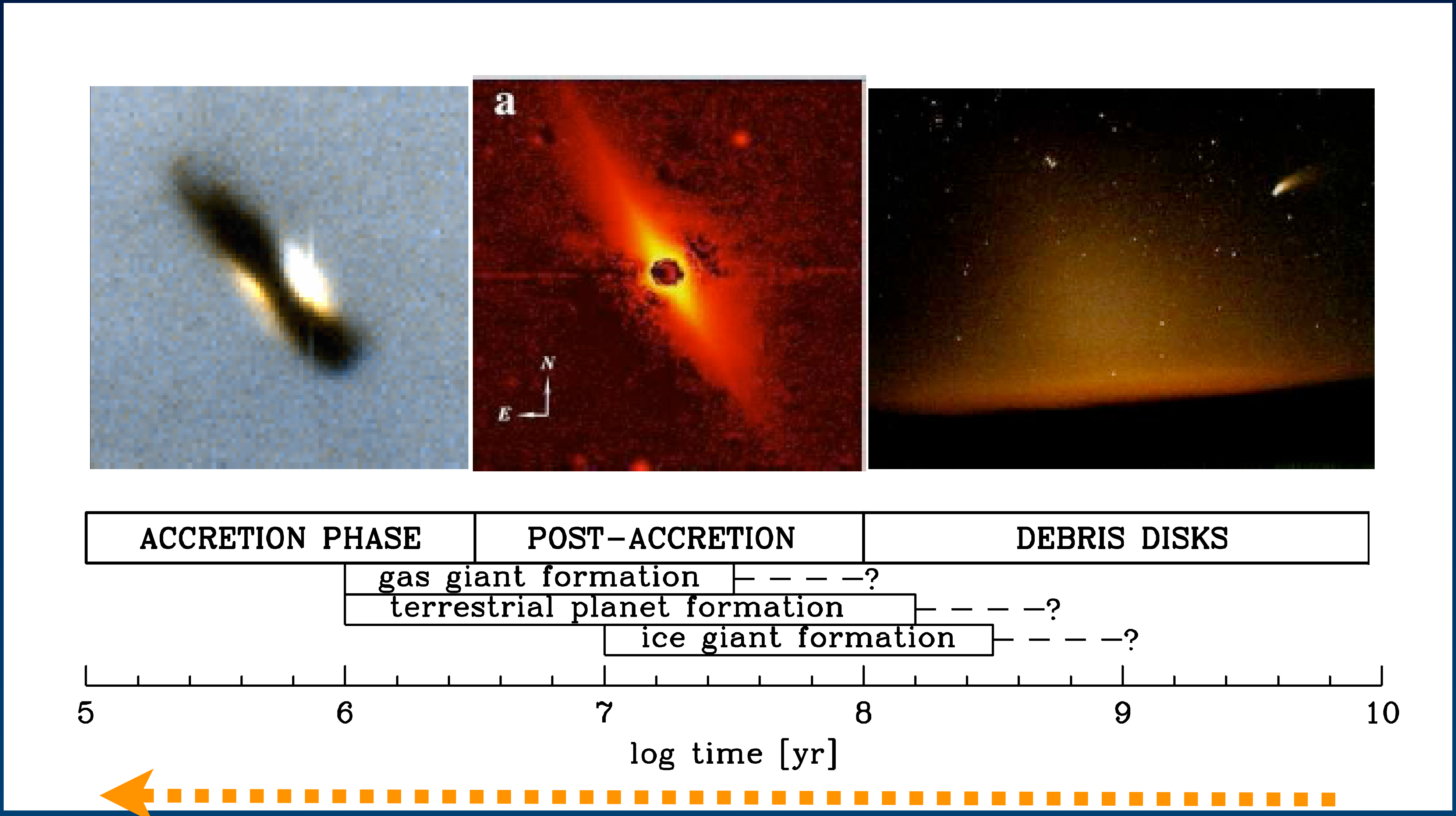
Circumstellar Disks: Past, Present & Future

Michael C. Liu
Institute for Astronomy
University of Hawaii

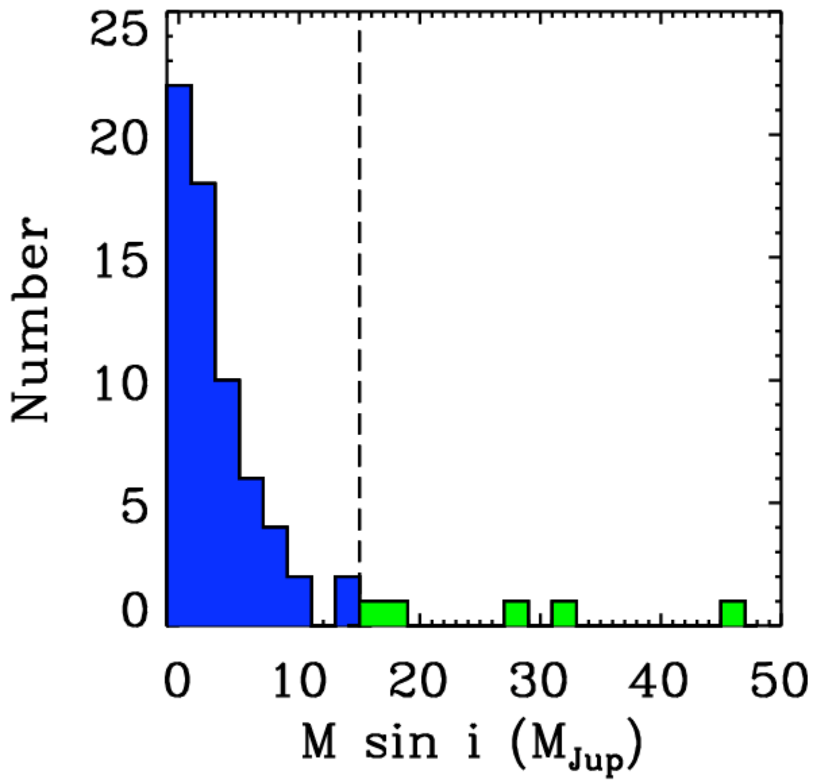
Overview of disk evolution



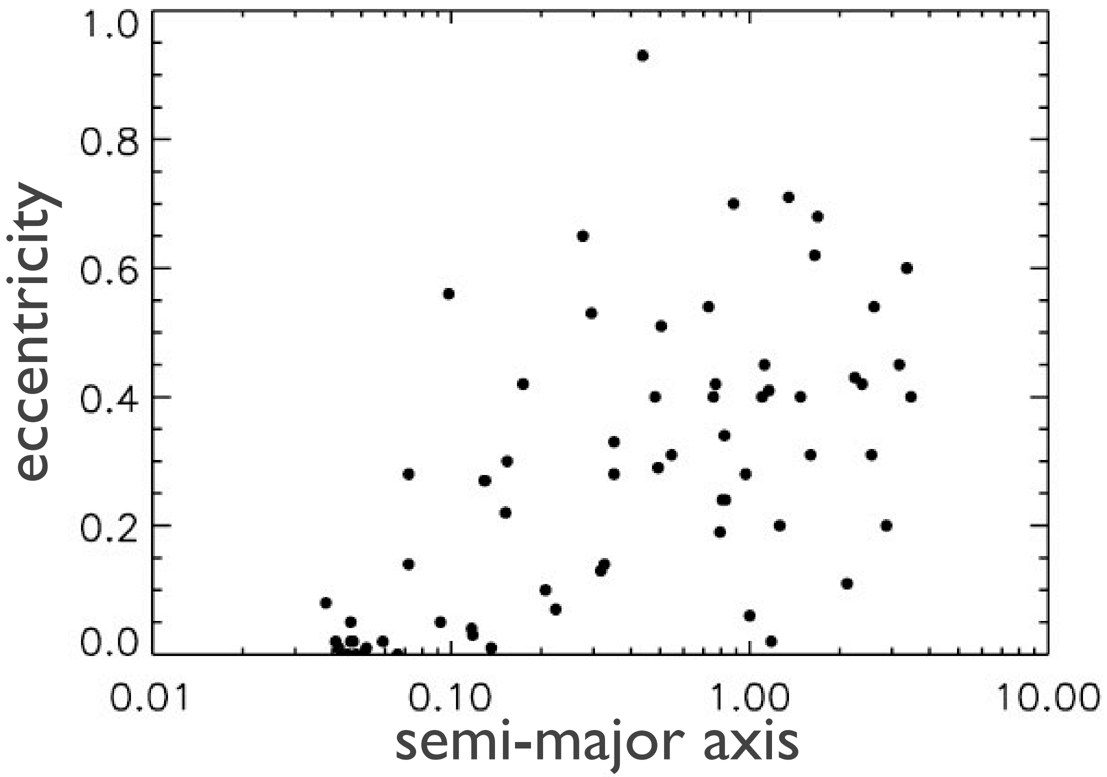
Observability

Extrasolar planets

Mass function

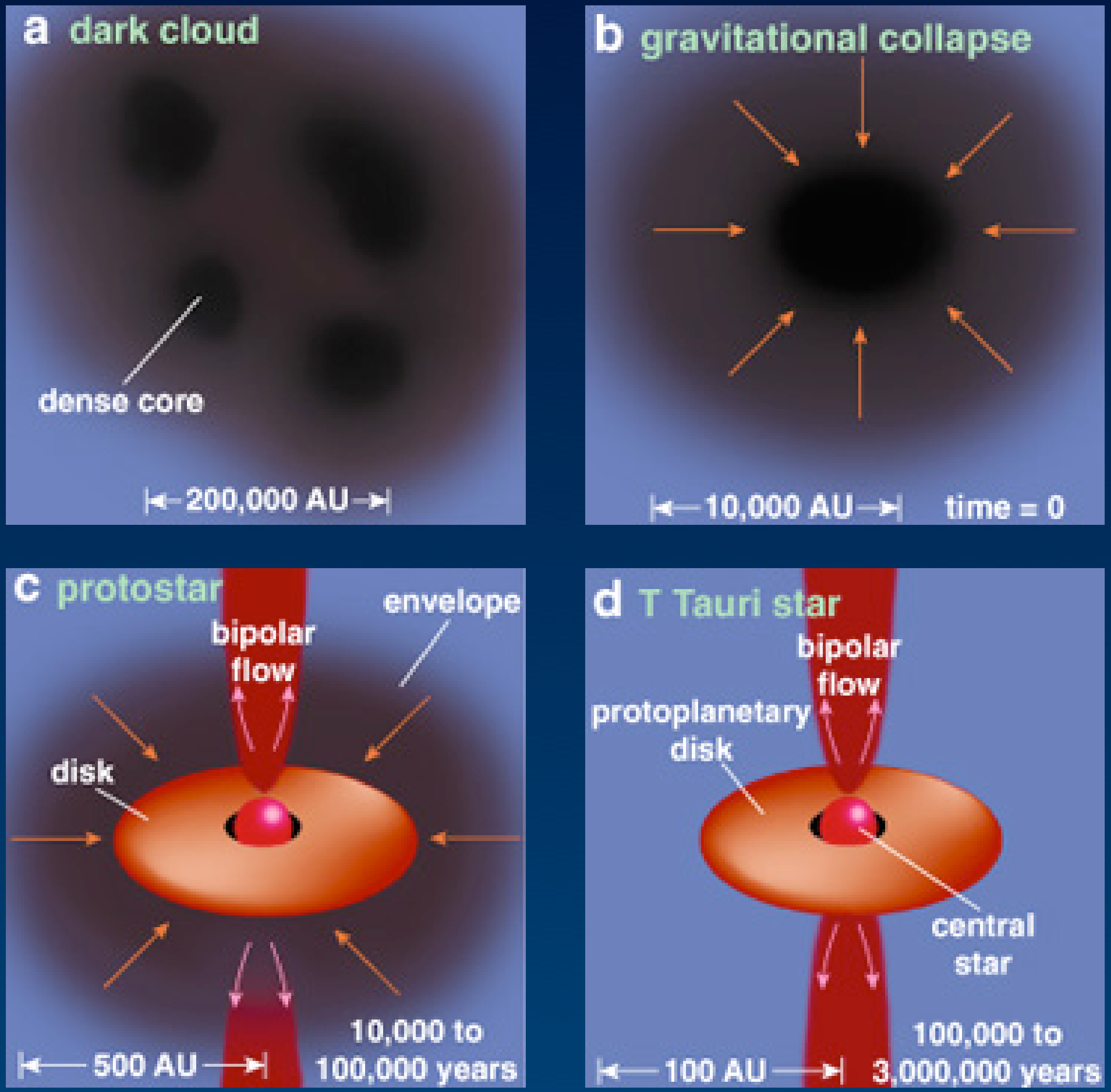


Orbital properties

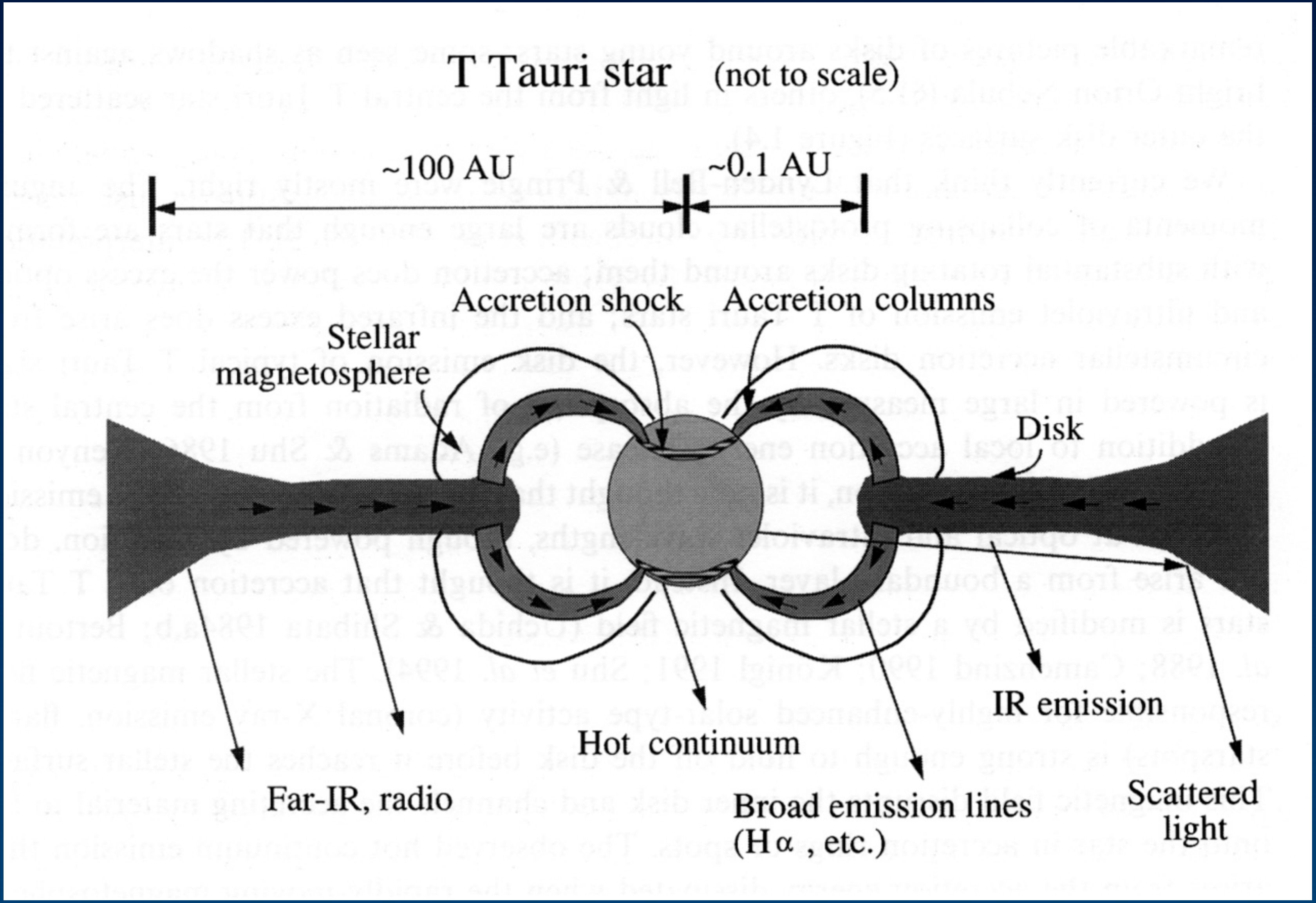


Primordial Disks

Obligatory star formation slide

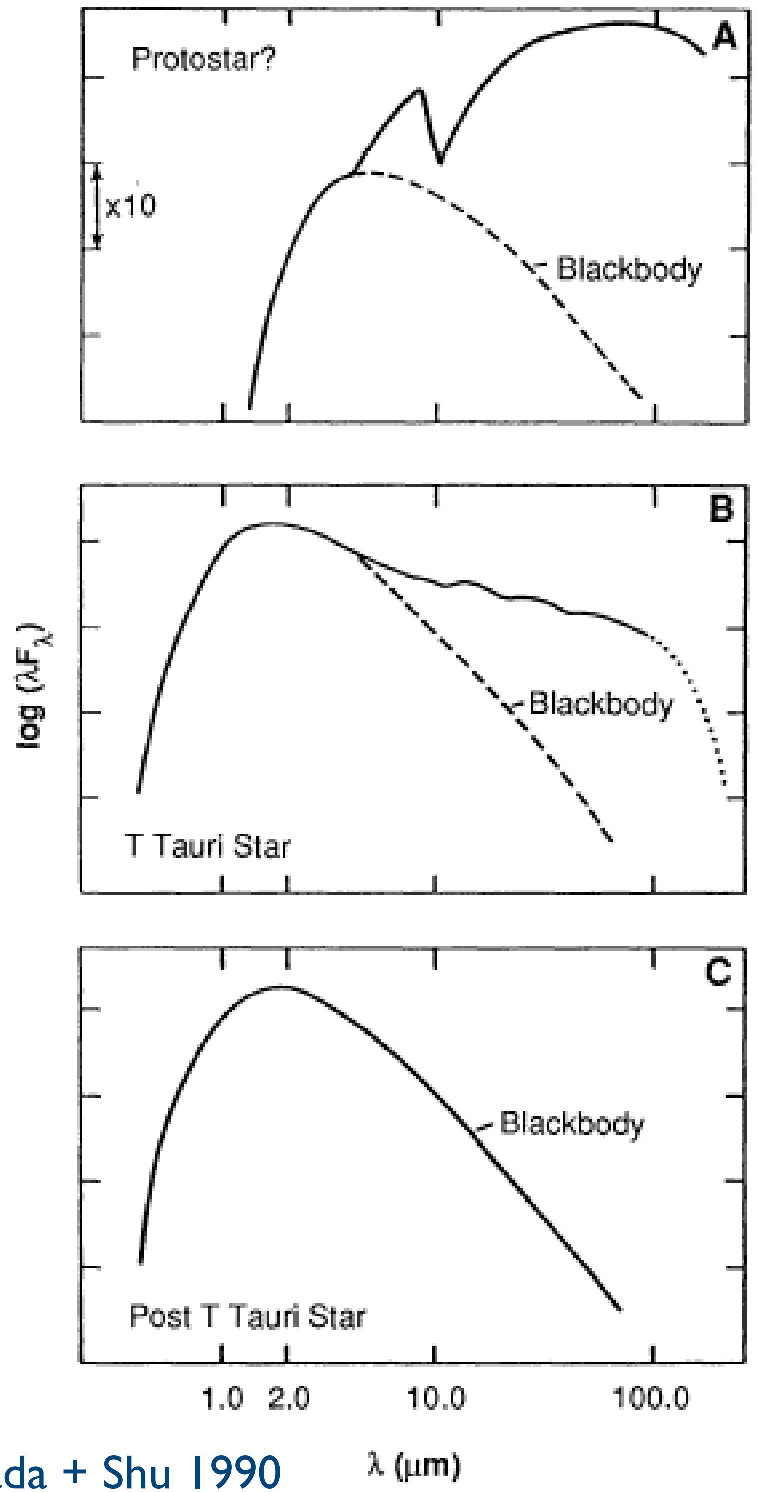


Disk anatomy: Multi-wavelength



Hartmann 1998

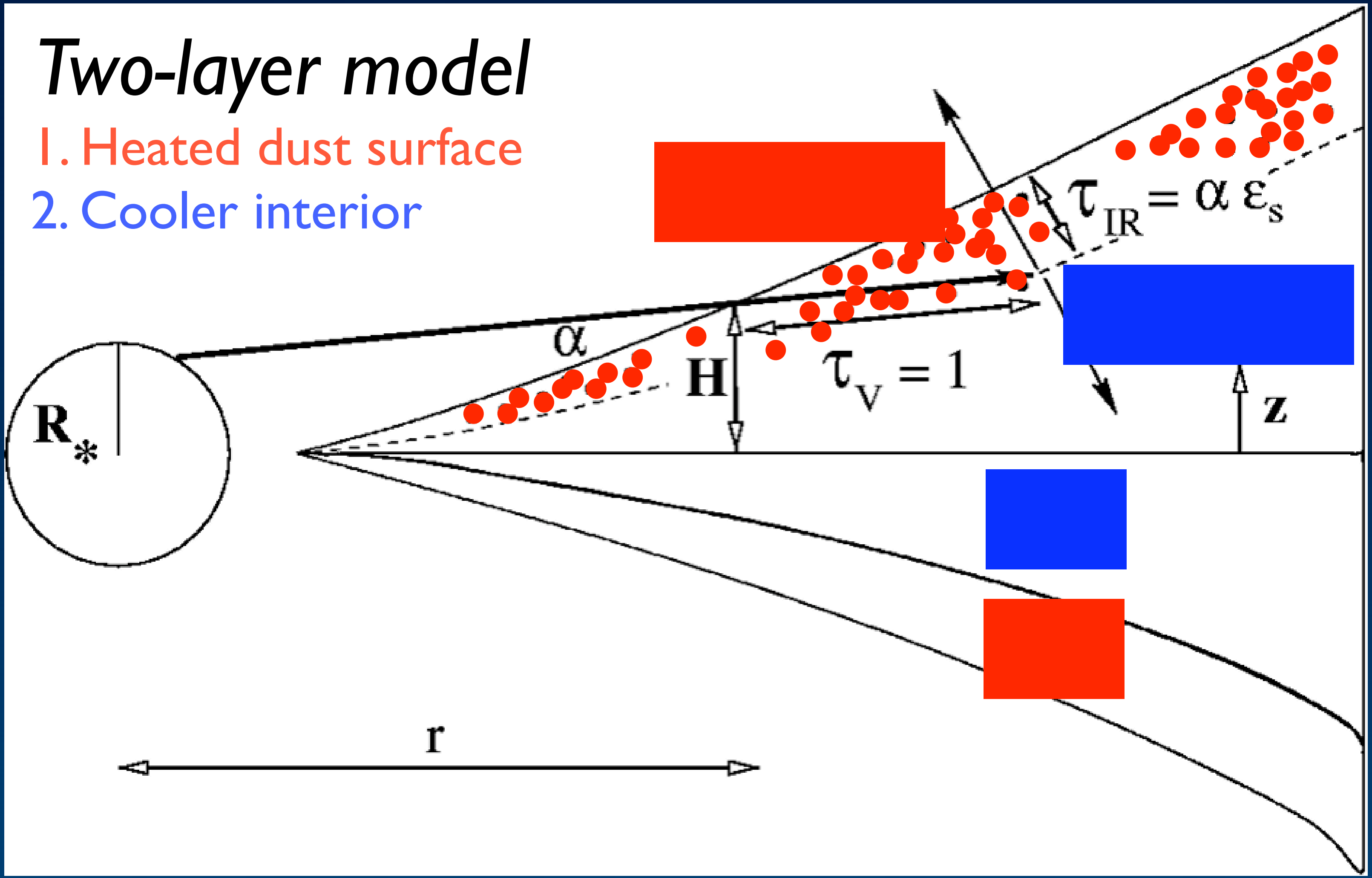
Spectral energy distributions



Lada + Shu 1990

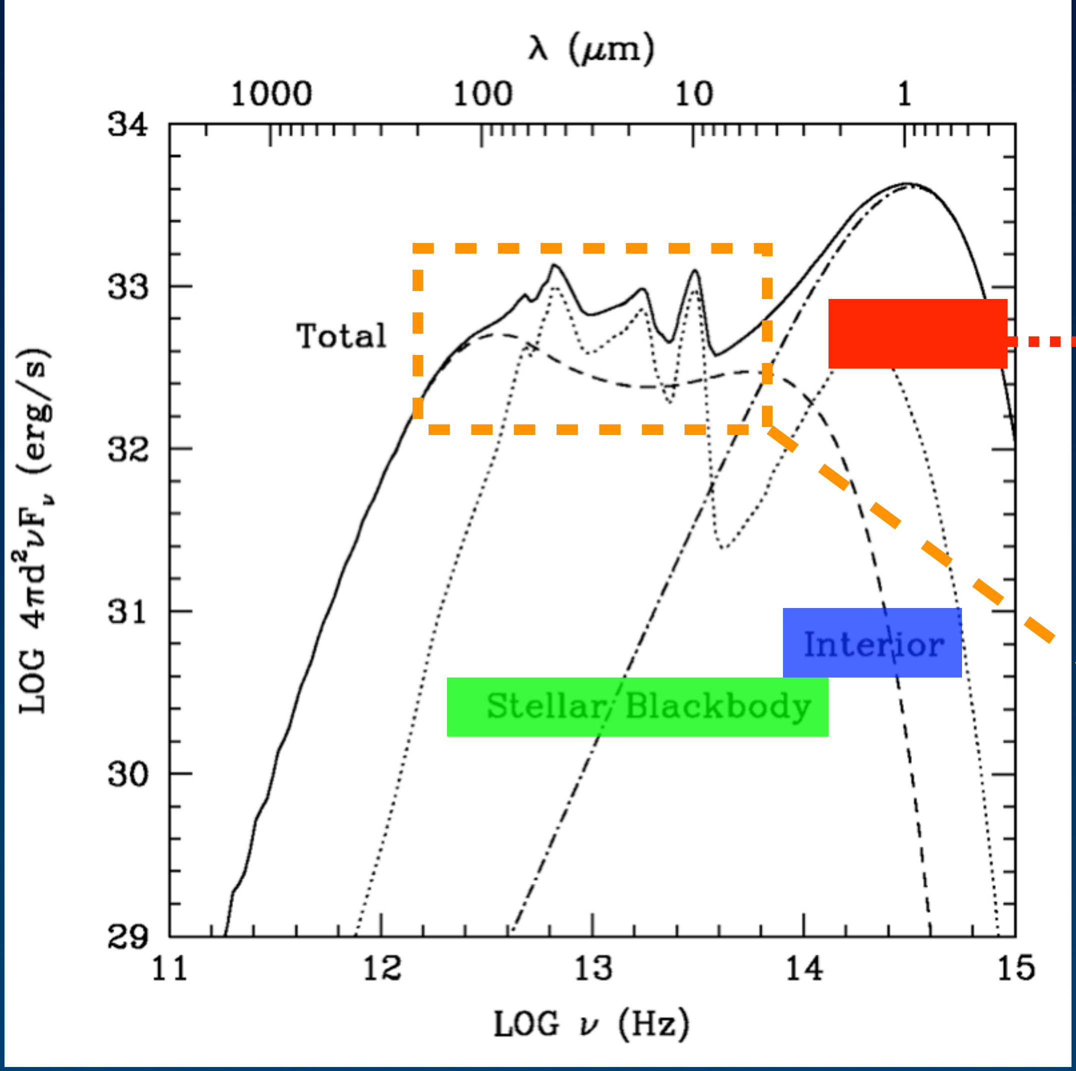
- Primary observation for studying physical properties of circumstellar material (dust).
- 1968: NIR excesses around T Tauri stars.
- 1974: viscous accretion disks.
- 1983: *IRAS* (12-100 um)
- c.1988: IR SEDs represent an evolutionary sequence, tracing the relative contributions of envelope, disk + star.
- Detailed modeling continues today.

Disk structure: IR emission



Chiang & Goldreich (1997)

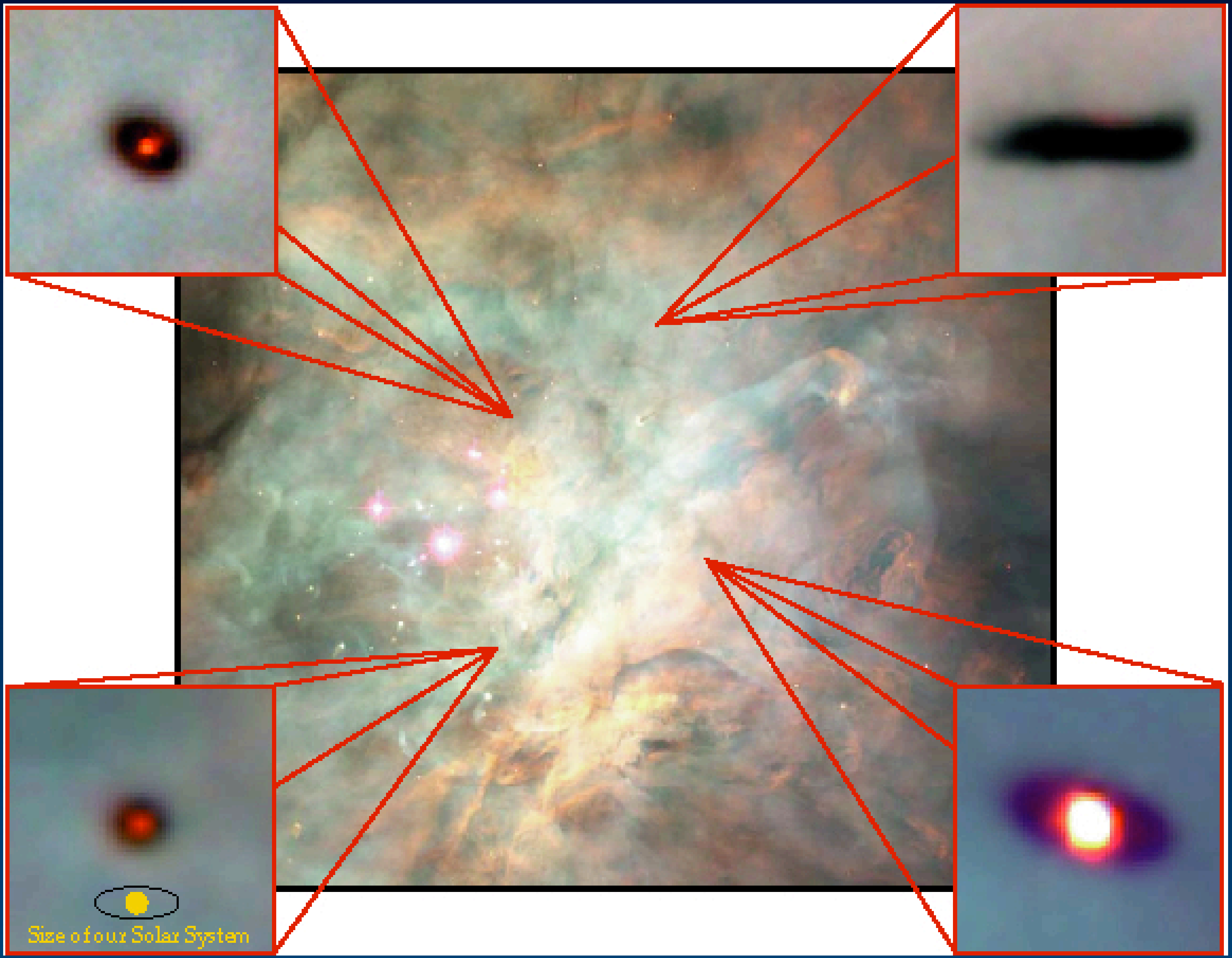
Disk structure: IR emission



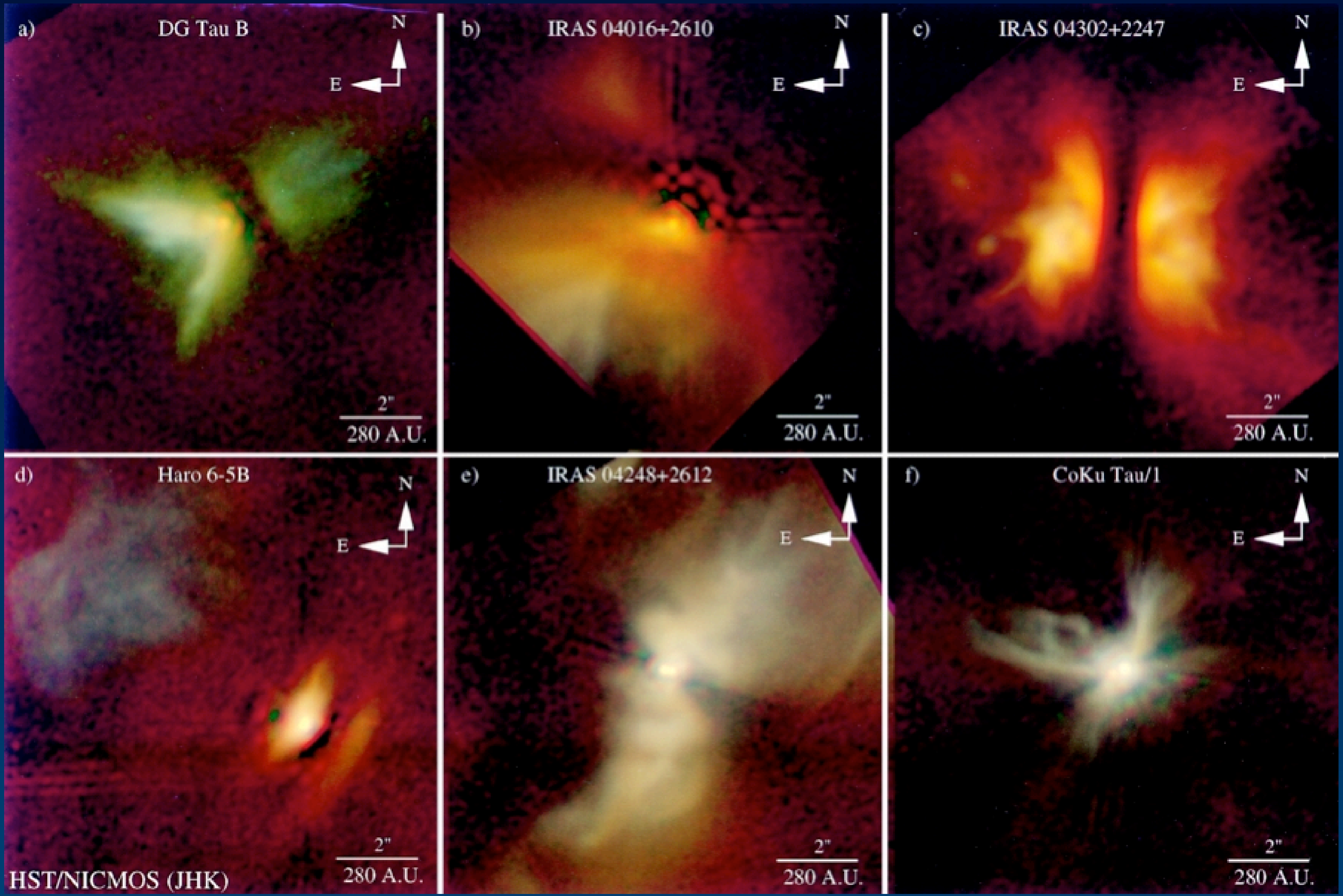
Chiang et al (2001)

depends on mixing of dust + gas (dust settling)

grain minerology (composition, sizes)

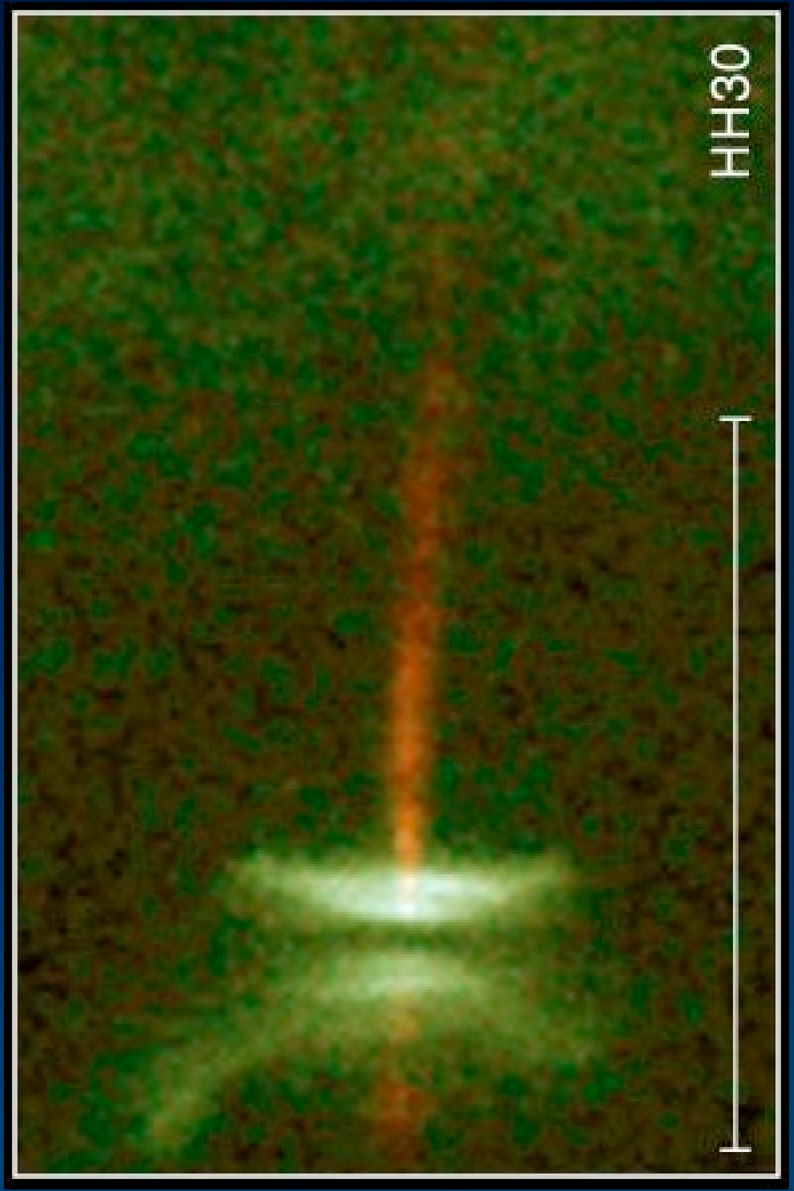


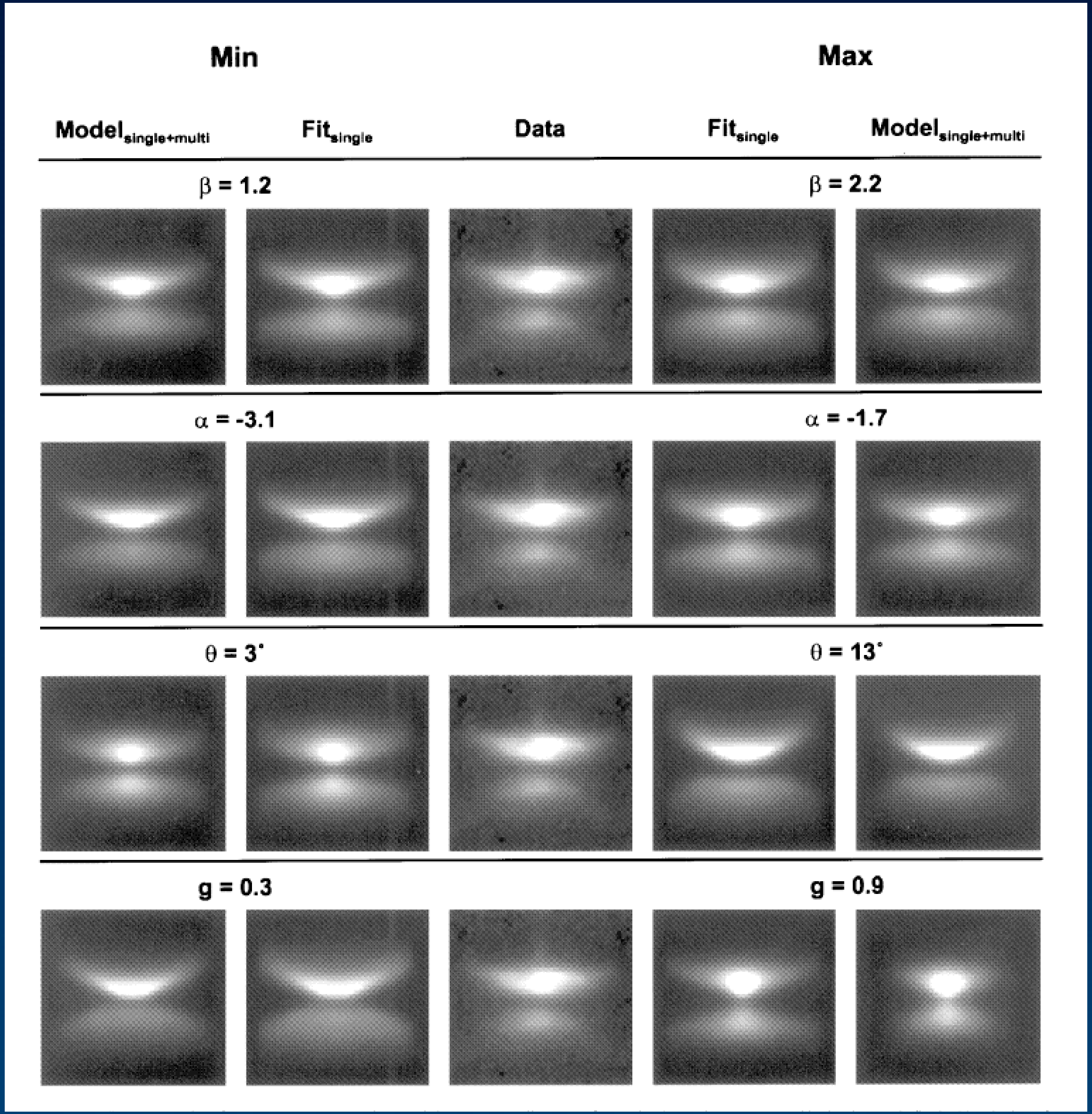
O’Dell et al (1996)



Padgett et al (1999)

Disk imaging: Scattered optical light

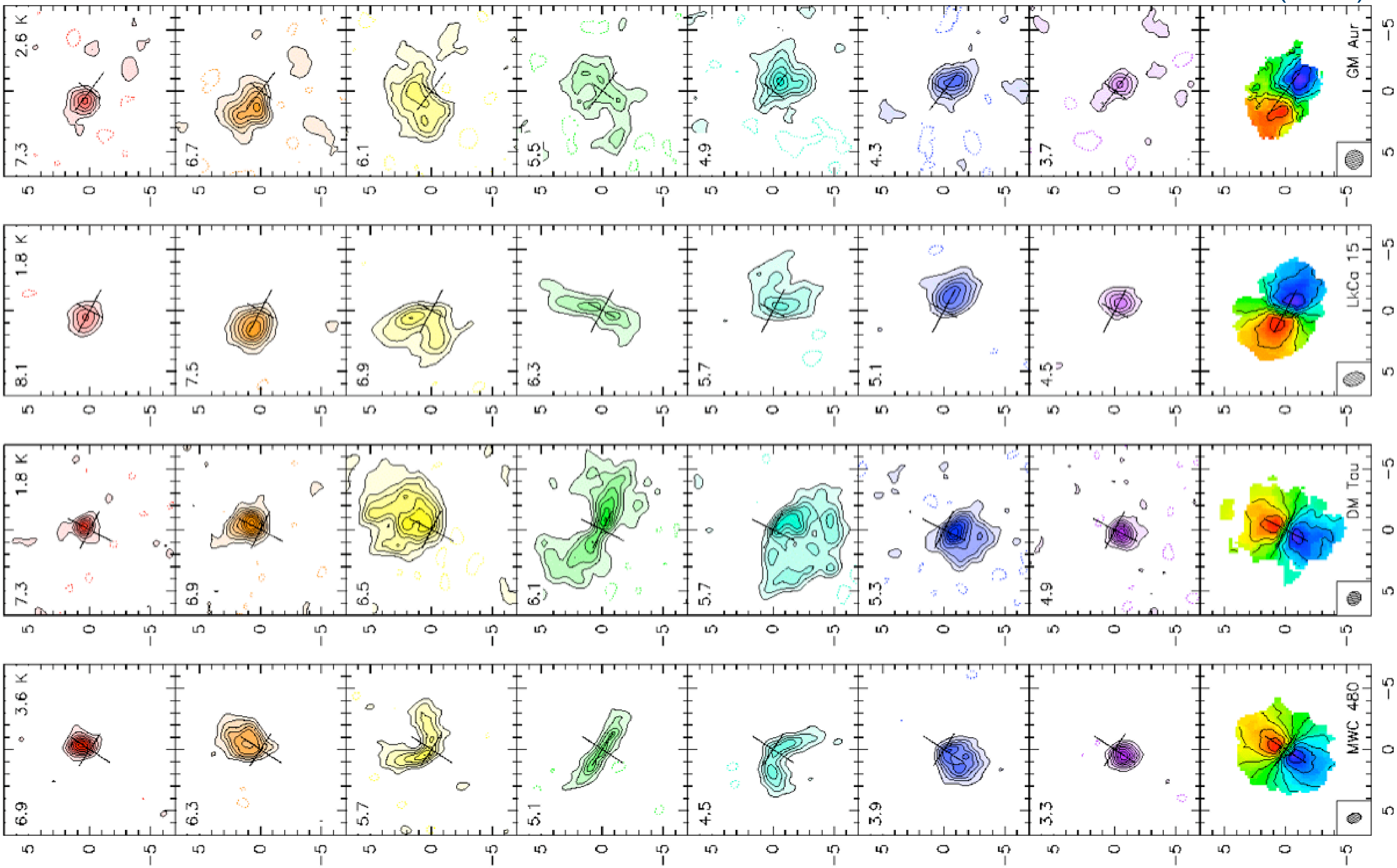




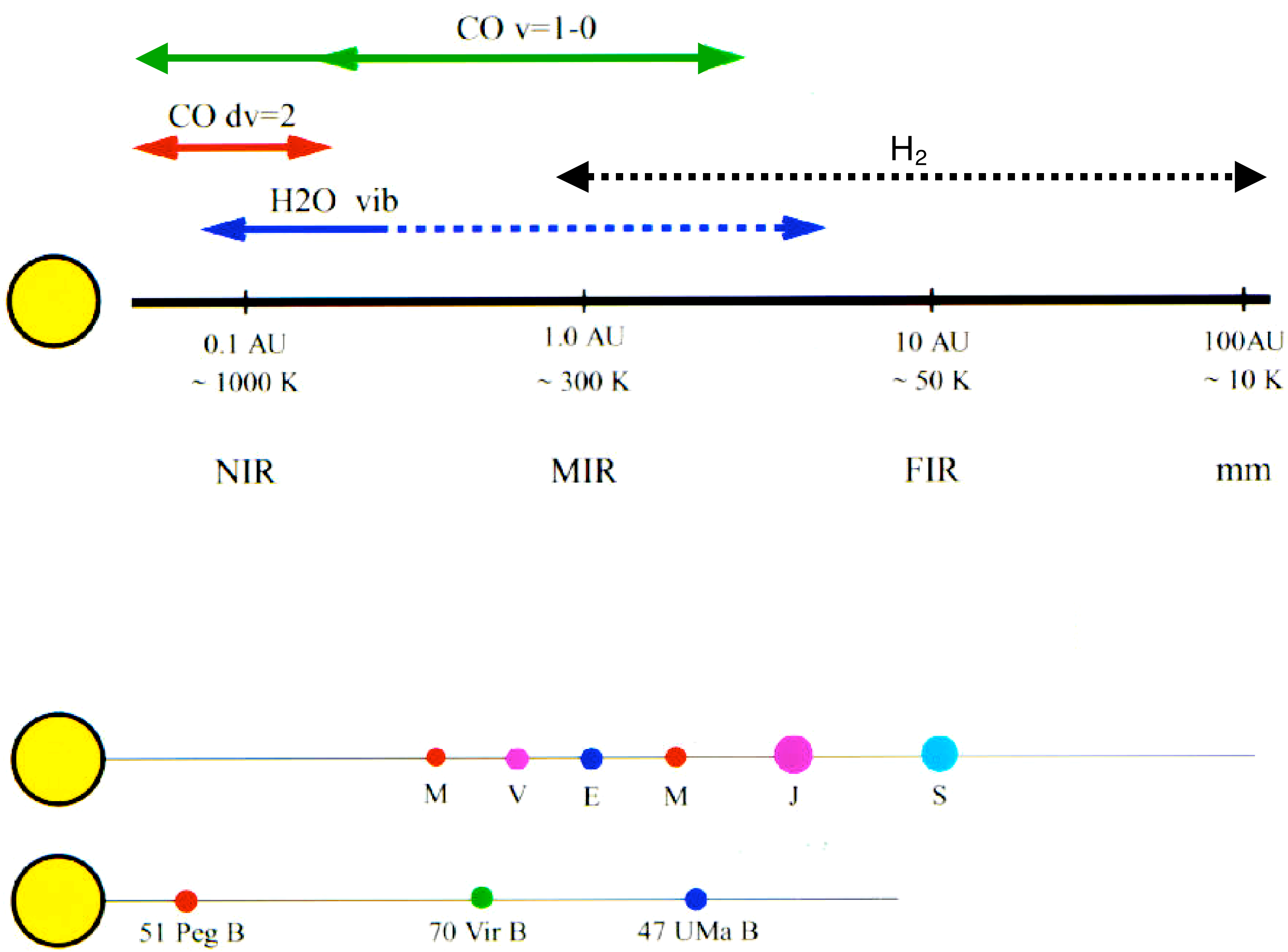
Burrows et al (1996)

Imaging of gas (CO) disks: Keplerian rotation

Simon et al (2000)



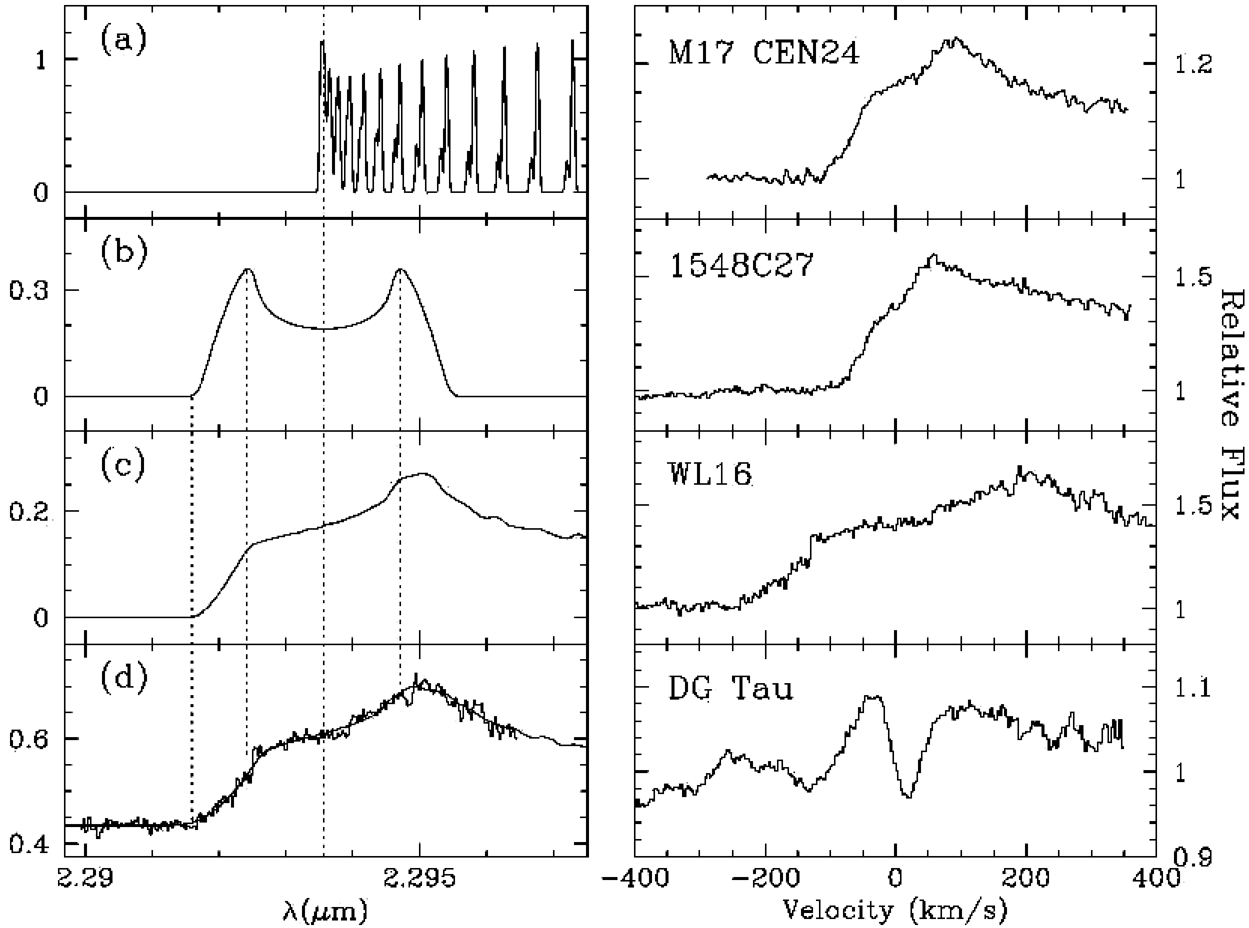
IR Diagnostics of Protoplanetary Disks



J. Najita

CO Overtone (Δv=2) Emission:
High Resolution

Carr, Najita, Greene, Lada et al.



~ 10 Msun

~ 4 Msun

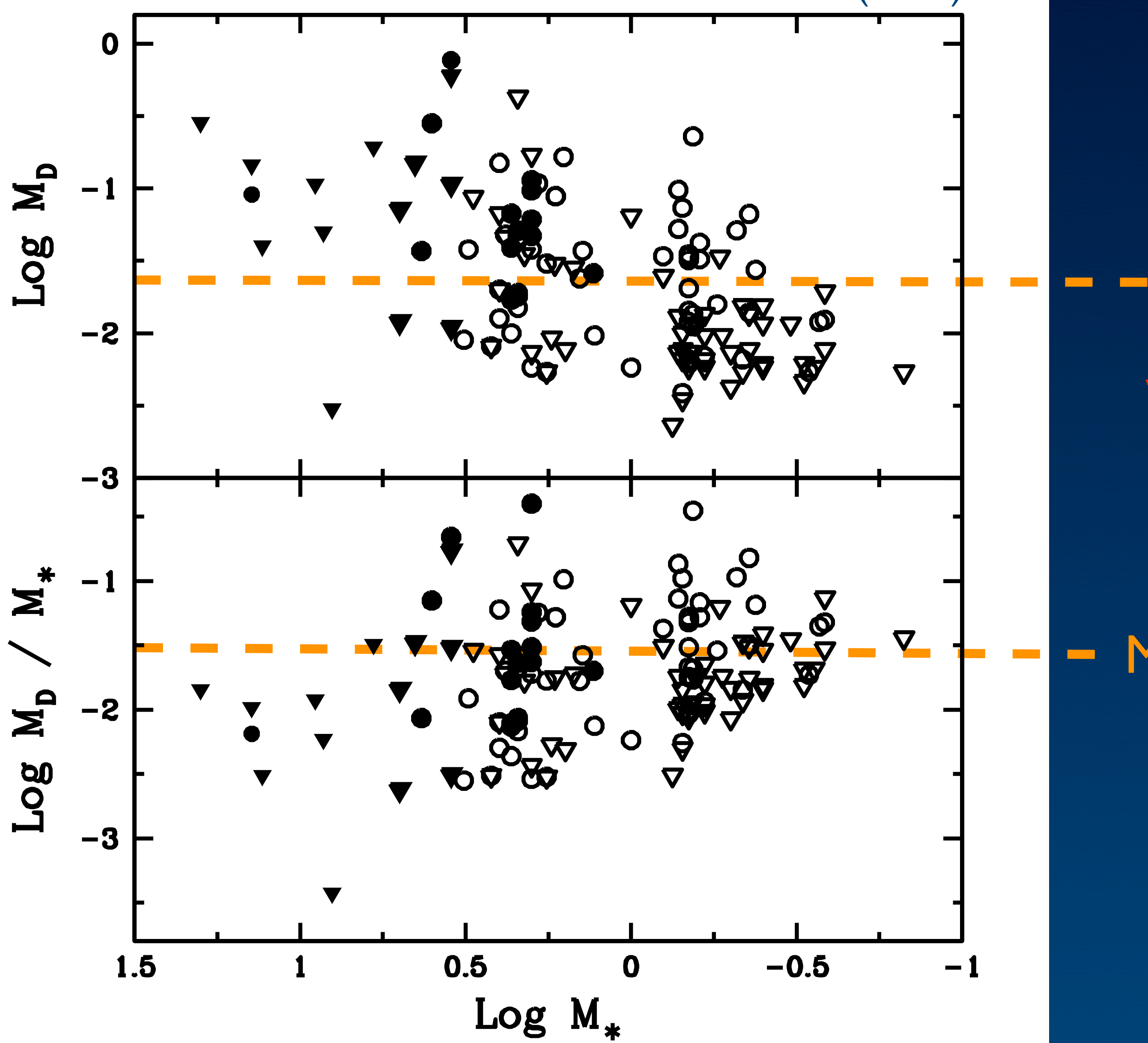
~ 2 Msun

~ 1 Msun

Evidence for rotating disks around young stars, low to high mass

Disk masses: millimeter fluxes

Natta (2003)



Minimum mass solar nebula

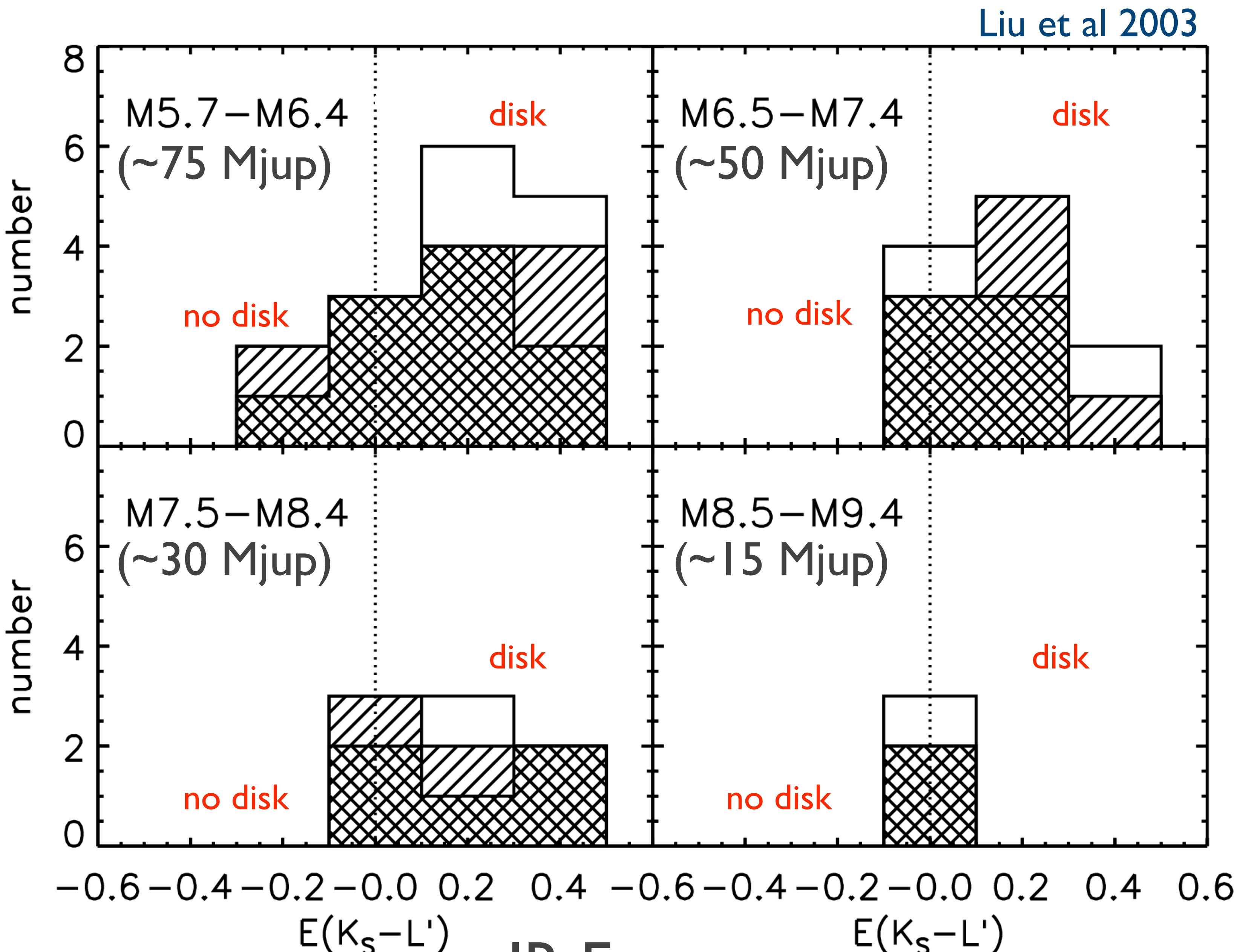
What produces the dispersion in disk properties?

M(disk) ~ 0.03 M(star)

How do disk properties change over the mass spectrum?

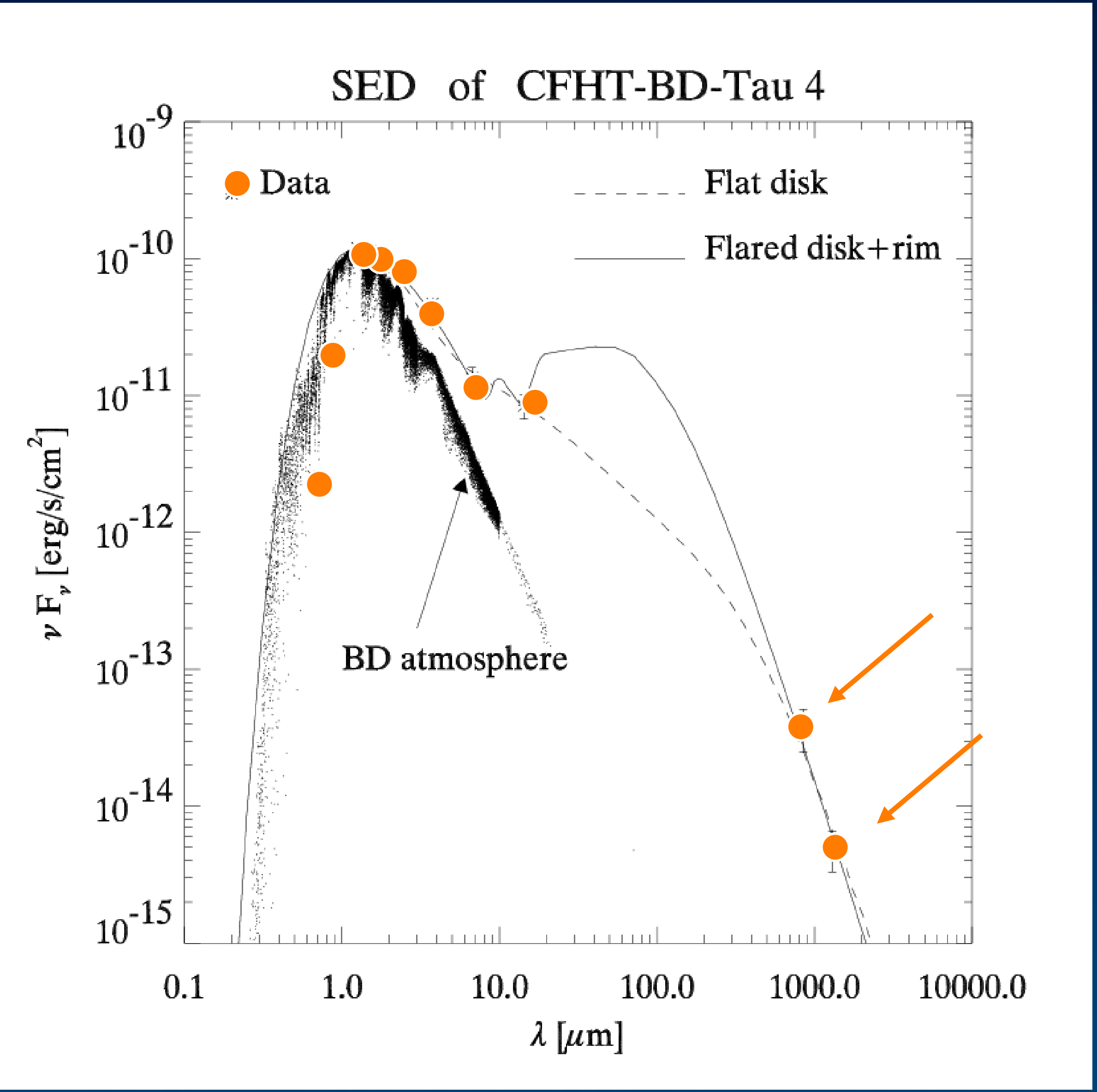
Disks around Brown Dwarfs

Disks around young brown dwarfs



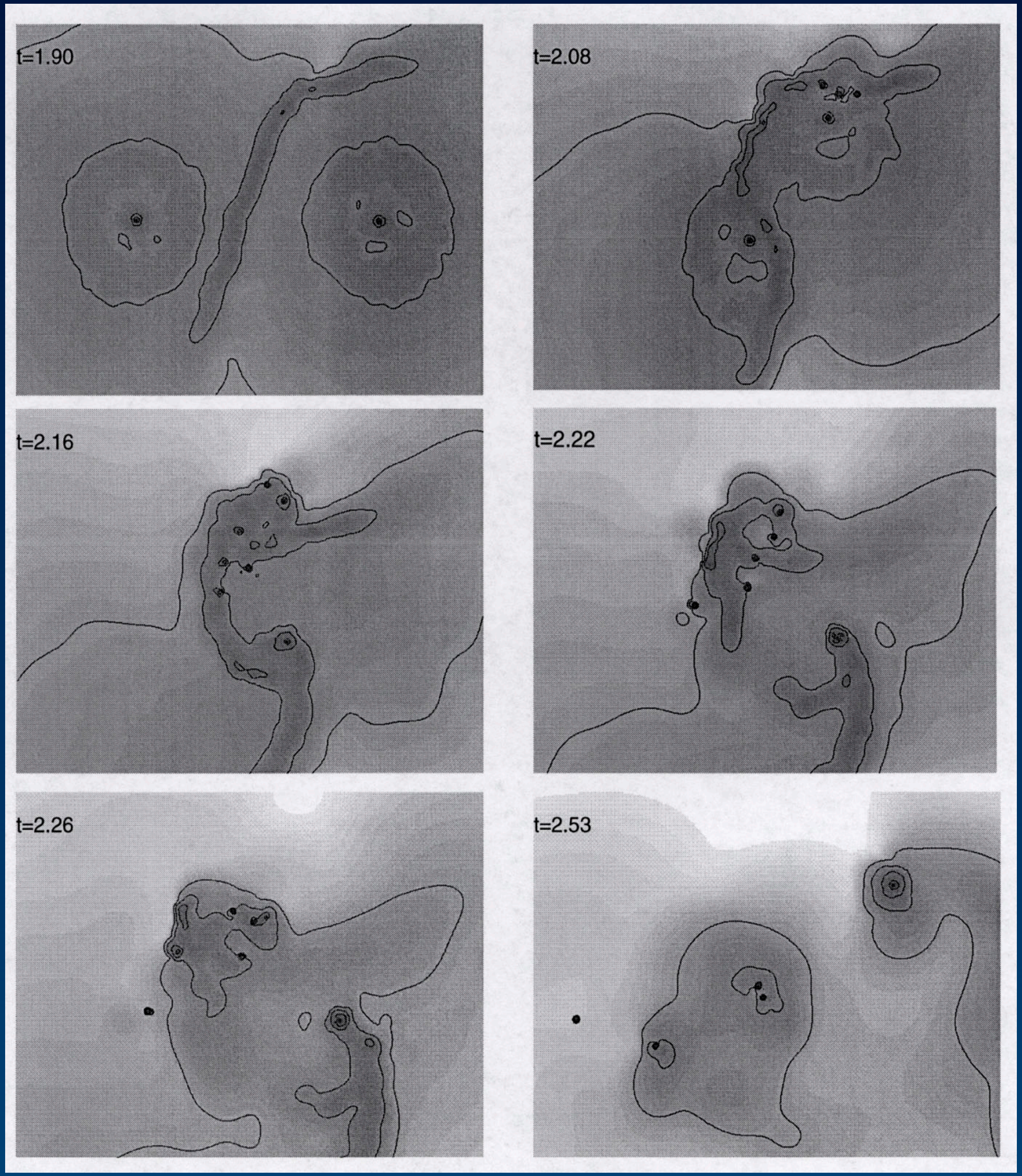
IR Excesses

Young BDs: sub-mm emission

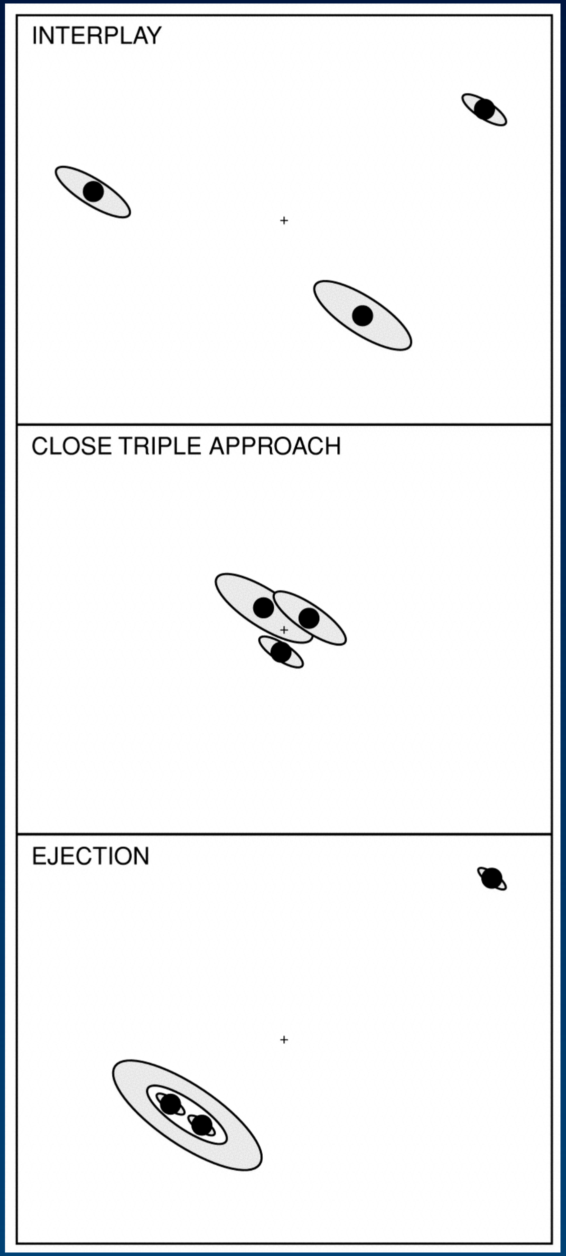


Pascucci et al 2003

Non "star-like" formation of brown dwarfs?

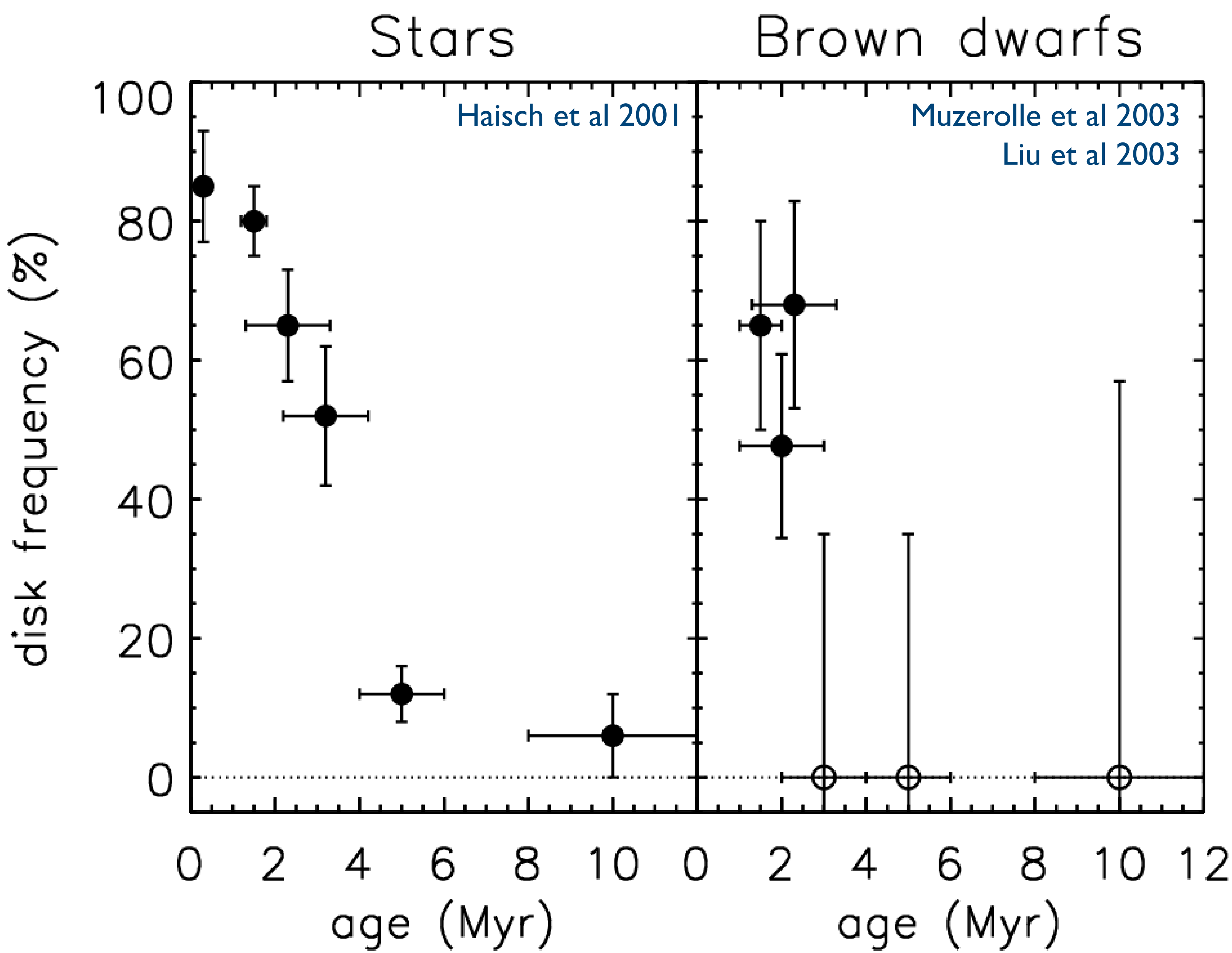


Watkins et al 1998 (2000 AU x 1500 AU)

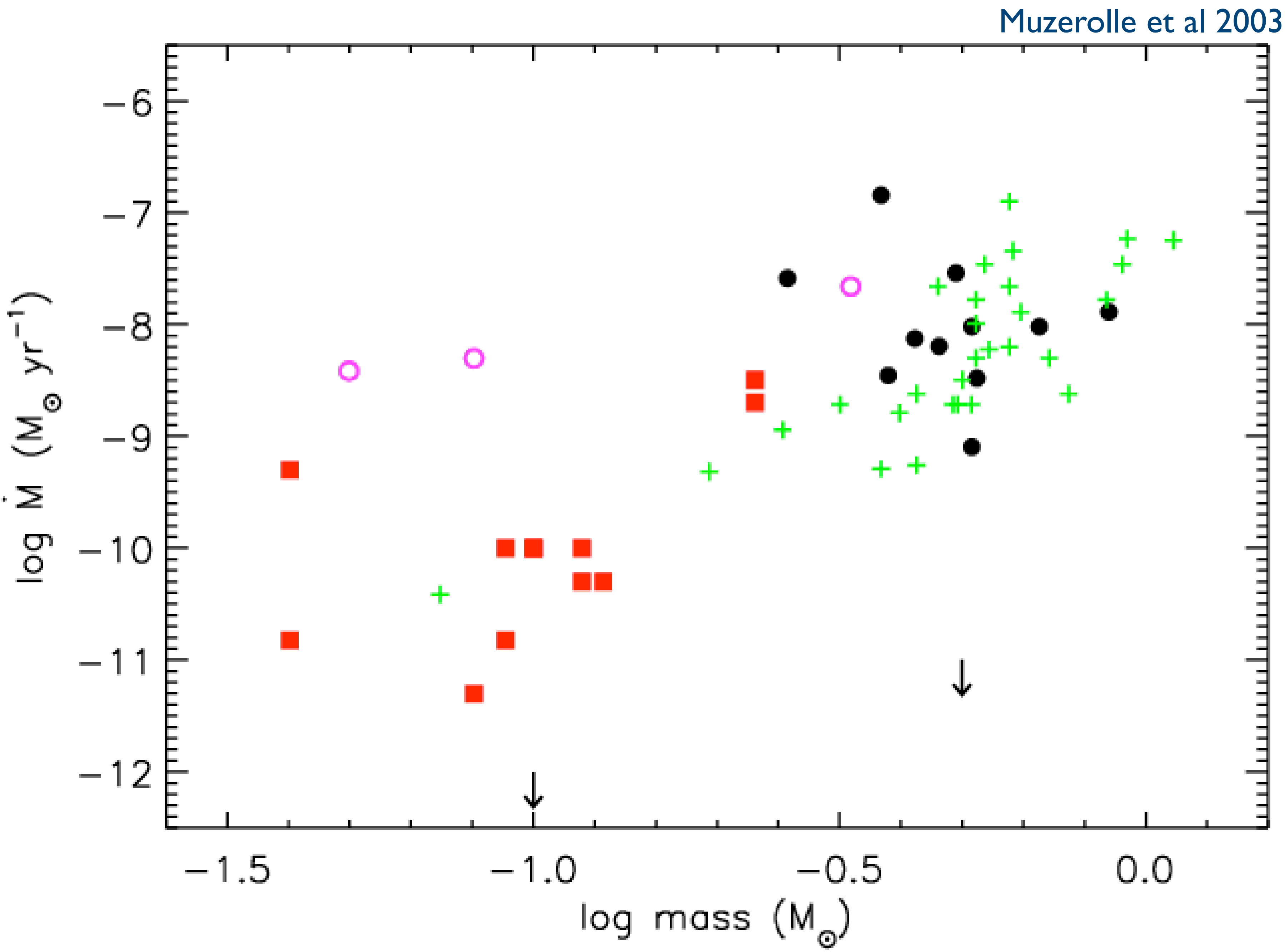


Reipurth 2000

Disk frequency

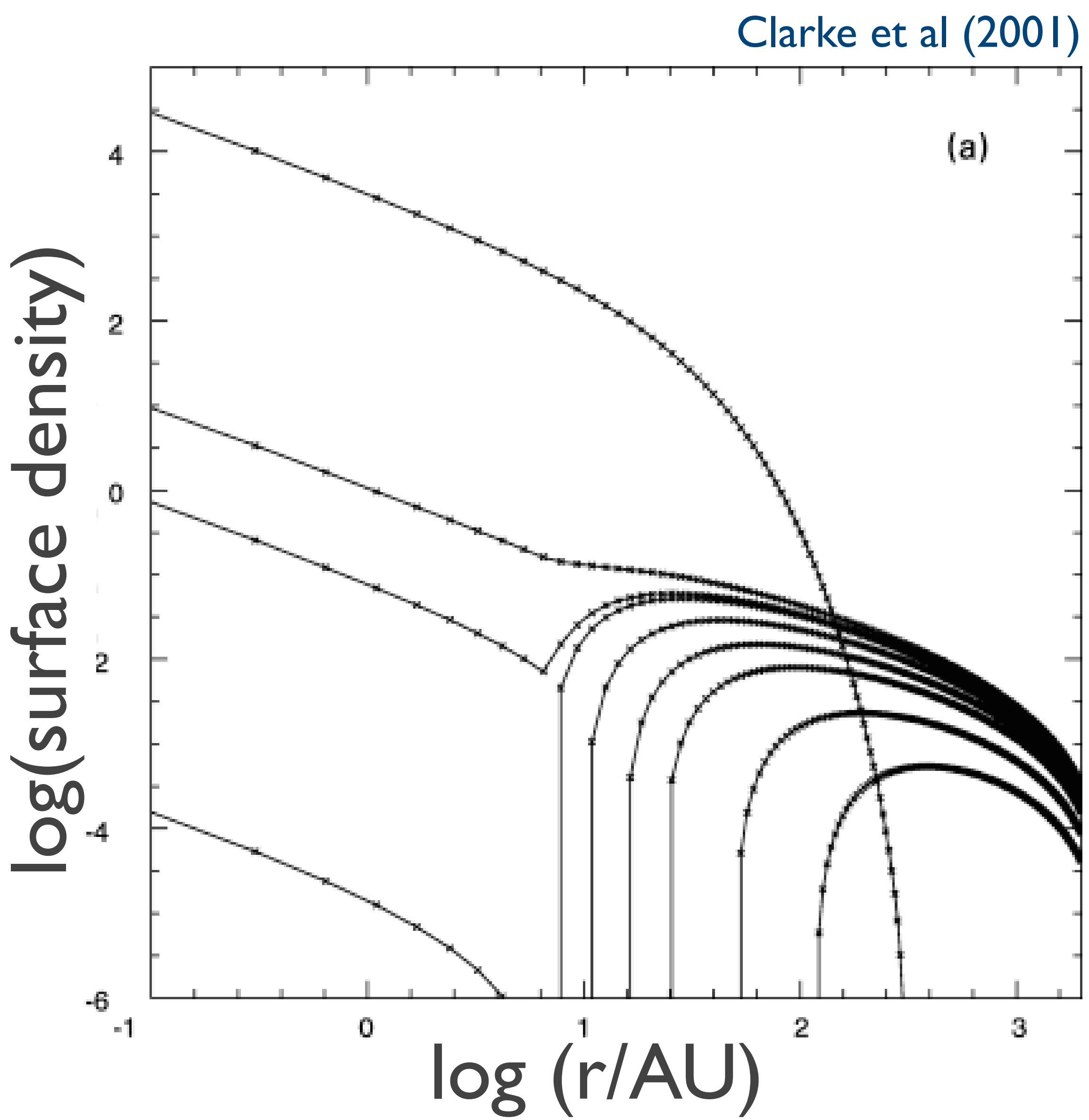


Disk accretion rates



Transition disks

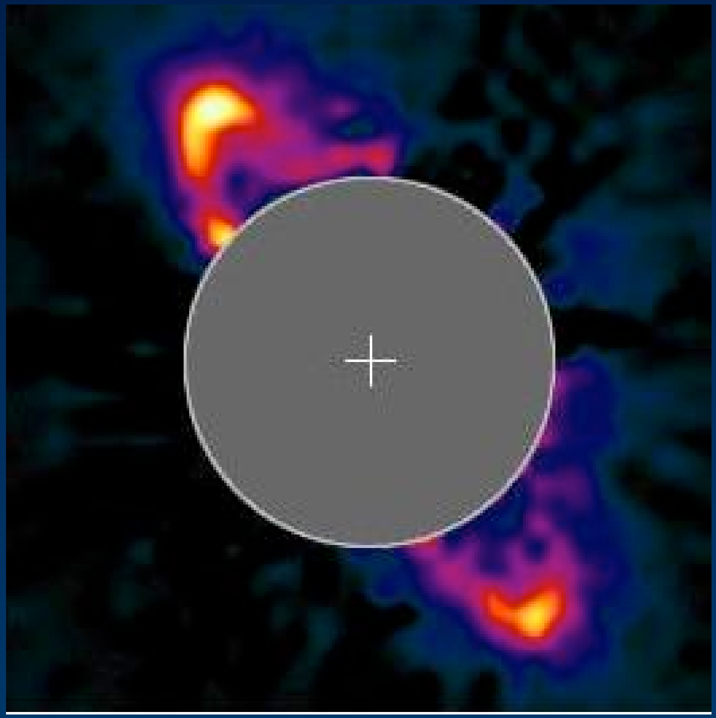
Disk evolution



- What governs the character & timescale(s) for disk evolution?
  - Inner disk: Viscous (??) accretion
  - Outer disk: Photoevaporation
  - Grain growth?

Disks in transition (~5-10 Myr)

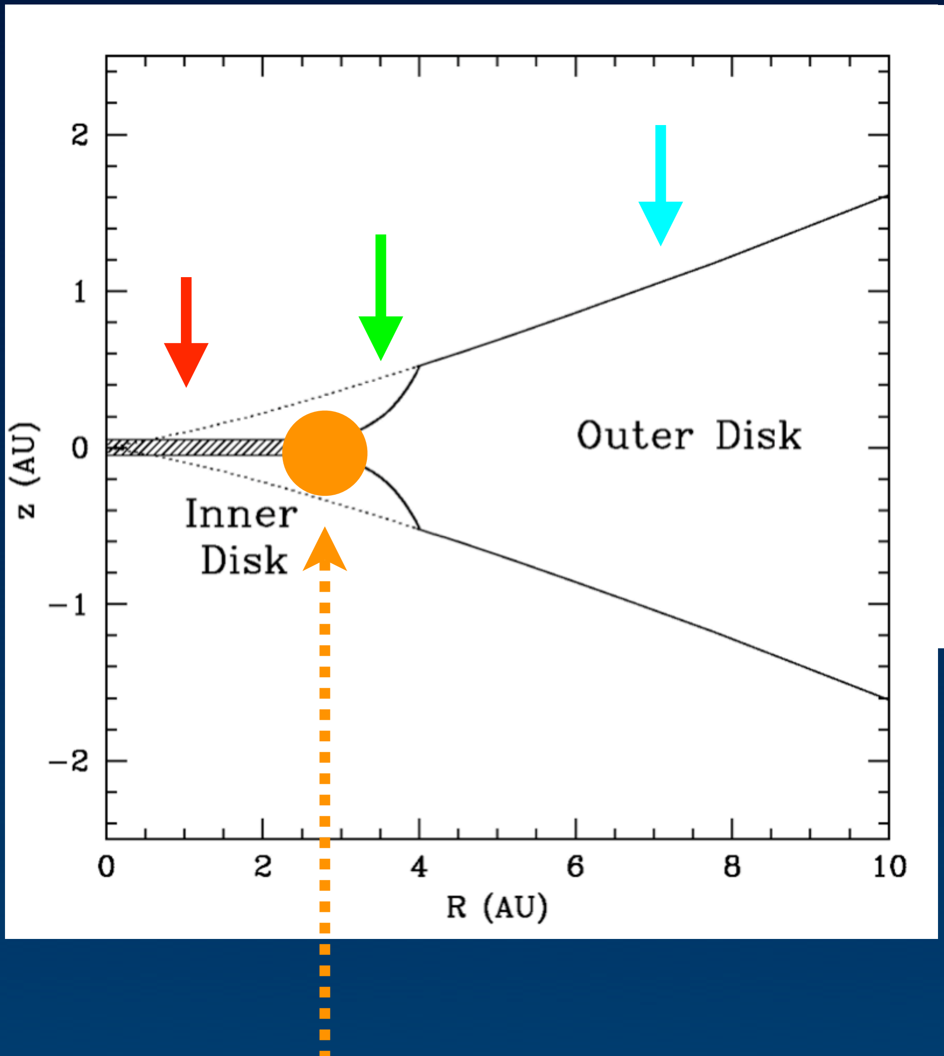
HR 4796: ~10 Myr (near-IR)

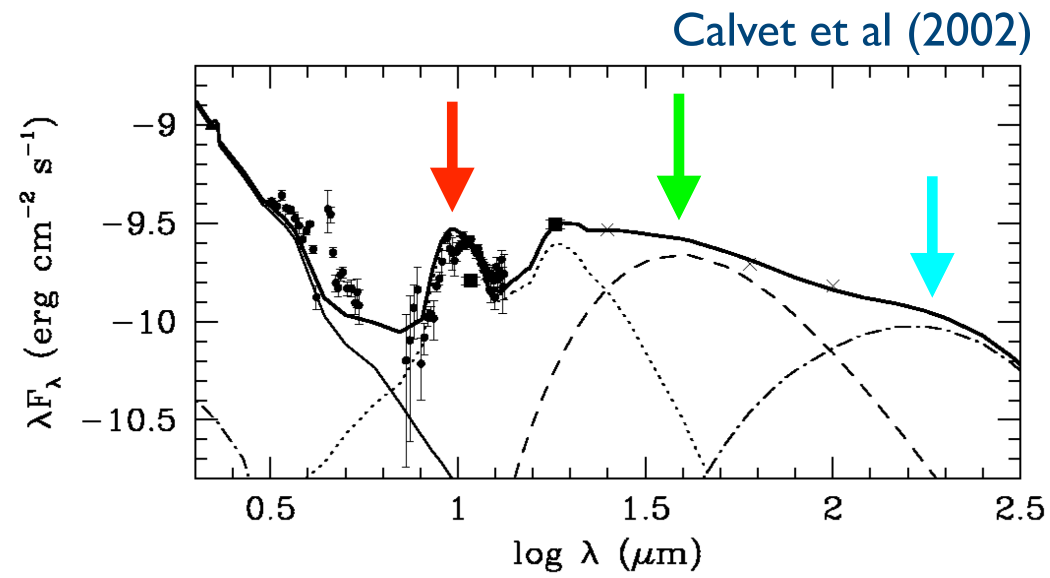


Schneider et al 1999

- Timescale for disappearance of inner disks ~5-10 Myr.
- Possible diagnostics of disk "aging":
  - Change in geometry (imaging)
  - Evolution of SED
  - Decrease in accretion rates
  - Grain growth & evolution
  - Decrease in dust + gas mass
  -
- Hard to find young stars at these ages.

Disks in transition: TW Hya (~10 Myr)



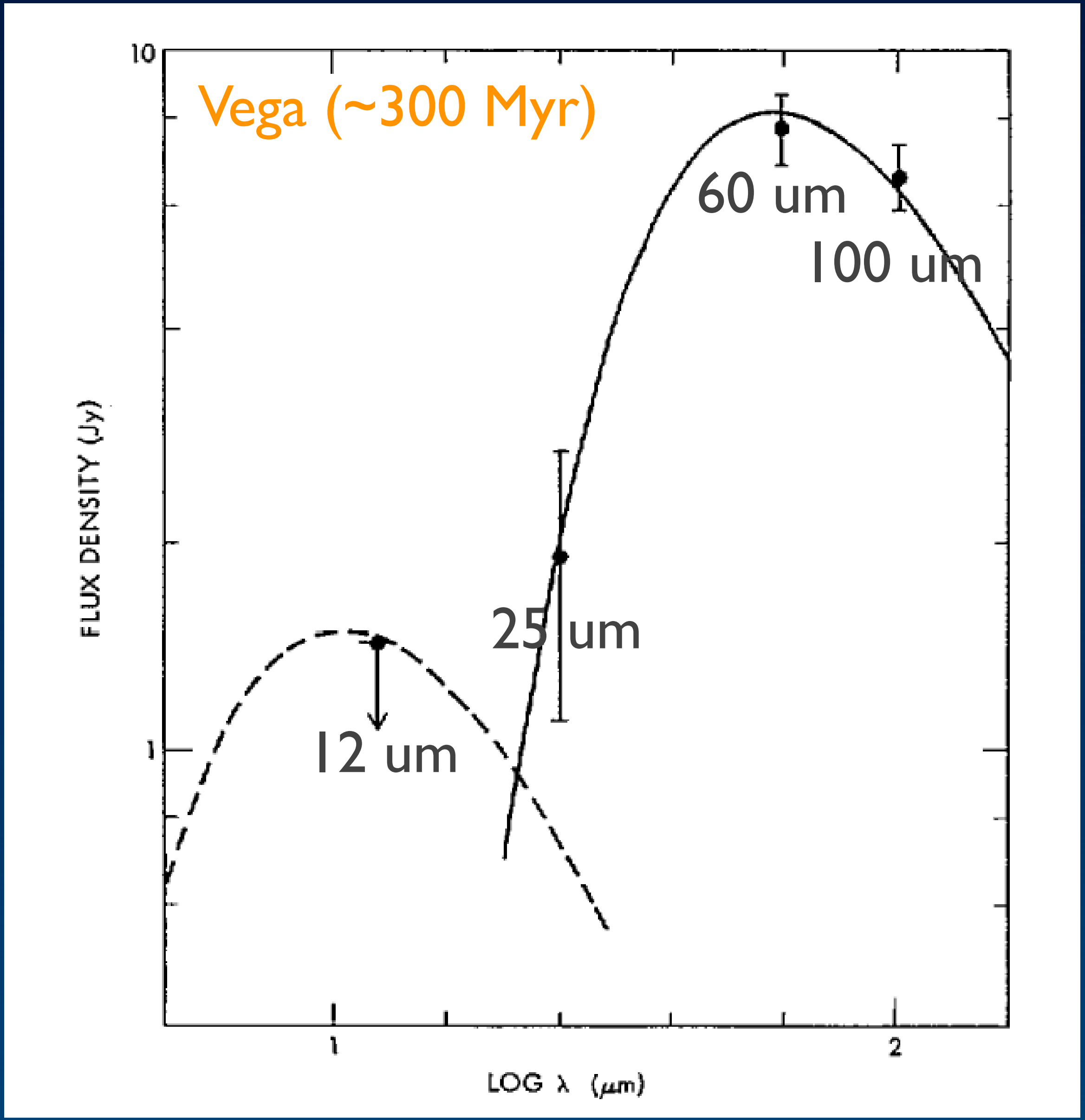


- far-IR: outer disk of gas + dust
- mid-IR: edge of outer disk ("wall")
- 10 um peak: inner disk of small grains
- mm flux: large (>1 cm) grain growth

Grain growth + evacuated inner disk = planet?

Debris disks

Debris disks (>~10 Myr)

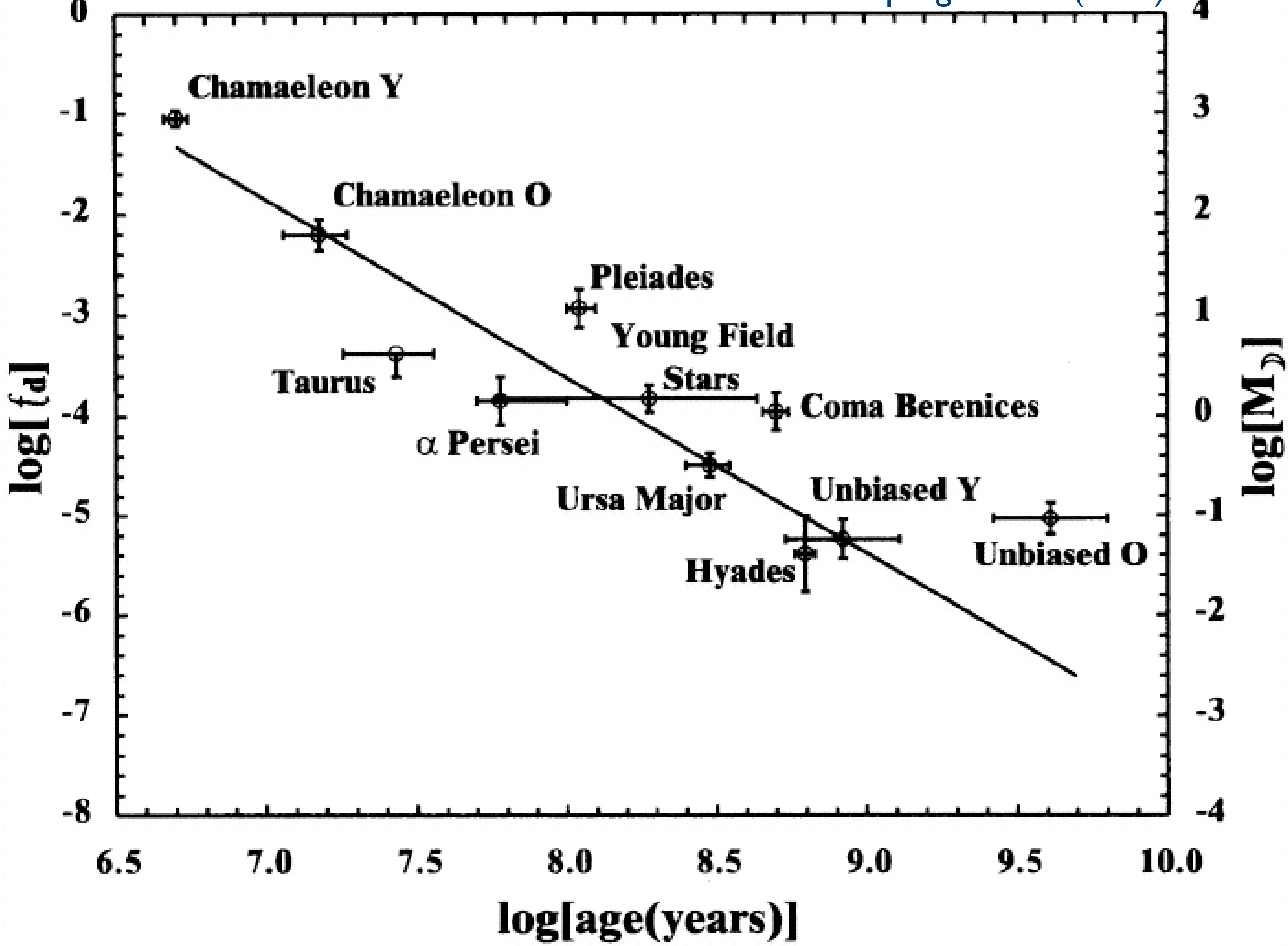


Aumann et al (1984)

- *IRAS*: ~15% of MS stars have far-IR excesses.
- Cold dust at >10's AU.
- Dust lifetime is short (PR drag, radiation pressure, collisions) compared to age of star.
- Dust from collisions of unseen larger bodies.
- M(dust) ~ few M(moon)
- Gas-poor.

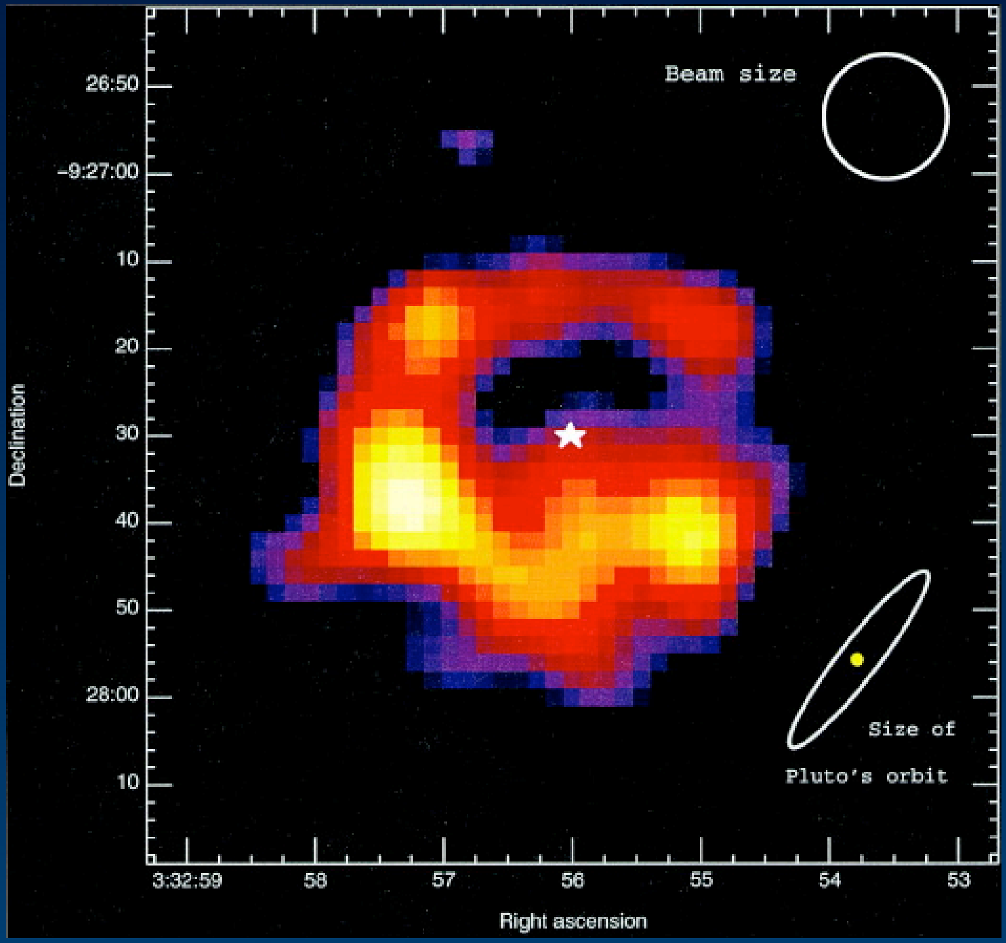
Debris disk evolution

Spangler et al (2001)



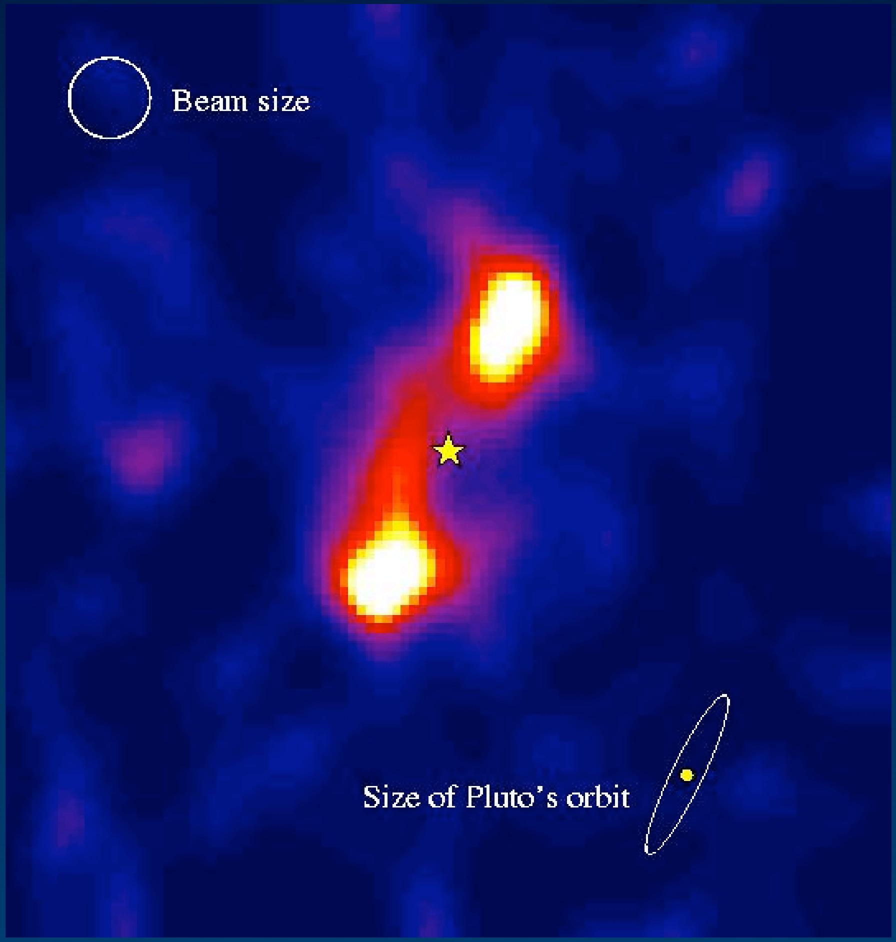
Dusty circumstellar disks (and planets)

epsilon Eridani: 700 Myr (sub-mm)



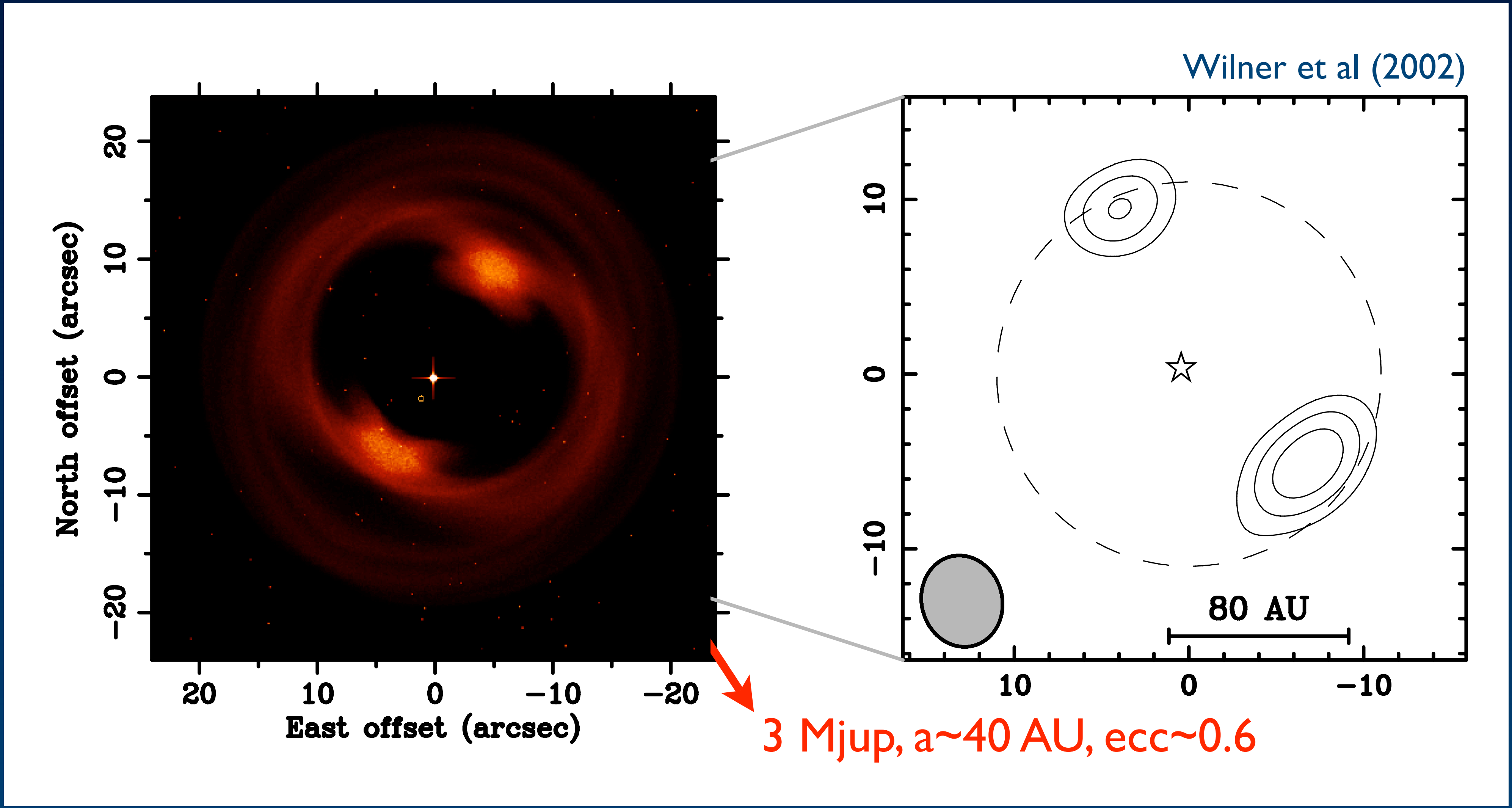
Greaves et al 1998

Fomalhaut: 200 Myr (sub-mm)



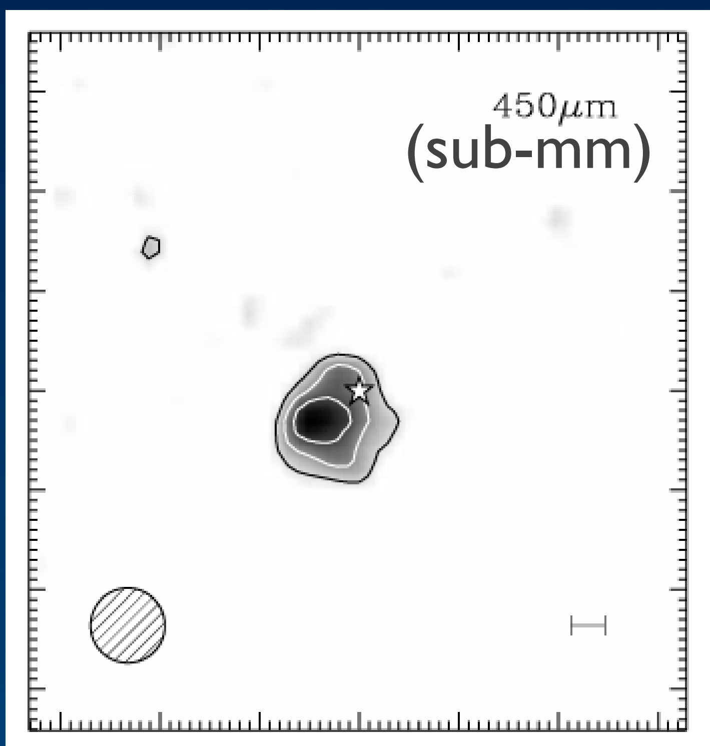
Holland et al 2003

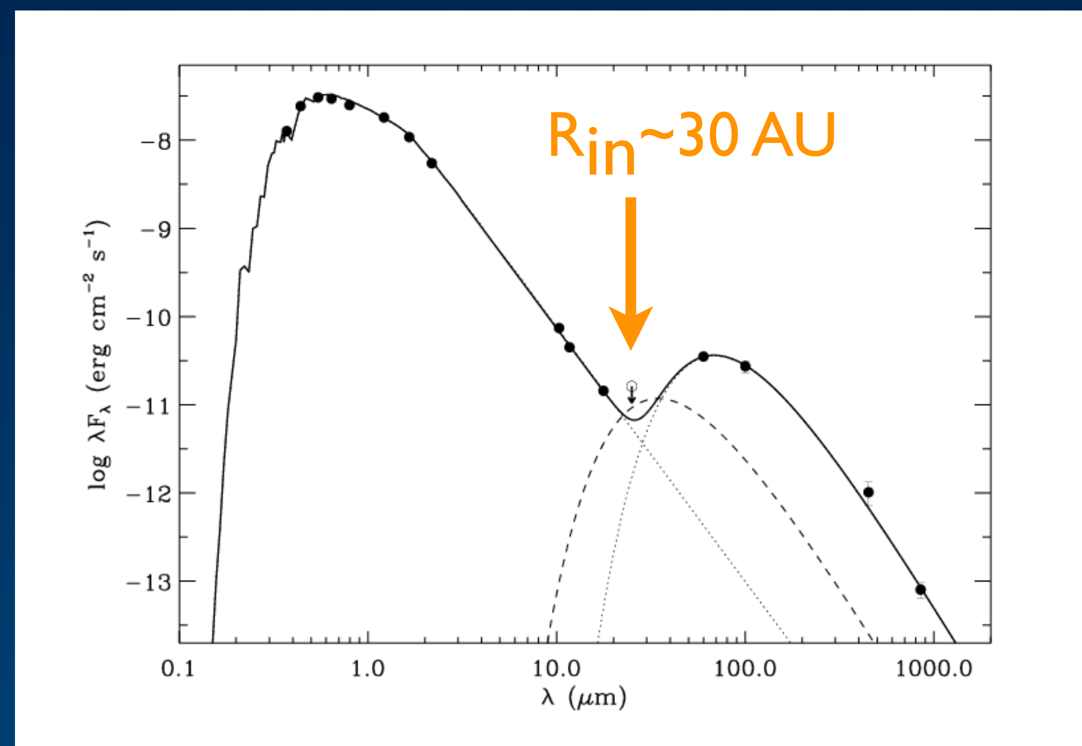
Vega's debris disk: mm interferometry



Dusty circumstellar disks (and planets)

- Known debris disk samples are incomplete (e.g. biased to more luminous stars).
- New disk around a young (~100 Myr), nearby (30 pc) Sun-like star

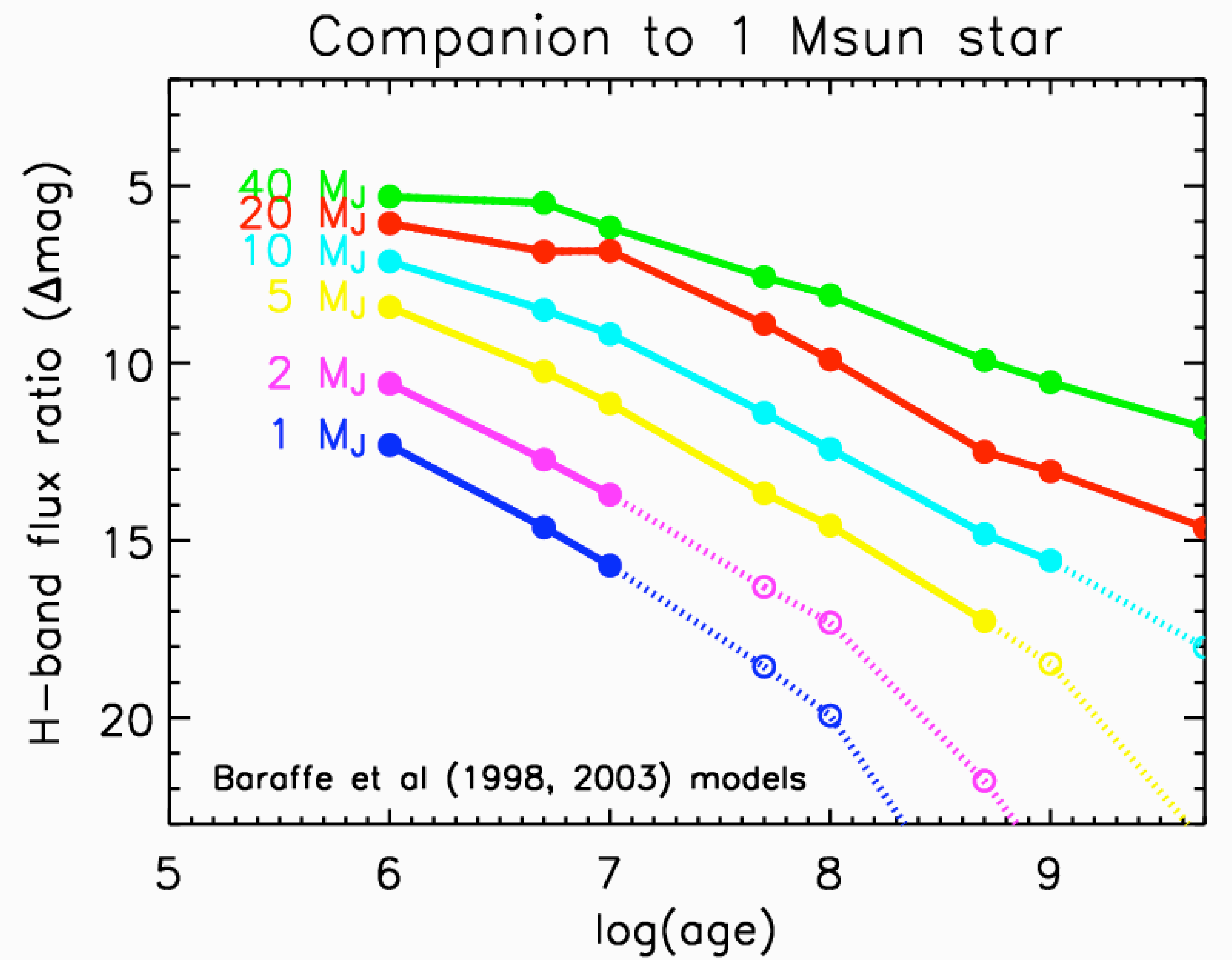




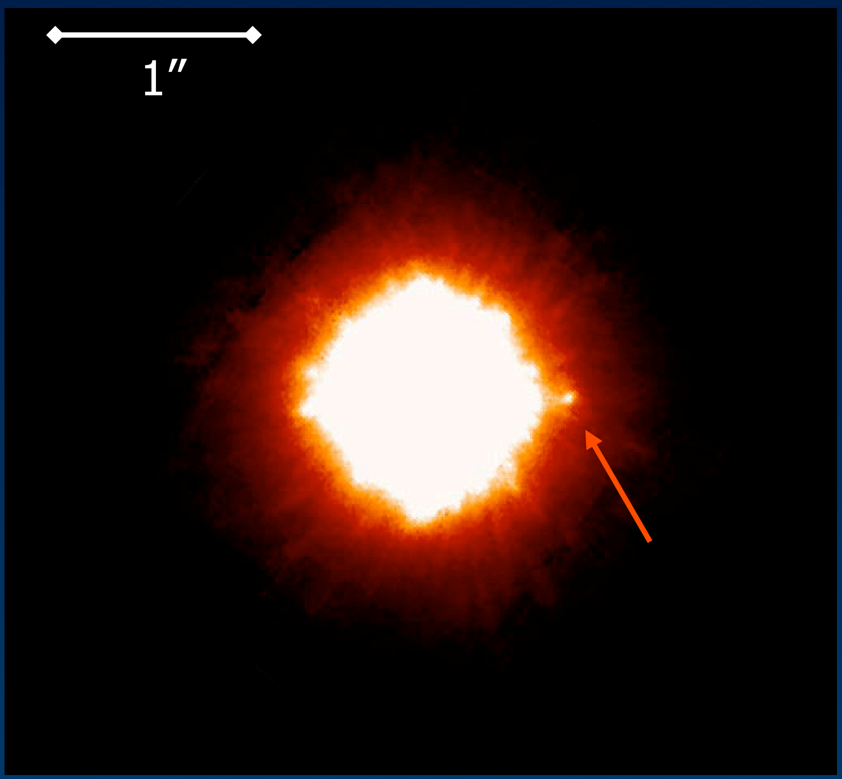
Williams, Najita, Liu et al 2003, submitted

The Disk-Planet Connection

Searching for young exoplanets



Searching for young exoplanets

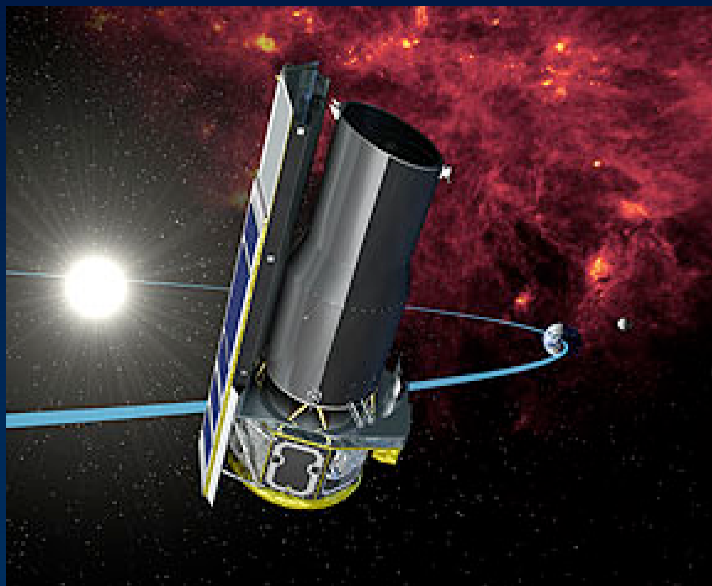


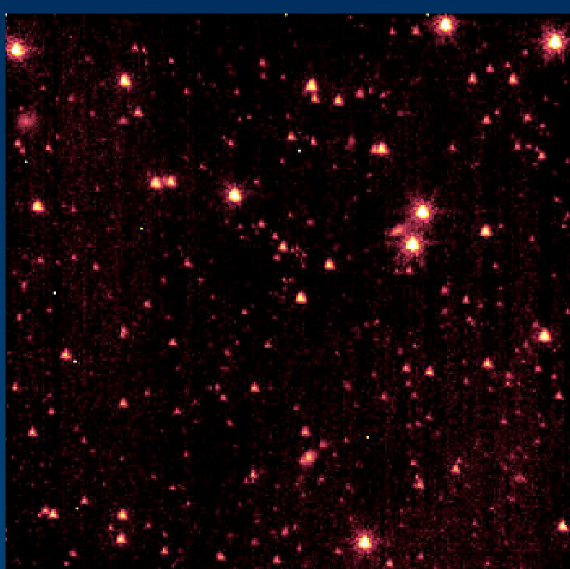
Keck AO: H-band (1.6 μm)

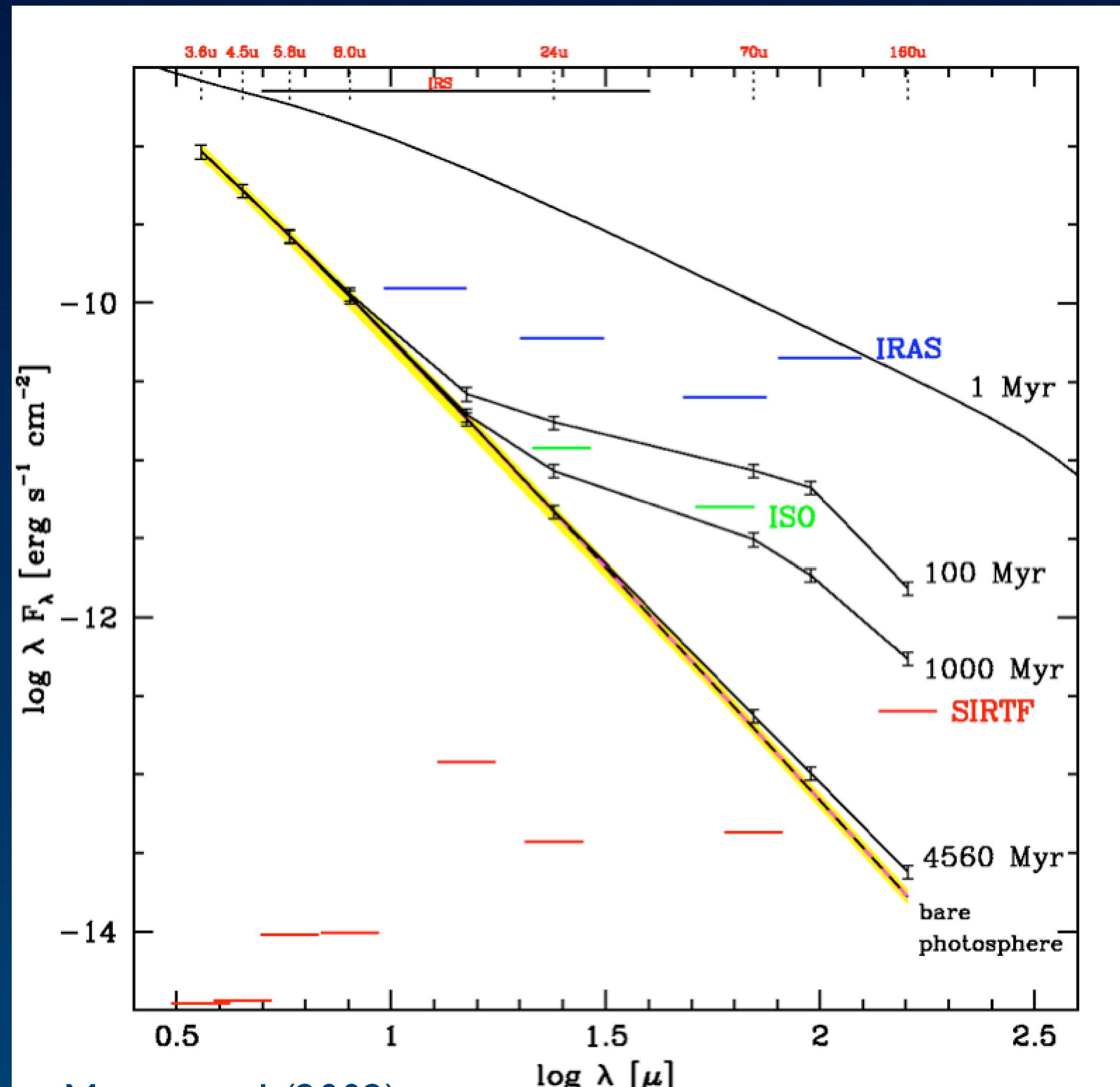
- Young (1-100 Myr) massive planets have significant thermal emission.
- Direct detection becomes tractable with adaptive optics on 8-10 m telescopes (Keck, Gemini, Subaru, VLT).
- Flux ratios of >10 mag at <1-2”.
- Measure colors, Teff, Lbol, atms.

Future Capabilities

SIRTF (Space IR Telescope Facility)







Meyer et al (2002)

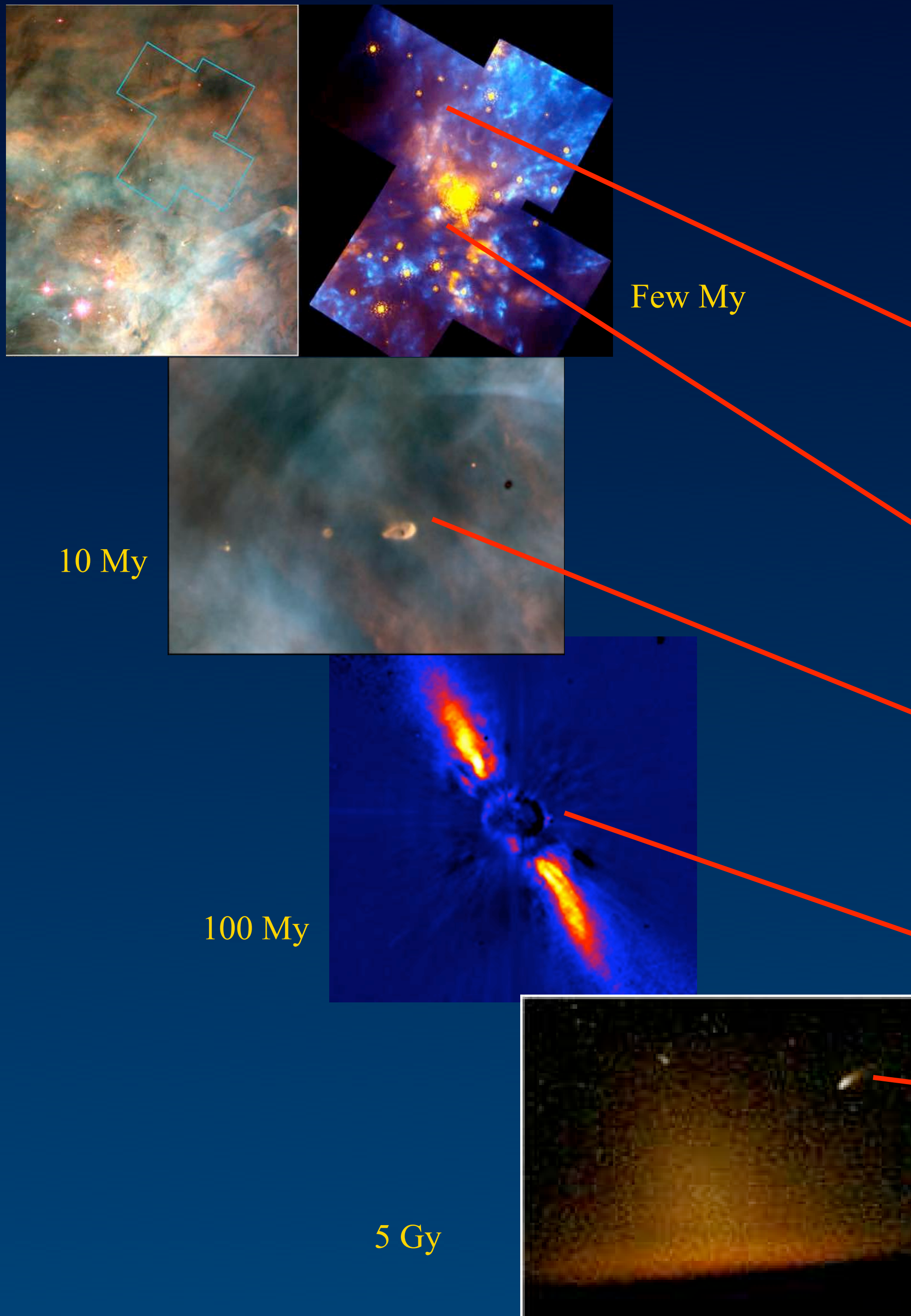
SIRTF (Evans et al): Disk spectral evolution

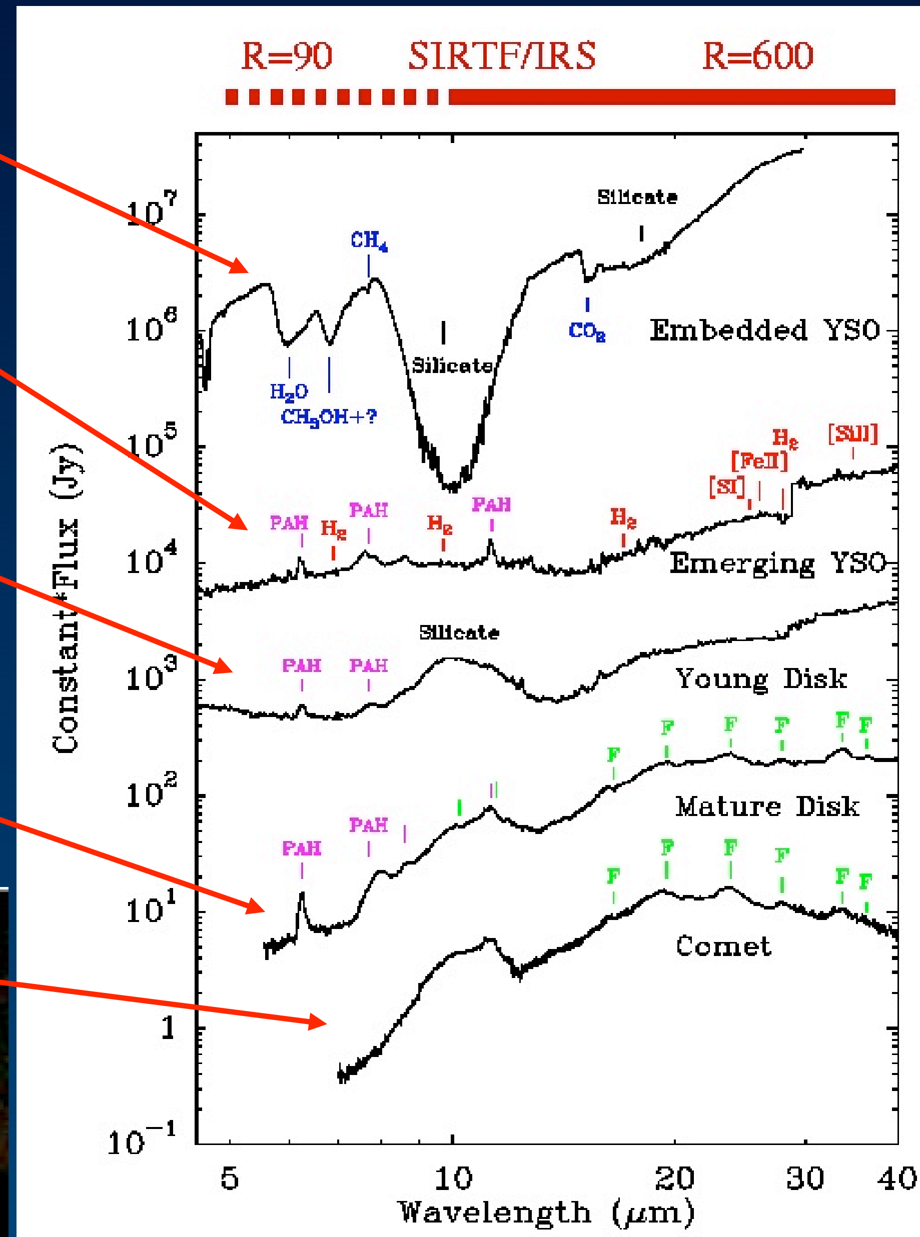
Few My

10 My

100 My

5 Gy

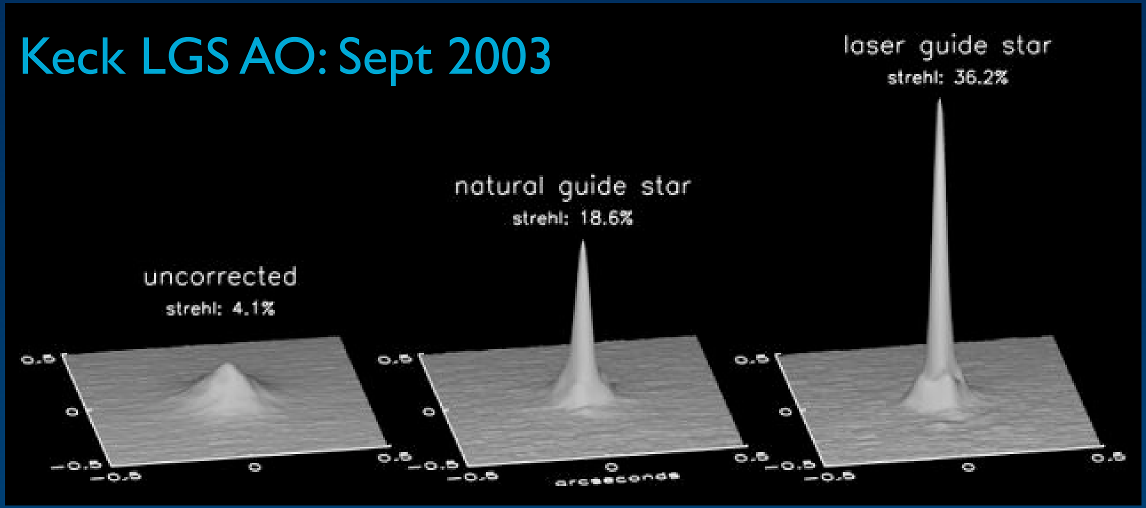




AO in the (near) future: Laser guide star

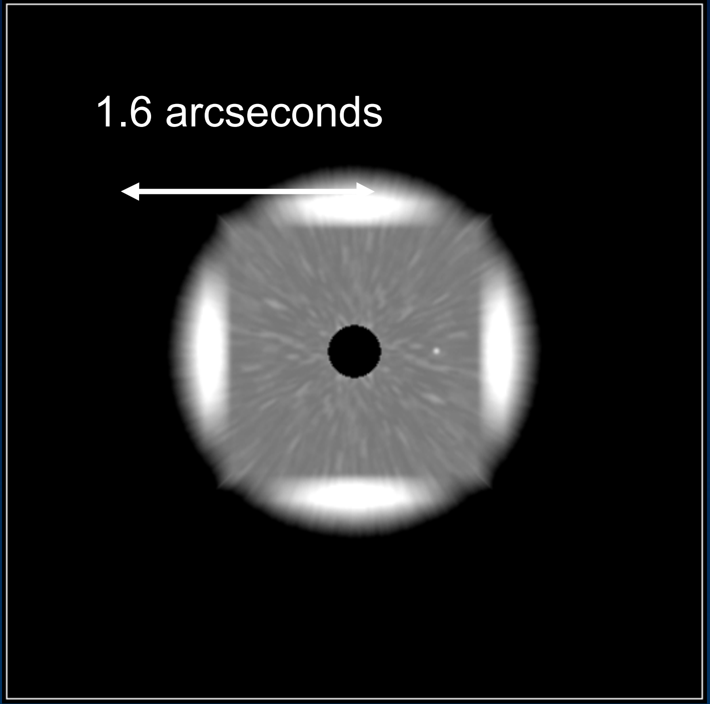
Keck Observatory

HL Tau (2.1 um)



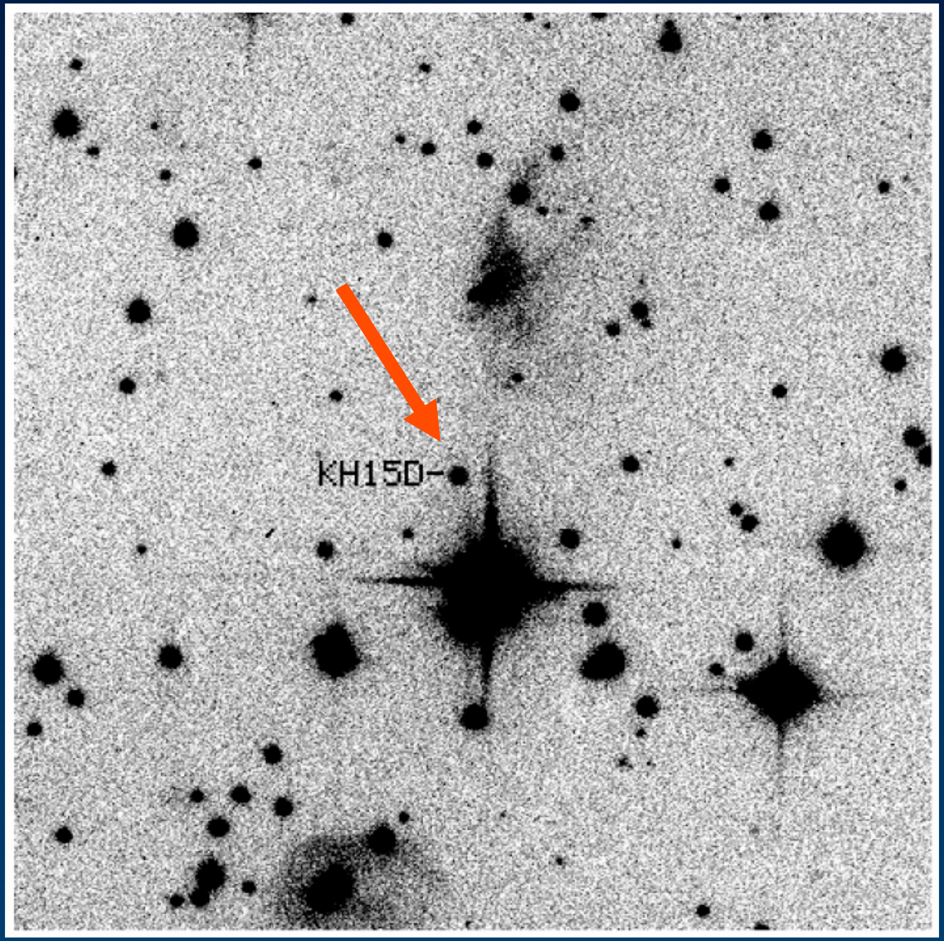
XAOPI: eXtreme Adaptive Optics Planet Imager

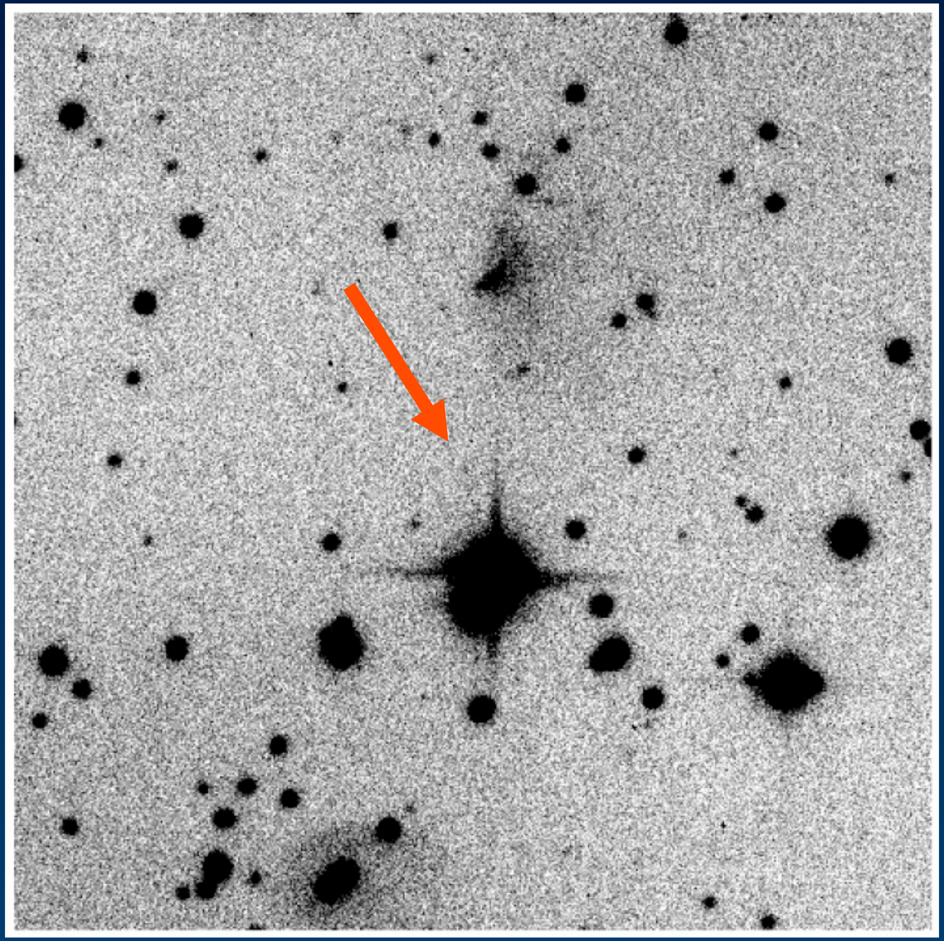
- LLNL, UC Berkeley, UCSC, UCLA, Caltech, JPL
  PI: Bruce Macintosh (LLNL)
- ~3000 actuator AO system for Keck 10-m
- Science goals
  - Direct detection of extrasolar planets.
  - Characterization of circumstellar dust.
- Status: 2002-2003 Conceptual design study
  - System could be deployed in 2007.
- System is intended to be facility-class
  - Wide variety of high-contrast science programs.
  - Targets brighter than m_R~7-10.



Simulated 15 minute XAOPI H-band image showing an 8 Jupiter-mass planet near a solar-type star

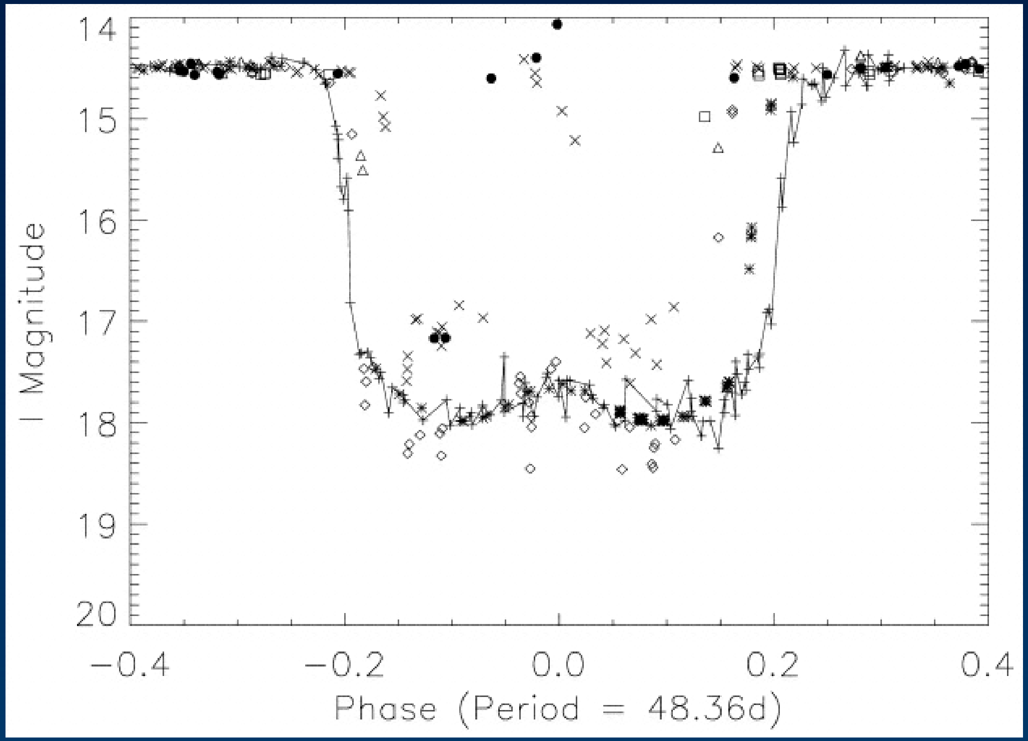
The time domain: KH 15D



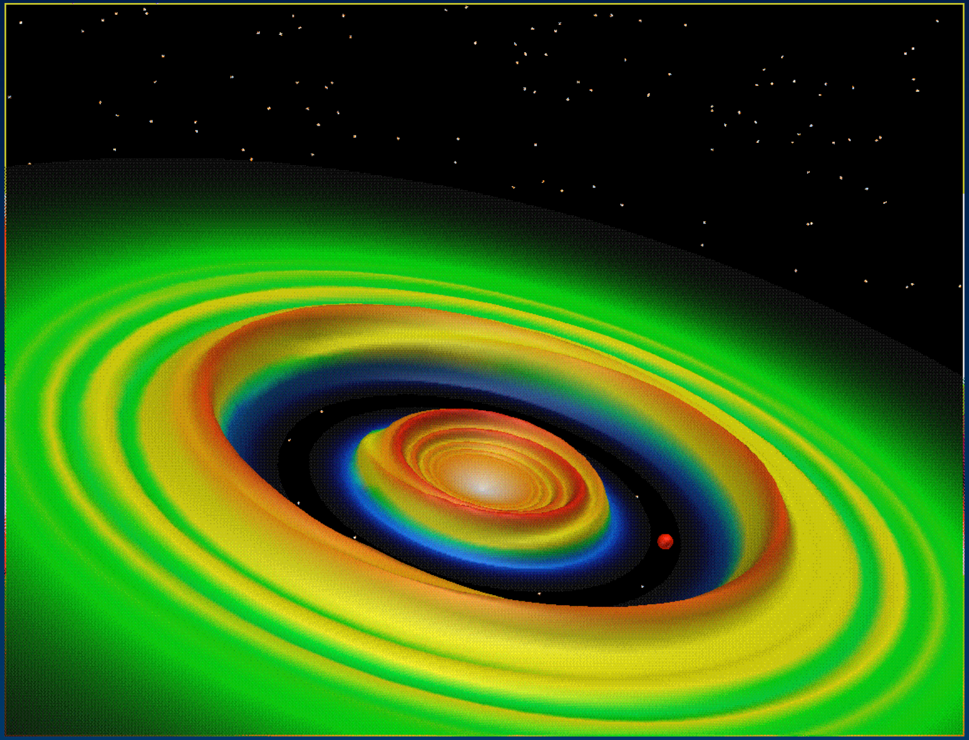


Herbst et al (2002)

The time domain: KH 15D

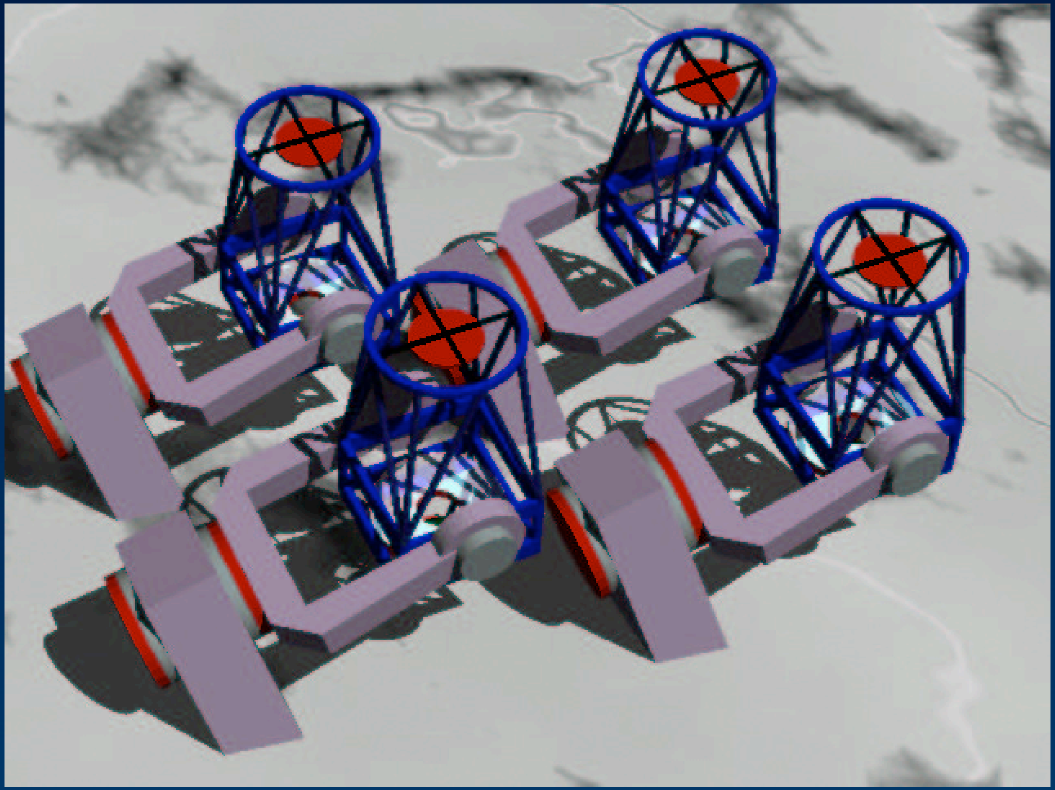


Herbst et al (2002)



Bryden et al (1999)

The time domain: Pan-STARRS



IfA/Hawaii, MHPCC, SAIC, Lincoln Lab
PI: Nick Kaiser

- Dedicated wide-field optical survey system.
- Four 2-m telescopes.
- FOV = 7 sq.deg,
  1 billion pixel OTCCD.
- Multi-color, multi-epoch record of the (northern) sky.
- Operational 2007.

- Physical & temporal evolution of dust + gas.
- Origin & consequences of the diversity of disks.
- Properties of disks across the mass spectrum.
-
- Concrete connections between disks and planets.