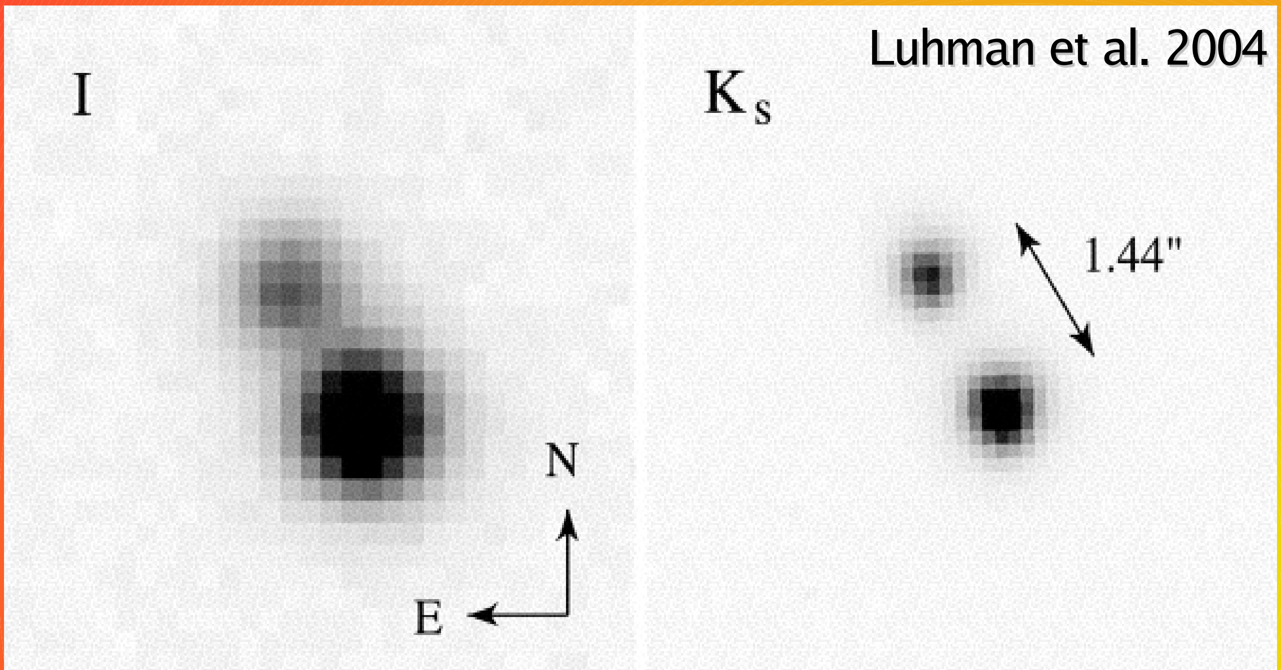




BD binaries exist: frequency 10-20%

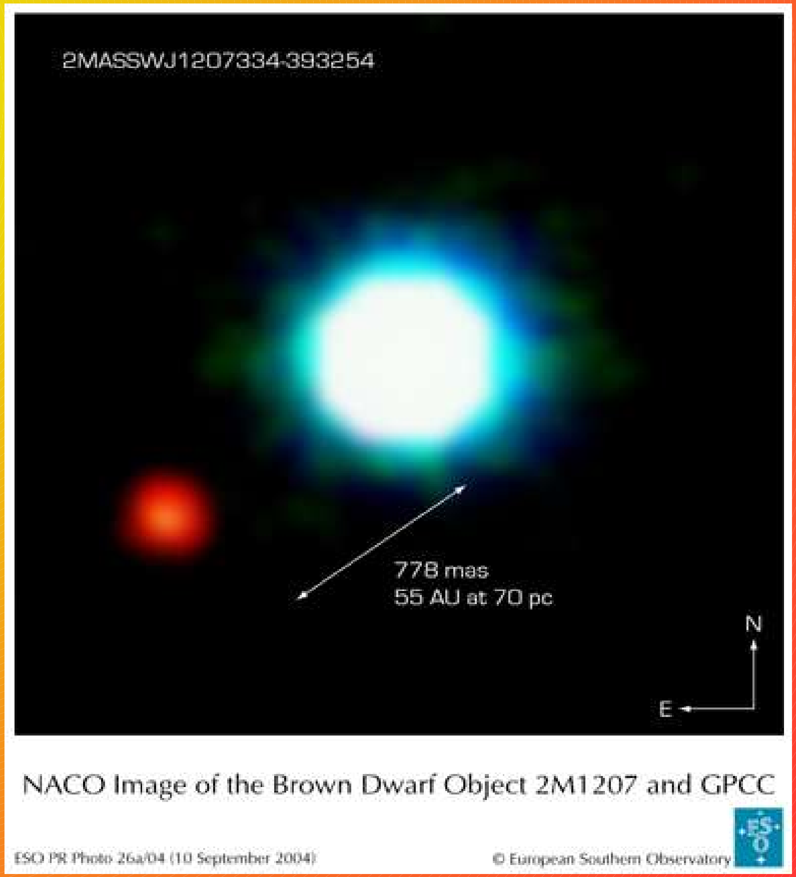
Wide Binaries

Luhman et al. 2004

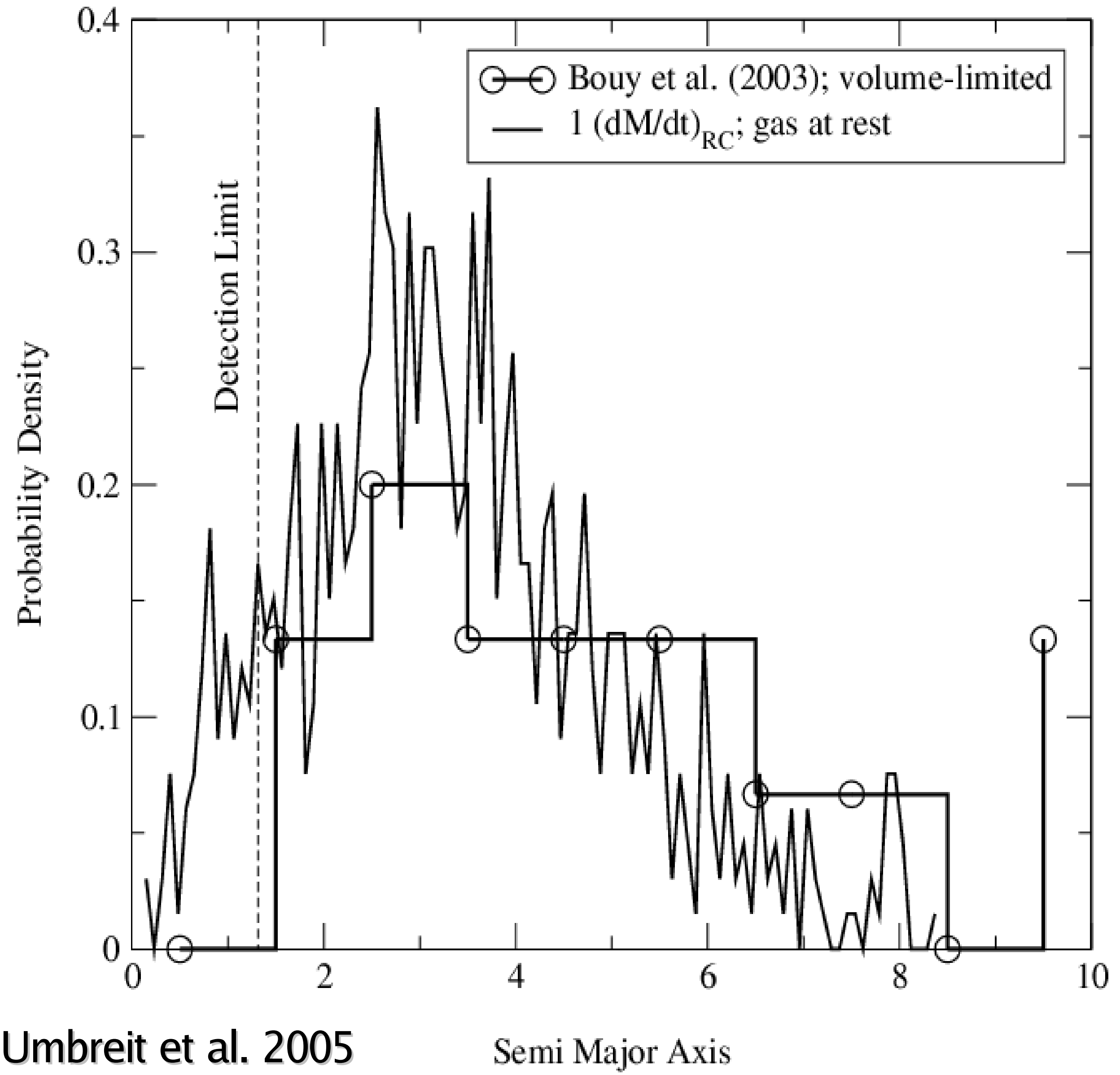


Wide binary BD in Chamaeleon (separation 240 AU)

Chauvin et al. 2004



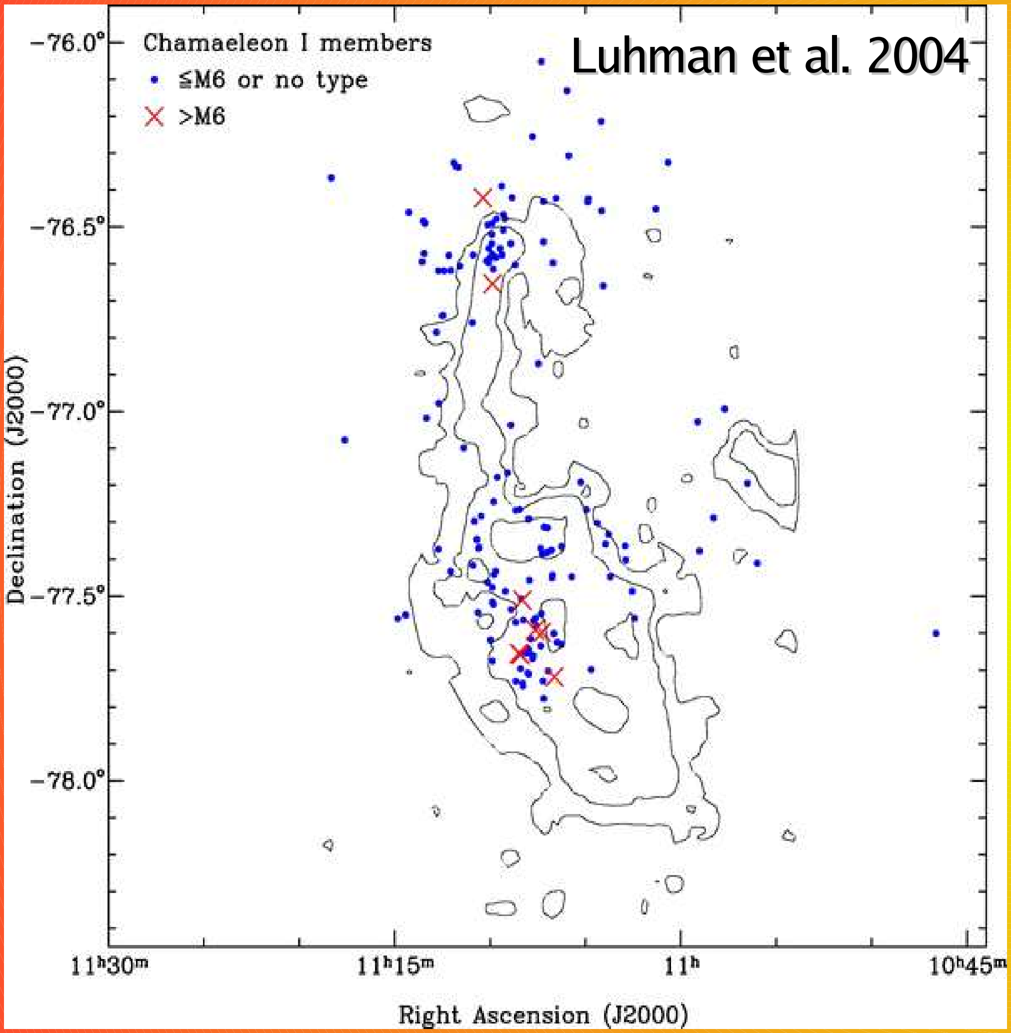
Binarity

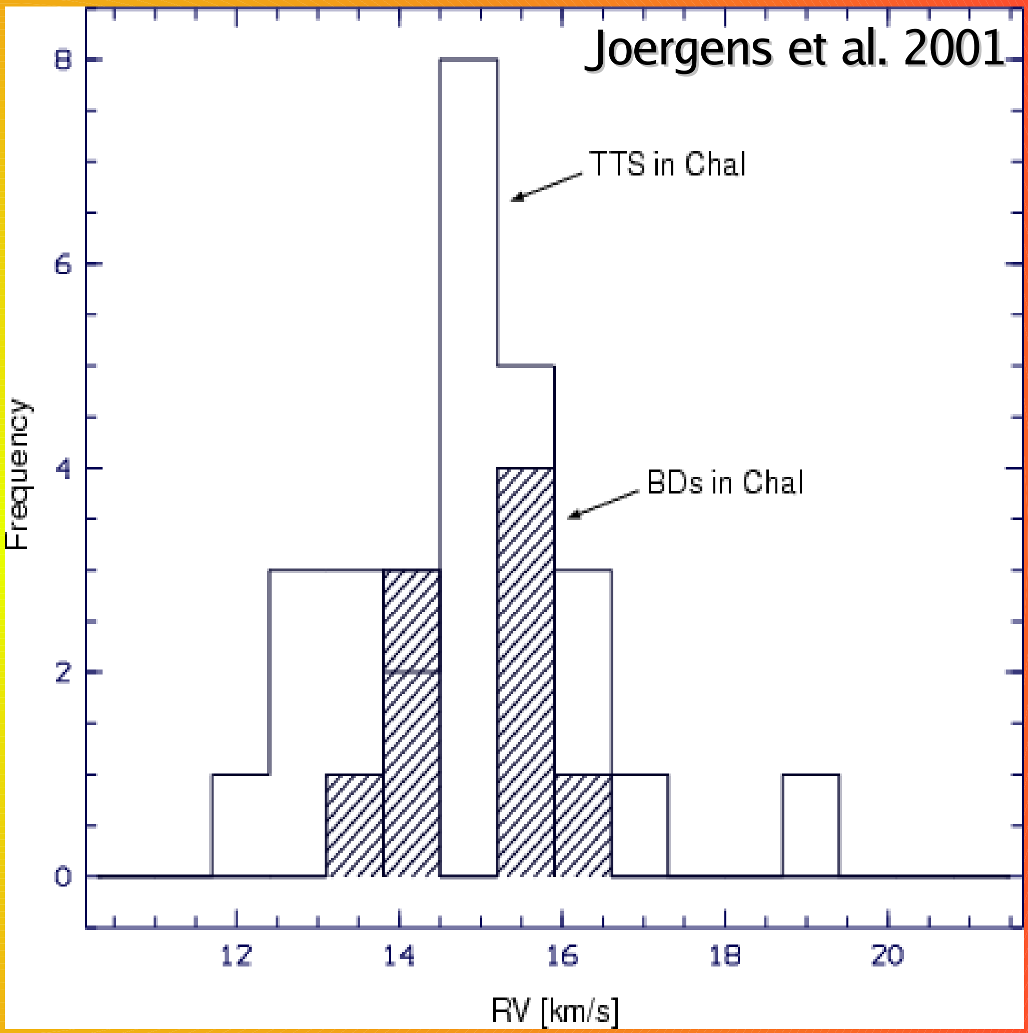


Umbreit et al. 2005

Simulated binary properties for ejection scenario in agreement with observations

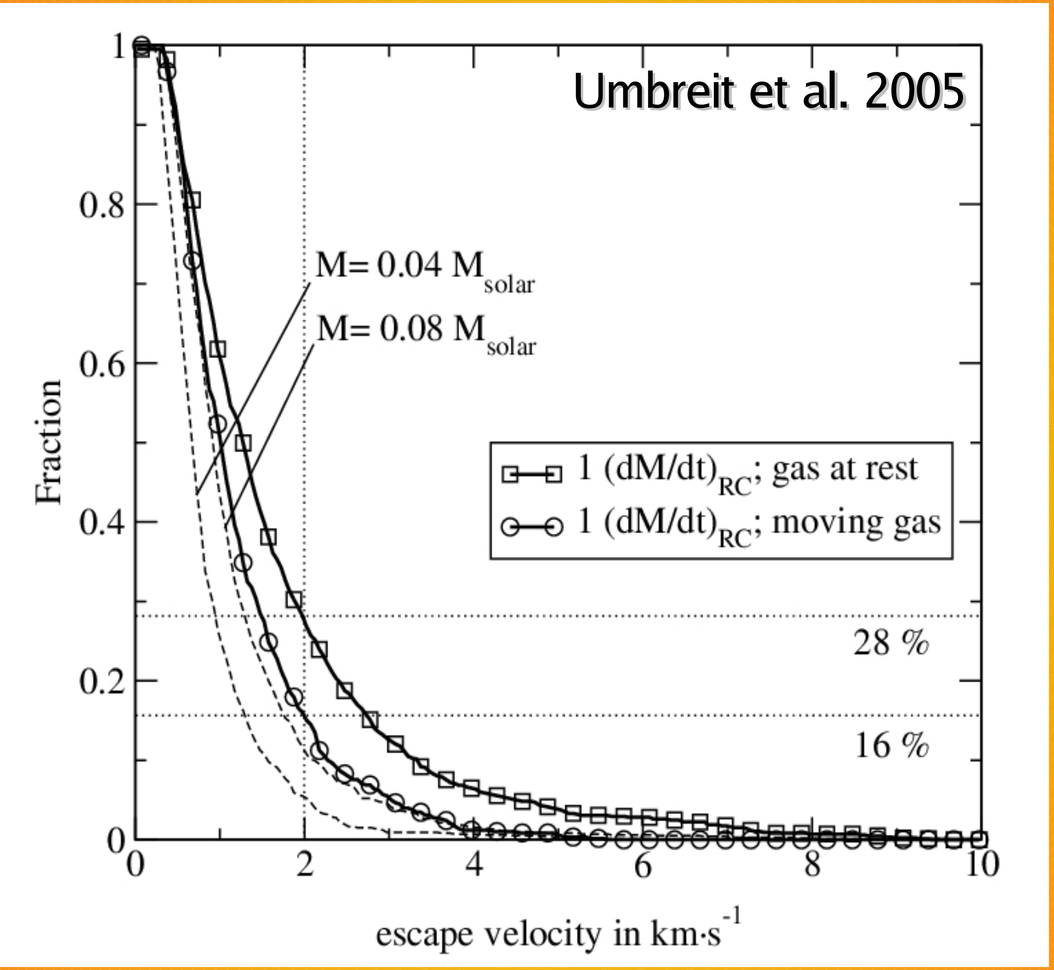
Kinematic





Brown dwarfs and stars not to distinguish

Kinematic



Only 10-20% should have high spatial velocities

And: potential well of the environment deccelerates the objects

Conclusion

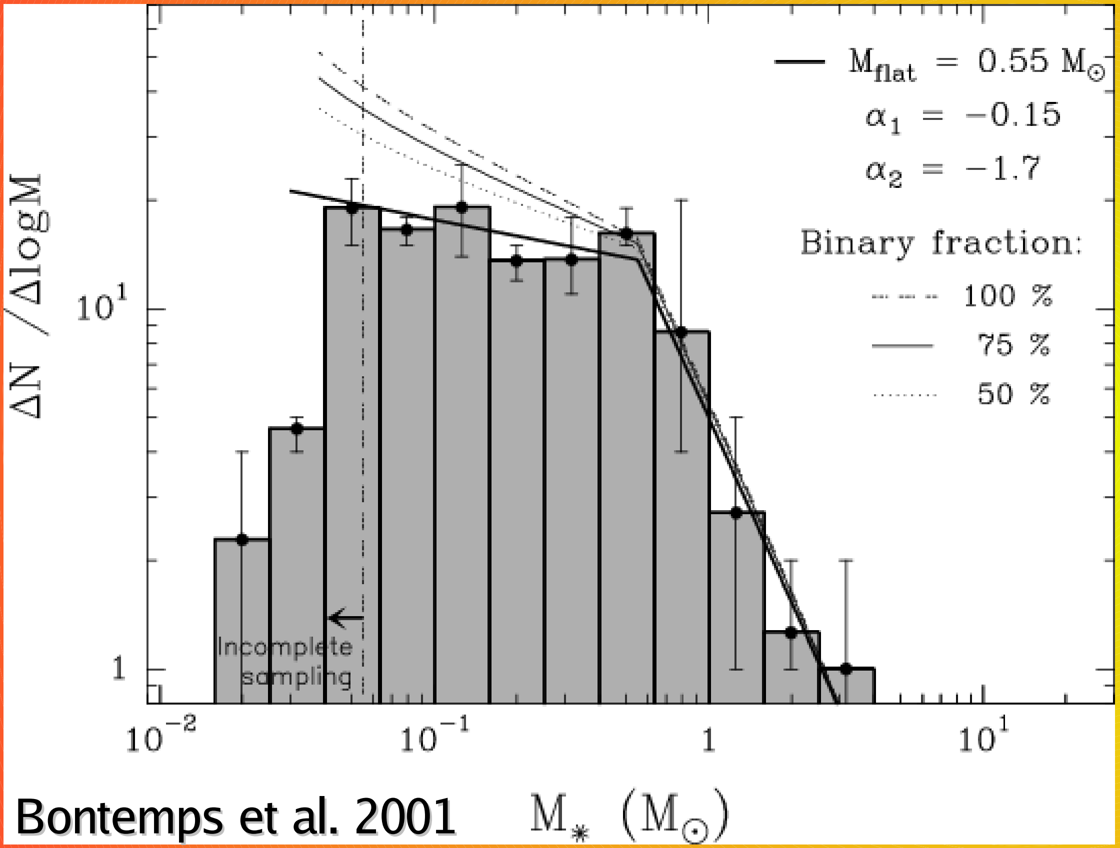
Two theories:

A) Fragmentation: the standard picture of star formation confirmed by all available observations

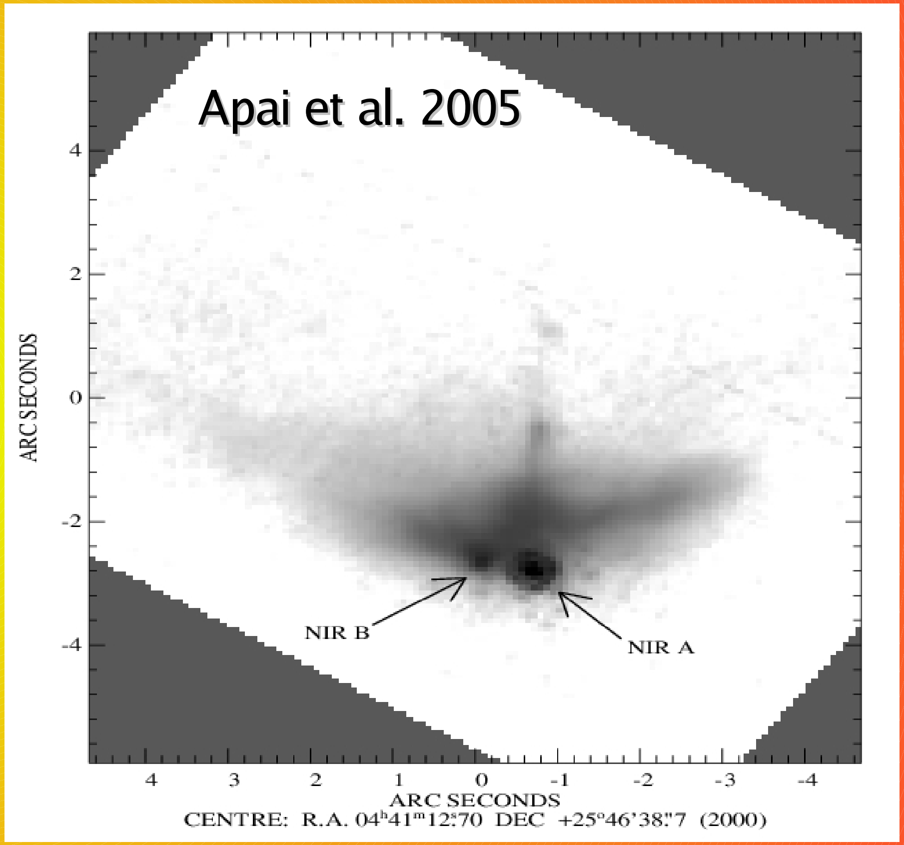
B) Ejection: an additional formation mode not to disprove with current observations

Maybe there is more than one way to form a brown dwarf.

Search for proto brown dwarfs

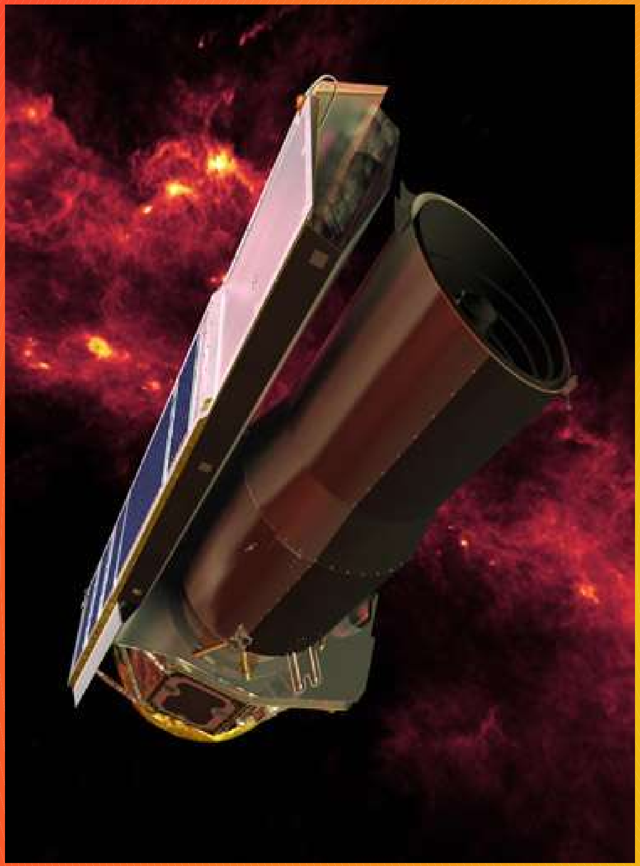


Class II brown dwarfs in Rho Oph



Potential Class I brown dwarf in Taurus

Future prospects



Spitzer - MIR SED for
BD disks, proto BDs