Observational Constraints on the Evolution of Circumstellar Disks

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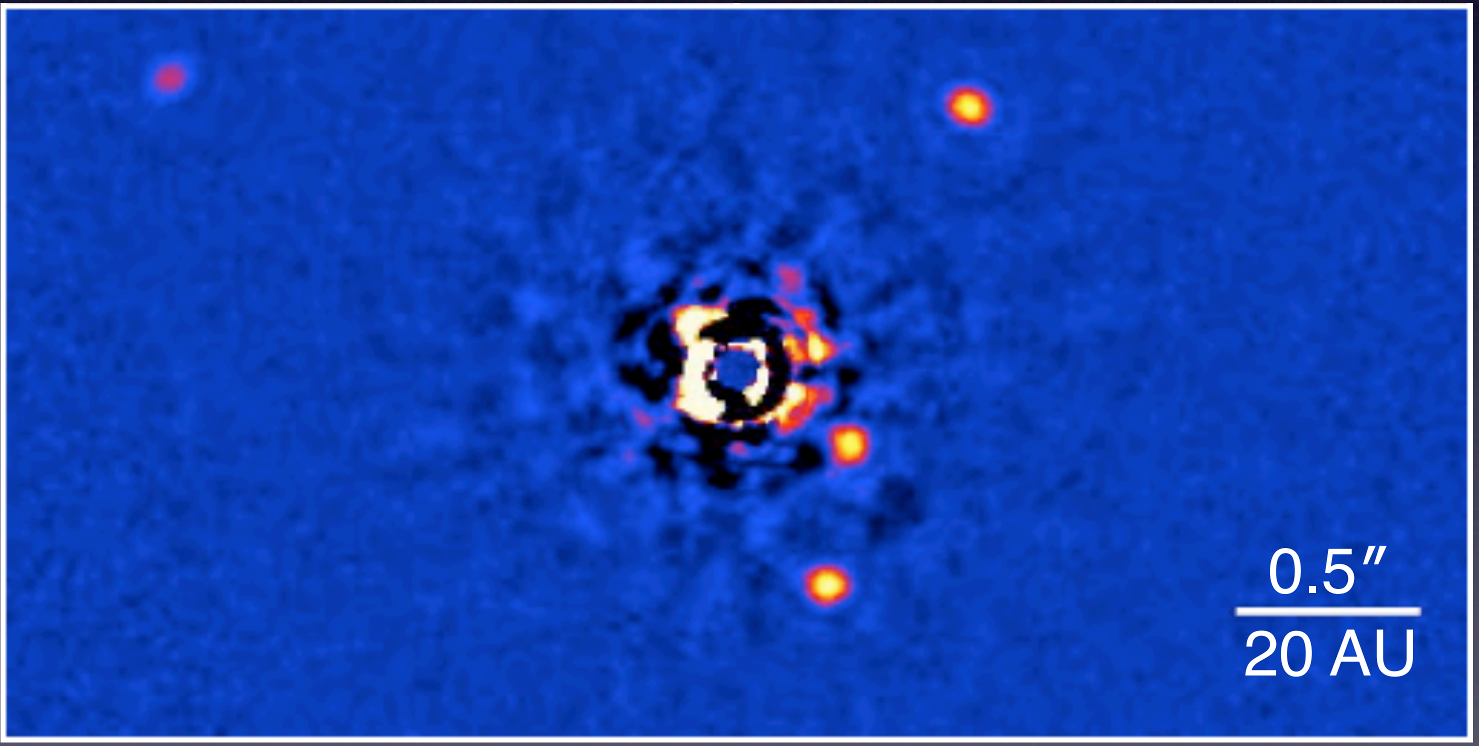
Caltech

Silhouette disk in Orion

NASA/ESA & L. Ricci

Planets around HR 8799

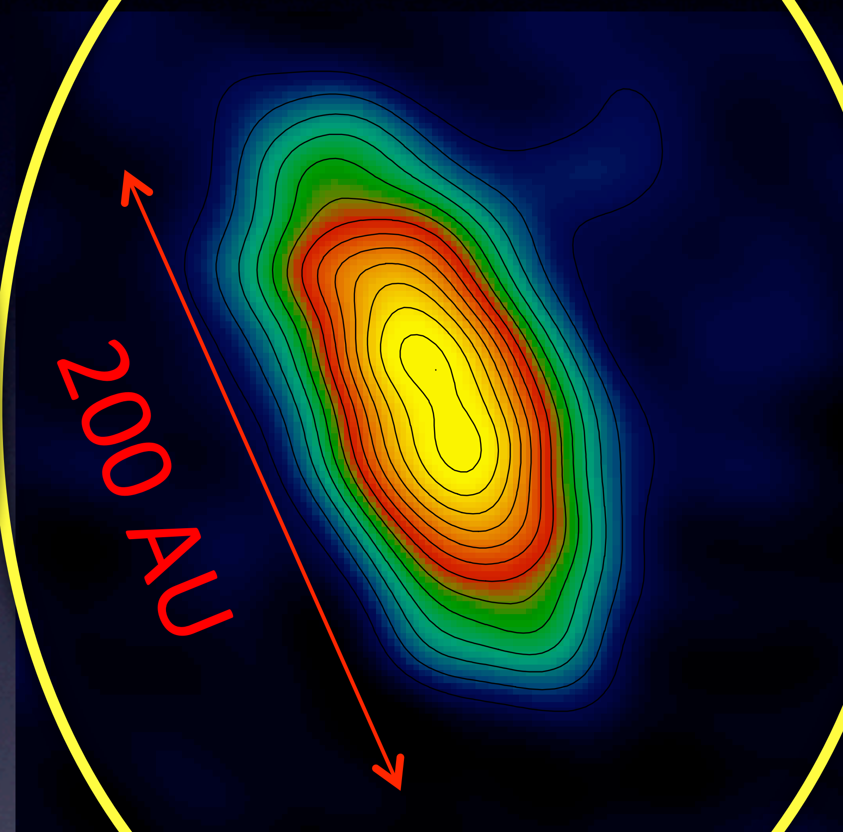


Marois et al. (2011)

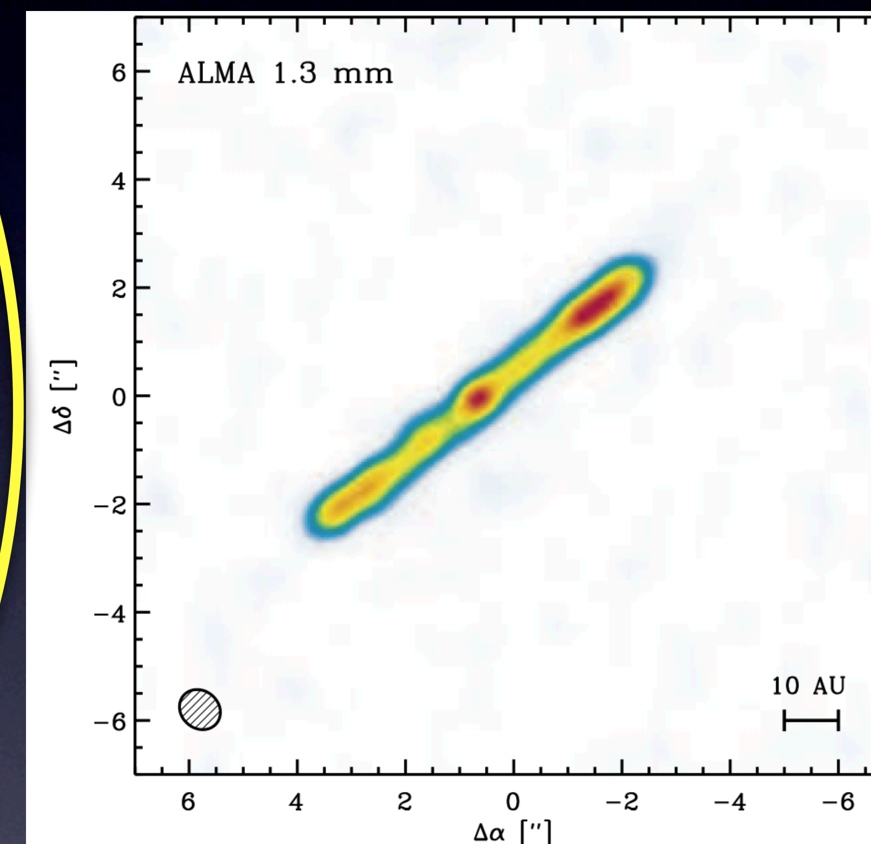
Evolution of Young Stars

Class 0/I → Class II → Debris

Tobin et al. (2012)



Isella et al. (2010)



MacGregor et al. (2013)

Jes Jørgensen
Susana Lizano

This talk;
Inga Kamp

Outline

Observe evolution of gas and dust to understand the planet formation process

Emphasis on large samples of stars

1) Disk evolution: infrared

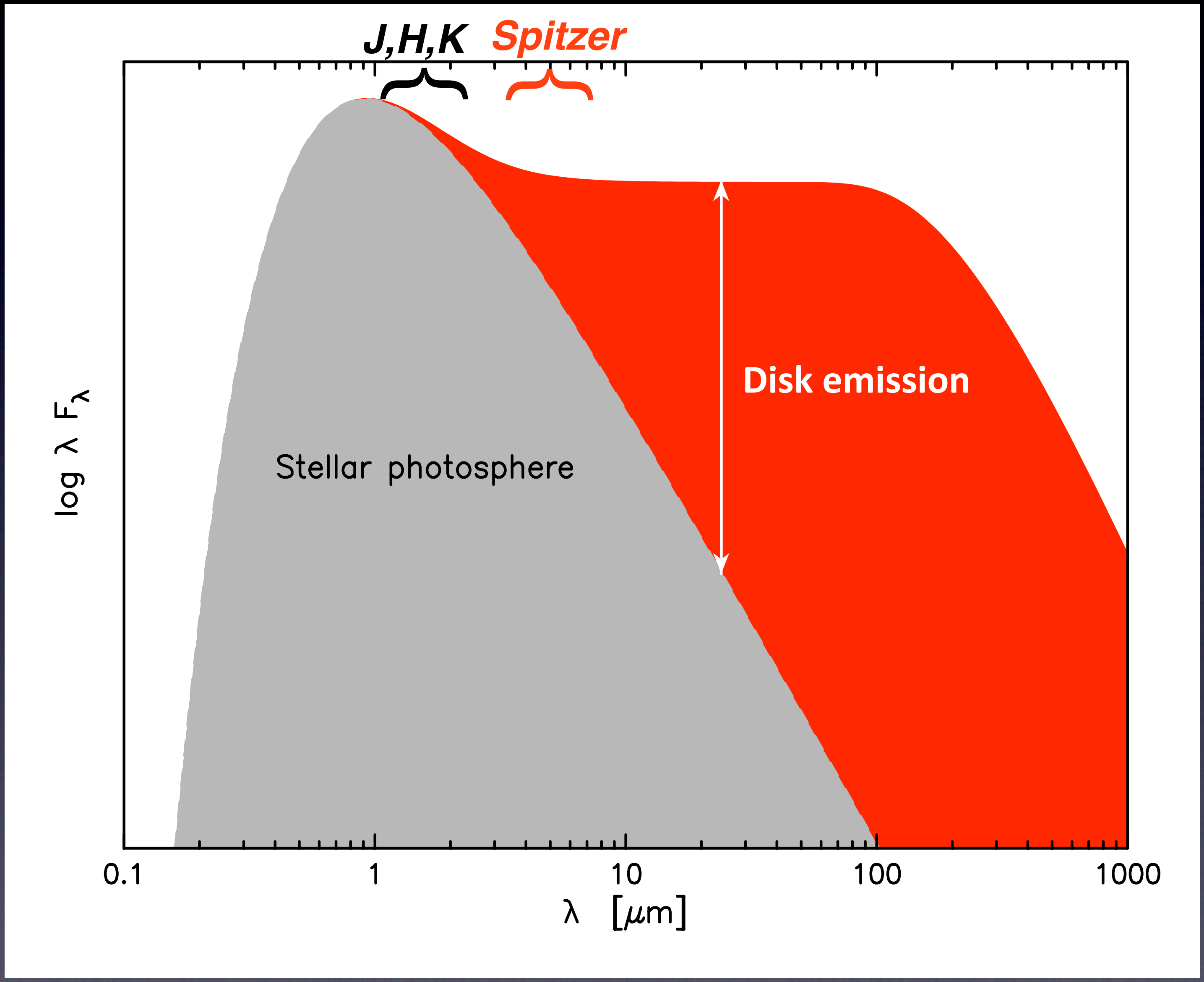
- timescales for disk dissipation
- dependence on stellar mass

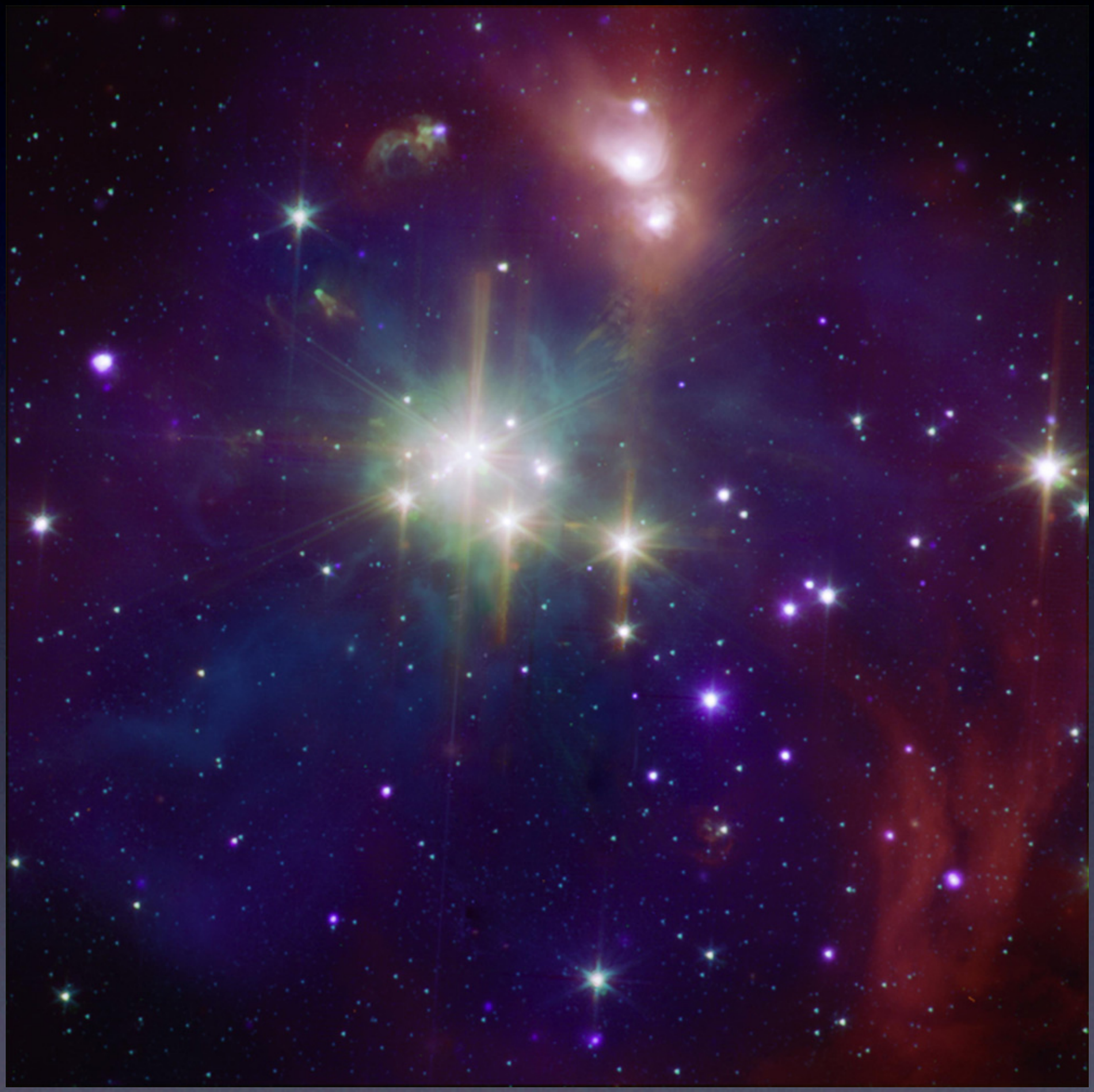
2) Disk evolution: submillimeter

- temporal evolution of disk properties

3) The role of ALMA

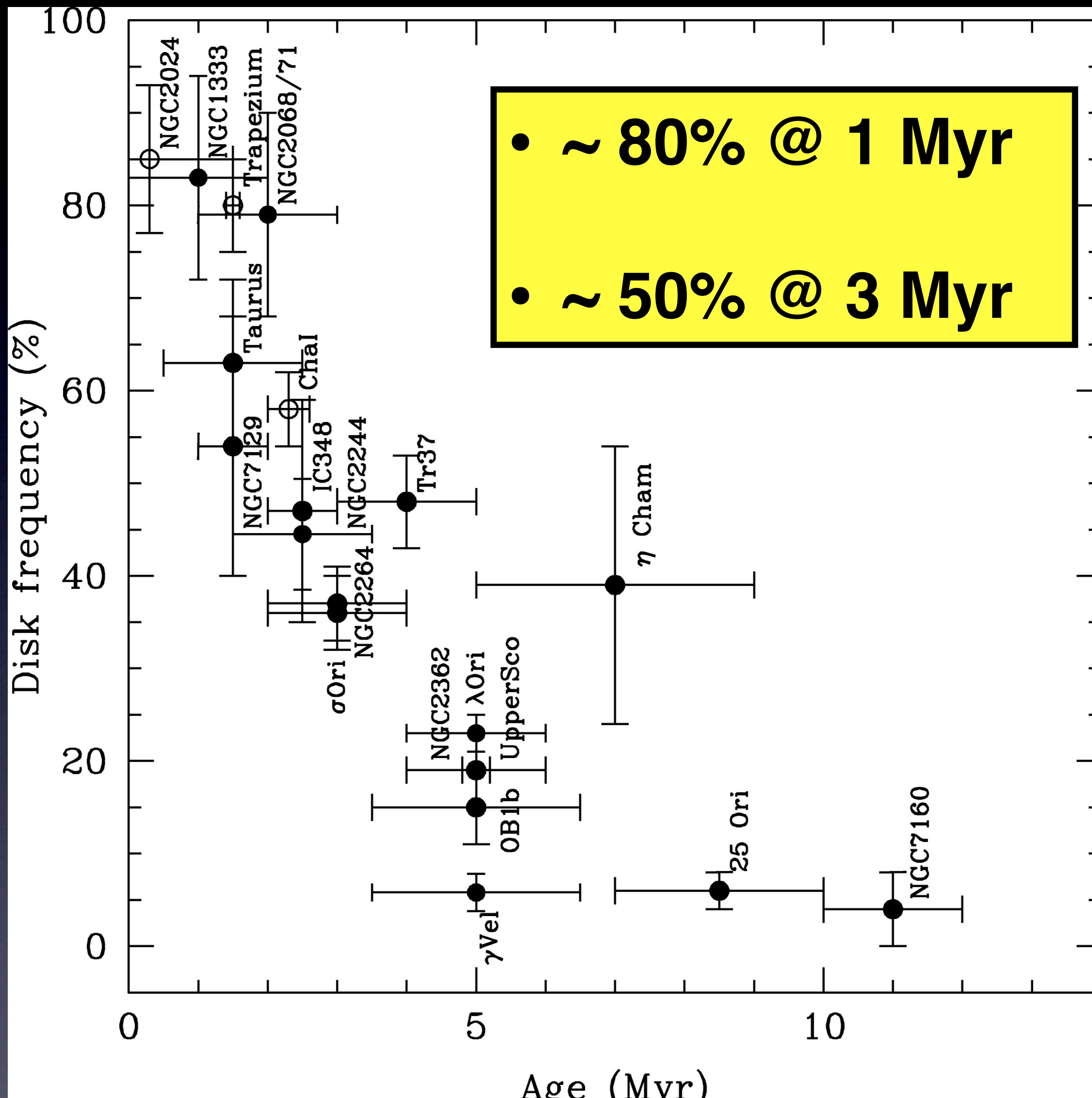
Identifying Disks in the Near-IR





Coronet Cluster

Timescales for Dust Dissipation

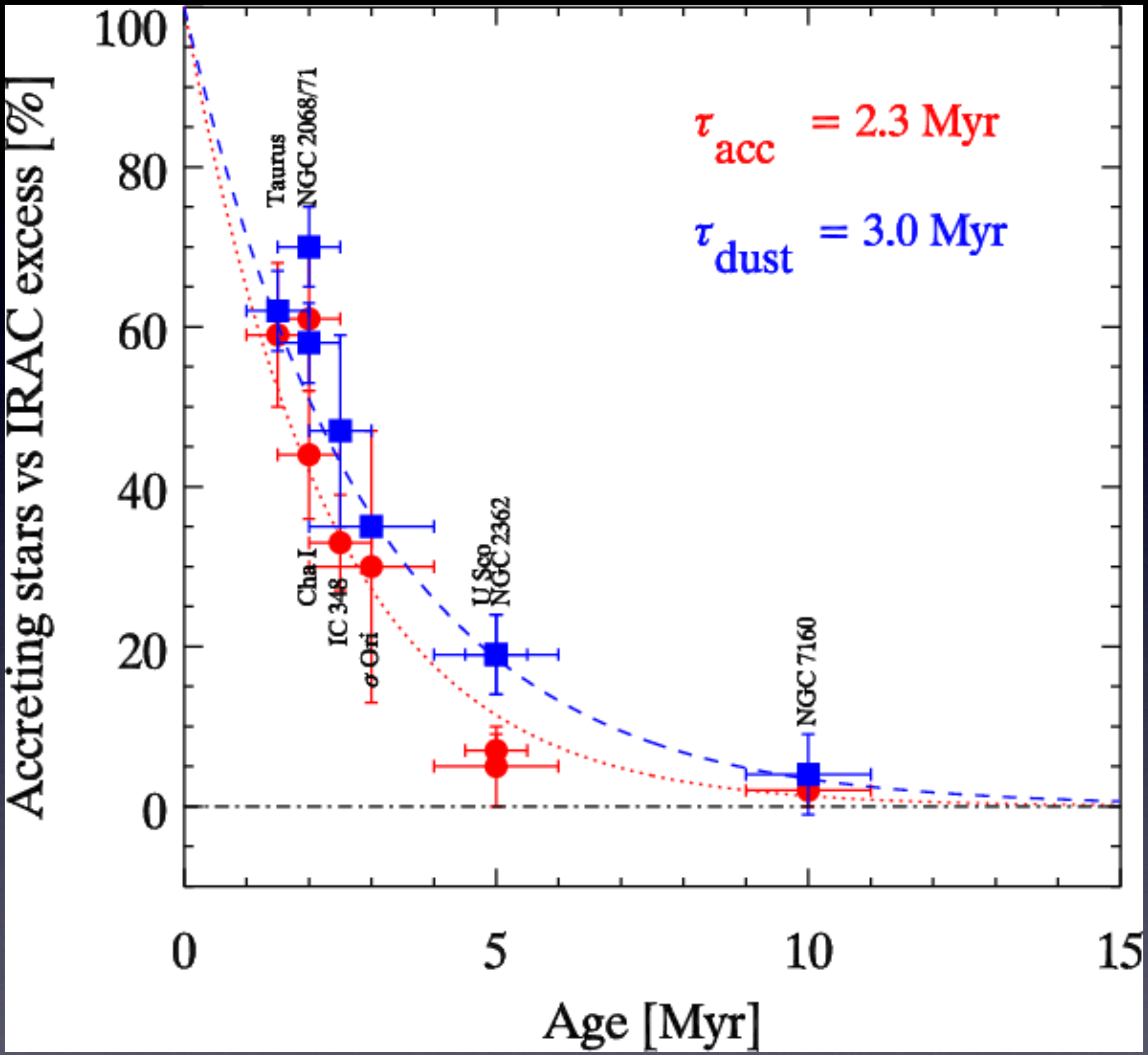


- 3.6 μm excess
- K5-M stars

Hernández et al. (2008)

See also: Haisch et al. (2001),
Mamajek et al. (2004), Hillenbrand (2005)

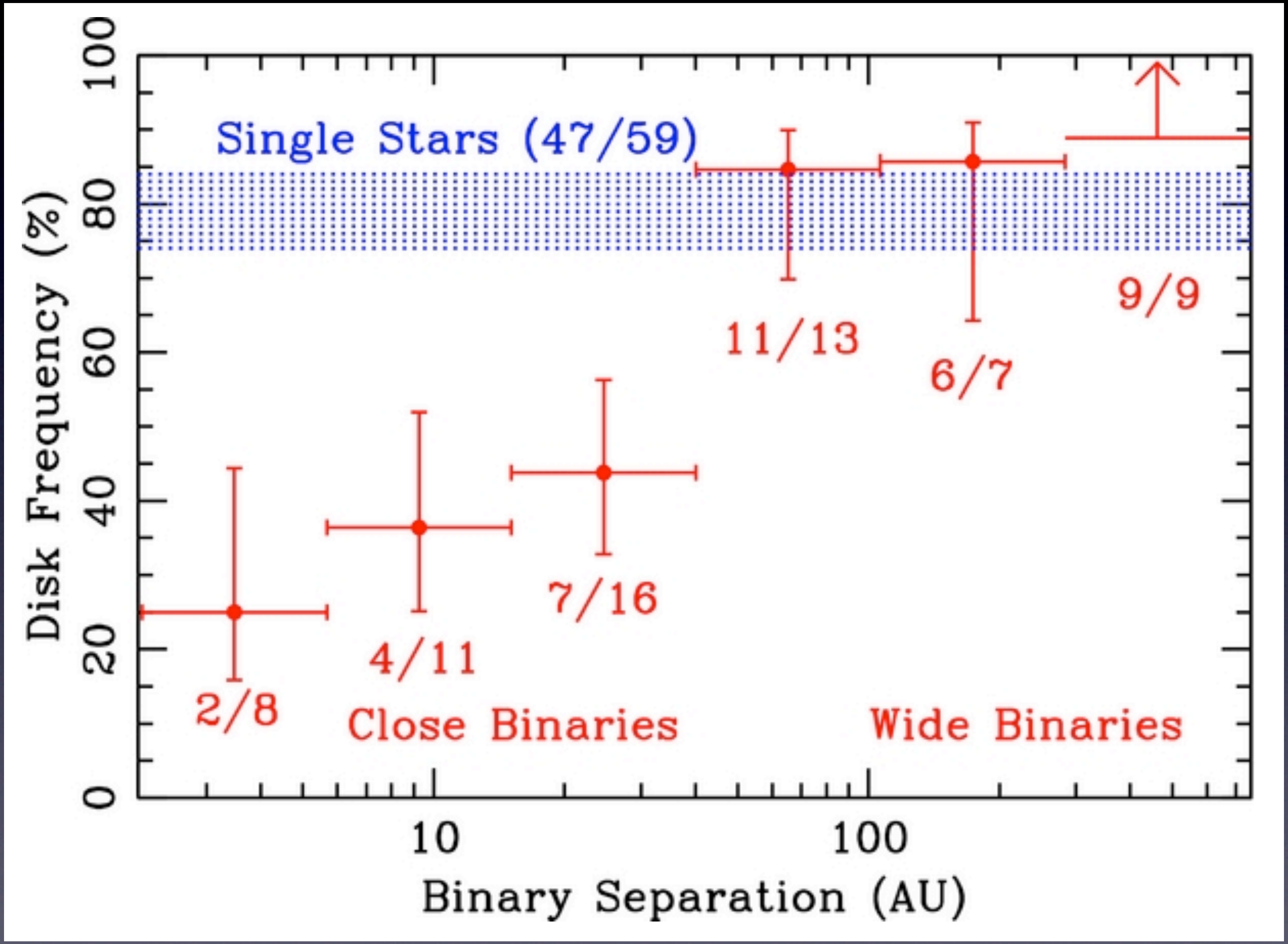
Timescales for Gas Dissipation



Fedele et al. (2010)

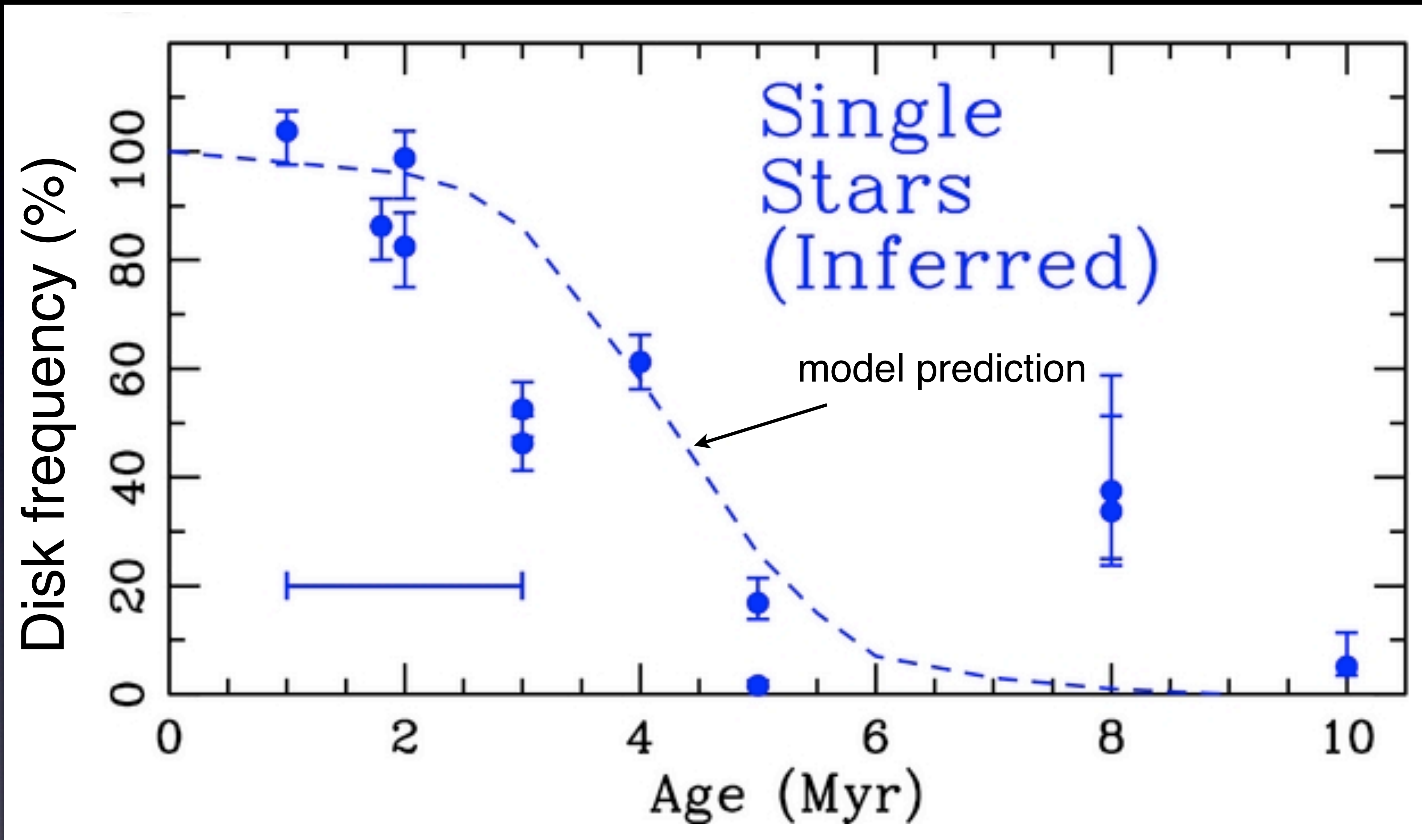
Disk Frequency & Multiplicity

Frequency vs. separation (Taurus)



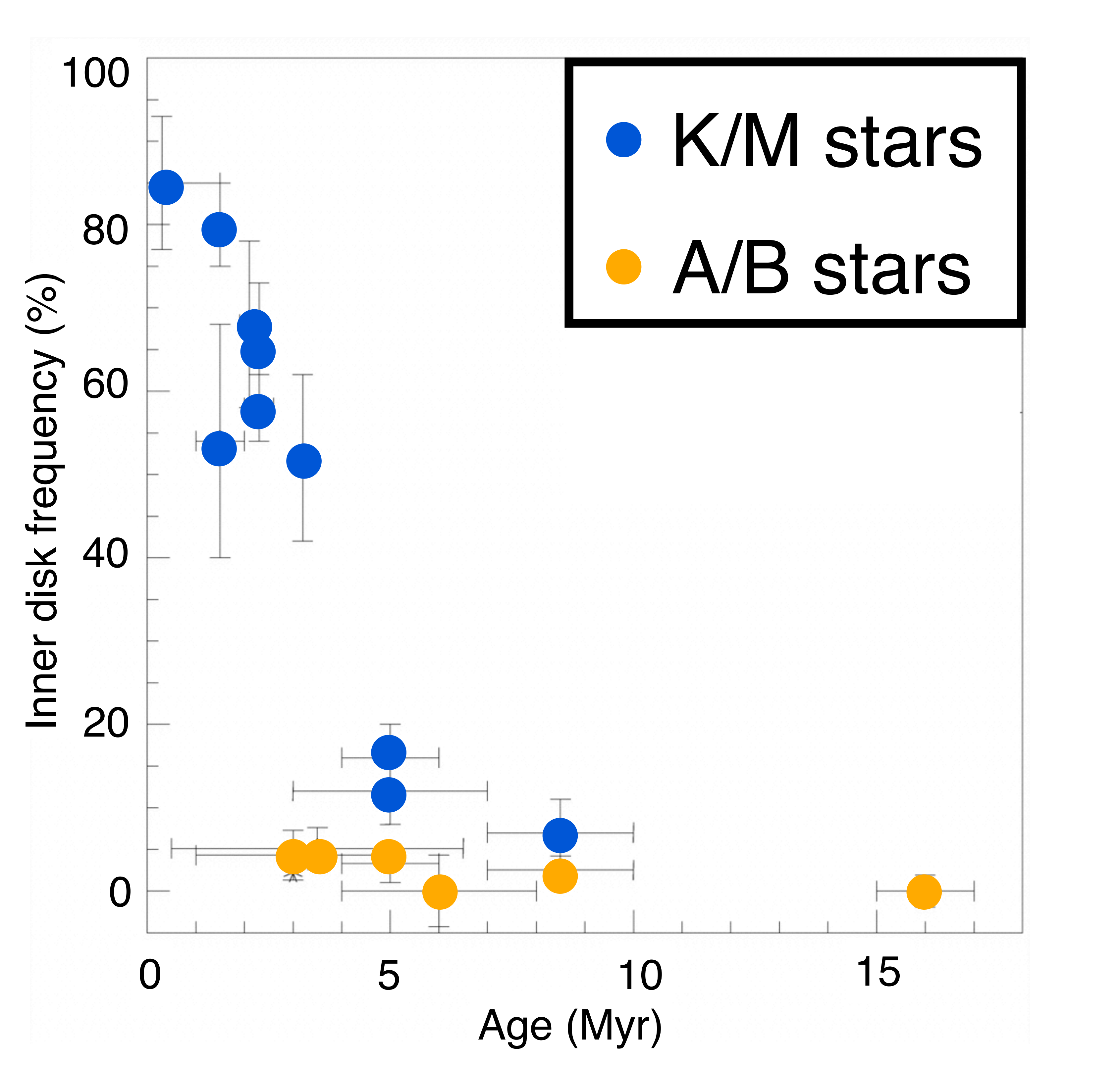
Kraus & Hillenbrand (2012)
See also Cieza et al. (2009), Daemgen et al. (2012)

Multiplicity and Disk Evolution



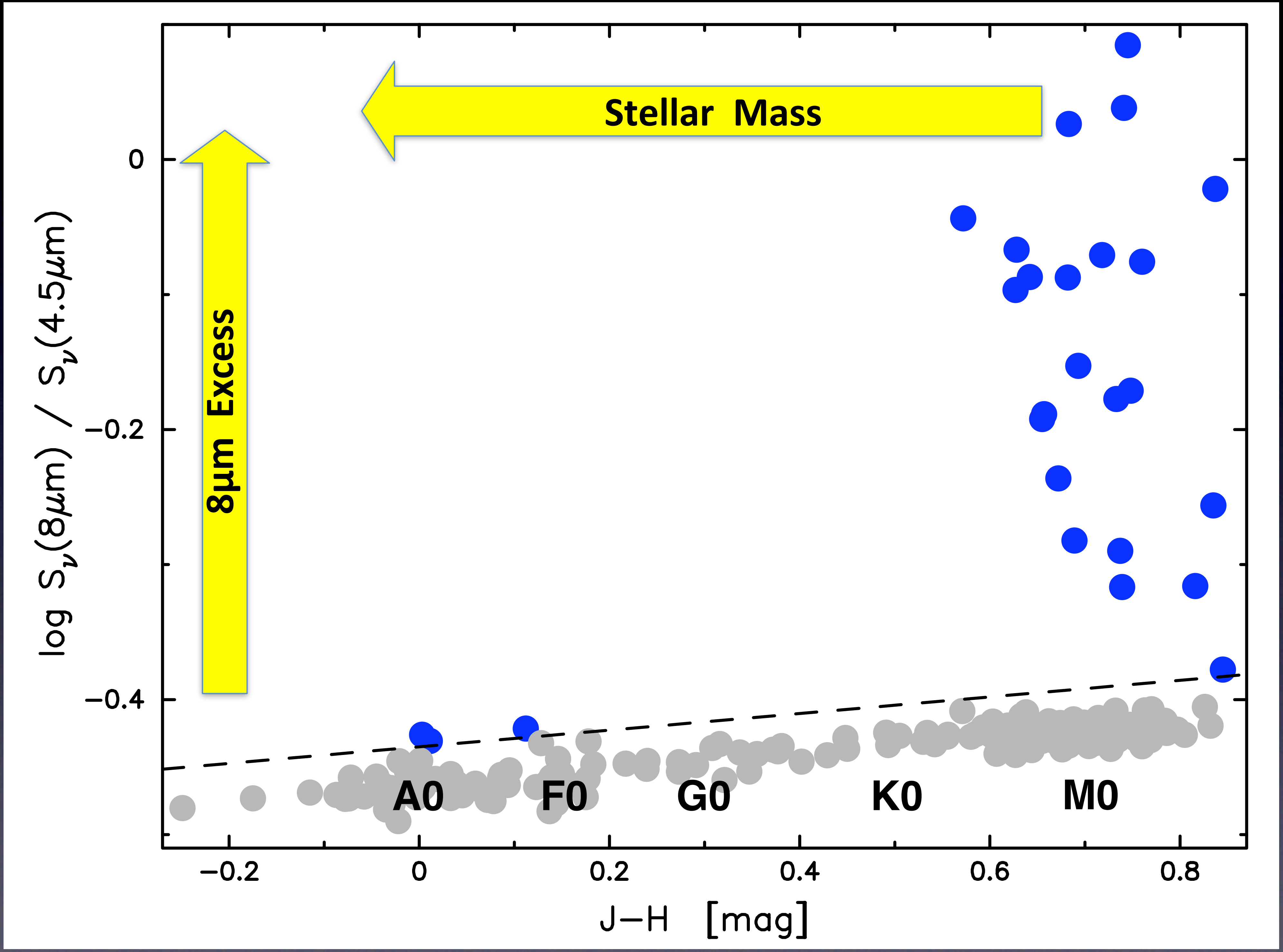
Kraus & Hillenbrand (2012)

Timescale depends on M_{star}



Hernández et al. (2005)

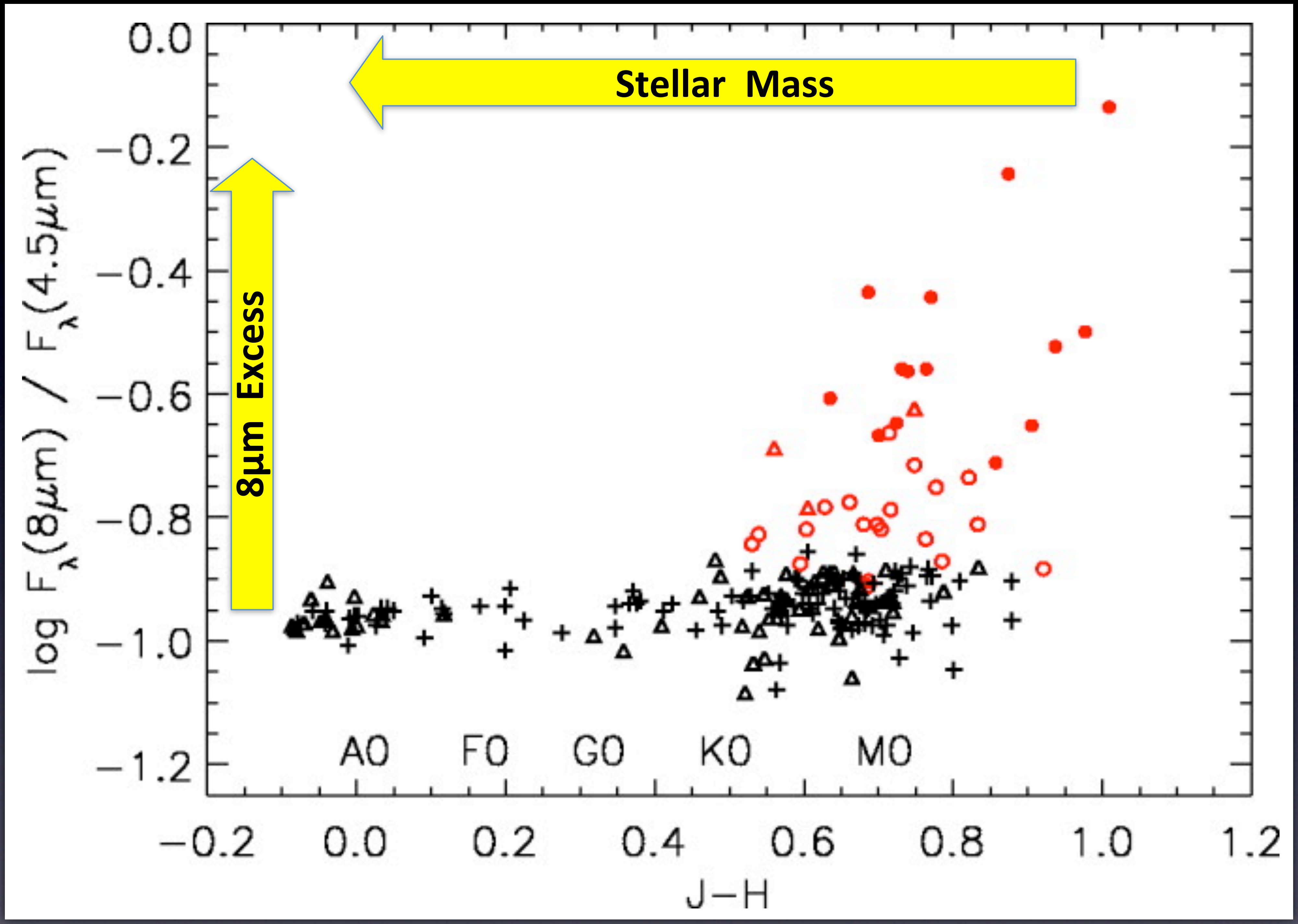
Timescale depends on M_{star}



Carpenter et al. (2009)

Upper Sco (5 Myr)

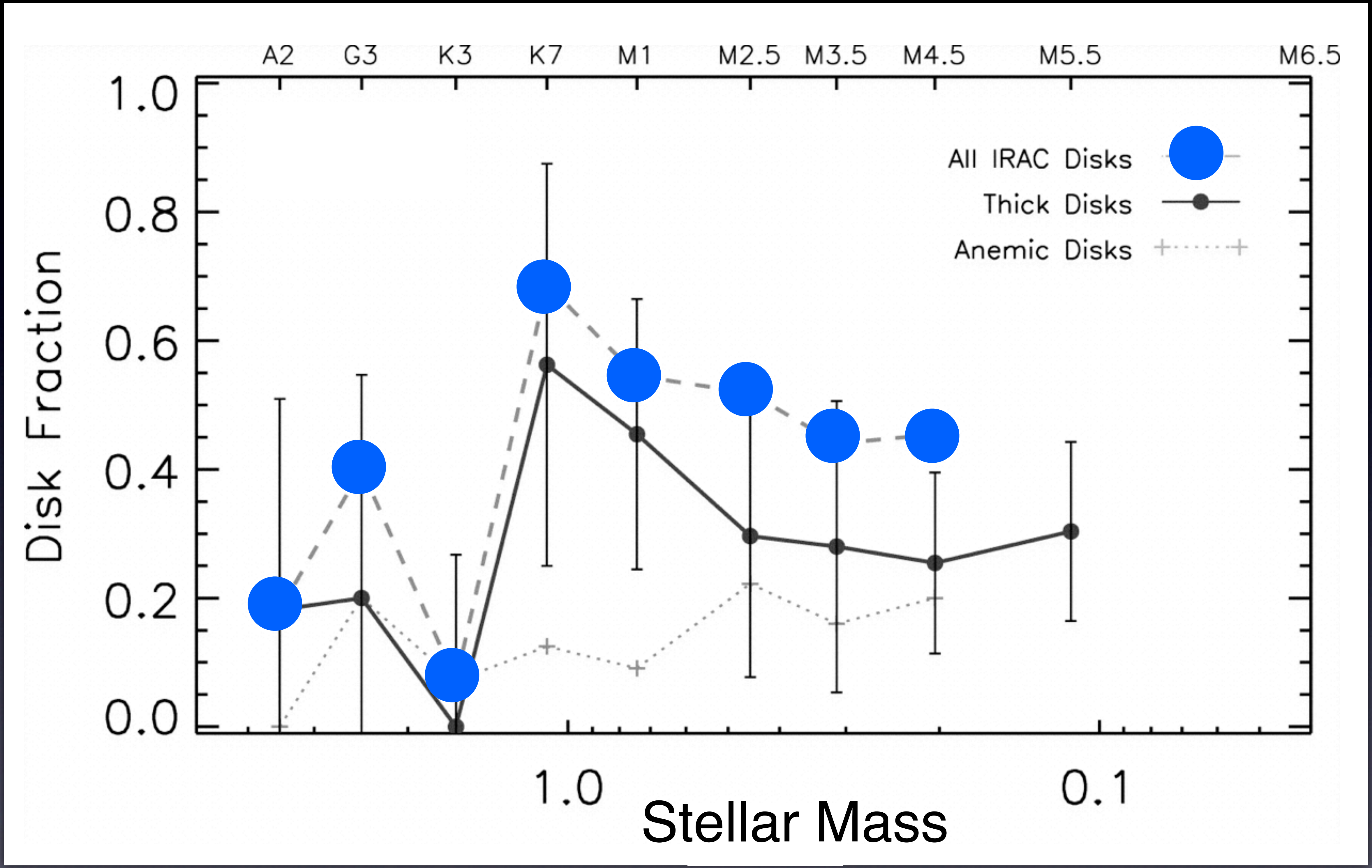
Timescale depends on M_{star}



Dahm & Hillenbrand (2007)

NGC 2362 (5 Myr)

Timescale depends on M_{star}



Lada et al. (2006)

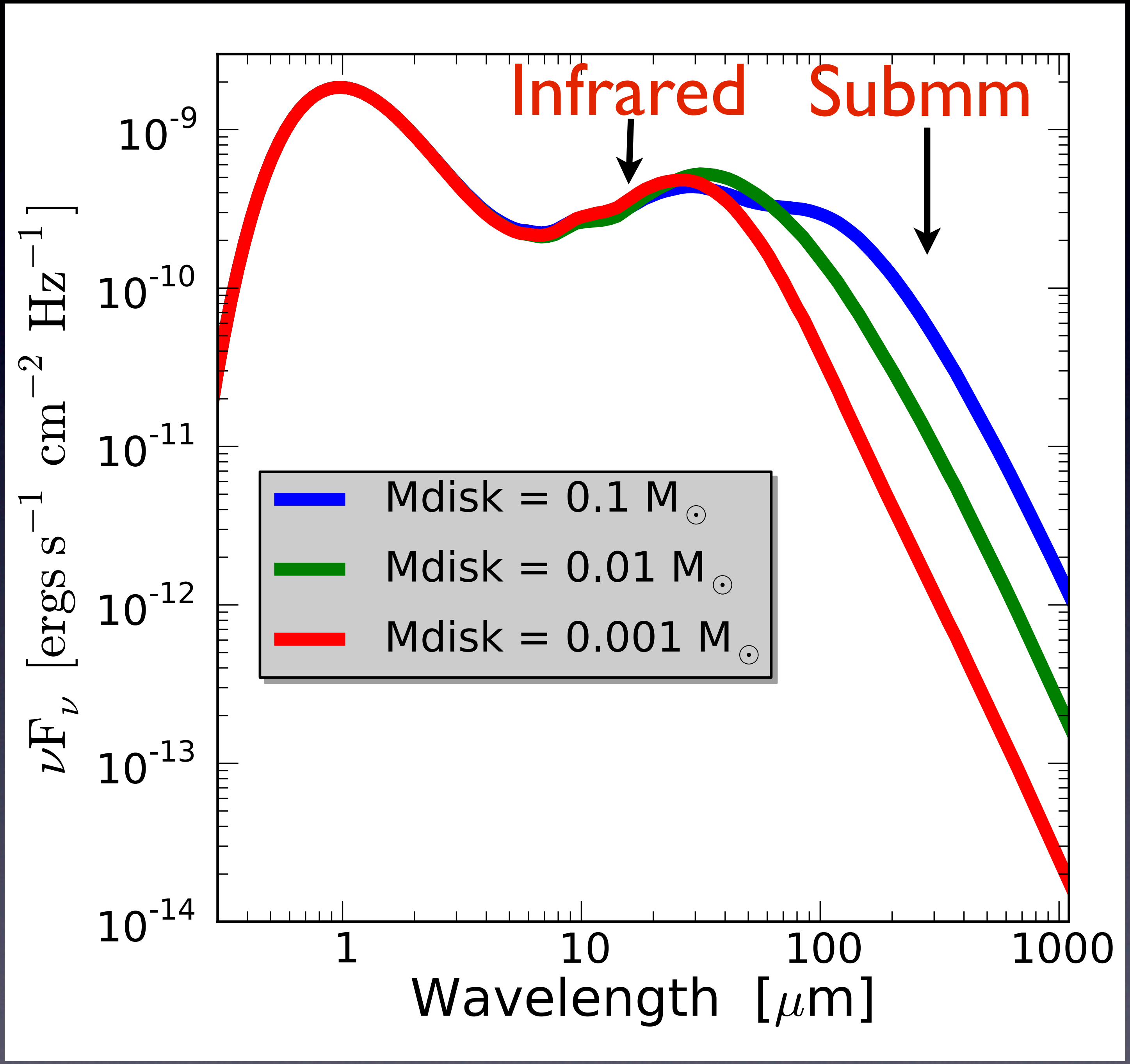
IC 348 (3 Myr)

Summary: infrared observations

- K/M type stars (~ 0.1 - 1 Msun)
  - 50% of inner disks dissipate by 3 Myr
  - no evidence for differences between 0.1 and 1 Msun (Ercolano et al. 2009)
  - evolution depends on multiplicity

- A/B type stars ($\gtrsim$ 2.5 Msun)
  - disks dissipate on faster time scales

Limitation of Infrared Surveys

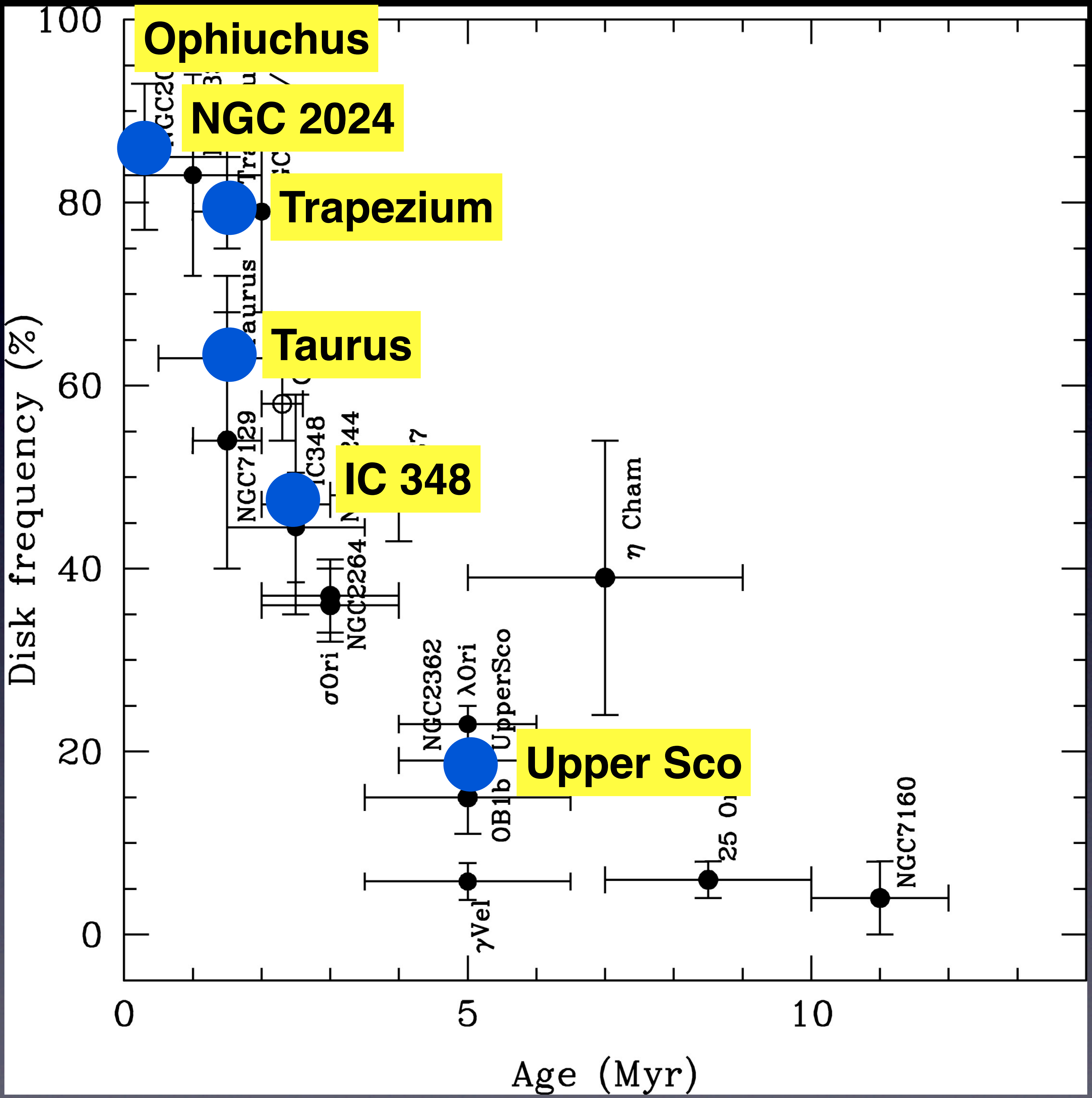


Model spectral energy distributions

- Probes inner (< 1 AU) disk
- Optically thick

⇒ (sub)-millimeter

(Sub)-millimeter Surveys of Disks



Hernández et al. (2008)

Measuring Disk Masses

$$F_\nu(R) \propto \Sigma_d(R) \cdot k_\nu(R) \cdot T(R)$$

observed flux density	surface density	dust opacity	dust temperature

Constraints:

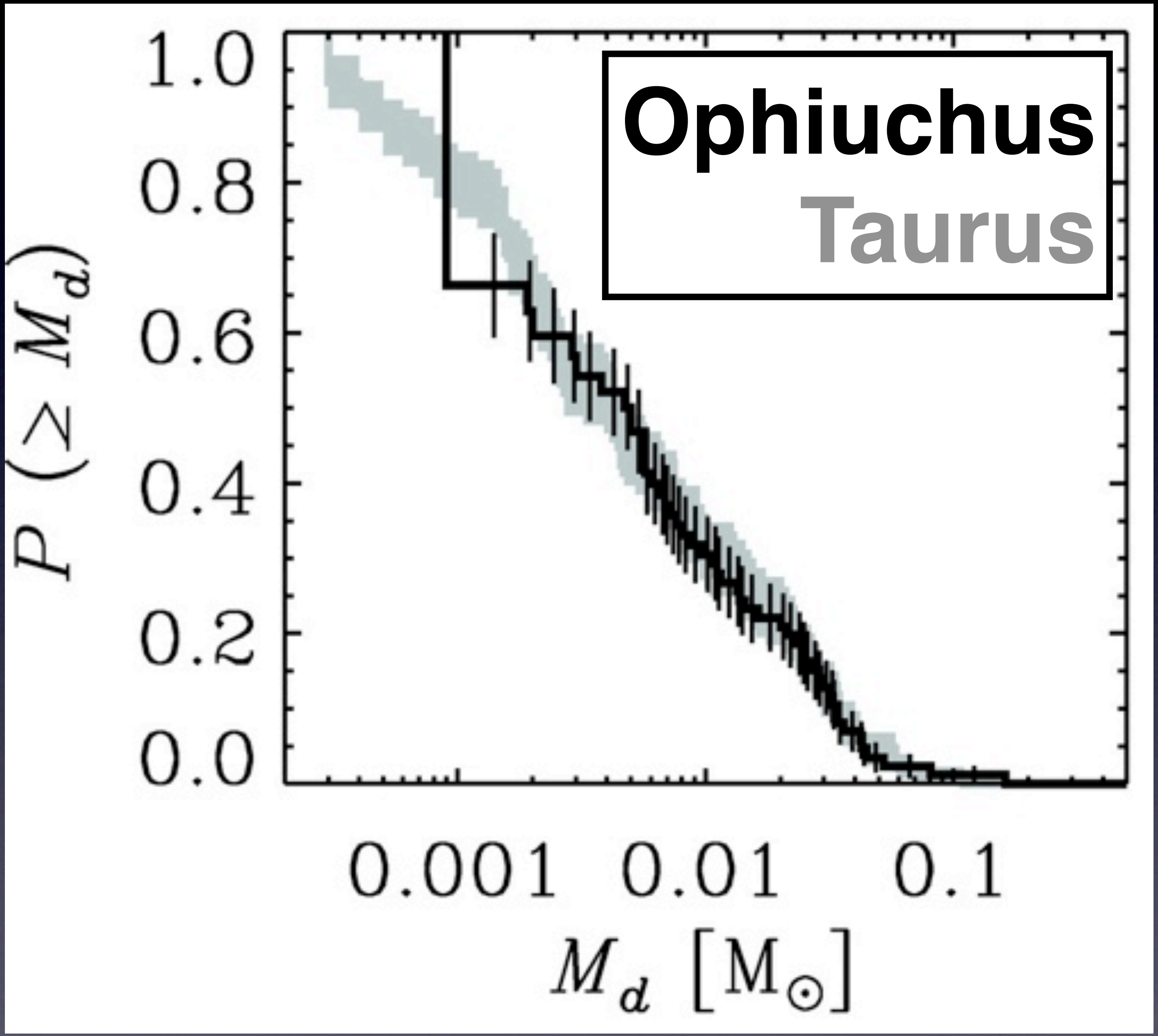
- spectral energy distribution
- sub-millimeter flux
- spatial information (interferometry)

Caveats:

- dust opacity
- gas-to-dust ratio

Disk Properties at 1-2 Myr

M_{disk} (gas + dust)



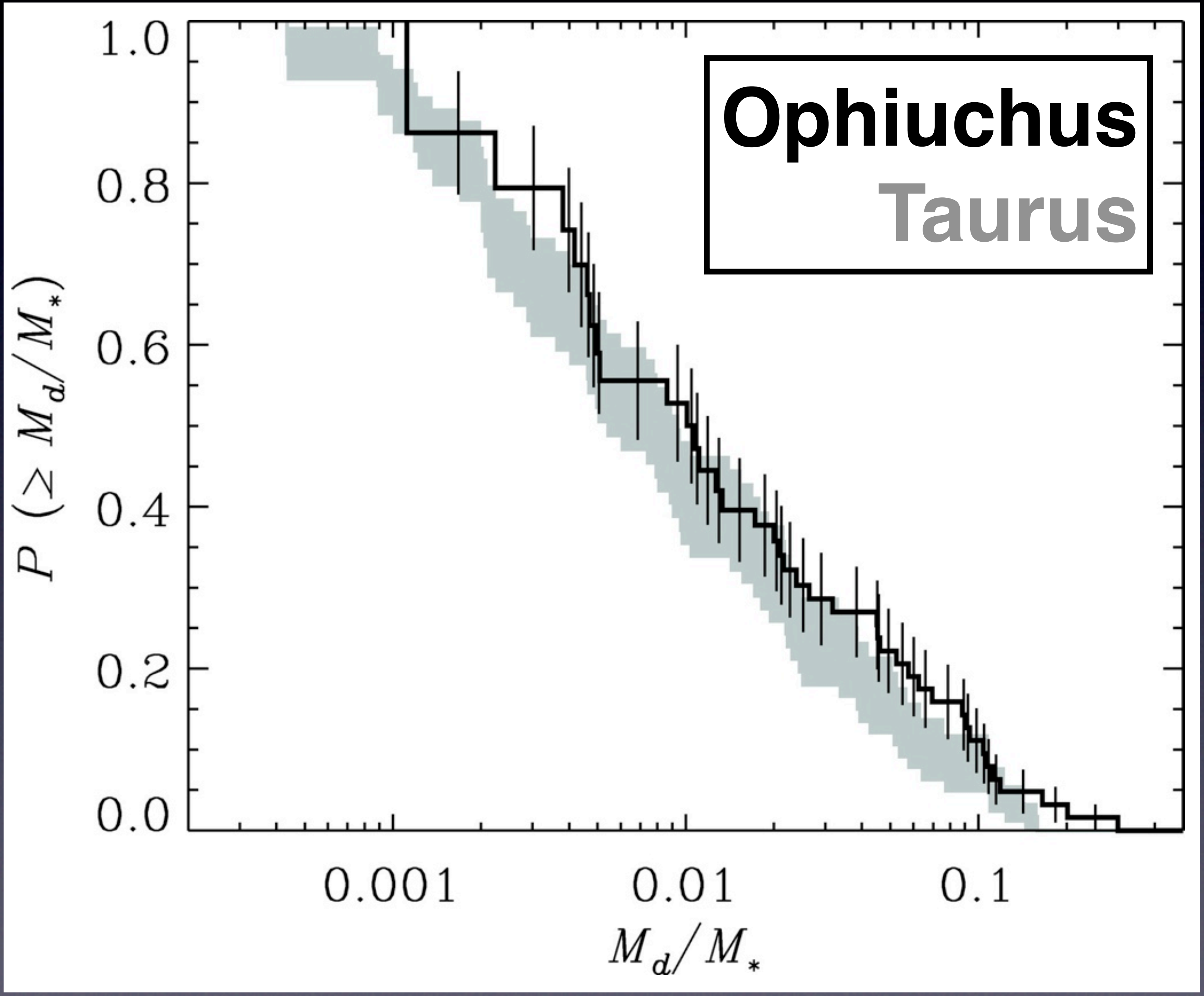
Andrews & Williams (2007)

- Class II sources
- $M_{disk} \approx 5\ M_{Jupiter}$ (median)

See also: Beckwith et al. (1990), Motte et al. (1998), Andrews & Williams (2005)

Disk Properties at 1-2 Myr

M_{disk} / M_*

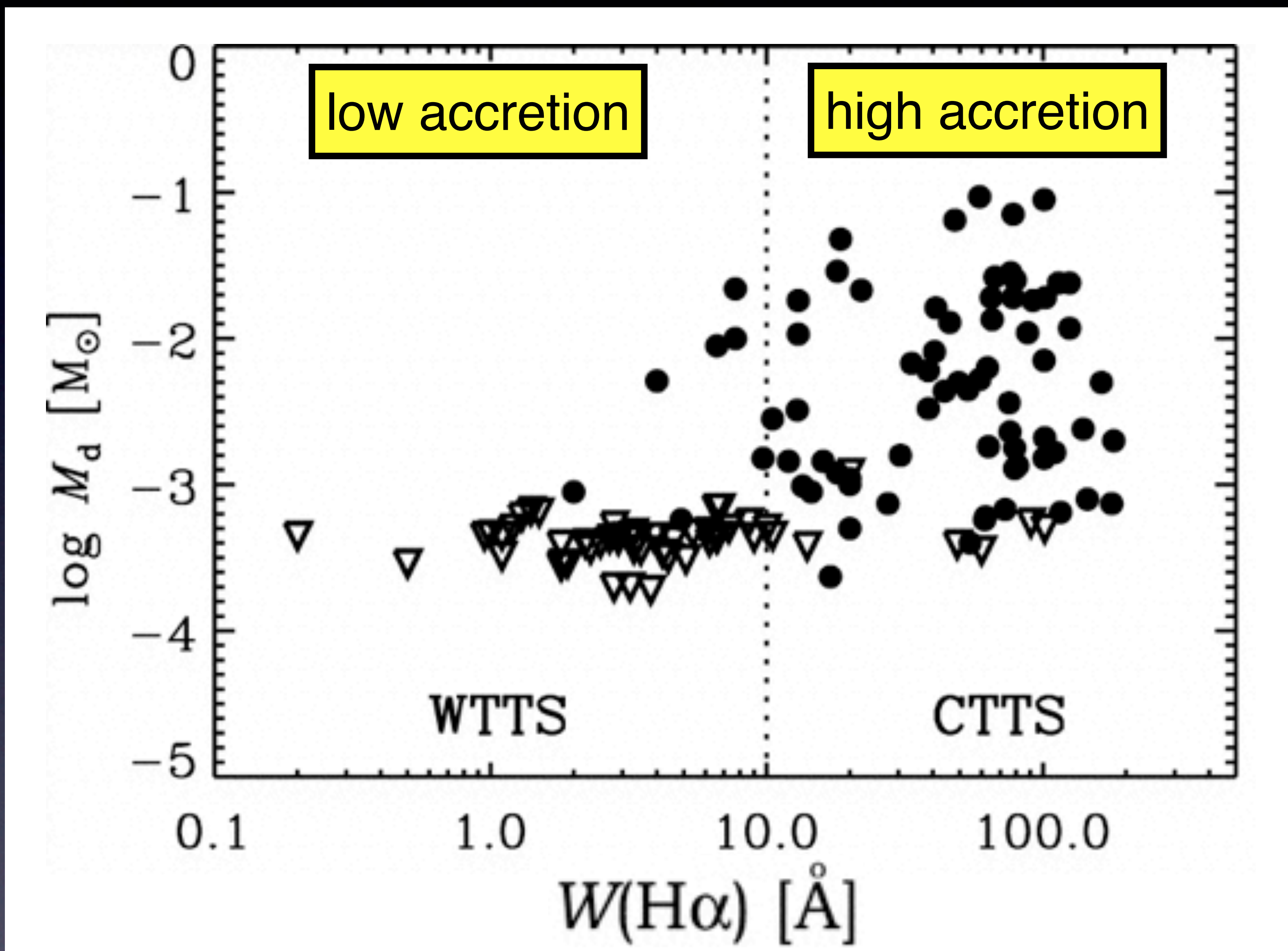


Andrews & Williams (2007)

- Class II sources
- $M_{disk}/M_* \approx$ 0.5-1% (median)

Dispersing the Outer Disk

M_{disk} vs. Hα equivalent width

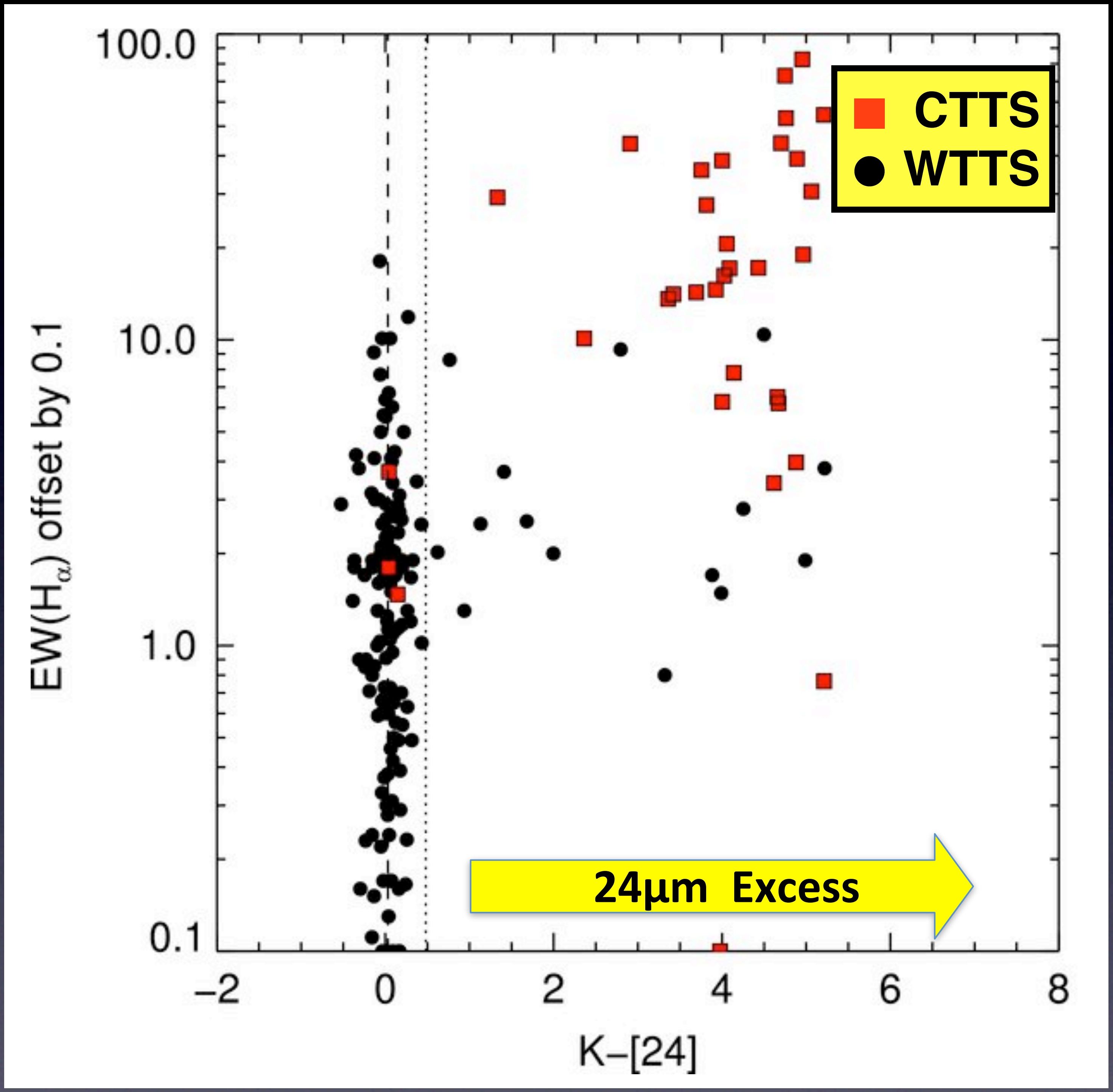


Andrews & Williams (2005)

See also Beckwith et al. (1990)

- Few outer disks around WTTS
- Suggests rapid disk dissipation over all radii
- B. Ercolano: modes of disk dispersal
- U. Gorti: transition disks

Disk Dispersal

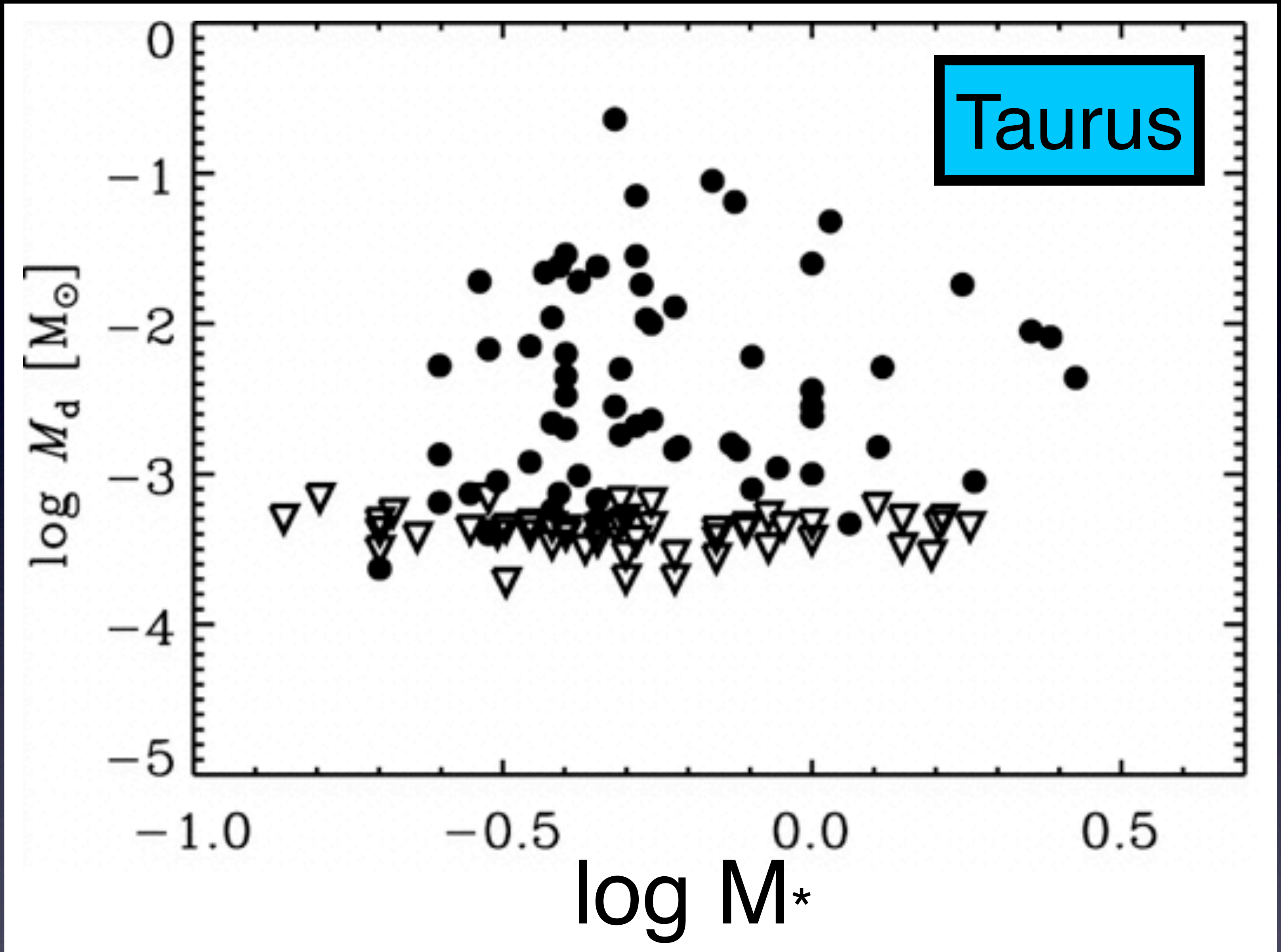


Wahhaj et al. (2010)

See also Padgett et al. (2006), Cieza et al. (2007,2013)

- Few outer disks around WTTS
- Suggests rapid disk dissipation over all radii
- B. Ercolano: modes of disk dispersal
- U. Gorti: transition disks

M_{disk} vs. M_{star} @ 2 Myr

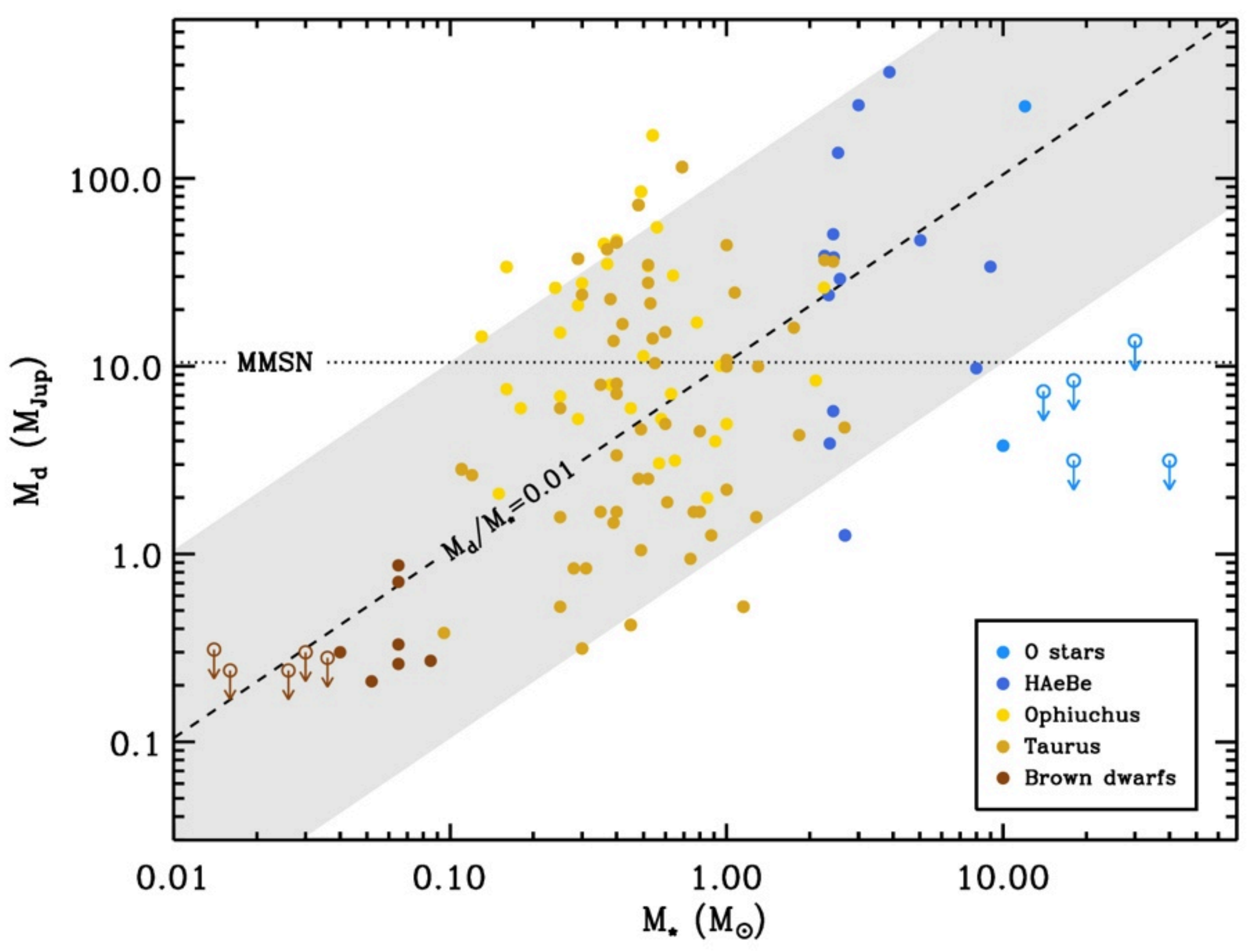


Andrews & Williams (2005)

See also Beckwith et al. (1990)

- No discernible trend for $M_* = 0.5$ to 3 M_{sun}

M_{disk} vs. M_{star}

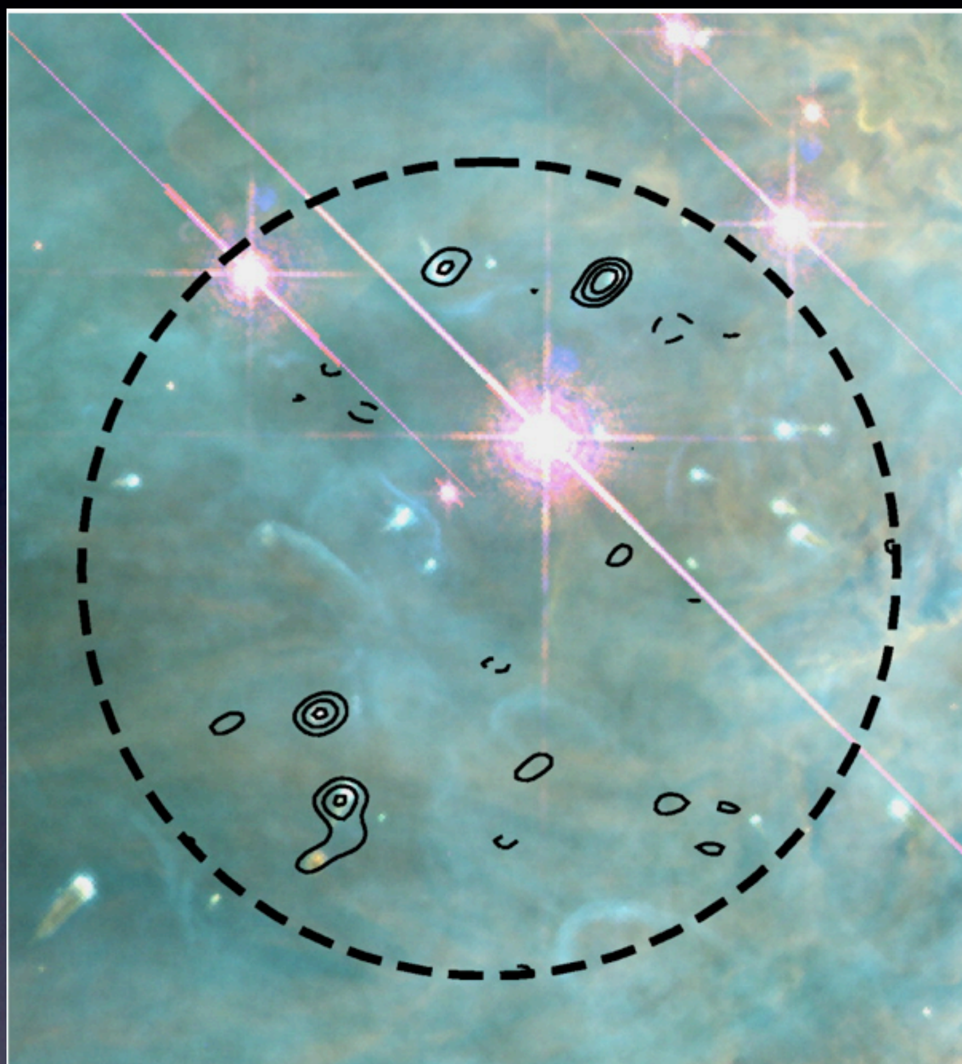


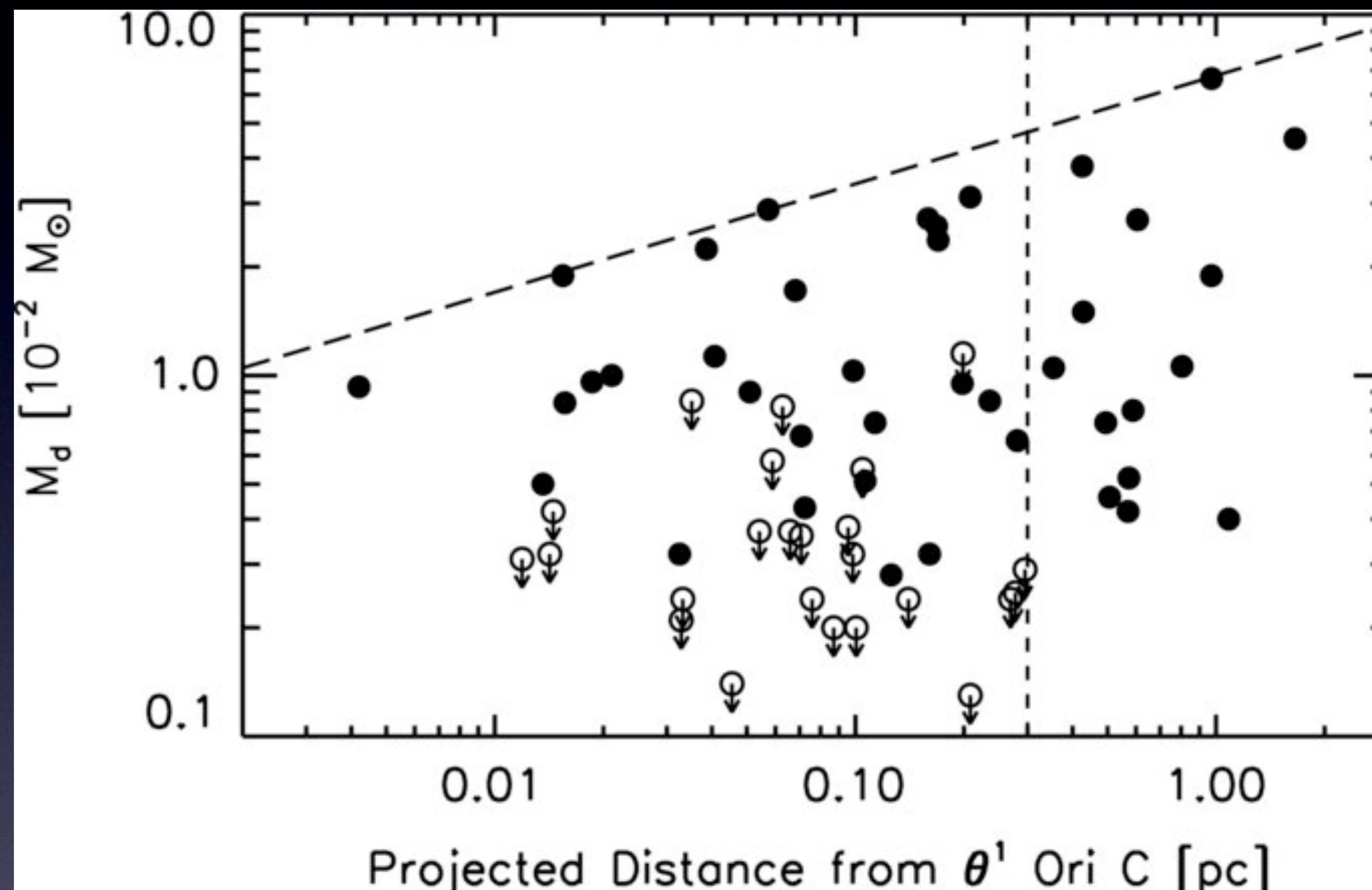
Williams & Cieza (2011)

See also Natta et al. (2000)

External Photoevaporation

SMA submm continuum survey of Orion Proplyds



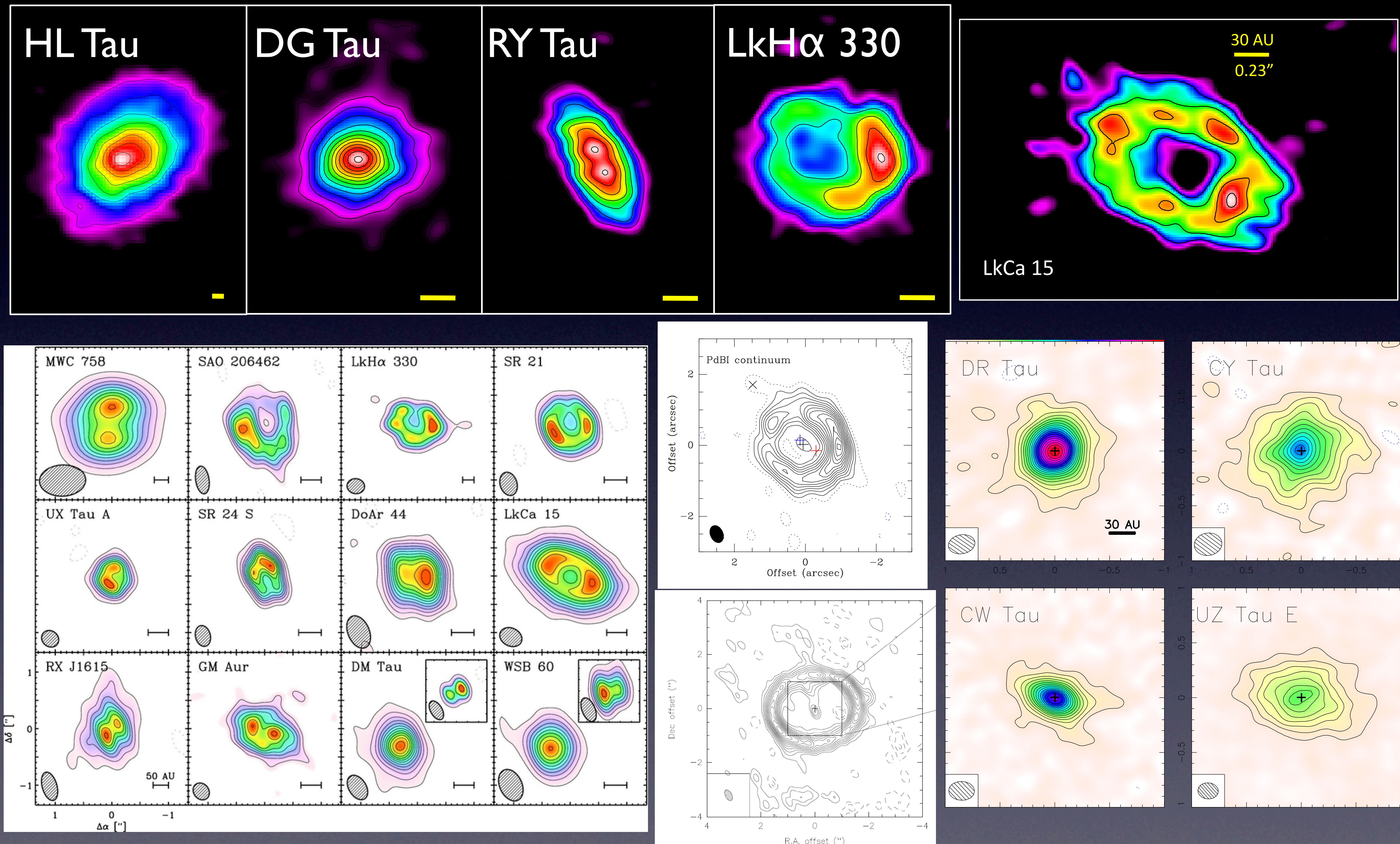


Williams et al. (2005)
See also Eisner et al. (2008)

Mann & Williams (2010)

- Low M_{disk} within 0.3 pc of Theta^1 C (O6 star)

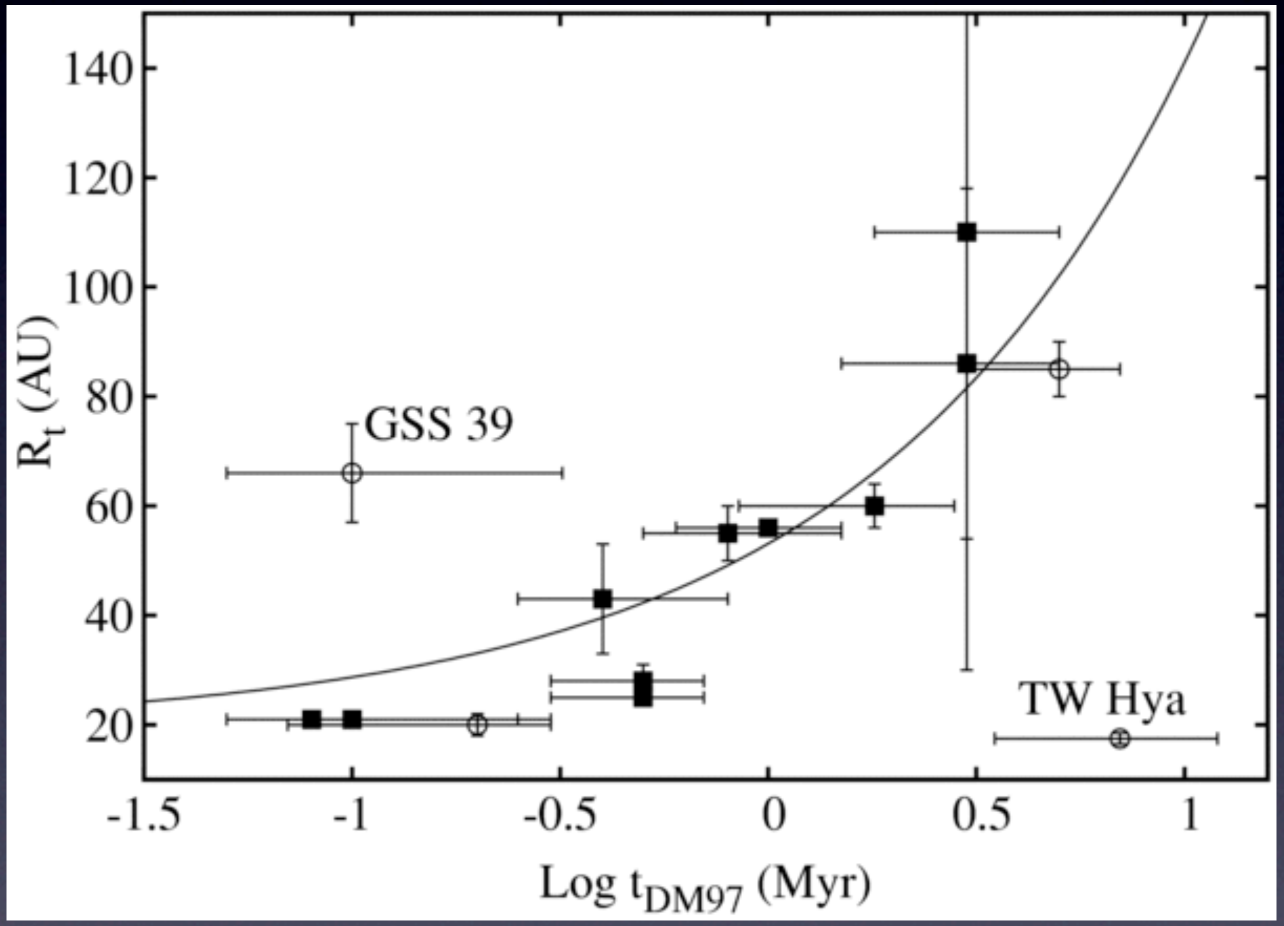
CARMA, SMA, and PdBI images



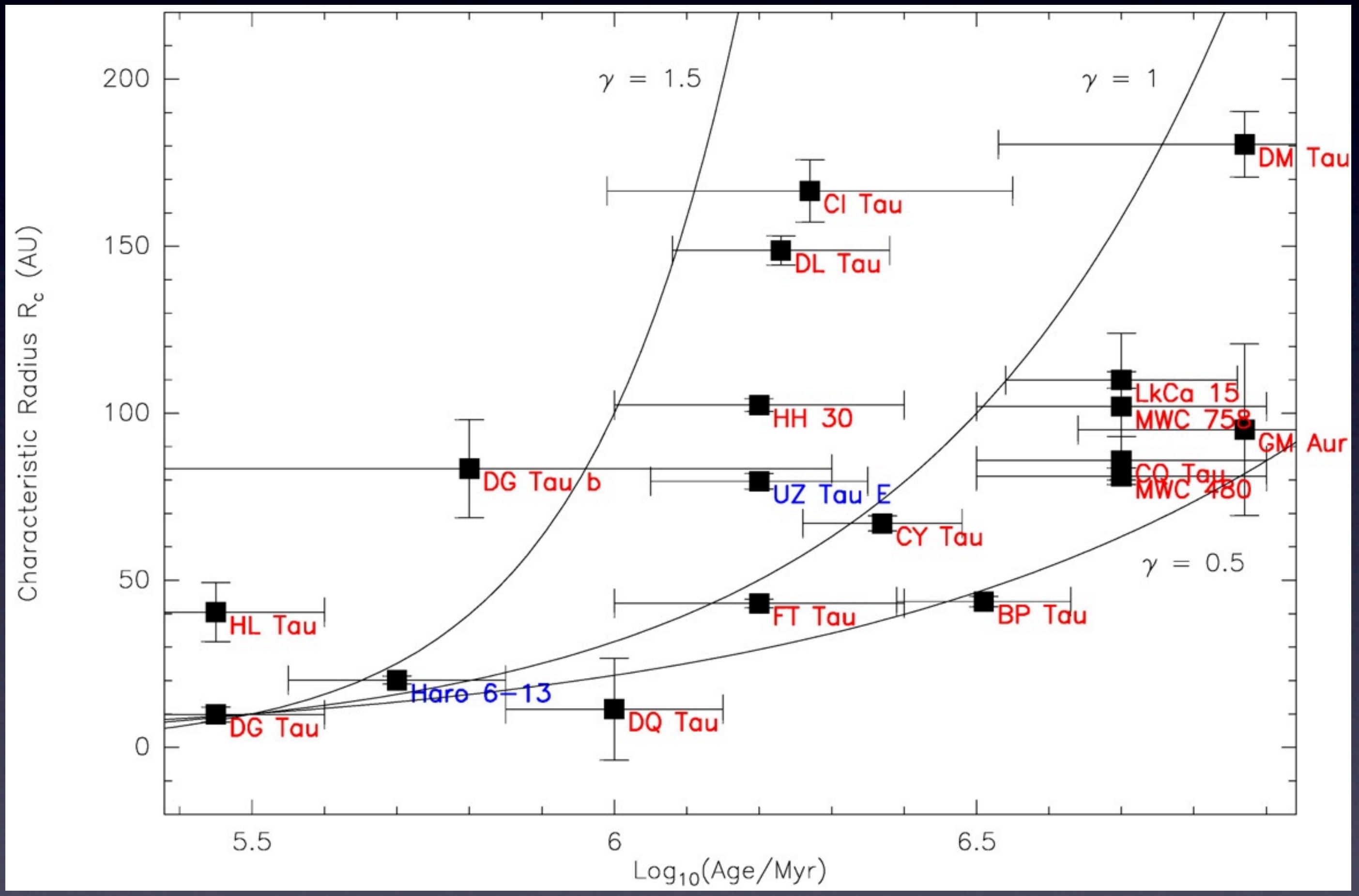
See series of papers by Andrews, Isella, Qi, Wilner, Öberg, Hughes, Piétu, Guilloteau, Dutrey, Pérez, Brown, Kitamura

Evolution in Disk Size?

Disk size vs. stellar age

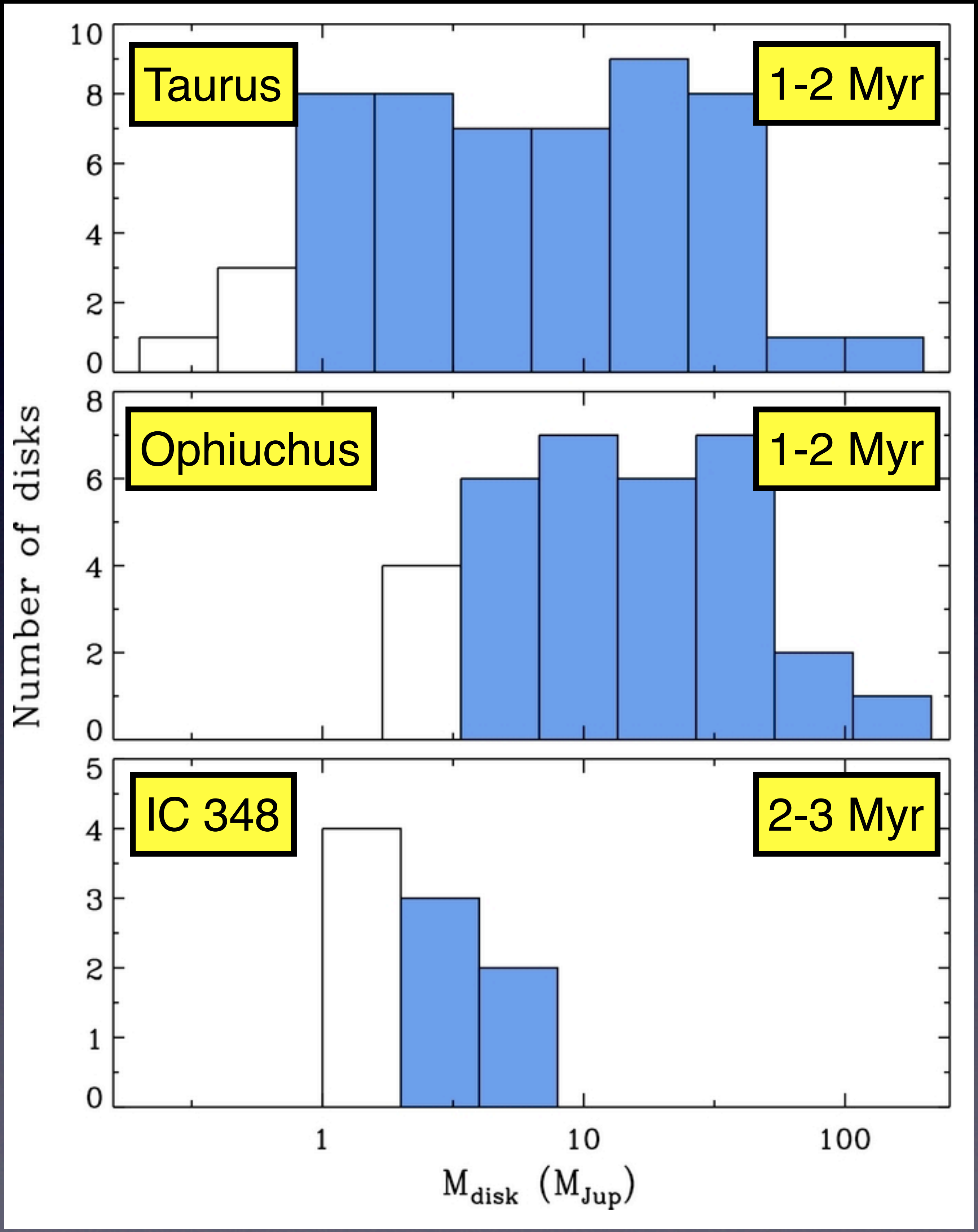


Isella et al. (2009)



Guilloteau et al. (2009)

Evolution of Disk Mass

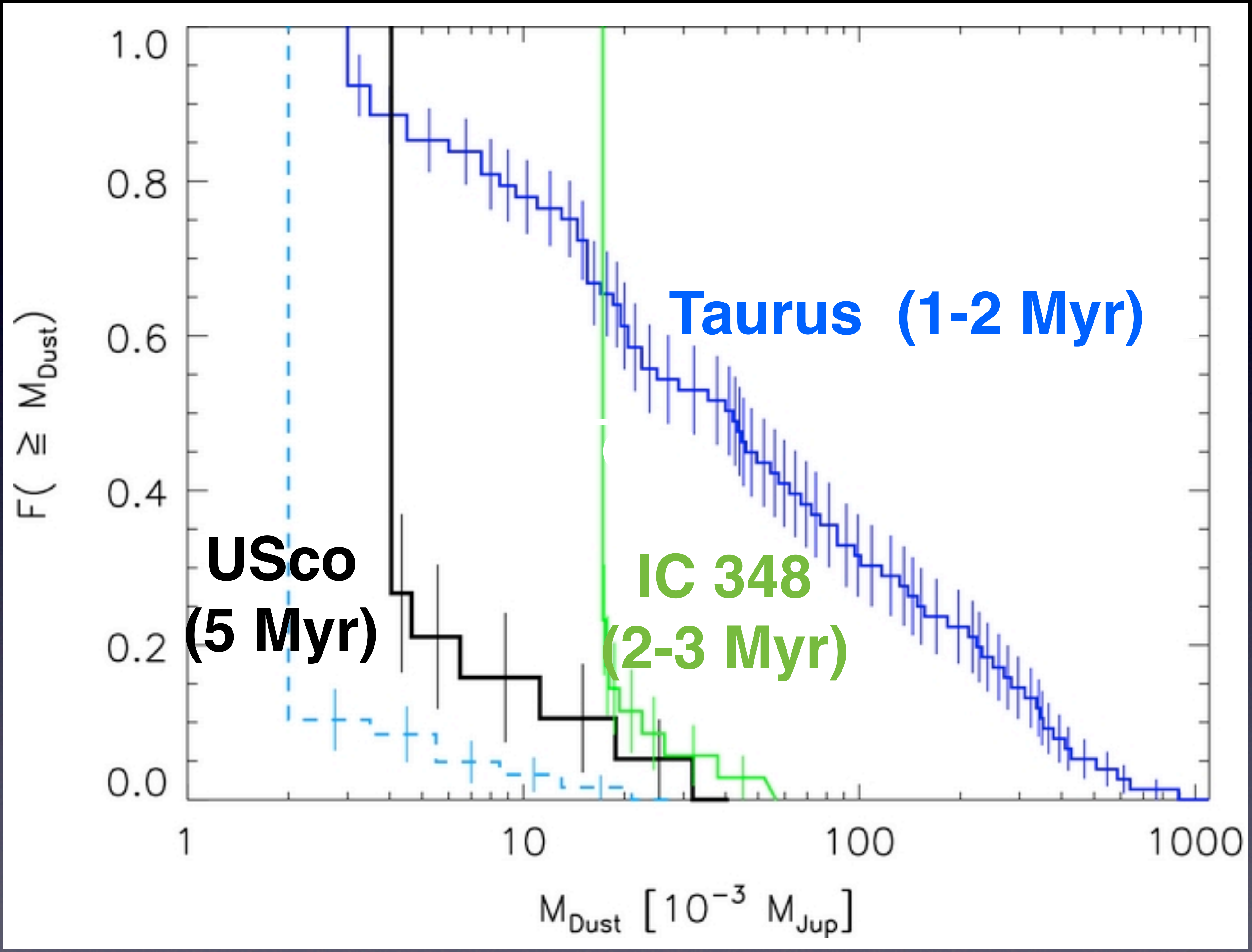


- Decline of ~ 20x in M_{disk} by 3 Myr

Lee et al. (2011)

See also Carpenter (2002), Eisner & Carpenter (2003)

Evolution of Dust Mass



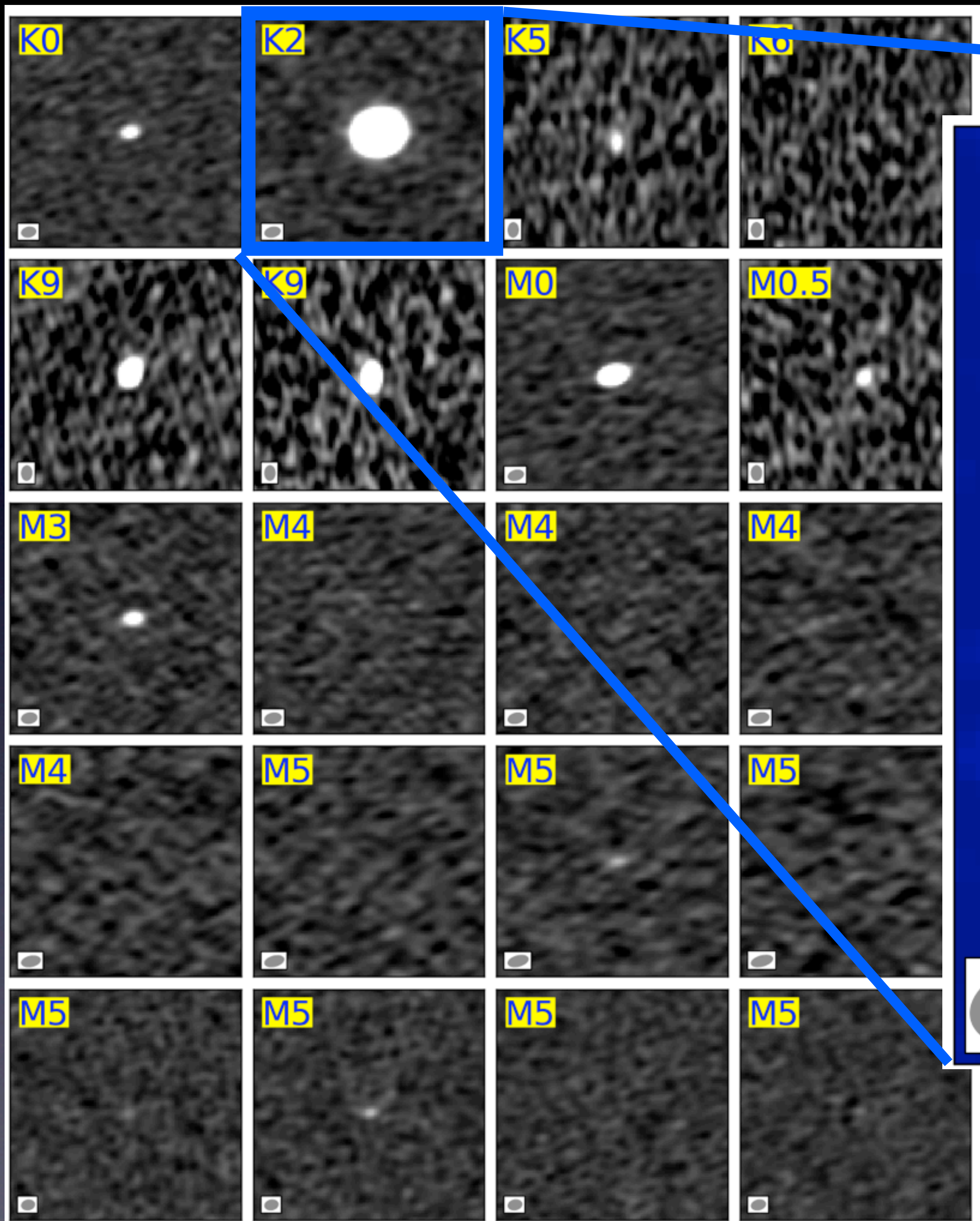
Mathews et al. (2012)

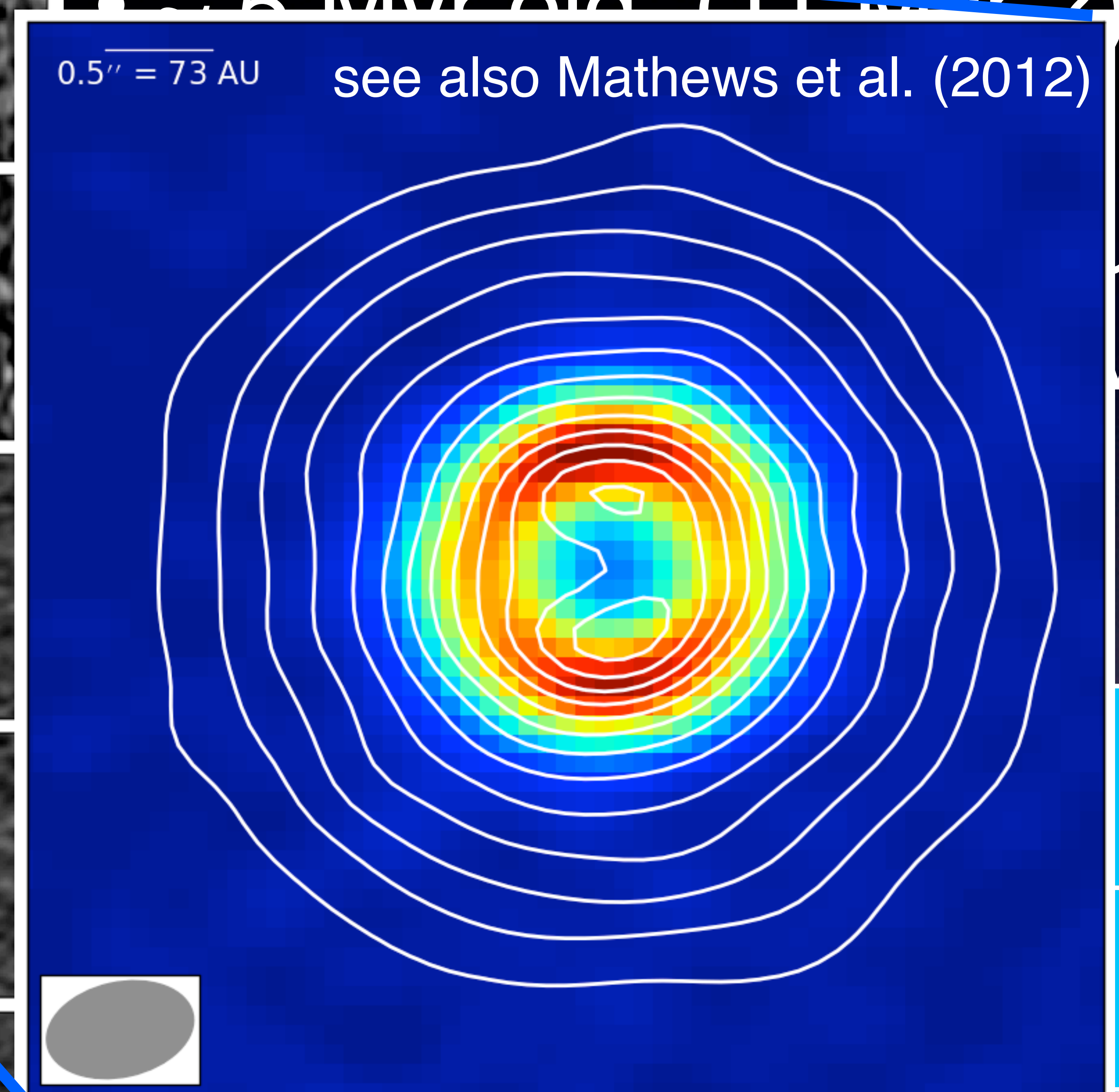
Disk Evolution with ALMA

- Extraordinary sensitivity
- High angular resolution to resolve disk
- continuum & ^{12}CO to trace dust & gas content

Credit: ESO/B. Tafreshi

ALMA Survey of Upper Sco



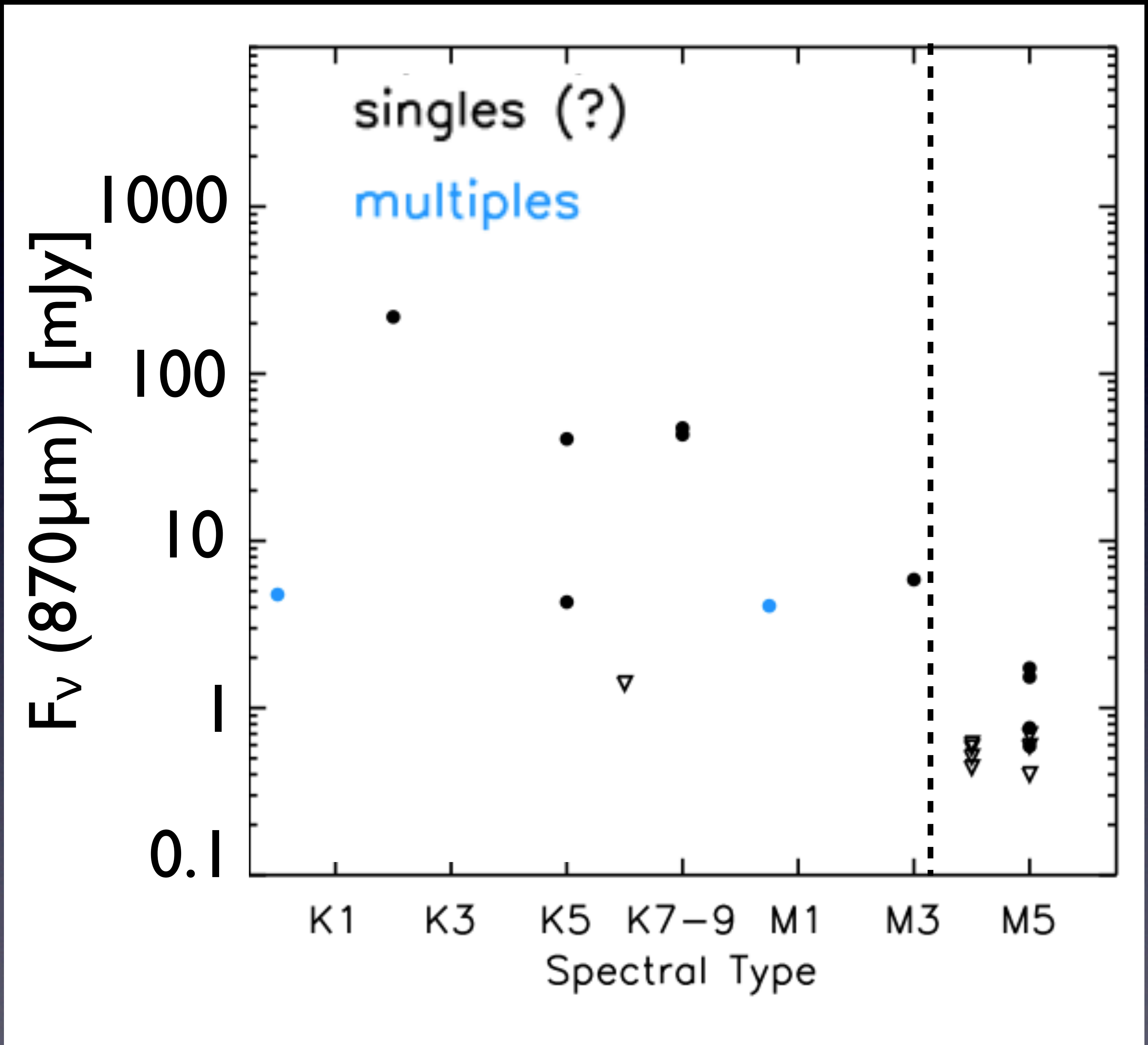


ALMA 870µm images

- ~ 5 Myr old (11 Myr ?)

Detection limit (3σ)	~ 0.03 M_{Jup} (gas+dust)

USco: 870μm Flux vs. Spectral Type

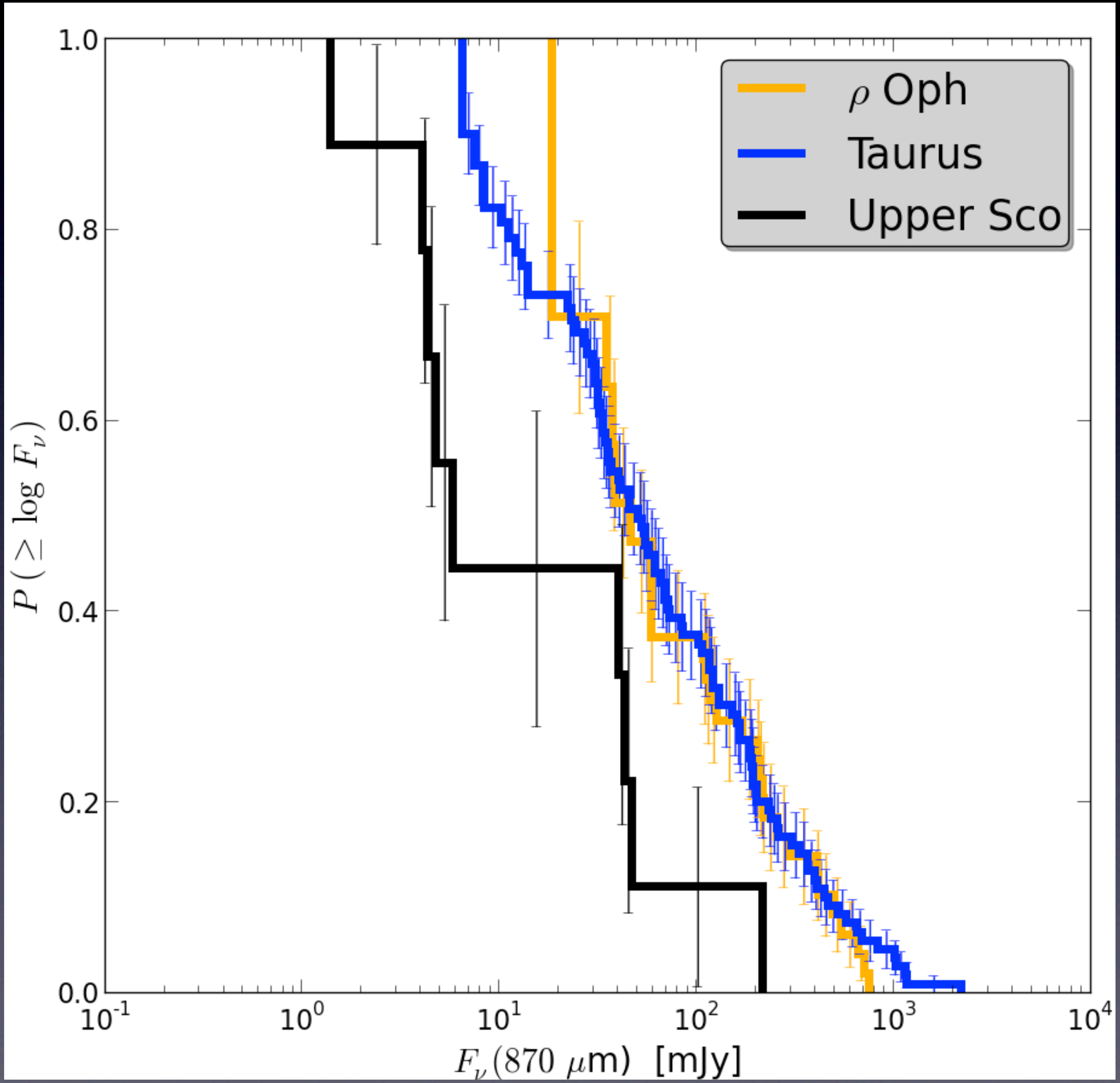


- Median 870μm flux decreases by > 10x from K0-M3 to M4-M5
- Probability that they have the same flux distribution is ~ 0.1%

K0: ≈ 1 M_{sun} M5: ≈ 0.1 M_{sun}

Disk Evolution: K0 - M3 stars

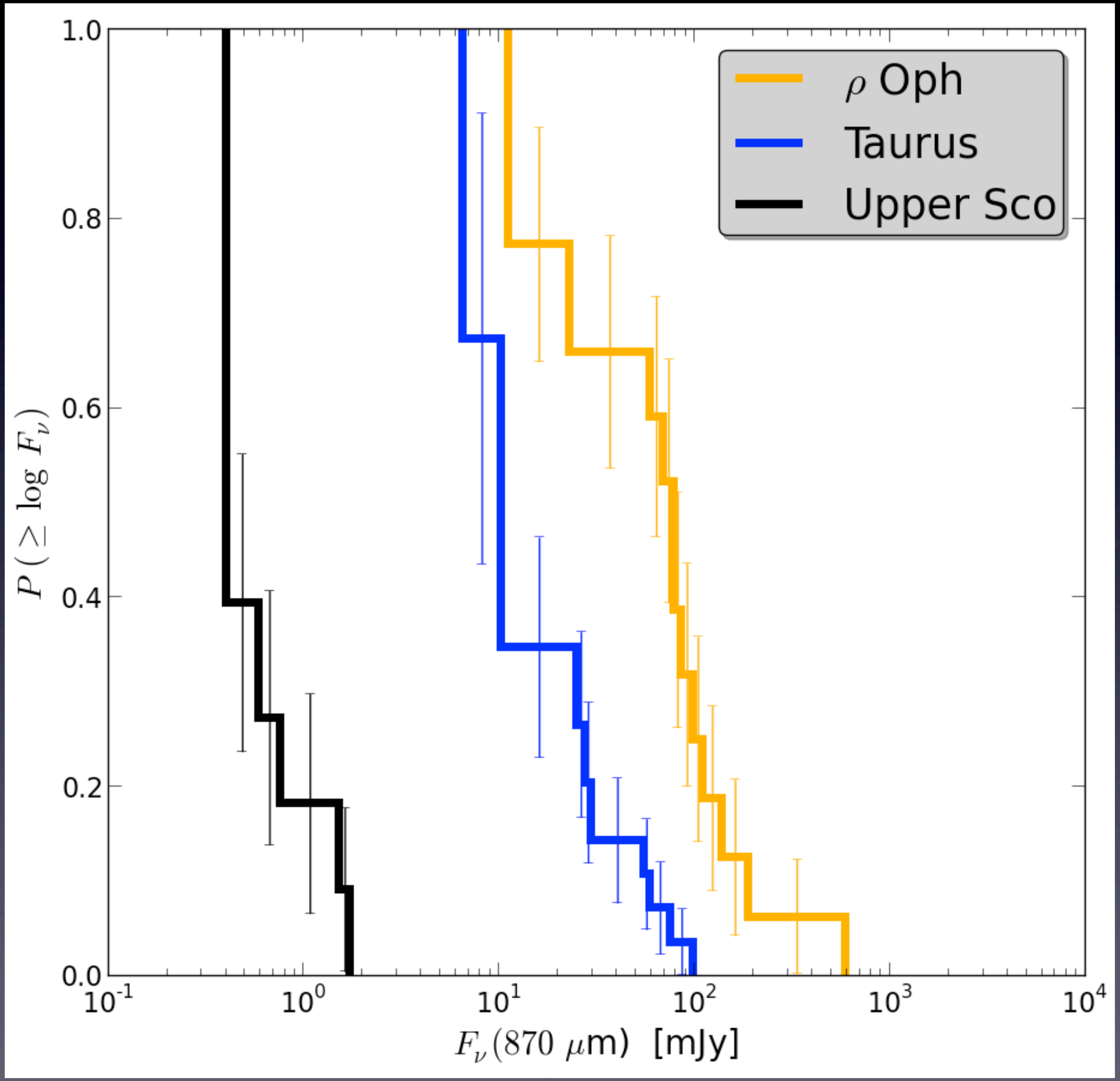
Cumulative 870µm flux density



- Median submm flux declines by ~ 5x
- Probability ~ 5%
- Taurus/ρ Oph : ~ 1-2 Myr
- USco: ~ 5 Myr

Disk Evolution: M4 - M5 stars

Cumulative 870µm flux density

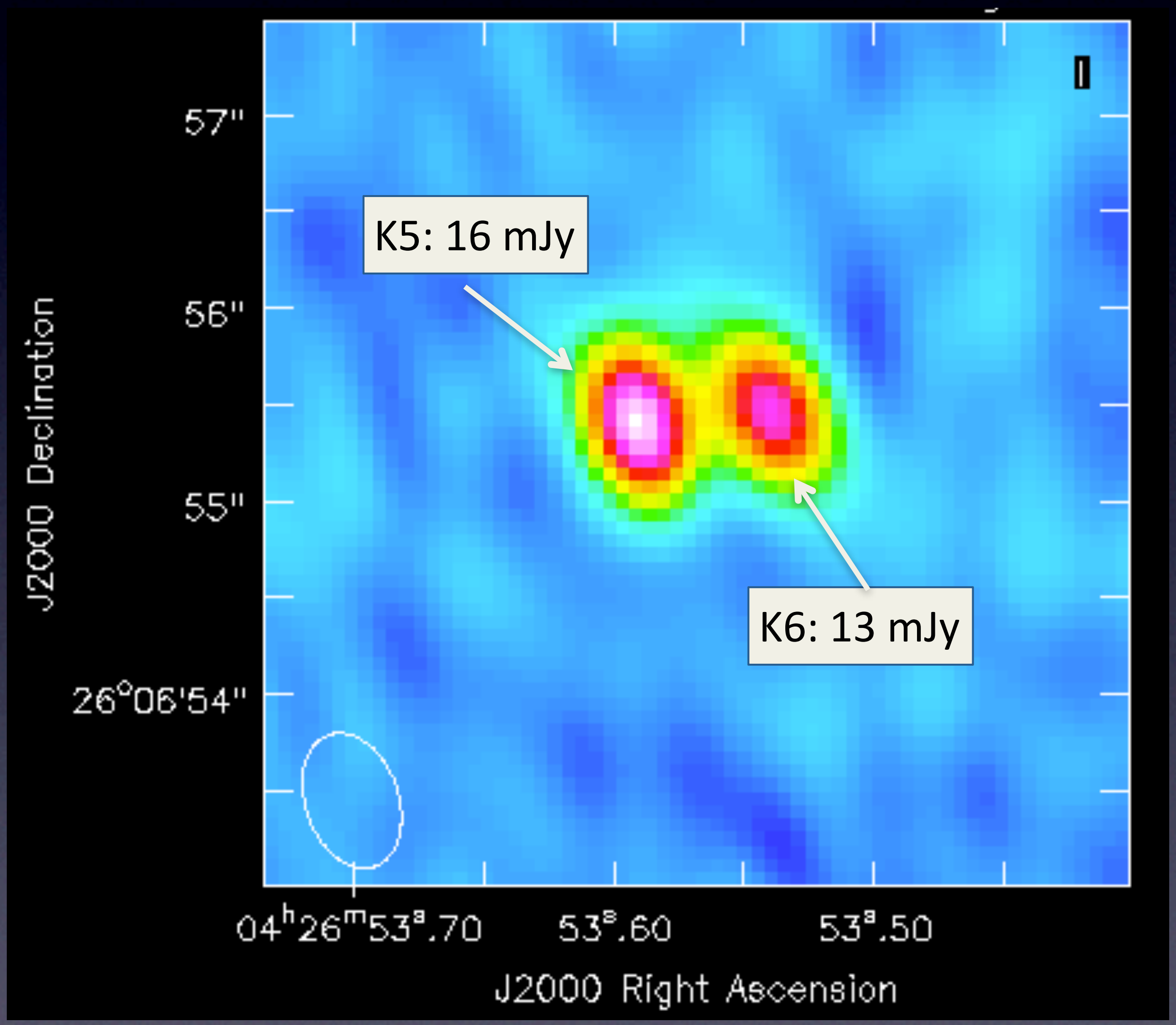


- Median submm flux declines by a factor of ~ 100
- Probability ~ 0.01% (ρOph vs. USco)

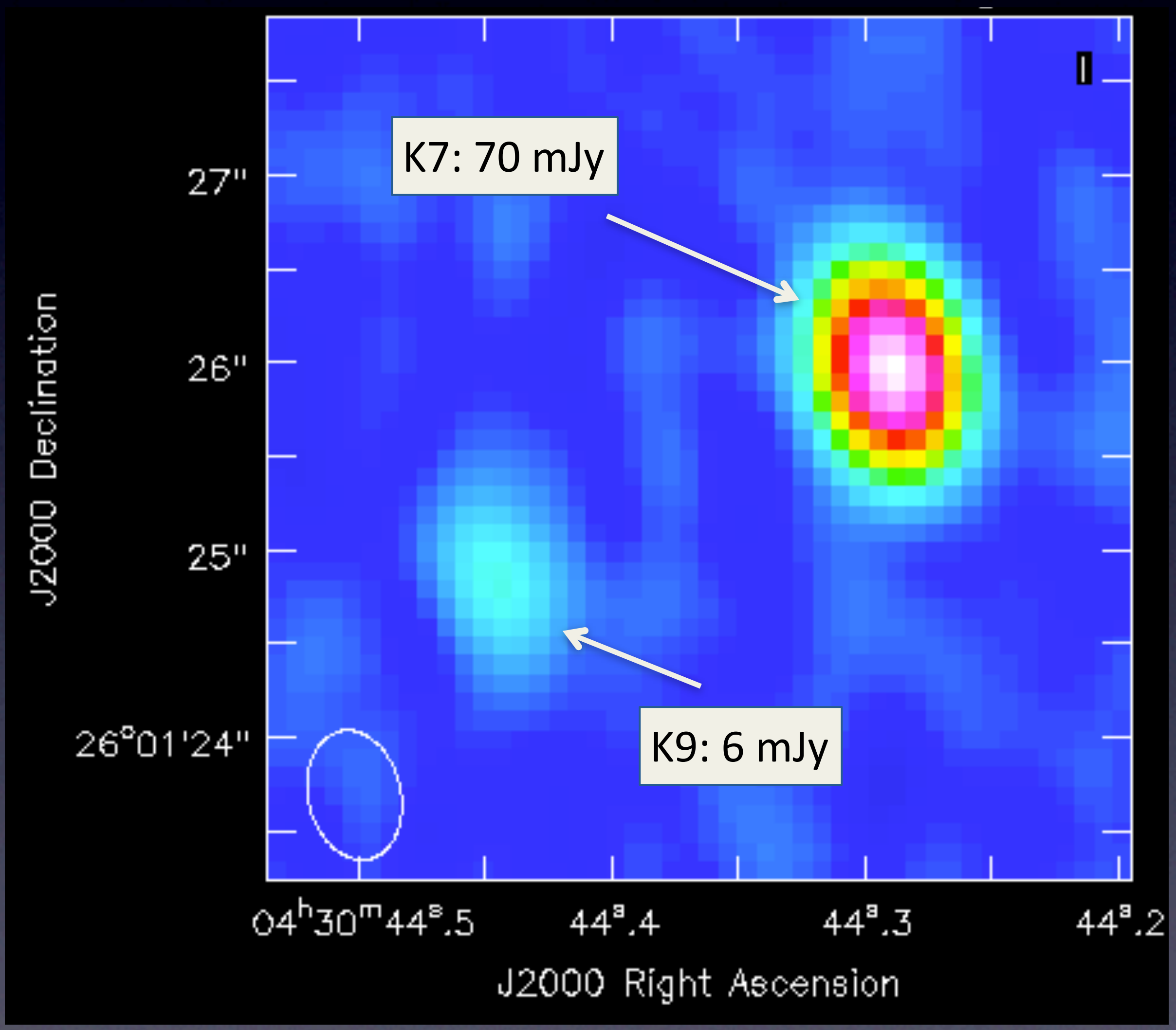
Multiplicity and Disk Evolution

ALMA 850μm continuum images

FV Tau



DK Tau

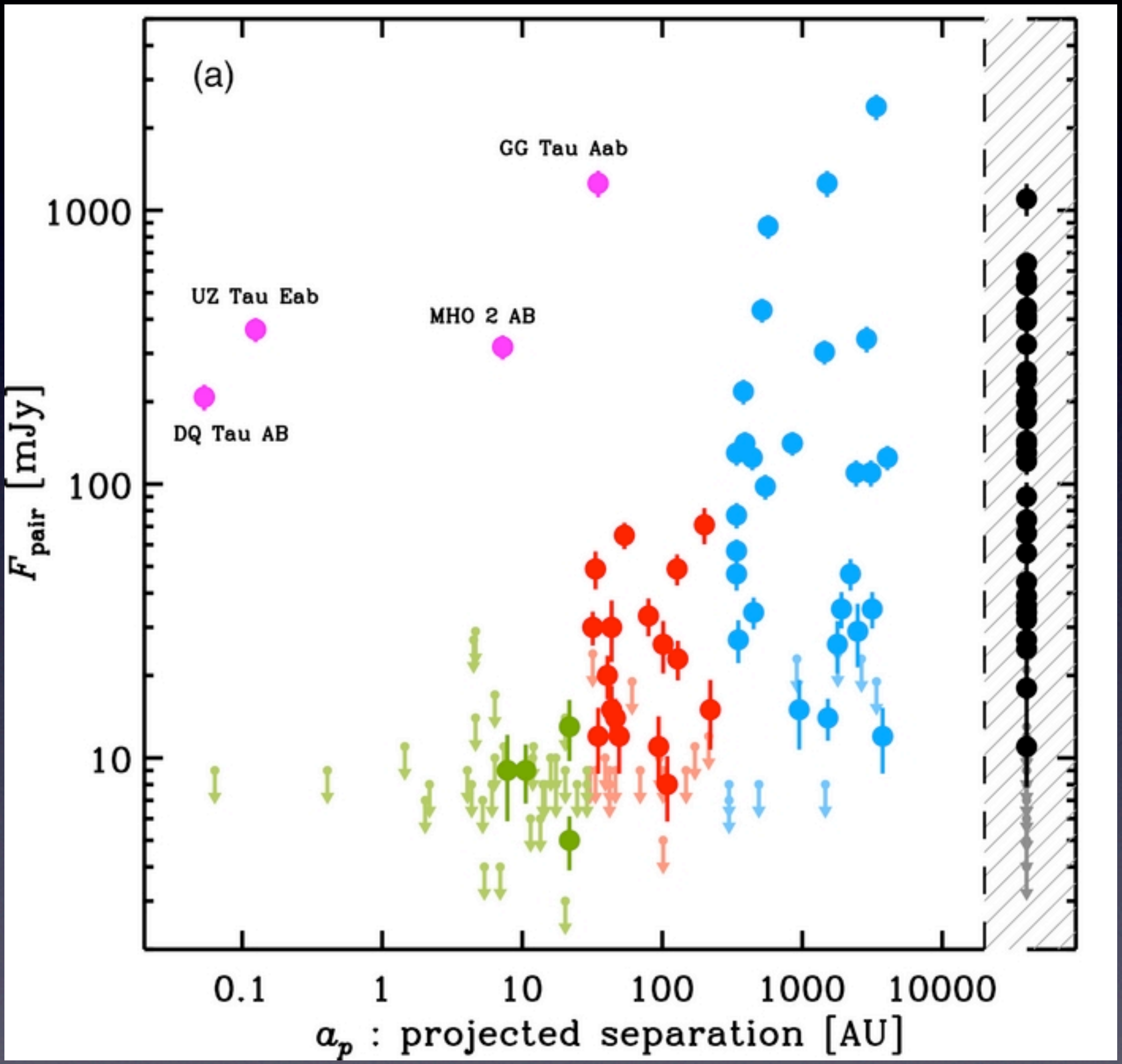


Akeson & Jensen (in prep)

- Both binaries contain 2 Classical T Tauri stars

Multiplicity and Disk Evolution

Flux density vs. separation



Harris et al. (2012)

see also Jensen et al. (1998)

- Single stars and wide (> 300 AU) binaries have similar fluxes
- 30-300 AU have 5x lower flux
- close pairs are 25x fainter

Summary

- Basic timescales for disk dissipation established from infrared data
- The role of ALMA
  - How much material is there, where is it, and for how long?
  - measure M_{disk} (t, R, M_*, environment)

ALMA images : Pérez, Casassus, Carpenter