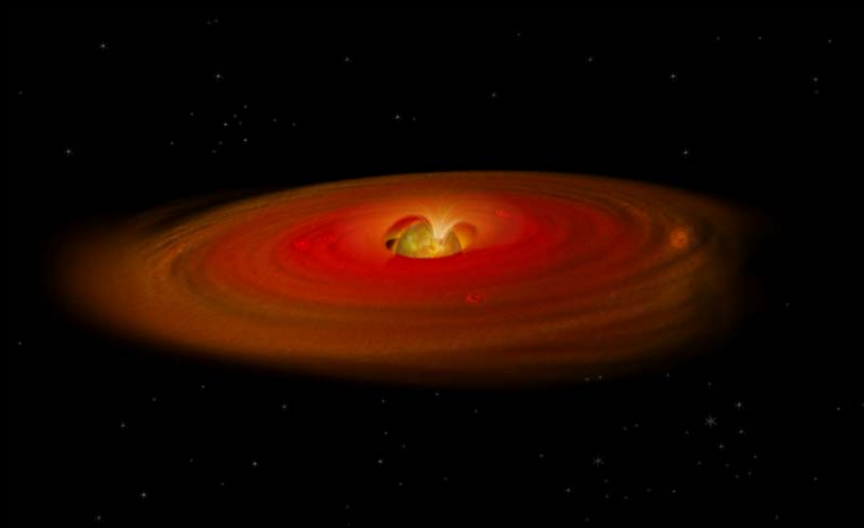
Probing Sub-AU Radii of Protoplanetary Disks: Observations with PTI and KI

Josh Eisner*

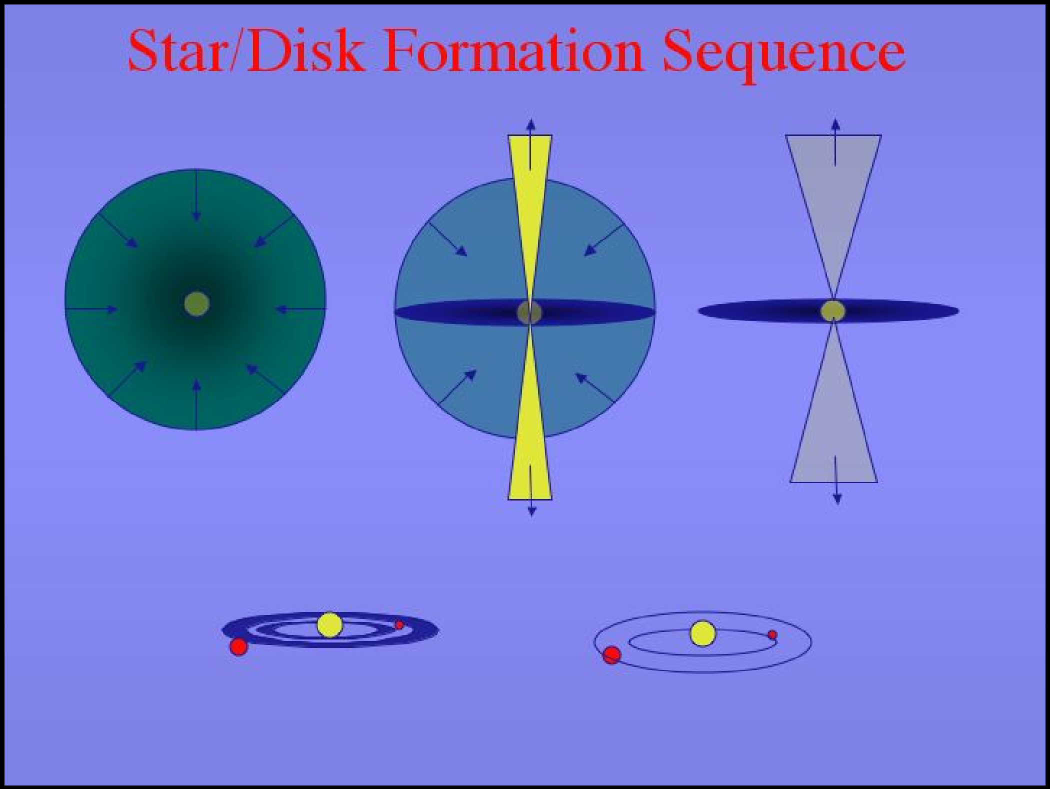
Collaborators: Rachel Akeson, Lynne Hillenbrand, Ben Lane, Anneila Sargent, Russel White



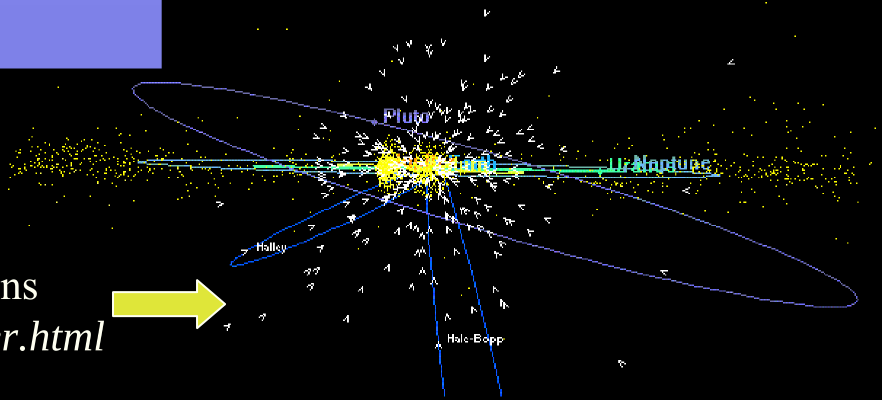
October 21, 2005

* Miller Research Fellow, UC Berkeley

Circumstellar Disks



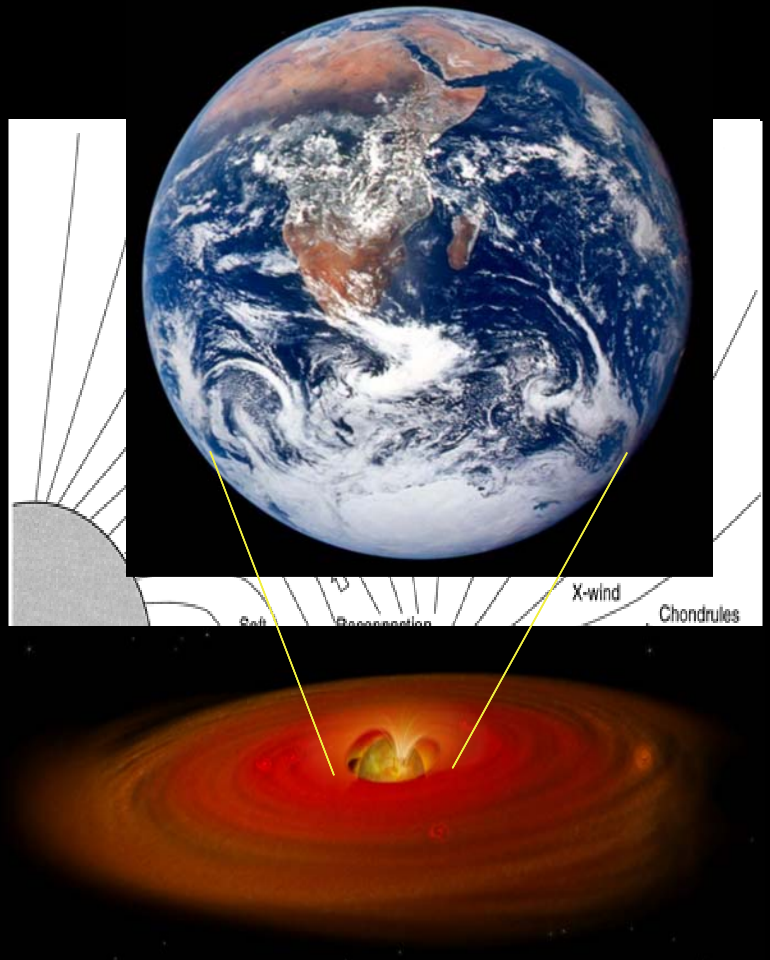
- Disk evolution constrains planet and star formation mechanisms
- Proto-solar nebula
- Extra-solar planets



Planet, Asteroid, and Comet Positions from *http://ssd.jpl.nasa.gov/orbits_outer.html*

Focus: Inner Disk

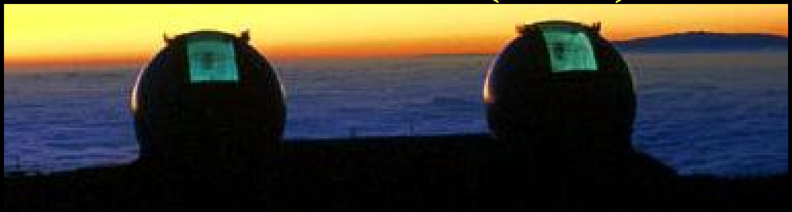
- Earth-like planet formation: dust/gas distributions & temperatures
- Giant planet migration:origin of “hot Jupiters”
- Inner disk accretion: magnetospheric accretion, outflows, stellar ang. mom.



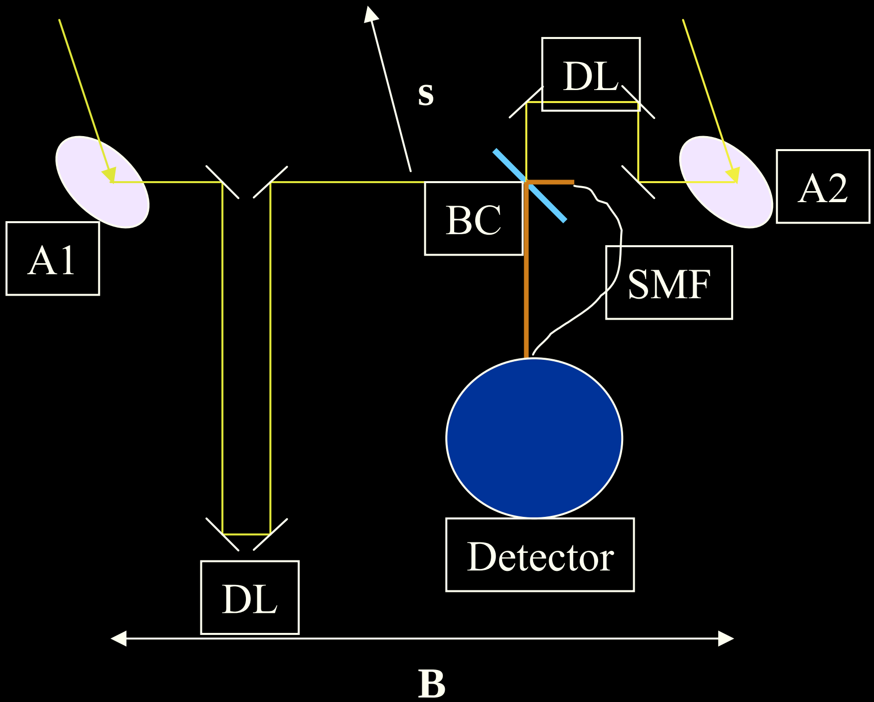
Palomar Testbed Interferometer (PTI)

- 3 telescopes each 0.4 m
  - 110 m NS oriented 20º E of N (4 mas)
  - 85 m NW oriented 81º E of N (5 mas)
  - 87 m SW baseline recently operational

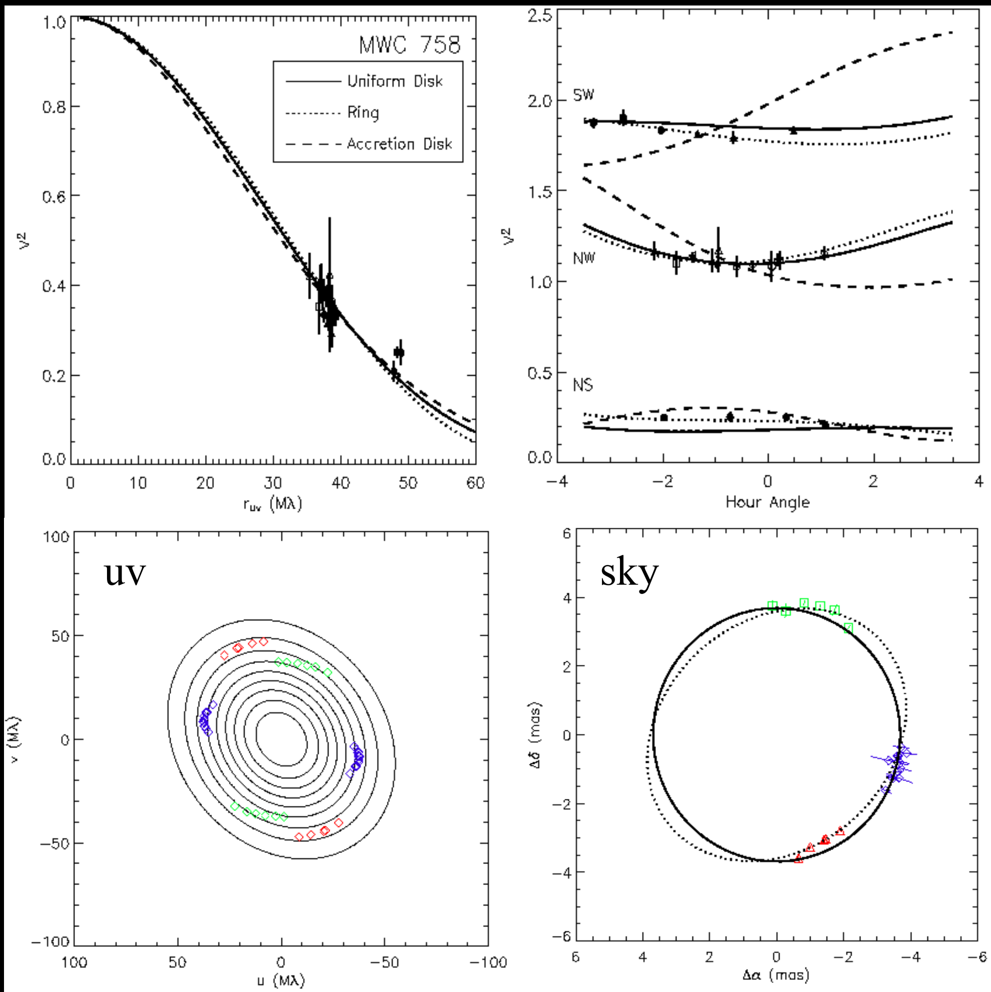
Keck-I (KI)



- One 85m baseline on MK



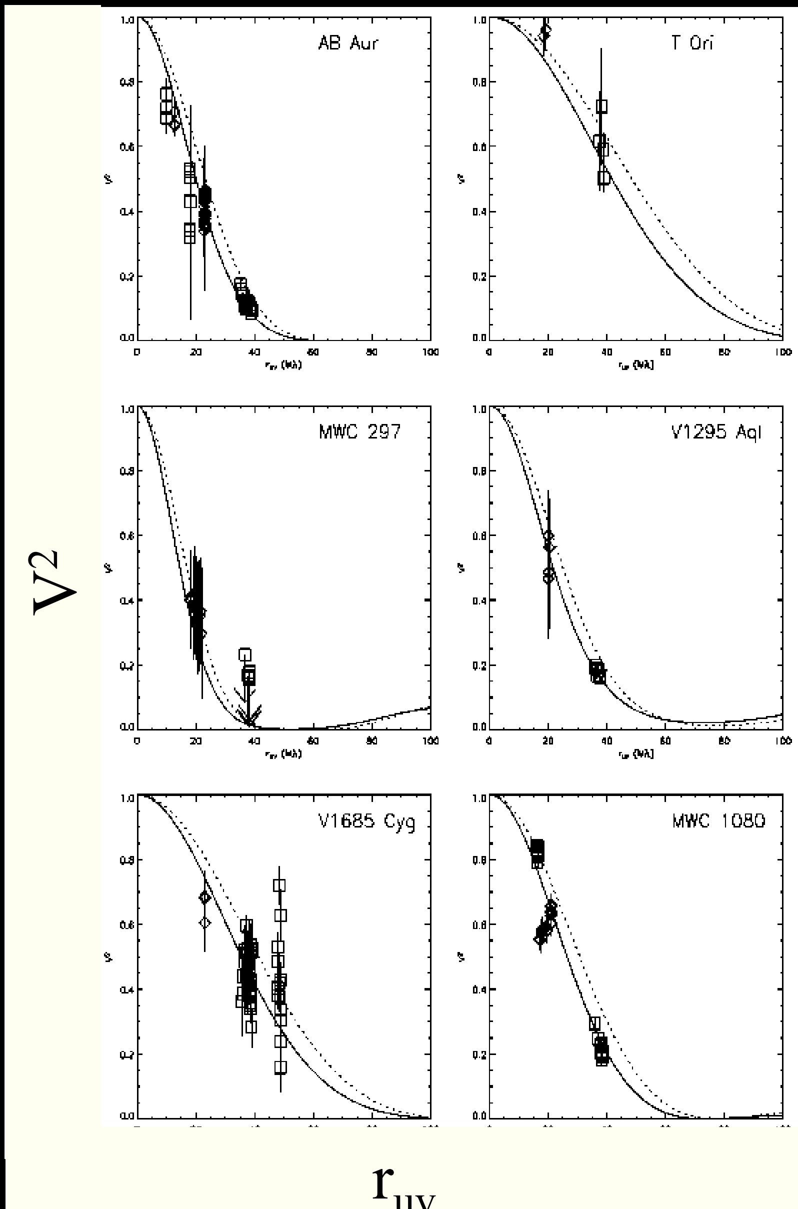
Results I: Disk Geometry



(Eisner et al. 2004)

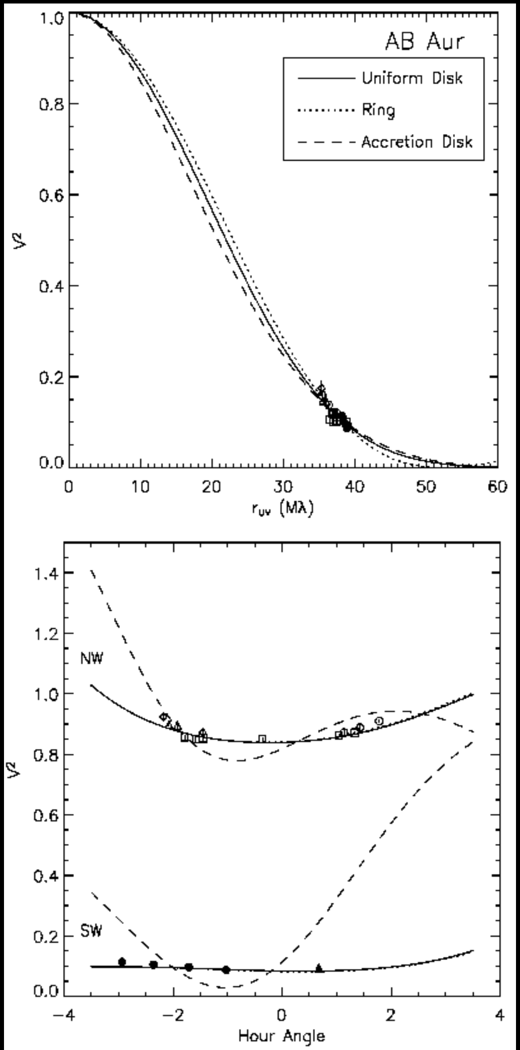
- Sample:
  - 14 HAEBEs (2-10 $M_\odot$)
  - 4 T Tauris (1-2 $M_\odot$)
- Fit geometric models to PTI, KI visibilities: uniform disk, Gaussian, ring (+ star)
- All but 2 sources (HD141569, HD158352) resolved
  - ***θ* ~1-6 mas**
- Most sources inclined
  - ***i* ~10-85°**

PTI+IOTA Data



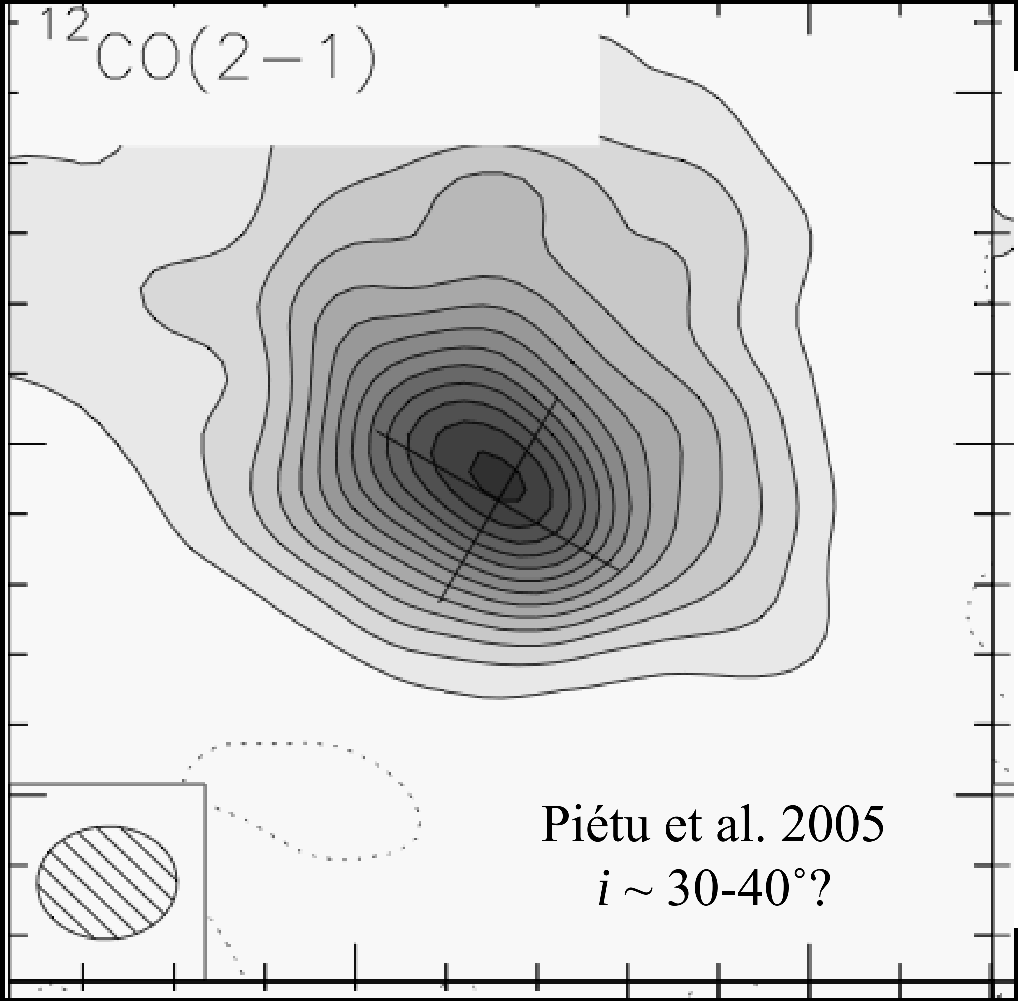
- Some objects also observed by IOTA (Millan-Gabet, Schloerb, & Traub 2001)
  - K-band: AB Aur, MWC 1080
  - H-band: AB Aur, T Ori, MWC 297, V1295 Aql, V1686 Cyg, MWC 1080
- Shorter baselines than PTI (20-40m vs. 85-110m)⇒additional constraints on geometry
- Larger FOV than PTI (3″ vs 1″) ⇒ constrains incoherent emission from extended dust
  - Scattered light around AB Aur?

Inner vs. Outer Disks: Warping?



(Eisner et al. 2004)

PTI+IOTA near-IR: $i \approx 10\text{-}20^{\circ}$



Piétu et al. 2005
$i \sim 30\text{-}40^{\circ}$?

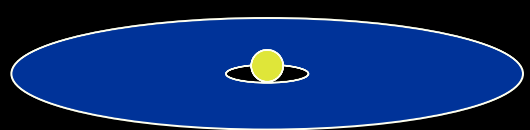
(Lack of) Disk Warping

Source	Inner disk inclination	Outer disk inclination	mm ref.
AB Aur	10-15°	~76°; **~20°; 17°, 40°**	Mannings & Sargent 1997; Corder, Eisner, & Sargent, 2005; Semenov et al. 2005, Piétu et al. 2005
MWC 480	24-32°	**~30°**	Mannings et al. 1997
MWC 758	33-37°	~46°	Mannings & Sargent 1997
CQ Tau	48°	~70°; **~45°**	Testi et al. 2003; Corder et al. in prep.

Physical Properties of YSO Disks

- Inner disk structure constrains disk accretion, planet formation
- R_{in}, *i* from interferometry **R_{in} ~ 0.1-1 AU, *i* ~ 10-85°**
- **Combined with SEDs**: T_{in}, vertical structure **T_{in} ~ 1000-2500 K**
  (stellar params from echelle spectroscopy & literature)

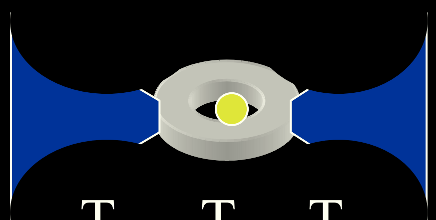
Geometrically flat accretion disk



$T(R) \propto R^{-3/4}$

Parameters: R_{in}, *i*, T_{in} (R_{out})

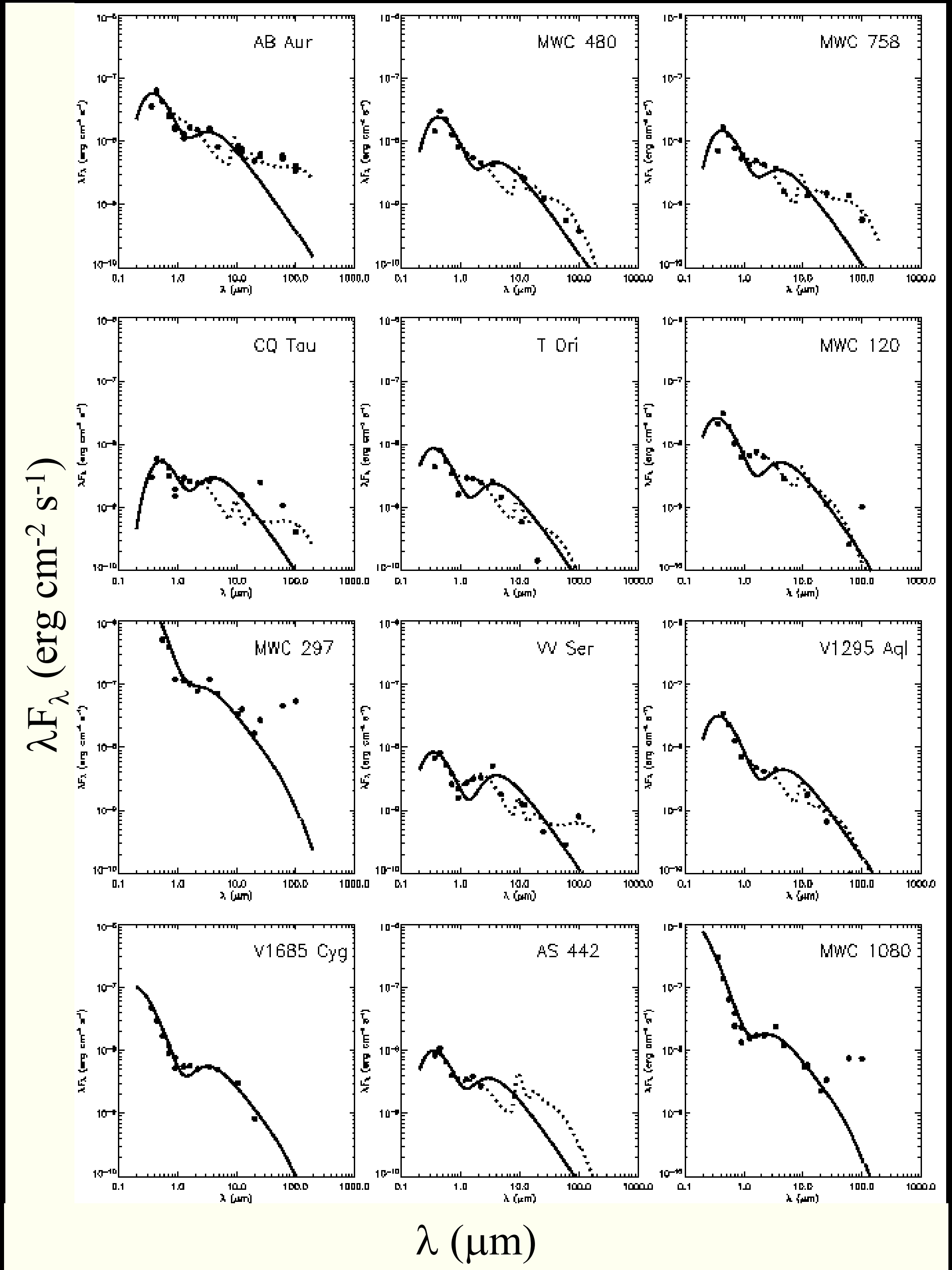
Flared 2-layer disk with puffed-up inner wall



T_{rim}, T_{int}, T_{surf}

Parameters: R_{in}, *i*, T_{in}, R_{out}, ξ, Σ, κ_ν

HAEBE Disk Structure

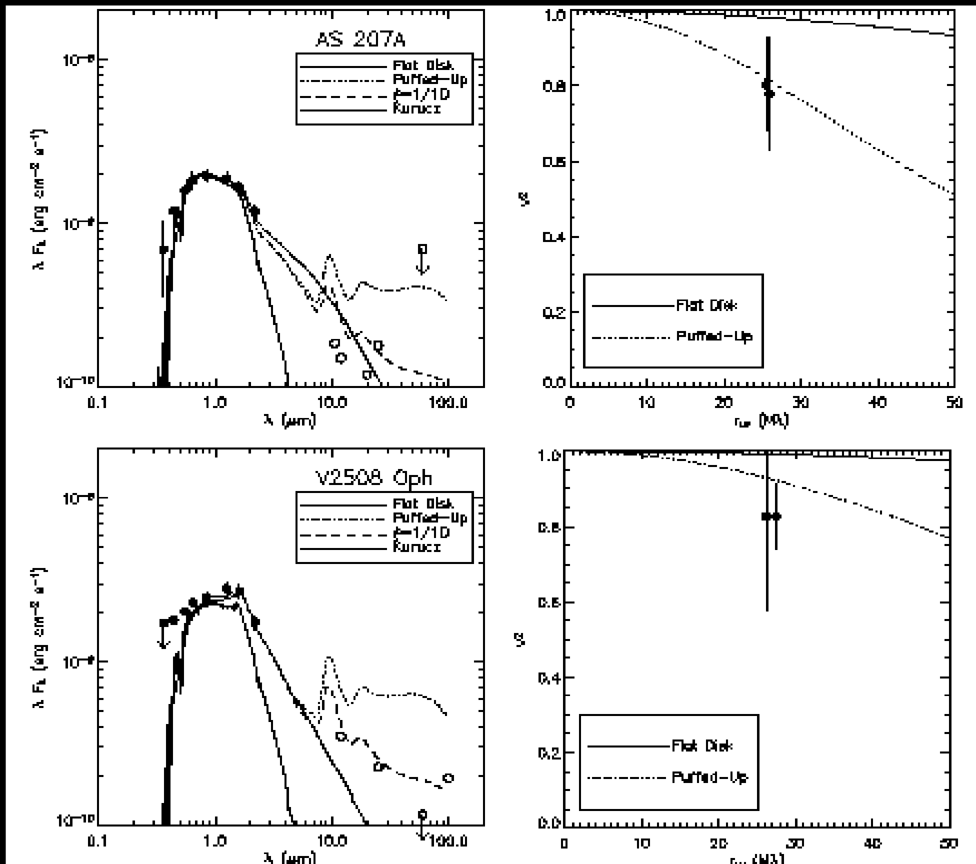


- R_{in} ~ 0.1-0.8 AU
  T_{in} ~ 1300-2100 K

- Earliest spectral types inconsistent with puffed-up; fit well by flat disk

- Dependence of inner disk structure on stellar luminosity? Accretion rate?

T Tauri Disk Structure

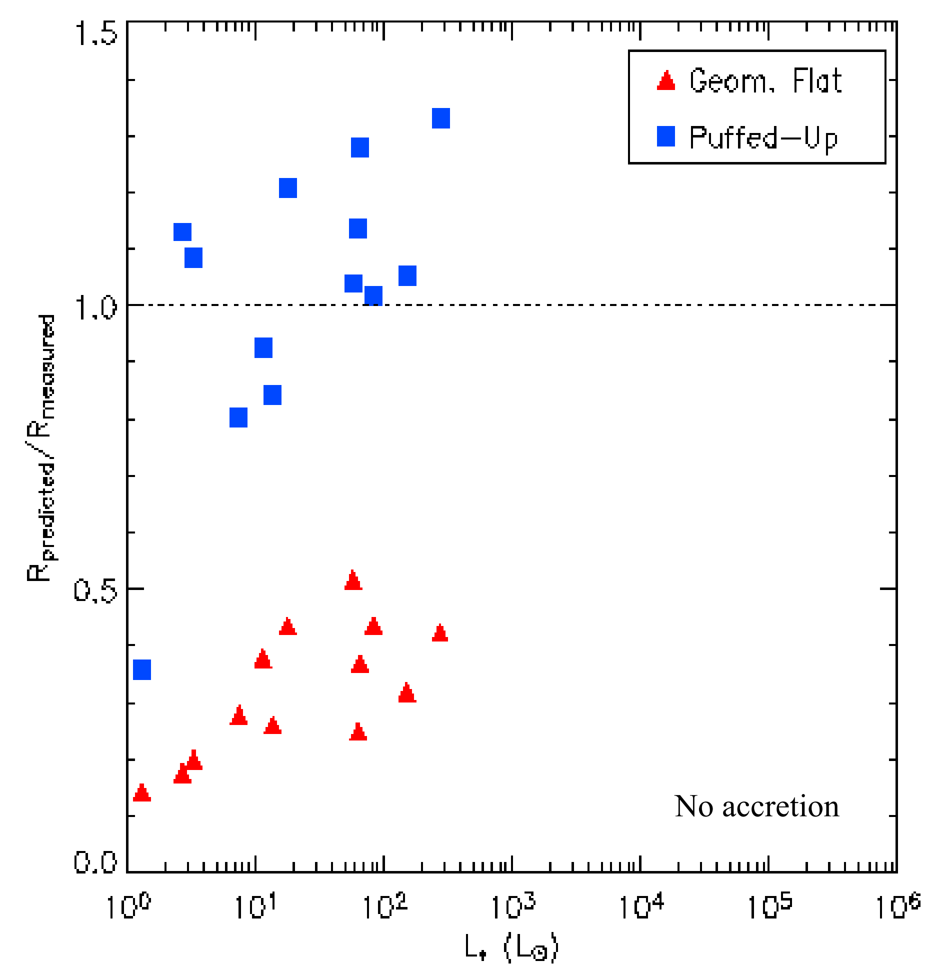


Flat Accretion Disks

Flared Disks with Puffed-Up Inner Walls

- KI observations: 4 solar-type T Tauri stars
  - AS 205A, AS 207A, V2508 Oph (1 $M_{\odot}$)
  - PX Vul (2 $M_{\odot}$)
- R_{in} ~ 0.1-0.3 AU
  T_{in}~1000-2000 K
- As HAEBEs, puffed-up inner disk models generally better

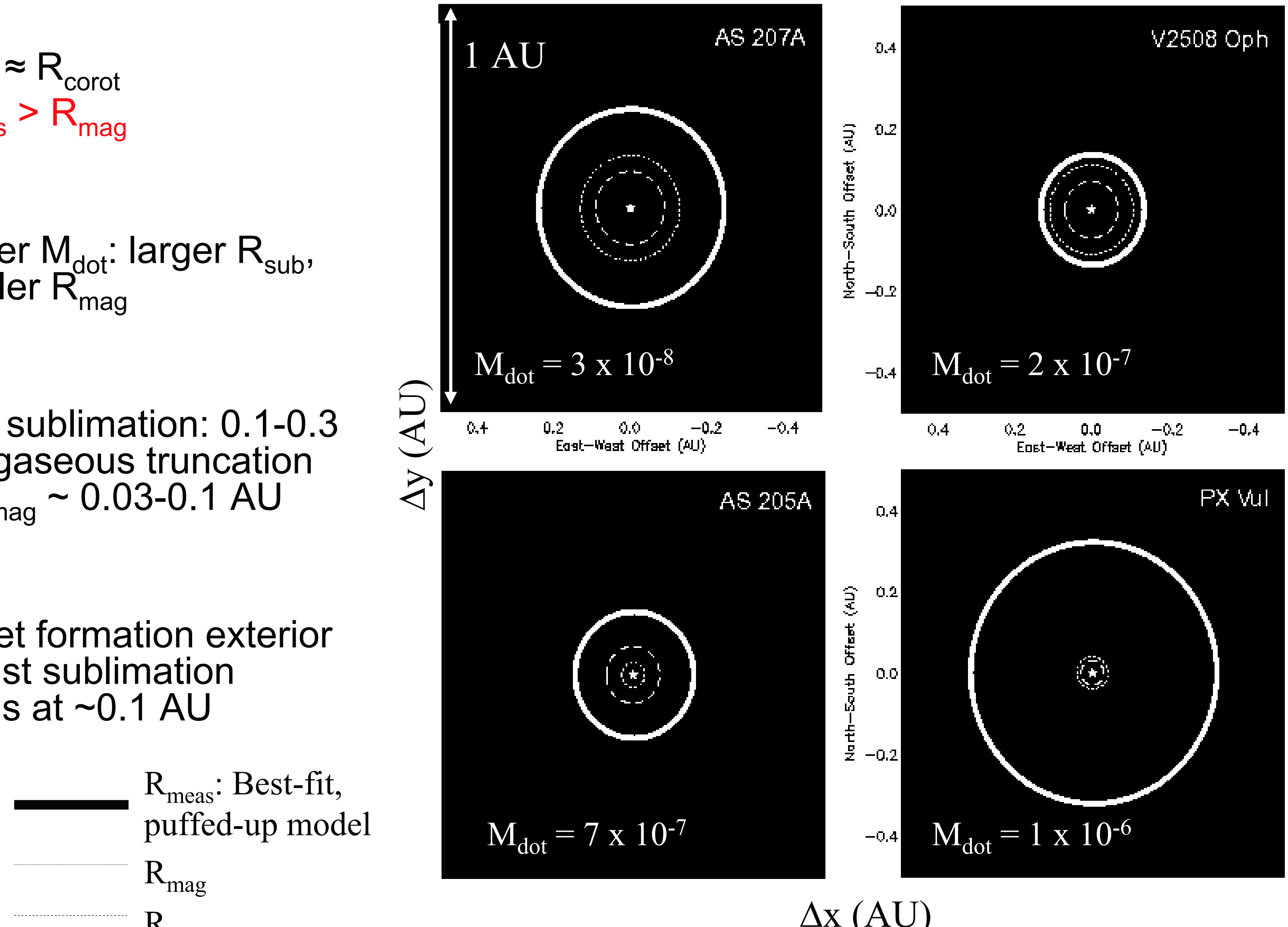
Inner Disk Vertical Structure



- For T Tauri stars and later-type HAEBEs, puffed-up inner disk models better
- Early-types are fit well by flat disk models; not at all by puffed-up inner walls
- Dependence on accretion rate, stellar properties? Different accretion mechanisms?

Disk Truncation Radii

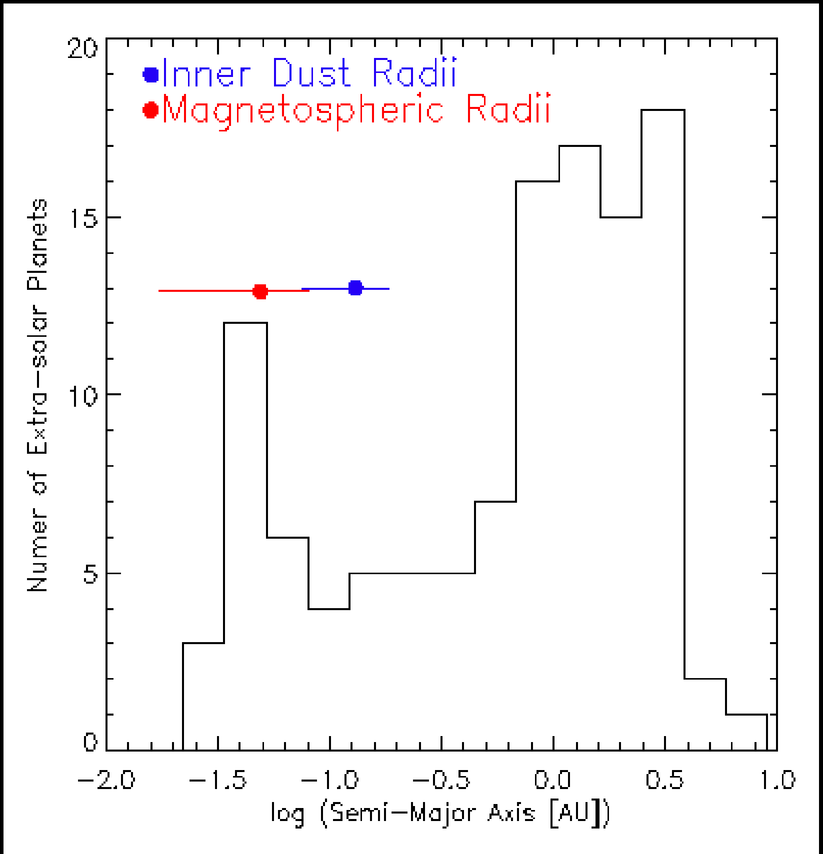
- $R_{mag} \approx R_{corot}$
- $R_{meas} > R_{mag}$
- Higher M_{dot}: larger R_{sub}, smaller R_{mag}
- Dust sublimation: 0.1-0.3 AU; gaseous truncation at R_{mag} ~ 0.03-0.1 AU
- Planet formation exterior to dust sublimation radius at ~0.1 AU



(Eisner et al. 2005)

Planetary Migration

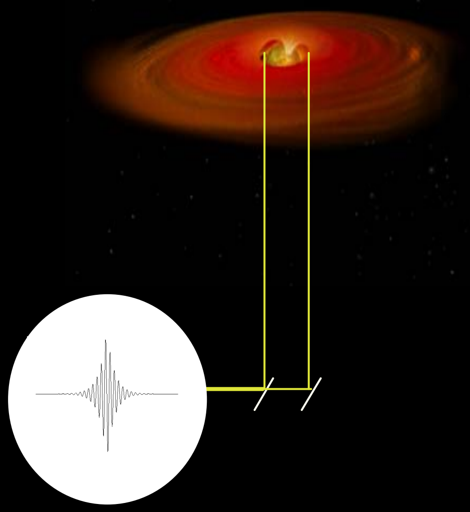
Source	0.63 R_{in} (dust) (AU)	0.63 R_{mag} (gas) (AU)
AS 205A	**0.09**	**0.02**
AS 207A	**0.15**	**0.08**
V2508 Oph	**0.08**	**0.07**
PX Vul	**0.20**	**0.03**



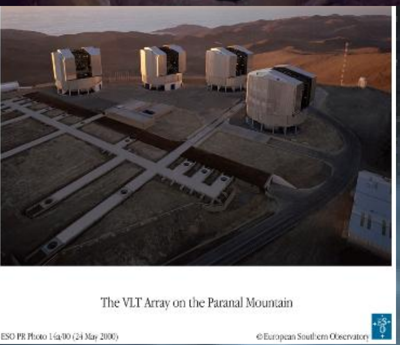
- Migration halts in 2:1 resonance with inner disk edge (0.63 R_{in}; Lin, Bodenheimer, and Richardson 1996)
- 0.63 R_{in} larger than observed pile-up location of extra-solar planets (e.g., Udry, Mayor, & Santos 2003; www.exoplanets.org)
- 0.63 R_{mag} more compatible → Halted by *gaseous* disk edge at R_{mag} (?)

Summary

- PTI observations of 14 HAEBEs:
  - 12 resolved (1-6 mas),
  - ≥7 significantly inclined
- KI observations of T Tauri stars (1-2 $M_\odot$):
  - all resolved (1-2 mas)
- Disk Warping: no significant mis-alignment of inner and outer disks



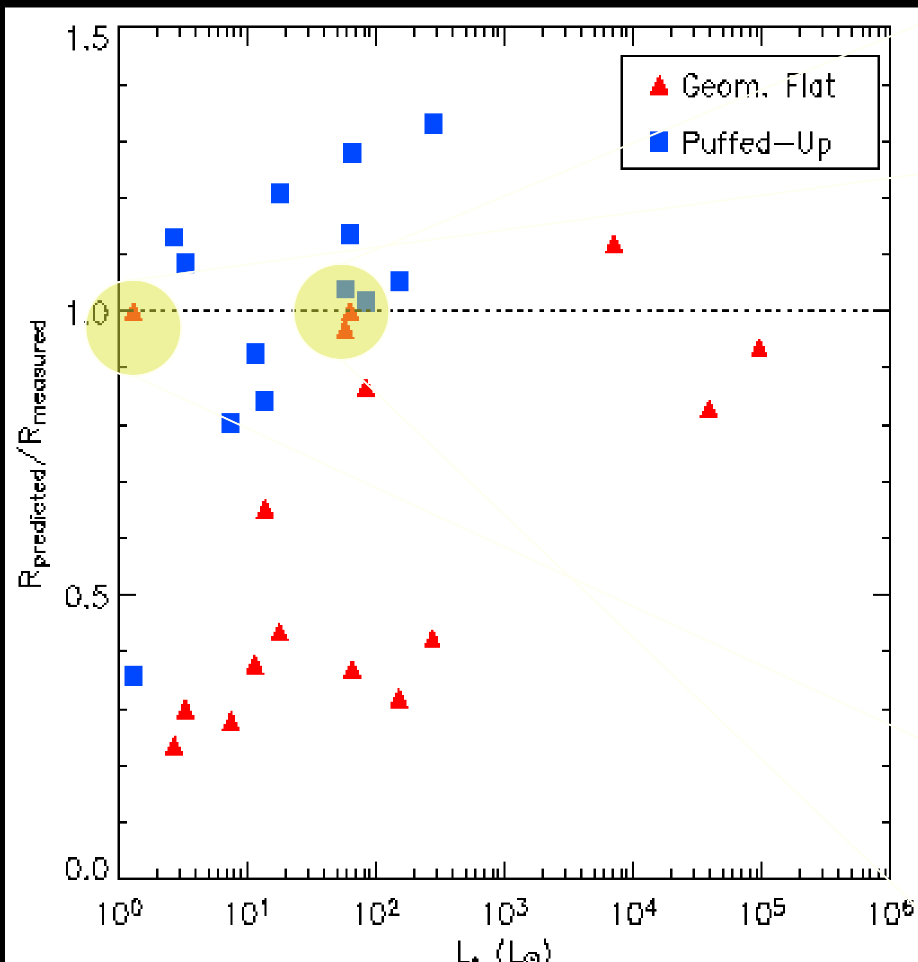
- Vertical disk structure:
  - Low-mass stars (< 5 $M_\odot$) have puffed-up, flared disks
  - High-mass/ accretion-dominated stars consistent with flat disks
- Measured sizes > magnetospheric, co-rotation radii
  - Gaseous material at smaller radii than dust truncation (?)
  - Implications for terrestrial planet formation, giant planet migration

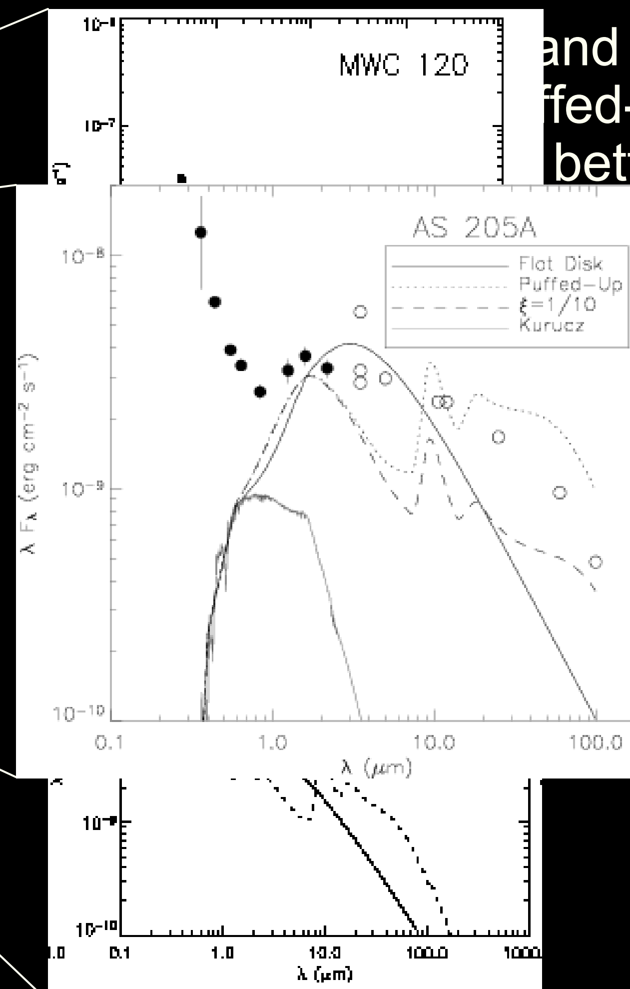


- **Enhanced Sensitivity:**
  - **Larger samples**
  - **range of masses, ages, accretion rates,…**
- **Spectroscopy:**
  - **R_{gas}**
  - **dist. of various molecules**
- **Variability:**
  - **variable accretion rates, B-fields? protoplanets?**

The End.

Inner Disk Vertical Structure





and later-
ffed-up
better
by
t all
ls
tion
?