Class 24: Disc dispersal

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Outline

- Demographics of late-stage discs
  - Accretion measures
  - Dust measures
  - Gas measures

- Models for disc dispersal
  - Viscous accretion
  - Photevaporation

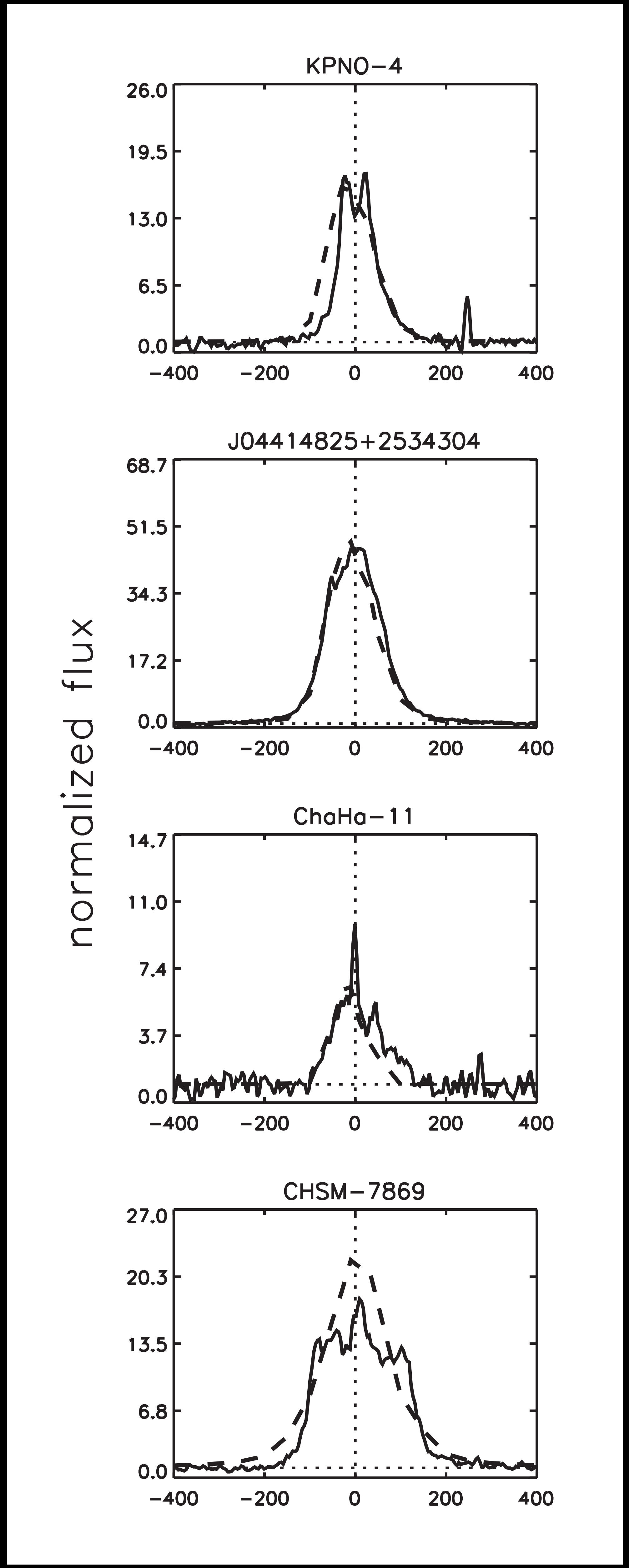
Context: disc demographic surveys

- To understand how discs go away, want to be able to do big survey for presence of discs, and disc properties
- Need to target a large range of stellar masses, and many star-forming regions of different age, to map out how disc properties change with mass and age
- Need for large samples means work mostly has to be done without imaging, because imaging is slow and expensive — at best can follow up some sources with imaging to check interpretation, resolve ambiguities
- Three main strategies meet this requirements: (1) optical line diagnostics of accretion onto stellar photosphere, (2) IR / sub-mm continuum observations of dust continuum emission, (3) unresolved molecular line observations

Accretion measures

The Hα line

- Easiest disc signature to see in optical is stellar accretion
- Most common accretion signature is Hα in emission
  - In most stars, Hα seen in absorption — signature of absorption by H atoms in n = 2 state in photosphere
  - Hα in emission requires gas above photosphere at T = 5 - 10 kK at density high enough to get close to LTE
  - Material must have velocity spread of hundreds of km/s
- Model: emission from dense shock on stellar surface; can estimate accretion rate from brightness of line

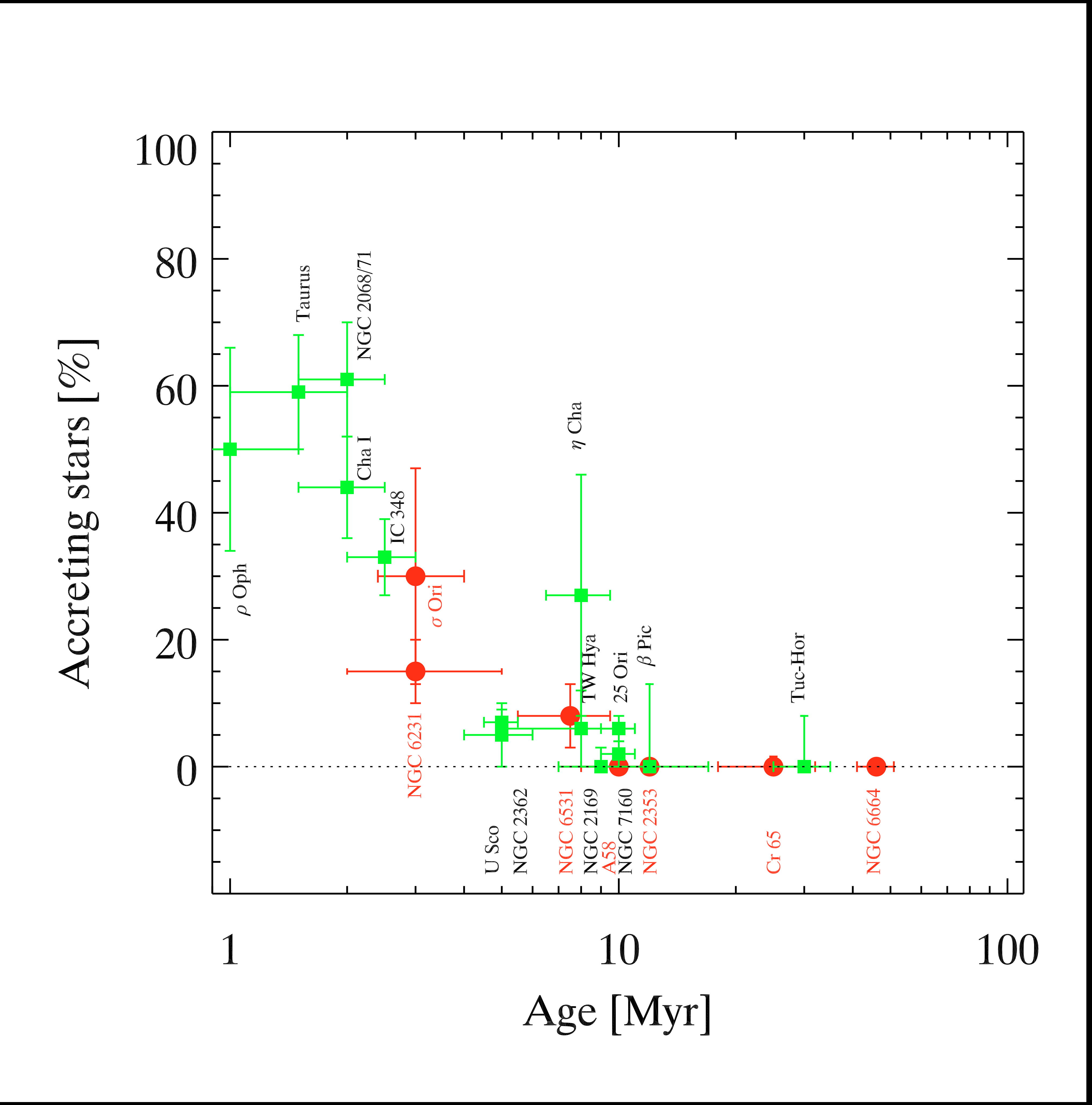


Muzerolle+ 2005

Accretion demographics

Results from surveys

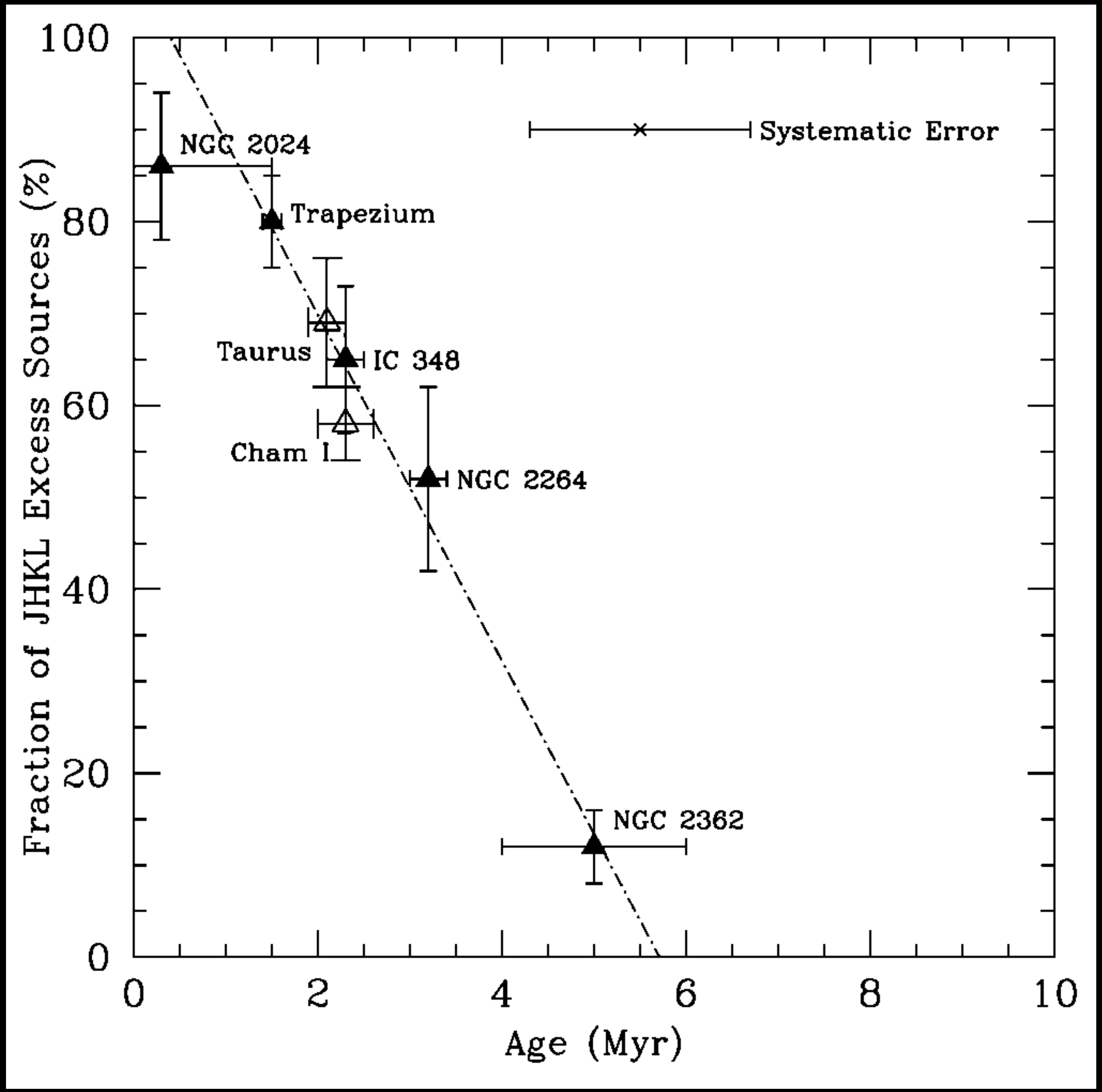
- Can do large surveys of star-forming regions to find stars w/Hα emission — these sources are relatively bright, so spectroscopy not too expensive
- Basic result: accretion fraction is ~50% at 3 Myr, ~10% at 10 Myr — e-folding time ≈ 2 - 3 Myr
- Accretion rate scales with stellar mass roughly as dM/dt ~ M^2, but large scatter



Fedele+ 2010

IR / mm surveys
Dust continuum emission

- IR / mm continuum traces dust in discs: NIR sensitive to dust near star (~1 AU), mm to dust far from star (~100 AU), intermediate wavelengths probe intermediate radii
- Basic result: e-folding time depends on wavelength / disc region
  - 2-3 Myr at NIR (~1 AU)
  - 4-6 Myr at MIR (~30 AU)
  - >10 Myr at mm (~100 AU)



Haisch+ 2001

Interpretation of dust continuum data

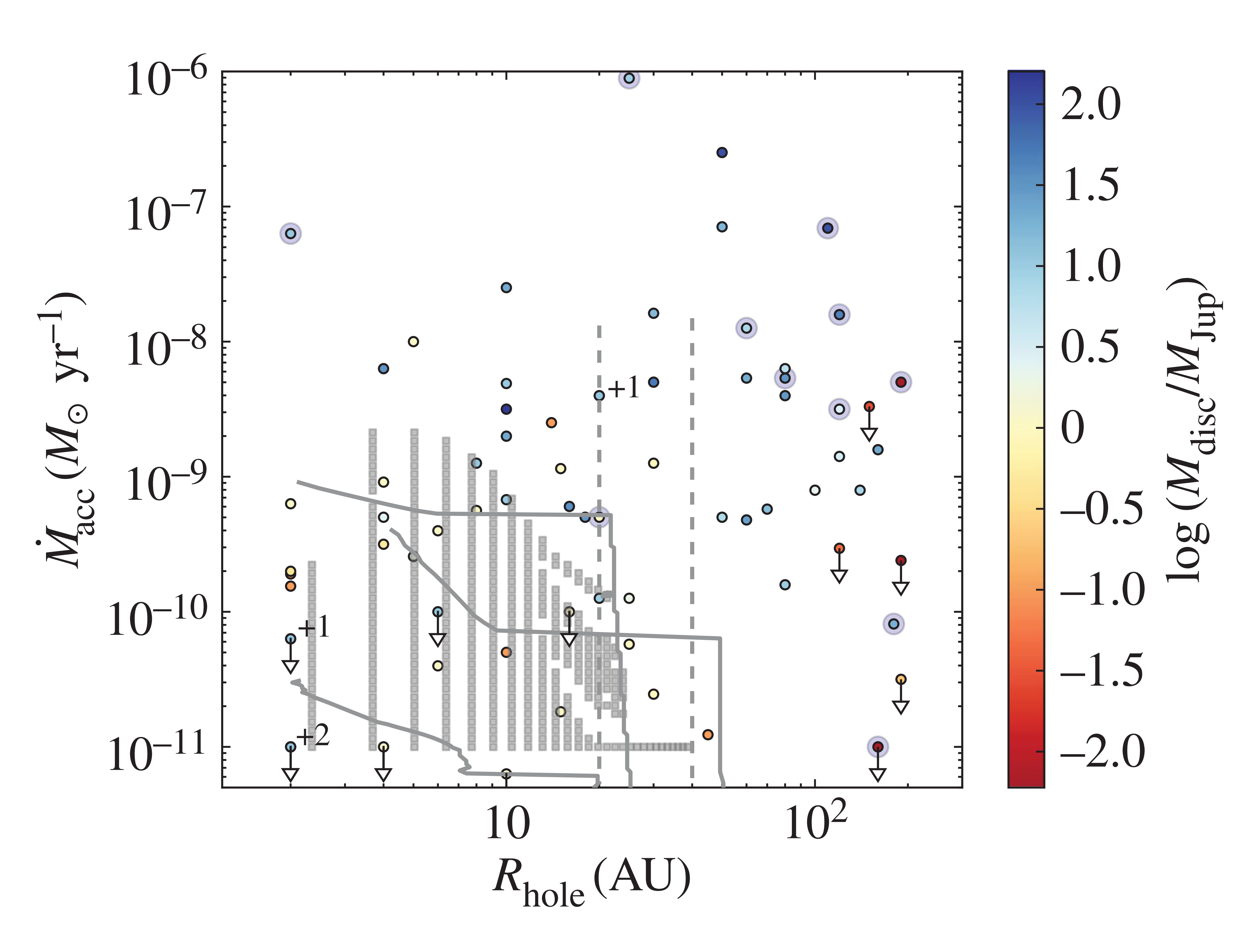
What is the wavelength dependence telling us?

- Possibility 1: discs are cleared inside-out, so grains at ~1 AU hot enough to emit in NIR disappear earlier than those at ~30 AU which emit in MIR — directly observed by imaging in some cases
- Possibility 2: longer wavelength emission at late times is not a signature of the original disc, but of a debris disc created when solid bodies created in first generation disc collide and produce dust
- Amount of dust required to produce longer wavelength emission is very small — 10^{-5} $M_{\oplus}$ sufficient (about mass of Vesta) — so possibility 2 plausible
- May be a combination of both

Dust vs accretion data

Very confusing

- Accretion and hot dust decrease in time with similar e-folding
- However, little object-by-object correlation between dust holes or dust mass and accretion rates
- Plenty of objects with > 10 AU dust cavities still have gas accretion rates > 10^{-8} $M_\odot$ / yr



Ercolano & Pascucci 2017

Gas measures

Challenges and status

- Resolved gas observations very expensive, so sample size still small — no statistical studies
- Unresolved observations cheaper, and can use spectra to make inferences about presence of gas close to star — revealed by high Doppler velocities
- However, optical depth effects make results difficult to interpret — for abundance species like CO, luminosity not just proportional to mass
- Gas clearing times seem roughly consistent with dust clearing times, but hard to be more specific given poor statistics and modelling uncertainties

Viscous accretion

Dispersal mechanism I

- Disc could disappear just by all accreting onto star at a few Myr
- Mass budget reasonable: observed accretion rates ~10^{-8} - 10^{-9} $M_\odot$ / yr can drain a 0.01 $M_\odot$ disc in ~1 - 10 Myr, about observed lifetime
- However, disc evolution obeys $\frac{\partial \Sigma}{\partial t} = \frac{3}{\varpi}\frac{\partial}{\partial \varpi}\left[\varpi^{1/2}\frac{\partial}{\partial \varpi}\left(\nu\Sigma\varpi^{1/2}\right)\right]$
- Generic solution for power law viscosity $\nu = \nu_1(\varpi/\varpi_1)^\gamma$ is:

$$\Sigma = \frac{C}{3\pi\nu_1 x^\gamma} T^{-(5-2\gamma)/(4-2\gamma)} \exp\left(-\frac{x^{2-\gamma}}{T}\right), \qquad x = \frac{\varpi}{\varpi_1}, \quad T = \frac{3(2-\gamma)\nu_1}{\varpi_1^2} t + 1$$

- Problem: for small *x* (inner disc), surface density decreases uniformly as a power law in time → disc never develops an inner hole

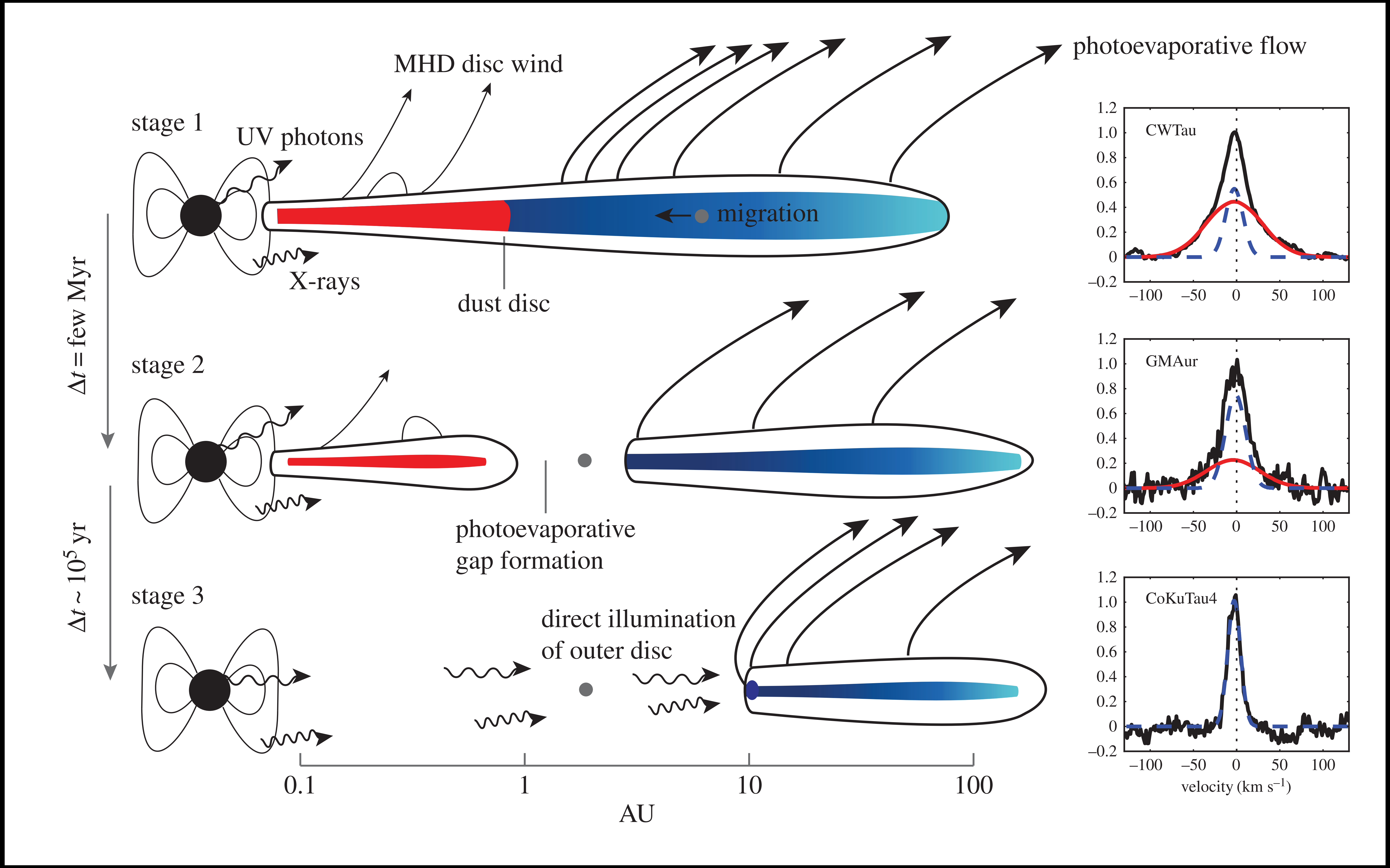
Viscous accretion

Advantages and problems

- Problem with viscous accretion model is generic: anything based on viscosity does not easily create holes, as observations seem to require
- Need some mechanism to produce sharp features in dust or gas distribution
- However, accretion clearly does occur, as shown by the Hα data, and observed accretion rates are sufficient to drain fair amount of mass from disc
- Most promising avenue is accretion combined with some other mechanism to produce sharp features

Dispersal mechanisms

II. Photoevaporation



Ercolano & Pascucci 2017

Photoevaporation

The basics

- Young stars produce FUV (11 - 13.6 eV) and EUV (13.6 eV - ~100 eV) thermally, and soft X-rays (~100 eV - few keV) via non-thermal processes in the magnetosphere

- The radiation heats a surface layer of the disc — to ~few hundred K (FUV), ~10^4 K (EUV), or hotter (X-ray)

- If the sound speed in the heated gas exceeds the escape speed from the location of the hot gas, thermal pressure will launch a wind off the disc

- This mechanism naturally produces a sharp feature in the disc: mass is only lost at sufficiently large radii

Photoevaporation

Example calculation for EUV

- EUV is simplest because chemistry and temperature are simple, though it is probably the least important of the three mechanisms
- Basic idea: wind flows where escape speed ≲ 10 km/s: $\varpi \gtrsim GM/c_s^2 \sim 9(M/M_\odot)$ au
- If ionising luminosity of star is Φ, ionisation balance requires that density n_0 at base of wind obey $$\Phi \sim \alpha_B n_0^2 \varpi^3 \quad \Longrightarrow \quad n_0 \sim \sqrt{\frac{\Phi}{\alpha_B} \frac{c_s^3}{(GM)^{3/2}}}$$
- Wind flows out at ~c_s, so $$\dot{M} \sim n_0 \mu m_\mathrm{H} c_s \sim \sqrt{\frac{\Phi}{\alpha_B} \frac{c_s^4 \mu m_\mathrm{H}}{(GM)^{3/2}}}$$
- Observed Φ values give ~10^{-10} $M_\odot$ / yr for EUV, but FUV and X-rays stronger

Possible scenario

Still not well understood

- Photoeavporation produces a gap in discs, perhaps aided by massive planets
- The gaps act as pressure traps that prevent dust grains from moving through; depending on evaporation rate and planet properties, may or may not also stop gas
- Material interior to the gap accretes onto star, and is not replenished due to the gap preventing material at larger radii from getting in
- Once the inner rim of the gap is exposed to direct starlight by accretion of the inner disc, evaporation rate rises, disc is removed fairly quickly