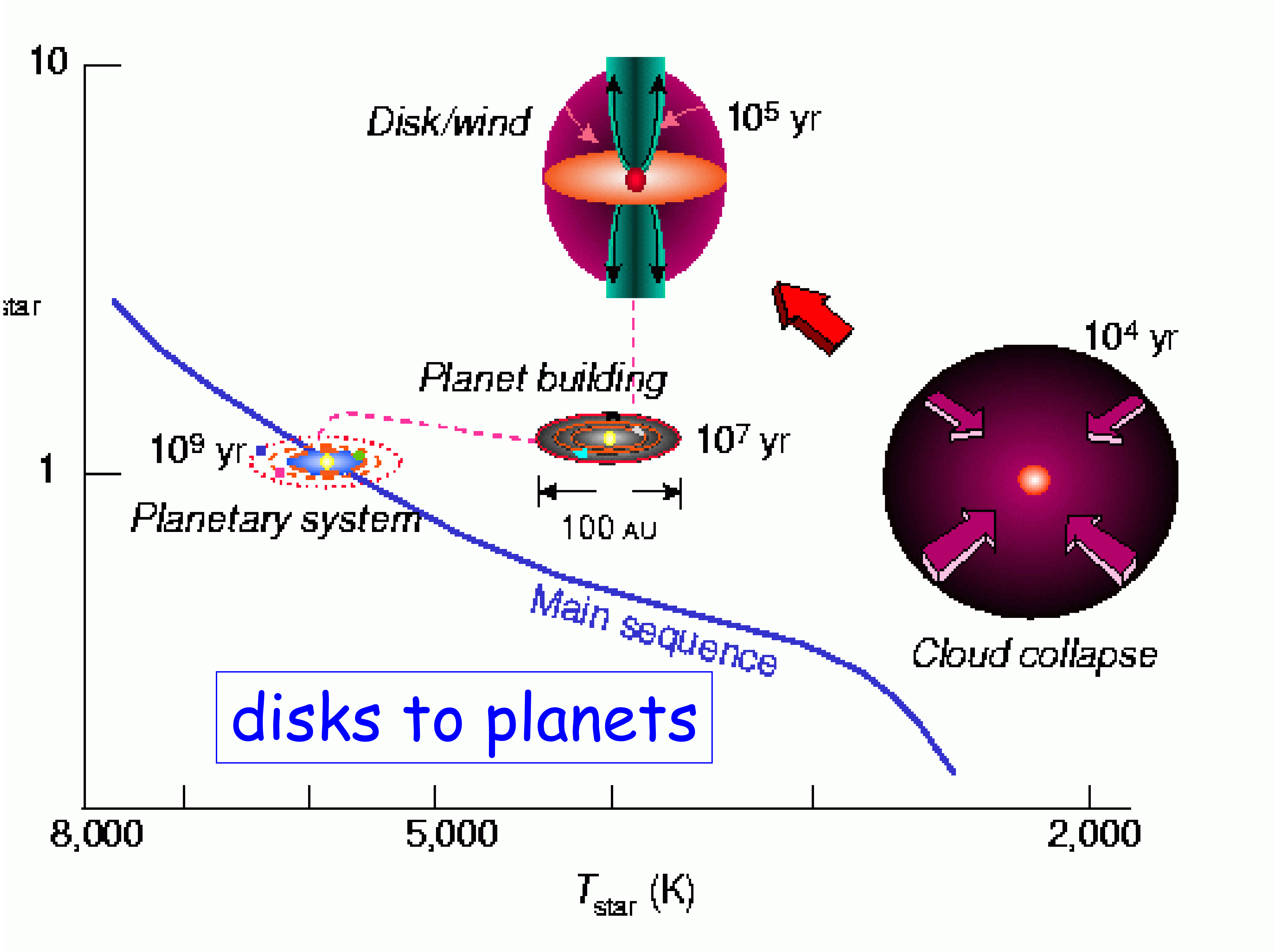
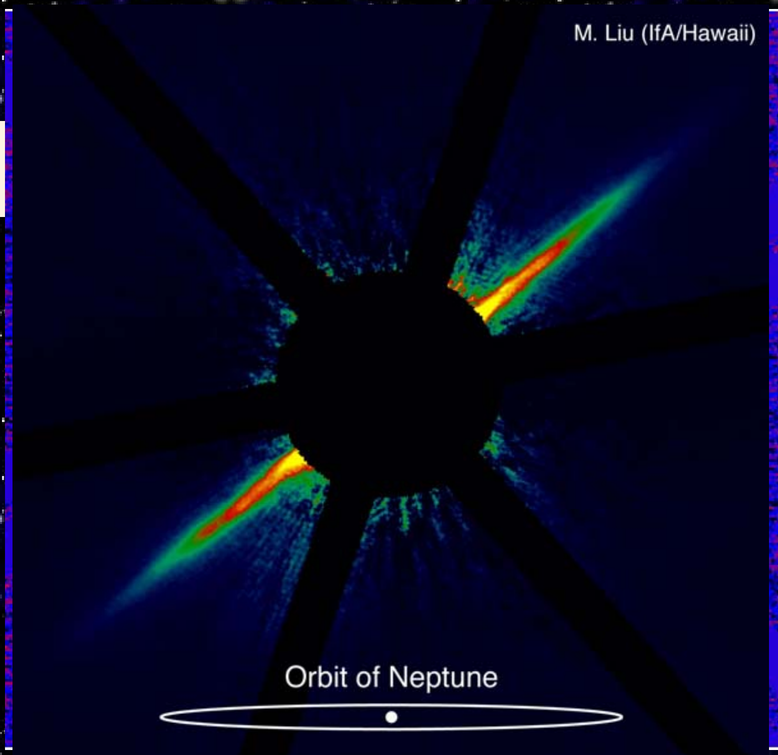
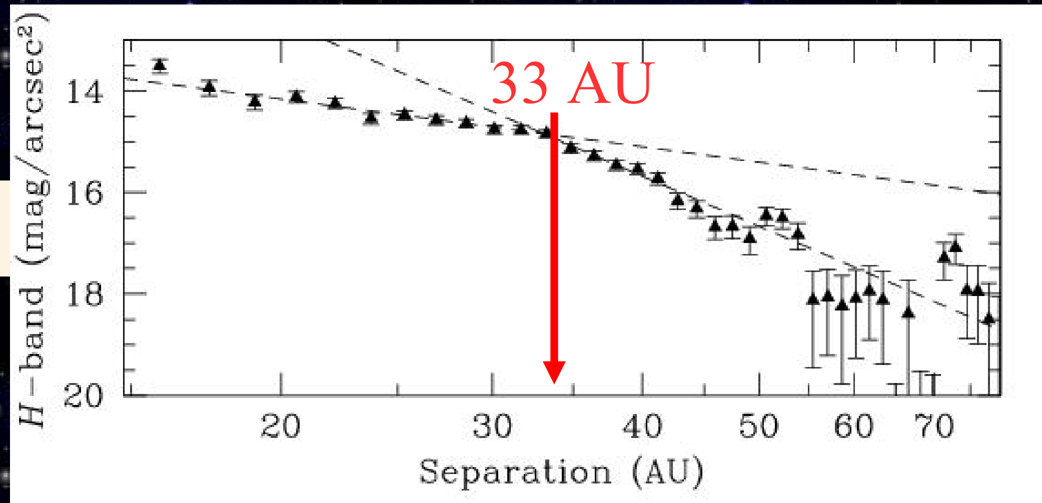


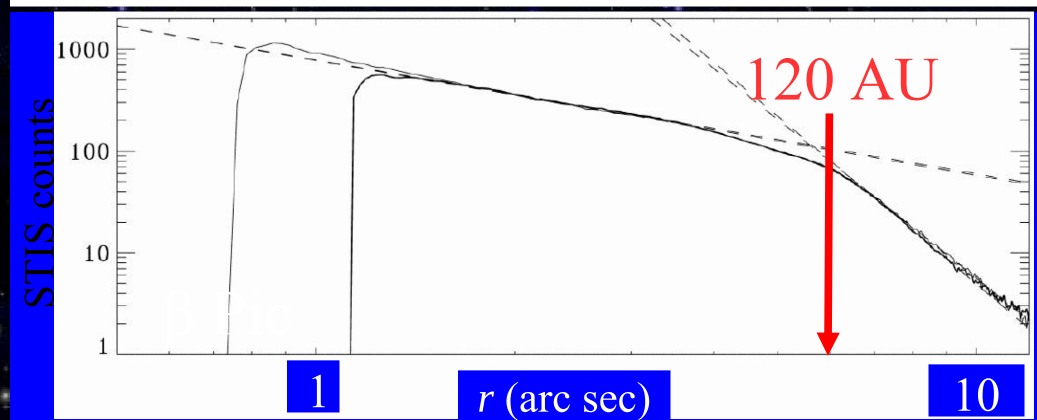
disks to planets
10
1
star
Disk/wind
10^5 yr
Planet building
10^7 yr
100 AU
10^9 yr
Planetary system
10^4 yr
Cloud collapse
Main sequence
8,000
5,000
2,000
T_{star} (K)

AU Mic: Transitional Disk?



[Liu 2004]





AU Mic:

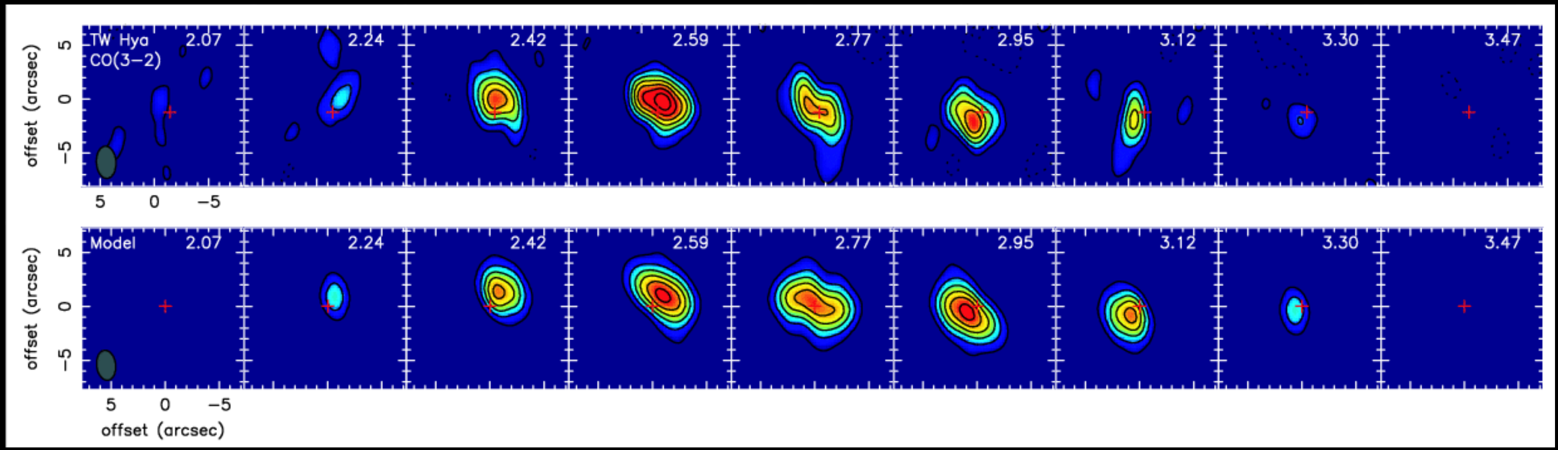
SED suggests inner disk clearing
AO and HST imaging resolves structure
no planets >1M_{Jup} at >20 AU

AU Mic vs. β Pic:

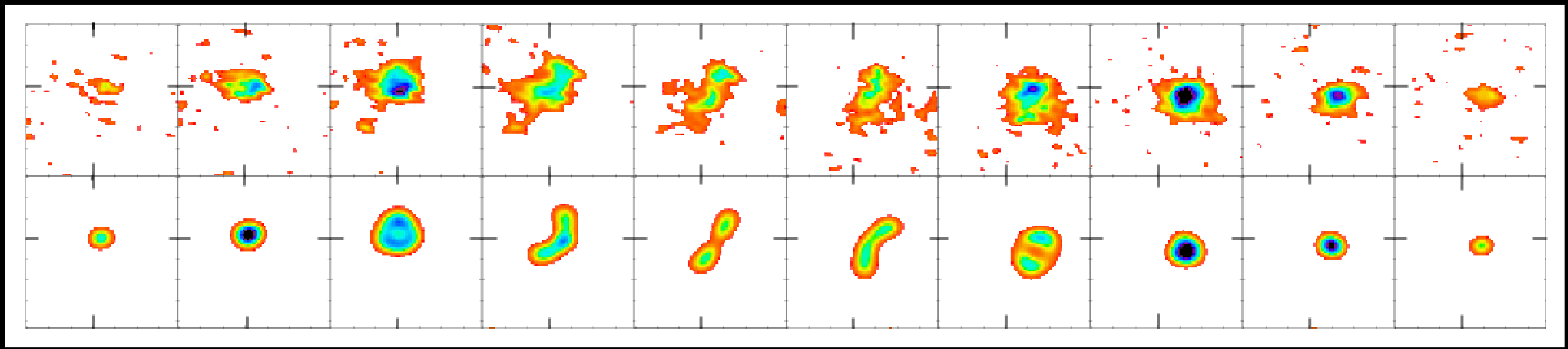
similar radial profiles
similar process: grain growth vs. collisions+PR

[Metchev et al. 2005; astro-ph/0412143]

$^{12}CO(3\text{–}2)$ emission from TW Hya



$^{13}CO(1\text{–}0)$ emission from AB Aur



Rotating, optically thick disks

Where are the transition disks?

- dust & gas (0.01 - 0.1 $M_{\odot}$) → dust (<1 M_{moon})
- dynamics: gas → radiation pressure /collisions
- grains growing → grain destruction
- SPITZER SEDS: FEPS, Chen & Werner

→ very few objects 5 – 15 Myr

flared - inner evacuated region 3- 10 Myrs

flat - mineralogical evolution

- transition times short (e.g. Skrutskie et al. 1990)

AU Mic: inner disk - collisional evolution,

outer - primordial dust (Metchev)

Spitzer →more and more debris disks

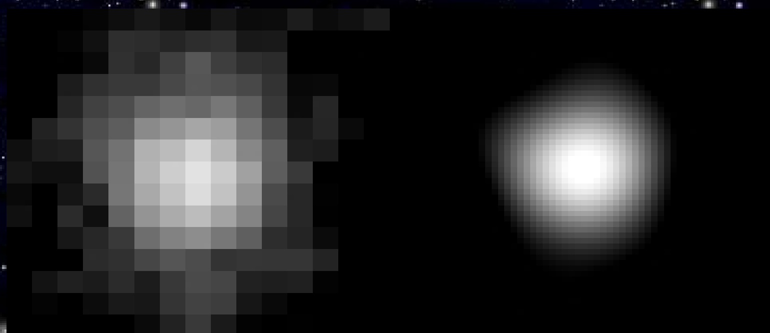
- New young debris disks
  - $2\times 10^{-7} M_{\odot}$ - $4 \times 10^{-10} M_{\odot}$
- More old & cold debris than expected (15-30%)
  - Kuiper belt analogs
- Fewer w. dust few x 100K
  - i.e asteroid like
- Hale Bopp-like spectrum (Beichman et al)
- Spectral signatures distinguish between primordial and debris disks?
- higher angular resolution FIR/submm
  - SOFIA, Hershel even Fir ALMA?
  - , compare with models e.g Gurti & Hollenbach

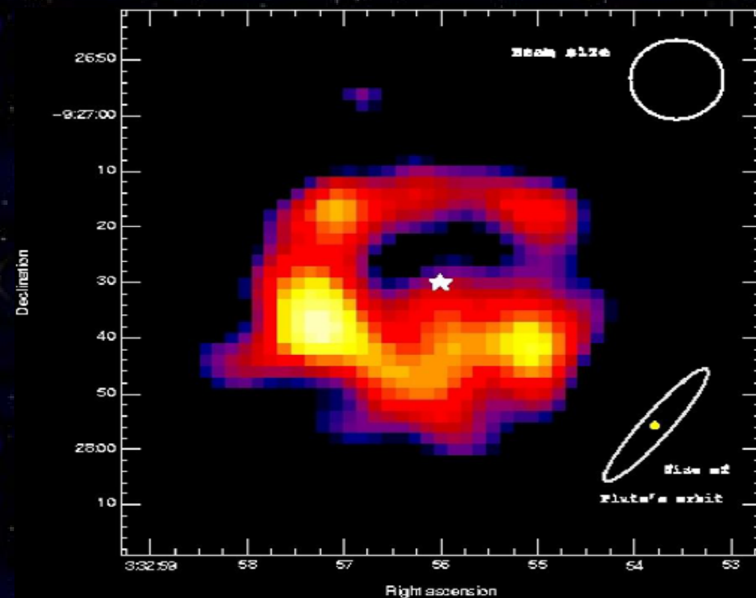
ε Eri MIPS 70 μm

(Megeath et al. 2005)

Left: 70 μm fine scale
Right: HIRES deconvolution

SCUBA 850 μm (Greaves et al. 1998)

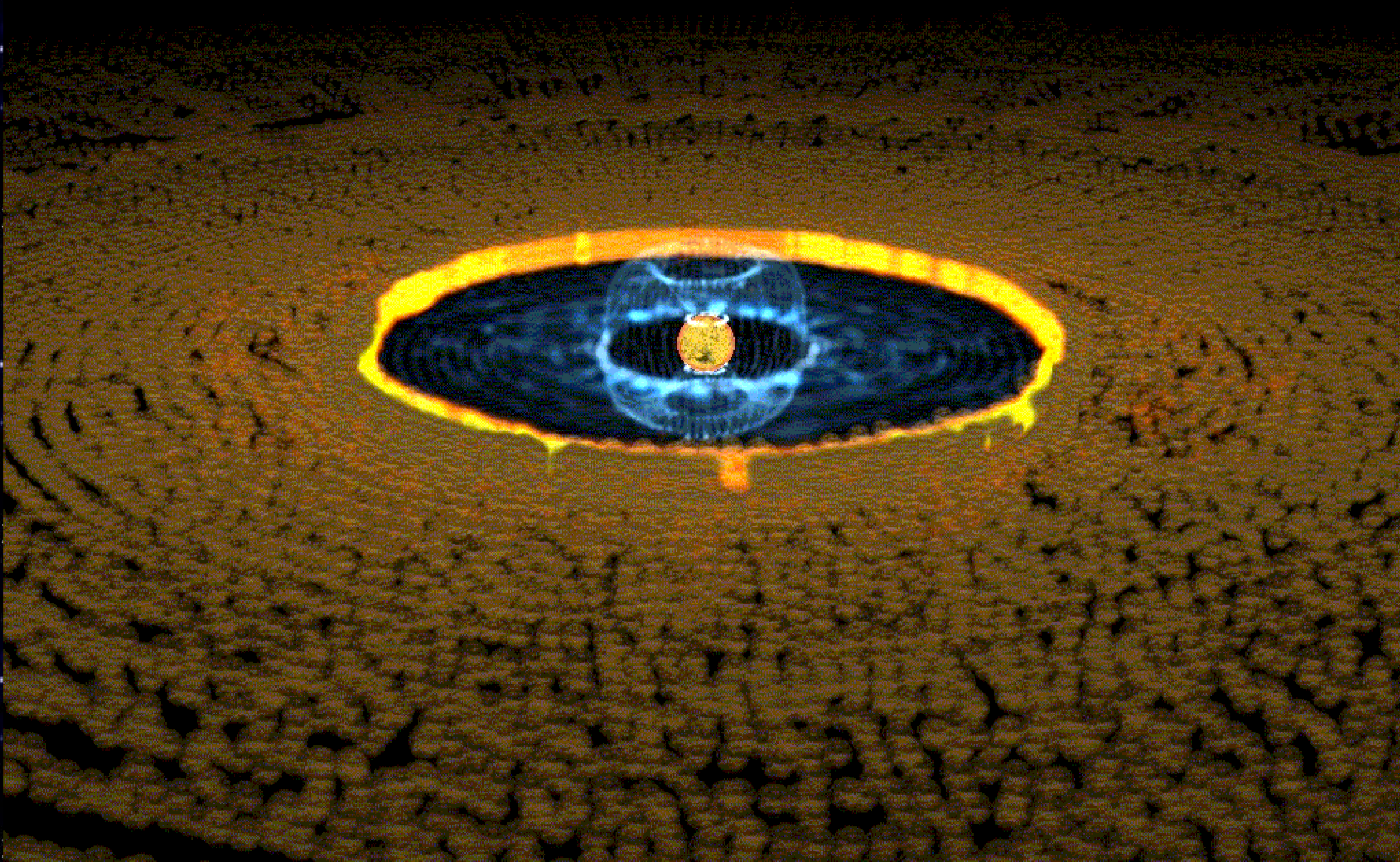




- 70 μm source has 15″ FWHM, and fills the interior of the submillimeter ring
- No extended 24 μm emission
- 160 μm data is still pending

All images shown at the same linear scale

Observing the inner disk



- Spitzer SEDs + models → not completely unambiguous
- Near-infrared interferometry probes

  PTI, IOTA, Keck, VLTI

  Phase closure
- Mid-infrared interferometry

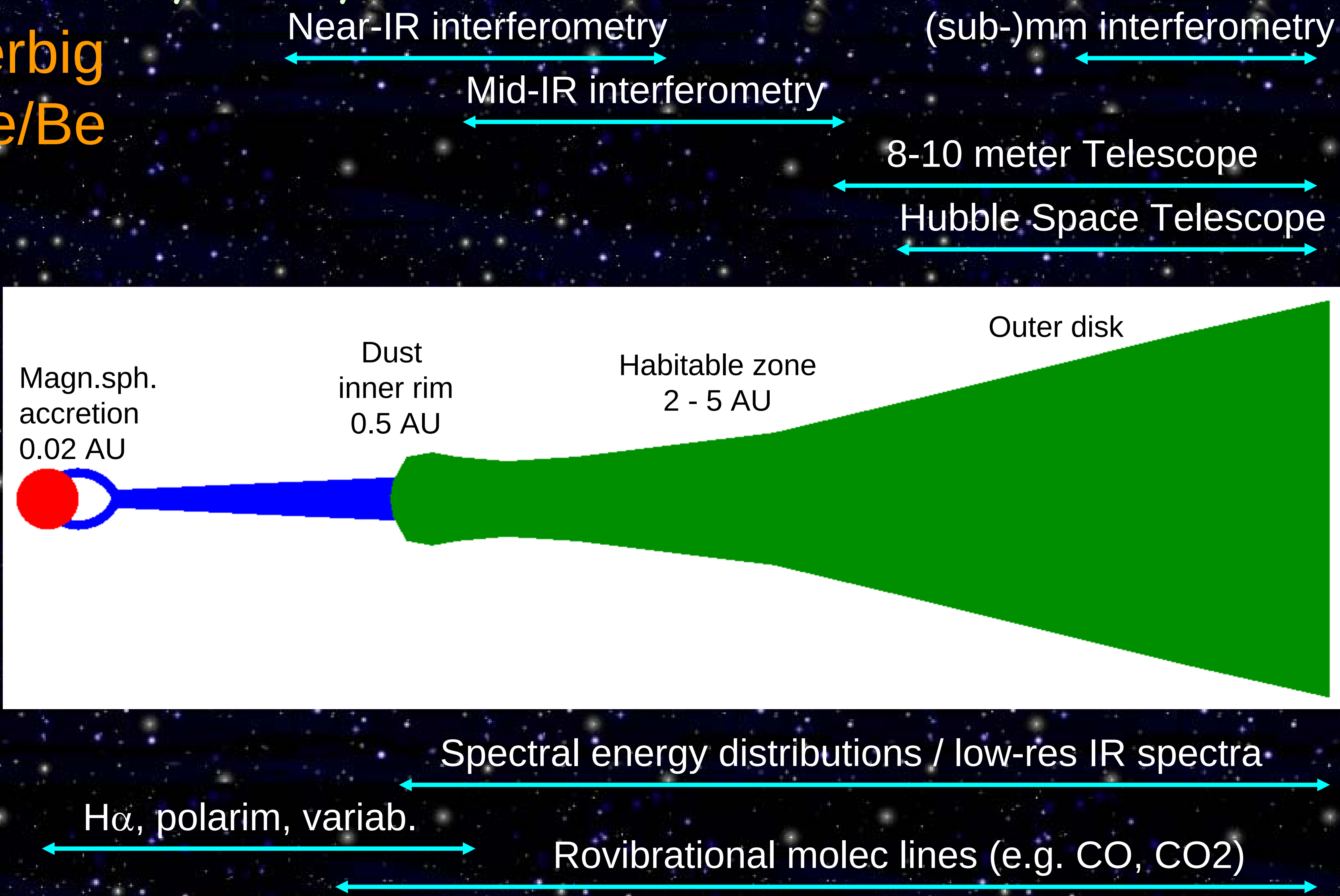
  Radius-dependent mineralogy

Spitzer SEDs + models - not completely unambiguous

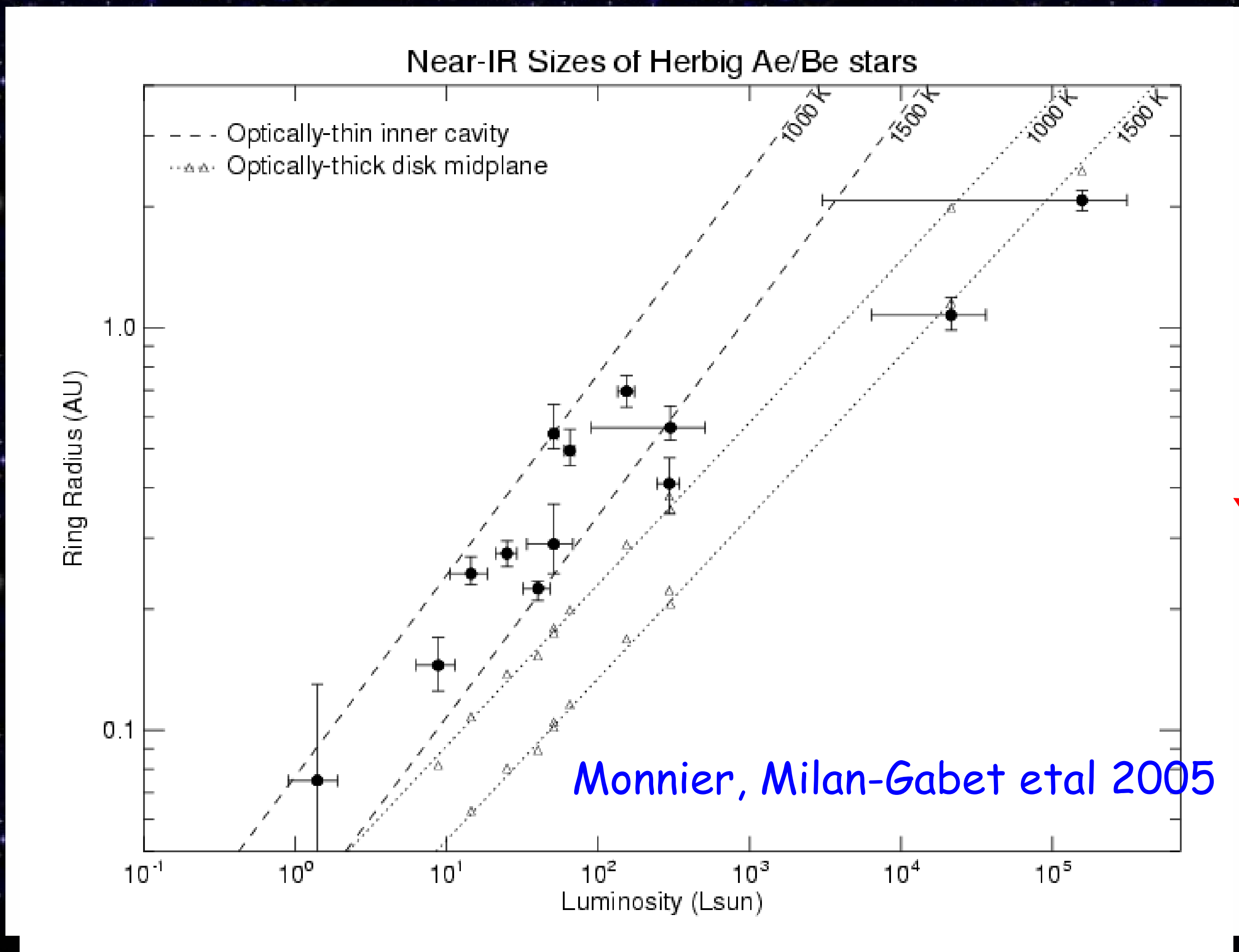
→ near-infrared interferometry

PTI, IOTA, Keck, VLTI .

Herbig Ae/Be



Size-luminosity relation

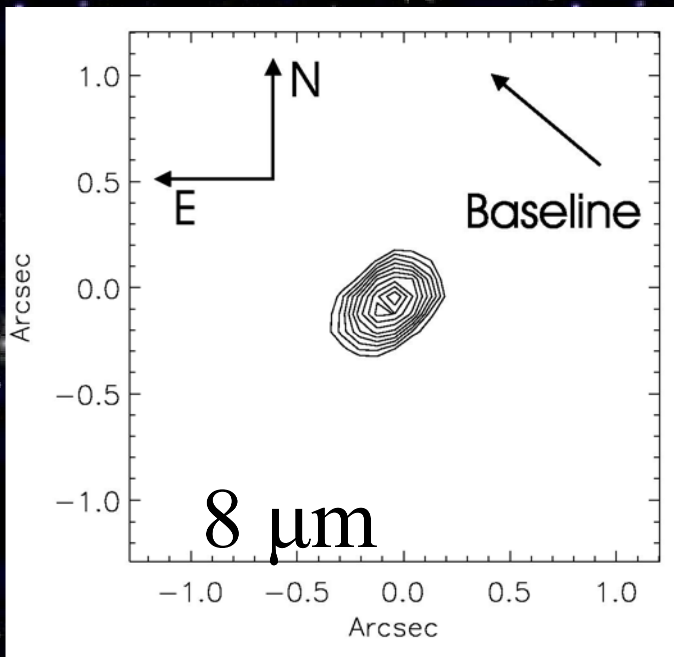


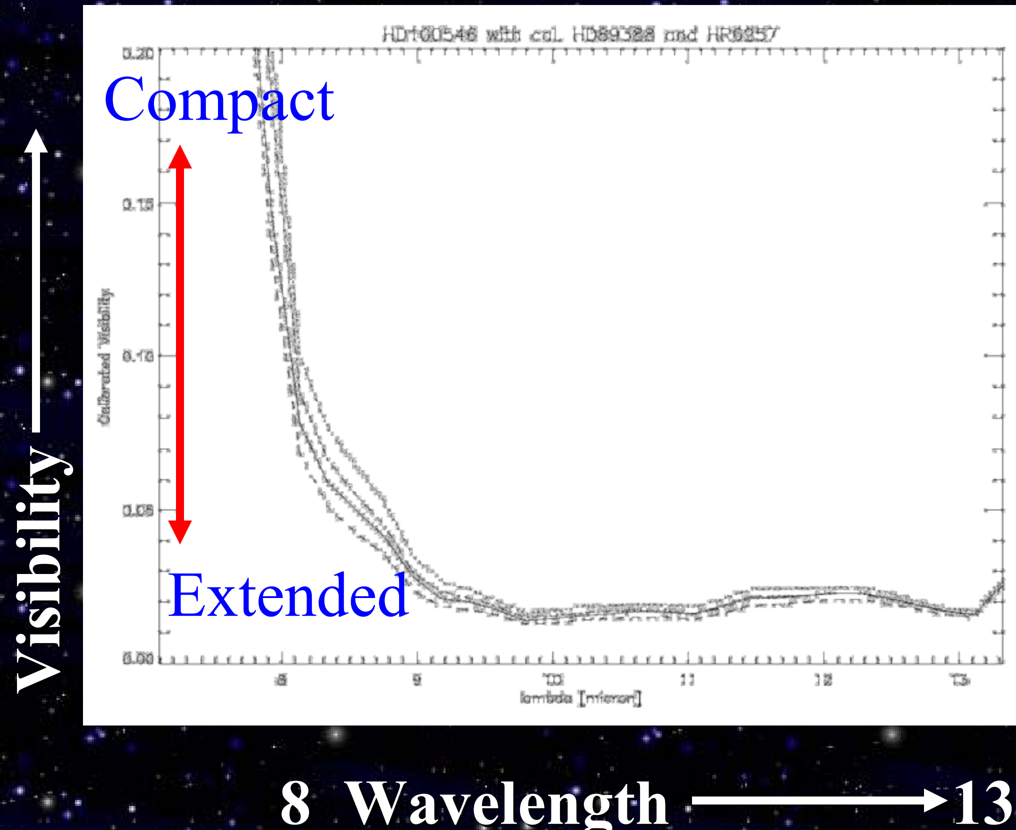
$r^{-3/4}$ law

Monnier & Millan-Gabet 2002

- Herbig Ae/Be
  - Well-defined near-IR size-luminosity relation
  - Some disks are elongated (and skewed!)
  - Next - imaging VLTI, CHARA
- T Tauris
  - New development of "hot inner rim"
    - *Early type stars (Herbig Be):* Accretion disk model fits best
    - *Later type stars (Herbig Ae):* Inner rim model fits best
  - Observed sizes are still TOO big (accretion luminosity onto star is huge!)
  - More sizes to come from KI & VLTI
- Mid-infrared Interferometry needed

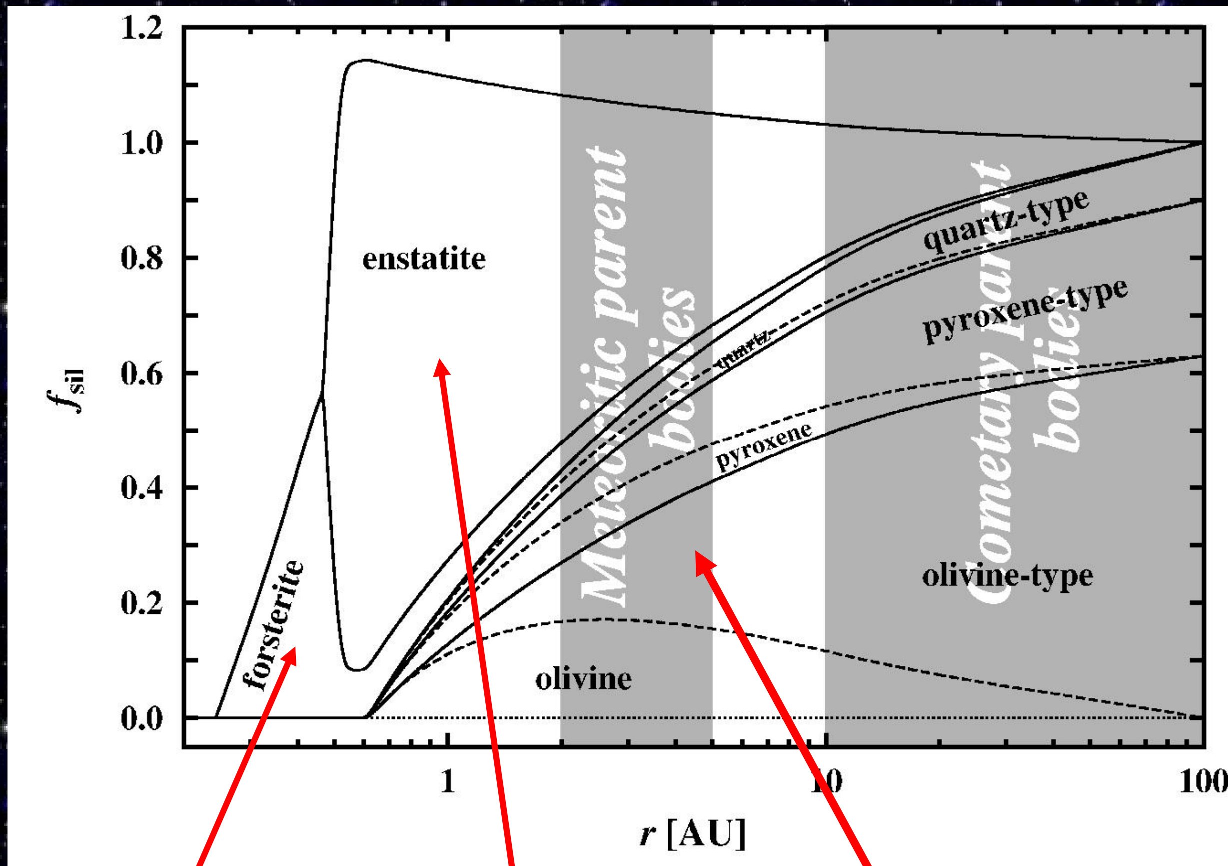
VLTI observations at 10 μm of HD100546 using MIDI
van Boekel, Waters





- Emission almost fully resolved on a scale of 20 milli-arcsec (!)
- "Wall" at ~10 AU? Bouwman et al. 2003, Liu et al 2004

Distribution of silicates



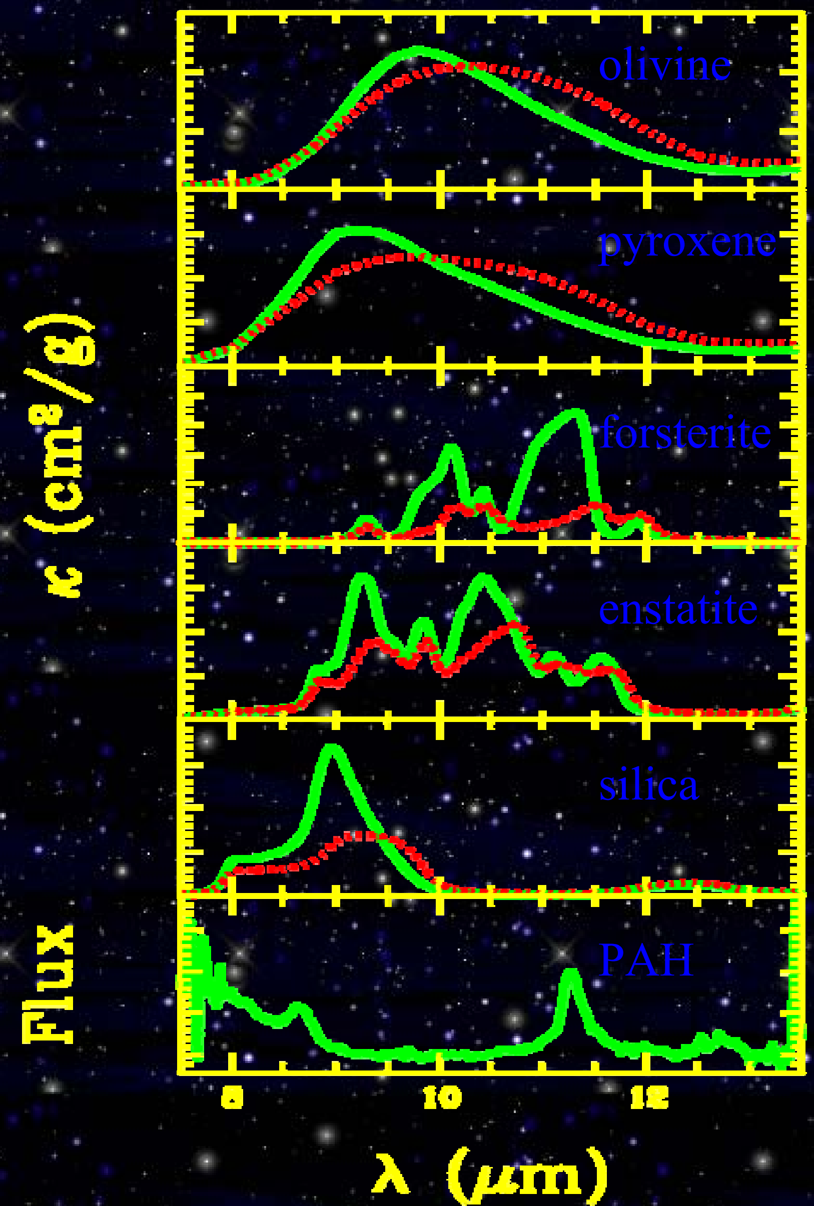
Gail (2004)

Forsterite Enstatite

Fe-rich amorphous olivines,pyroxenes

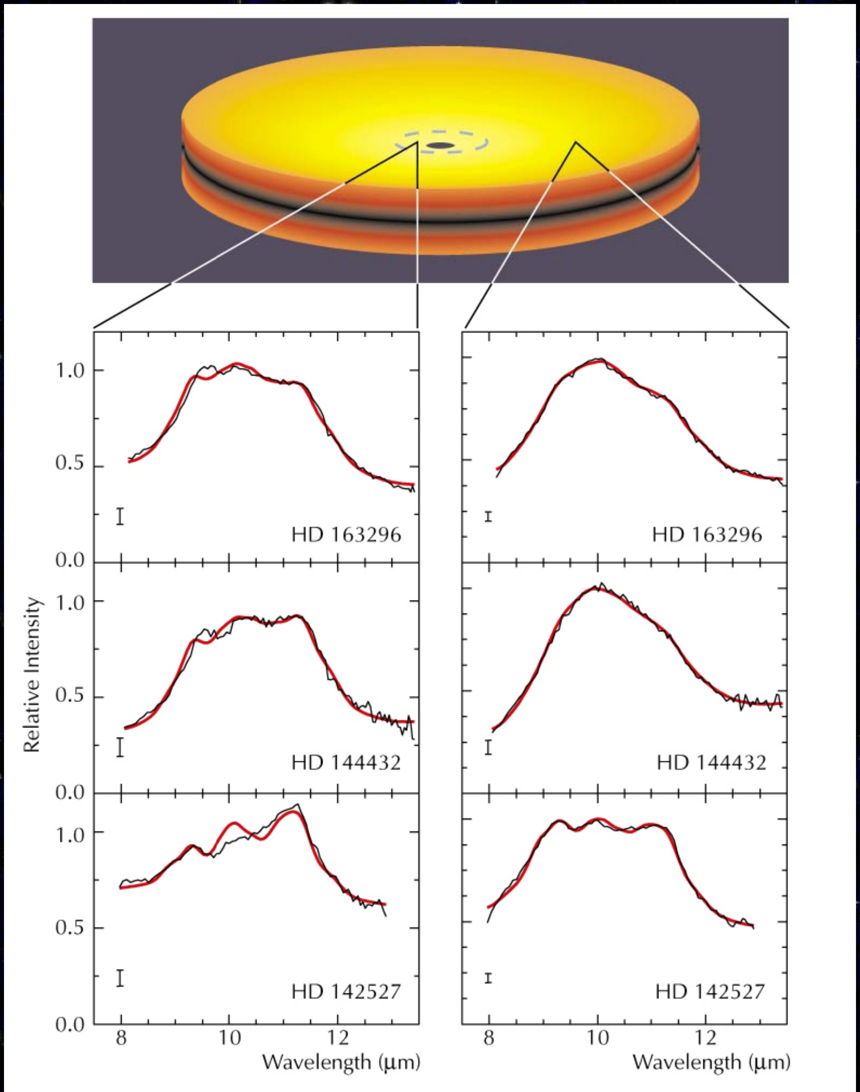
Compositional fits

- Optically thin model
- Olivine, Pyroxene, forsterite, Enstatite, Silica, PAH
- Distribution of hollow spheres (DHS)
- 0.1 μm (“small”) and 1.5 μm (“large”) grains
- Single temperature (Uniform composition)



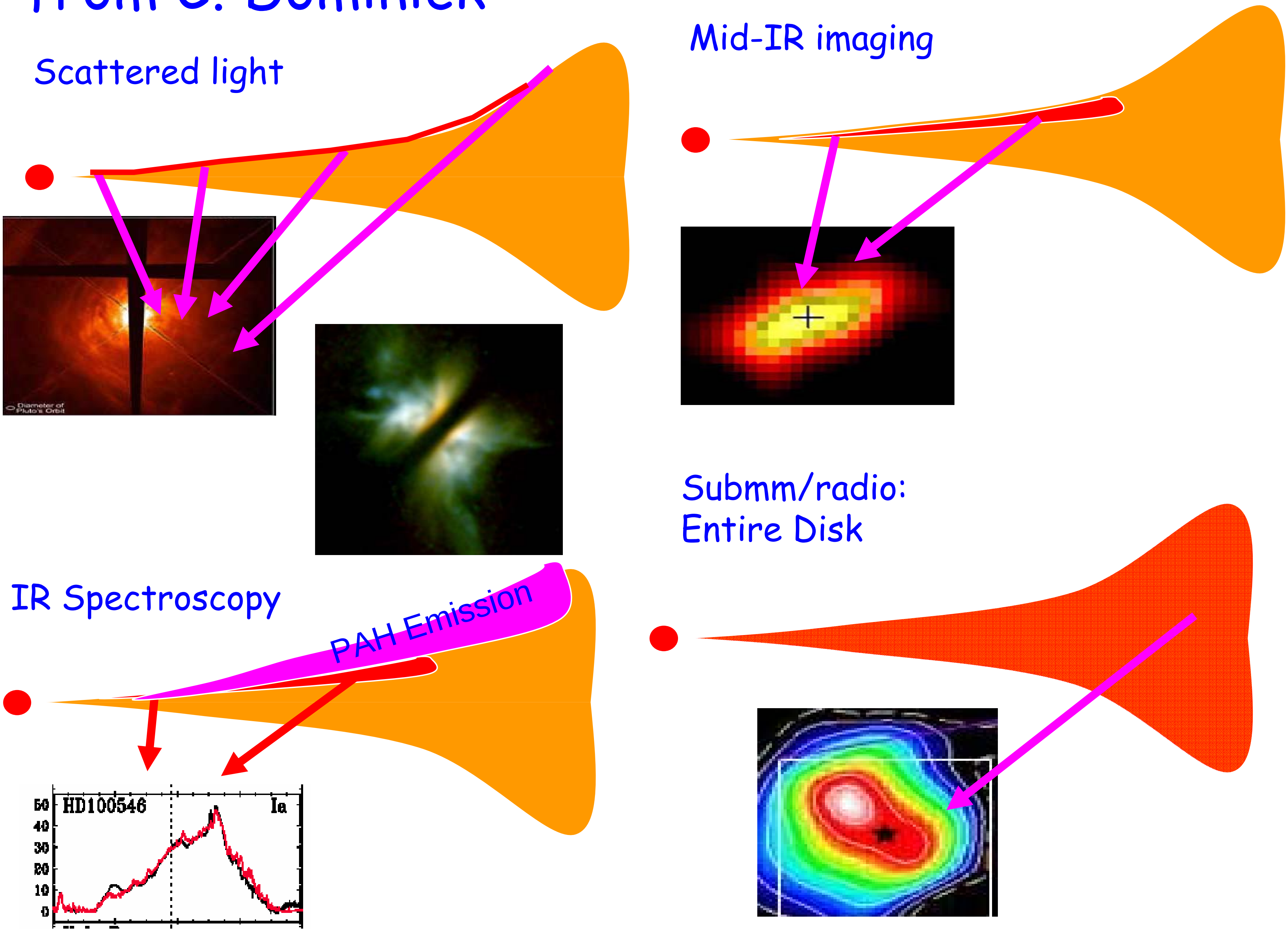
Spatial distribution of the dust

- Crystalline grains concentrated in central disk regions
- Outer disks can be “pristine” while inner disks are “evolved”.
- In disks with low crystallinity, crystals seem restricted to innermost disk region
- In disks with high crystallinity, crystals are present also further out.
- HD 142527: inner disk mostly forsterite, further out more enstatite



MIDI @ VLTI Nature, **432**, 479

from C. Dominick



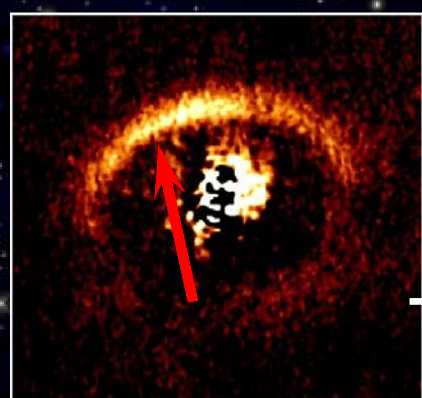
Disk evolution

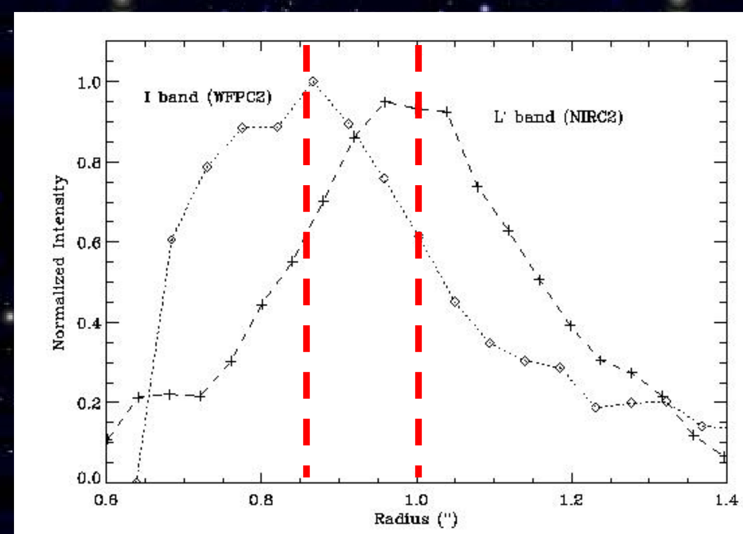
- Grains in protoplanetary disks grow
- SED analyses bsuggest both growth and settling
- Silicate emission, optical scattered light
  - →reveal small grains in surface
- radio thermal emission
  - →large grains in the disk midplane (μm, mm, cm-size)

Disk stratification observations

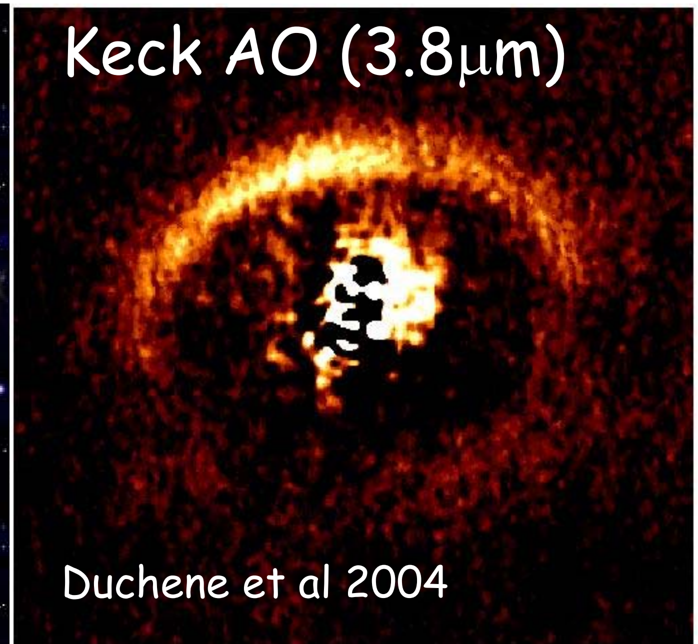
GG Tau most direct evidence of dust stratification to date? *Duchêne et al. (2004)*

- Scattered light at L′ comes from 25AU above the midplane; I band, 50AU above





- Height and opacity of edge-on disks (D'Alessio)
- Scattered light asymmetries (Duchene) IMAGE GG TAU?
- Flaring/Shadowing (Wood, Dullemond, Hartmann Furlan)
- PAH emission: which grains are absorbing?
- Silicate emission: which grains are emitting?
- Silicate feature shape band strength (v. Boekel)
- Dust-to-gas ratio on high inclination sightlines (Rettig/Brittain)



CO Ro-vibrational lines from inner disk region Brittain, Najita, Carr

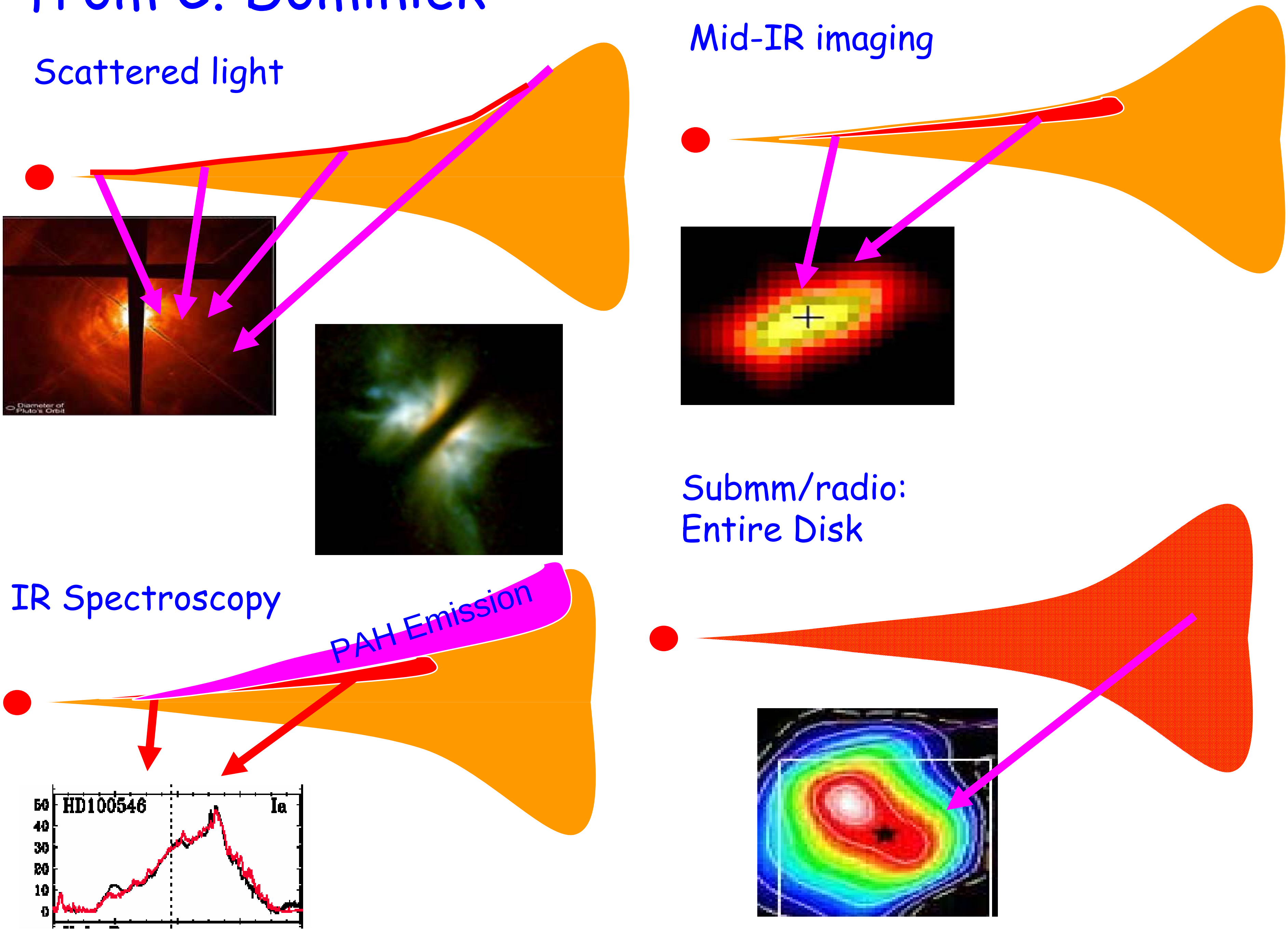
UV observations of H2 Bergin, Martin et al.

Spectropolarimetry, Vink

Clearing-out of inner disk, Forrest et al. 2004,

Internal physics of inner disks (coagulation/chemistry) Blum

from C. Dominick

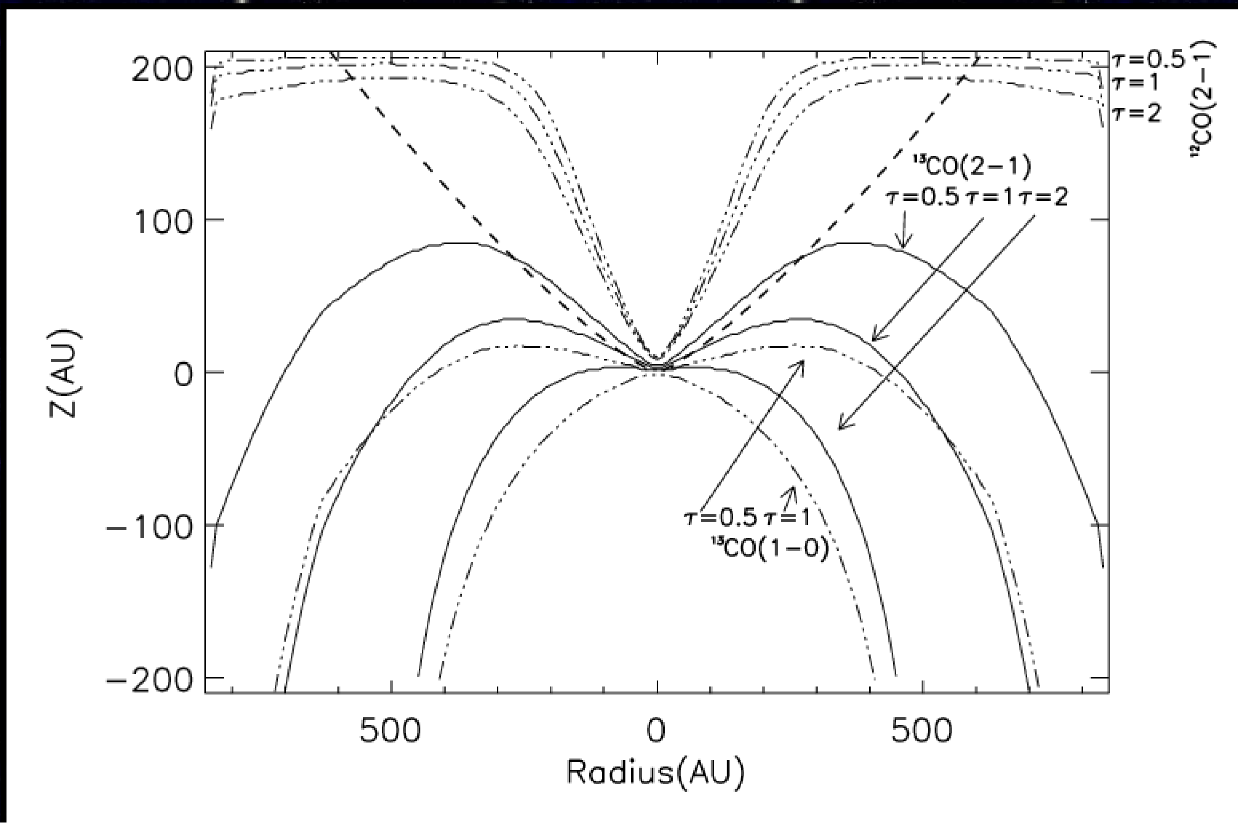


mm/submm imaging ALMA (SMA, CARMA, PdBI

- primordial disk mass measures (dust continuum)
- discriminate between rotation, infall, envelope
  - spatially resolved images + models
- disk chemical processes, evolution of grains
- evolution of structure (gaps?)
- molecular line caveats:
  - radiative transfer more complicated; chemical and physical processes (e.g., freeze-out) affect abundances as a function of T and ρ; optically-thick lines don't trace all mass

Vertical disk structure

- Dartois et al. (2003): $^{12}CO(2\text{–}1)$, $^{13}CO(2\text{–}1)$, and $^{13}CO(1\text{–}0)$ constant τ surfaces vs. radius and height (see also Piétu et al., poster #43)



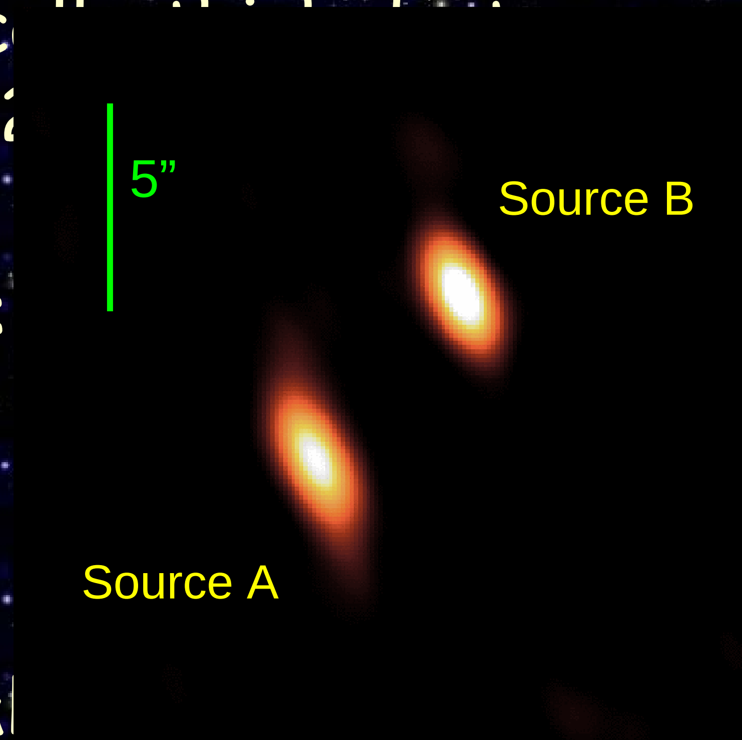
Vertical structure: DM Tau

- Dartois et al. observe $^{12}CO(2\text{–}1)/(1\text{–}0)$, $^{13}CO(2\text{–}1)/(1\text{–}0)$, and $C^{18}O(2\text{–}1)$
- ^{12}CO samples 2–4 scale heights
- $^{13}CO(2\text{–}1)$ samples ~1 scale height
- $^{13}CO(1\text{–}0)/C^{18}O(2\text{–}1)$ sample disk midplane
- Evidence that the outer layer is warmer (~30 K) than the midplane (~13–20 K)

- Only the most massive TT disks can be detected in molecules due to typical depletions ~10–100
- Will have to wait for ALMA to know whether these techniques will work for lower mass disks as well

Disentangling disks and envelopes IRAS 16293–2422

- Class 0 binary protostar in ρ Oph
- Component B has optic
  emission with T_B=$S\lambda^2/2$
  GHz on scales of ~1″
- Good molecules to try:
  H_2CO, HCN, HCO^+,
  SO, CS, etc.

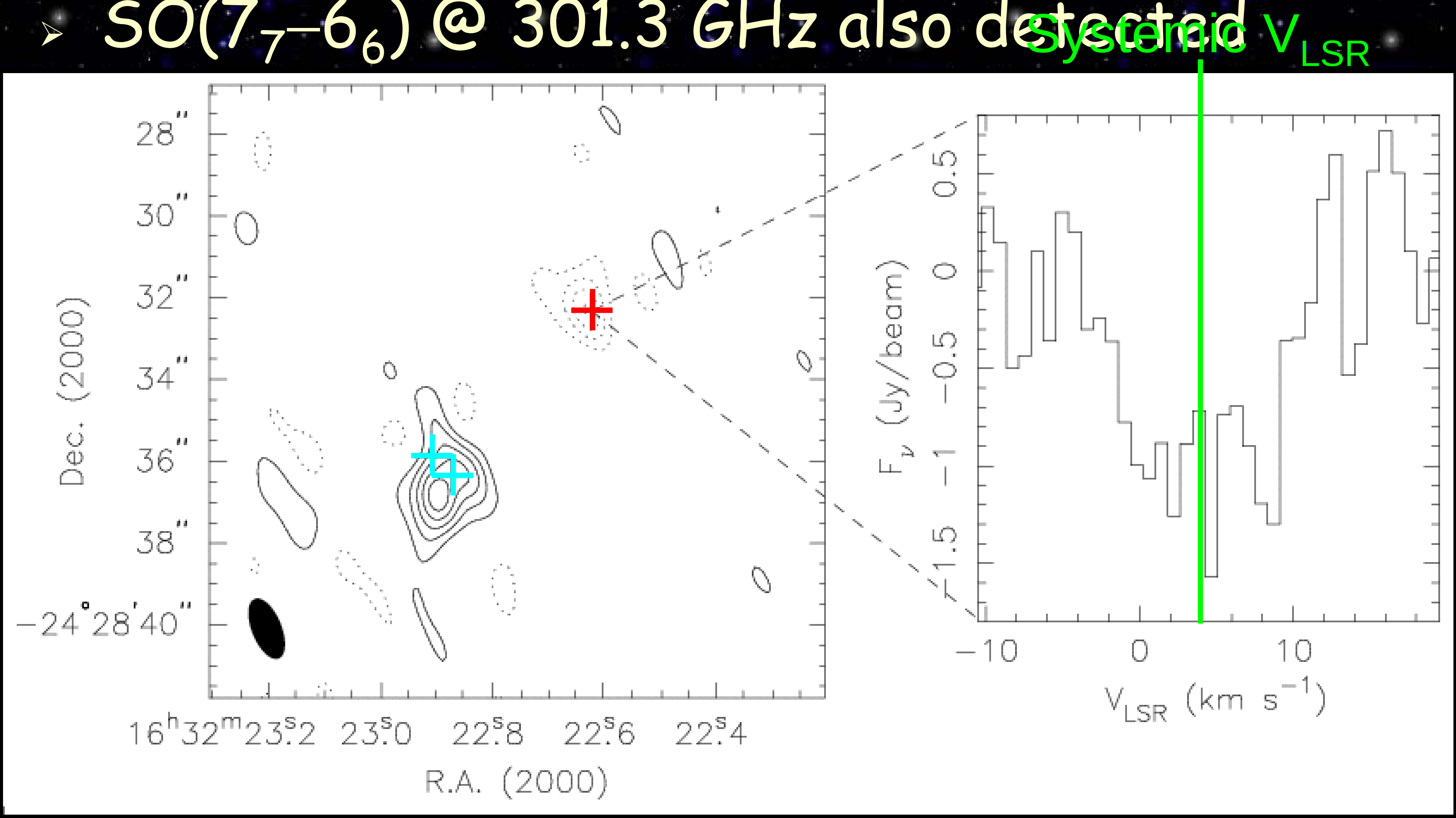


- Set out to detect infal
  using H_2CO (4_{13}–3_{12}) @
  300.8 GHz (E = 48 K)

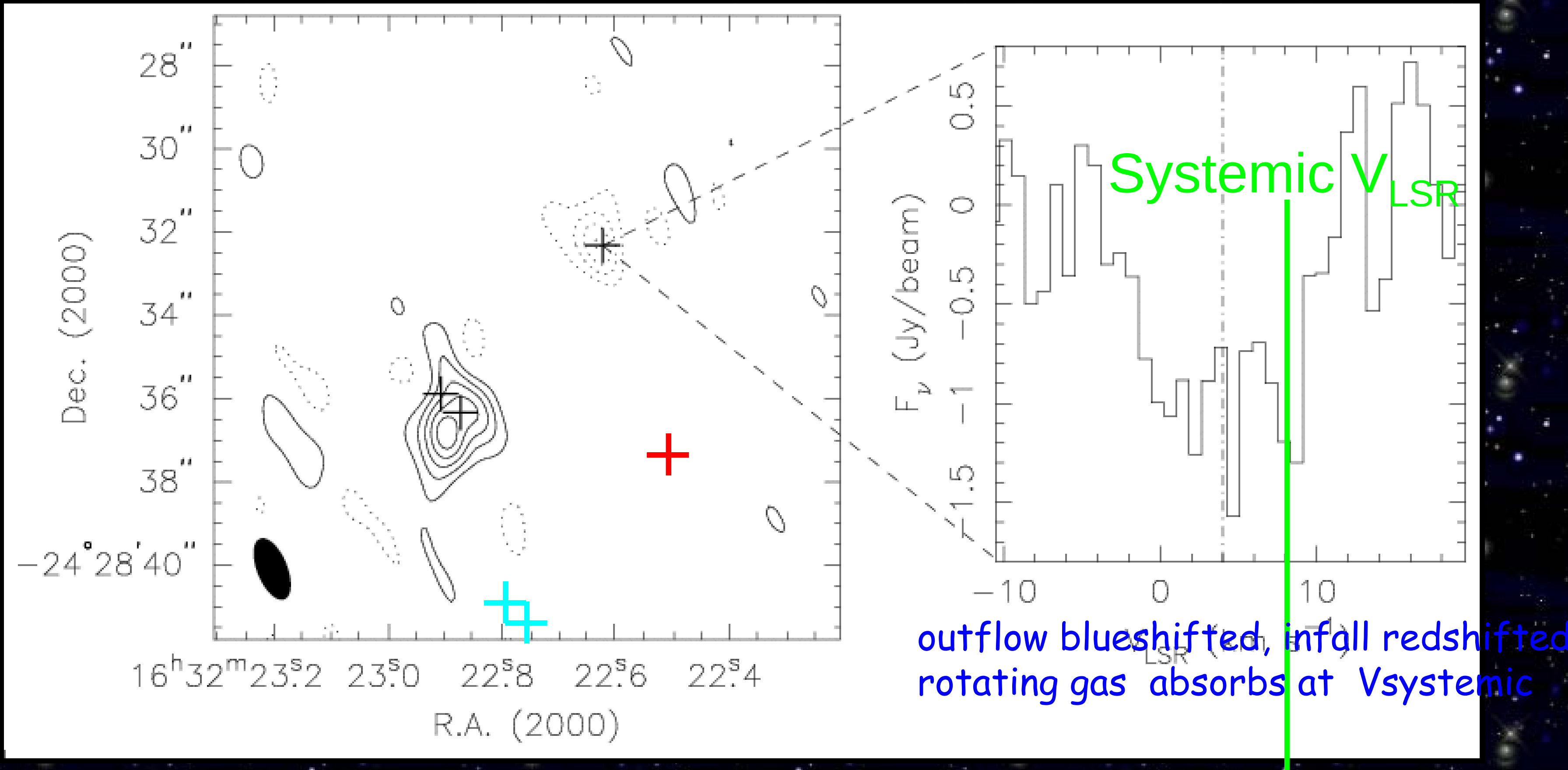
Chandler et al. (poster #9)

SO(7_7–6_6) absorption against source B

- SO(7_7–6_6) @ 301.3 GHz also detected



SO(7_7–6_6) absorption against source Bb



ALMA provides best opportunity

Forming Planets – theory meets observations

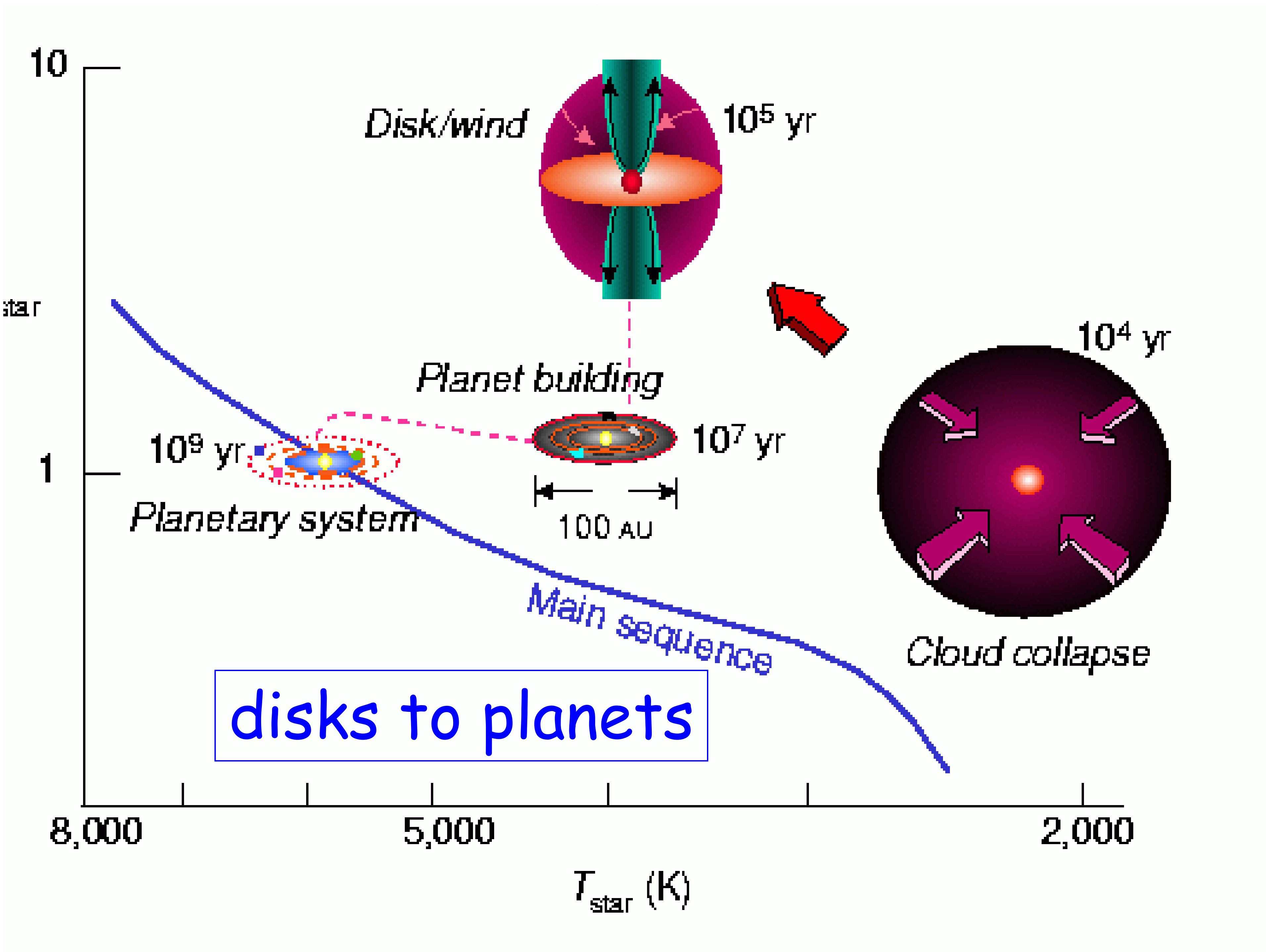
- core accretion model, magnetohydrodynamic disks, magnetospheric accretion, hydrodynamic disks

  lots of questions

- correlation w. metallicity and planets favors core accretion model
- Hot Jupiter search may illuminate

Disk dispersal

- Some gas disks can persist up to 20 Myr, but large range in lifetimes
- Better observational statistics needed to
  - Constrain lifetime inner + outer gas disk
  - Compare lifetimes gas + dust disks
- Accretion + photoevaporation *may* explain disk lifetimes of 1-10 Myr, but model results depend critically on adopted EUV and FUV fields



10
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star
Disk/wind
10^5 yr
Planet building
10^7 yr
100 AU
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Planetary system
10^4 yr
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Main sequence
disks to planets
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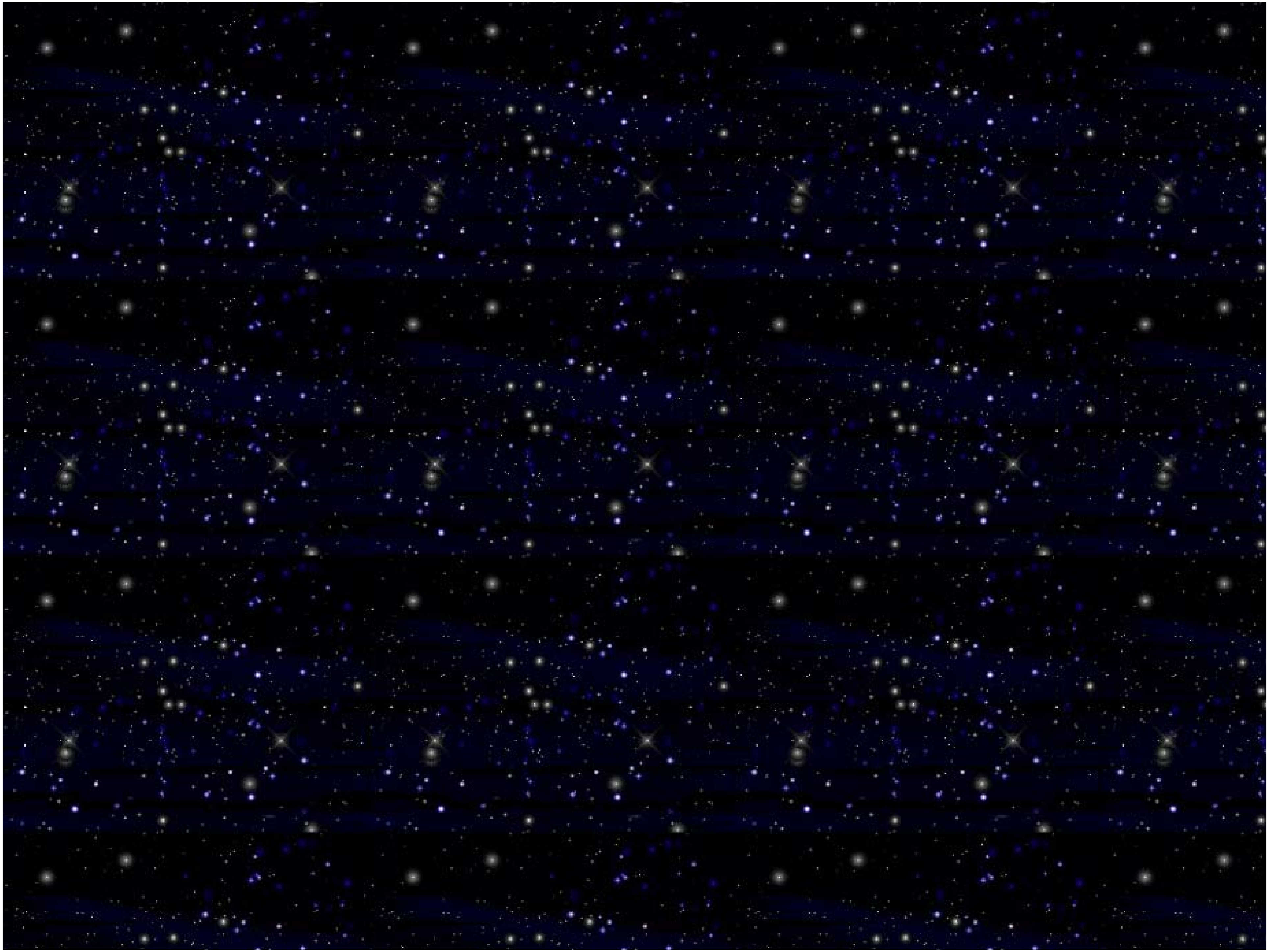
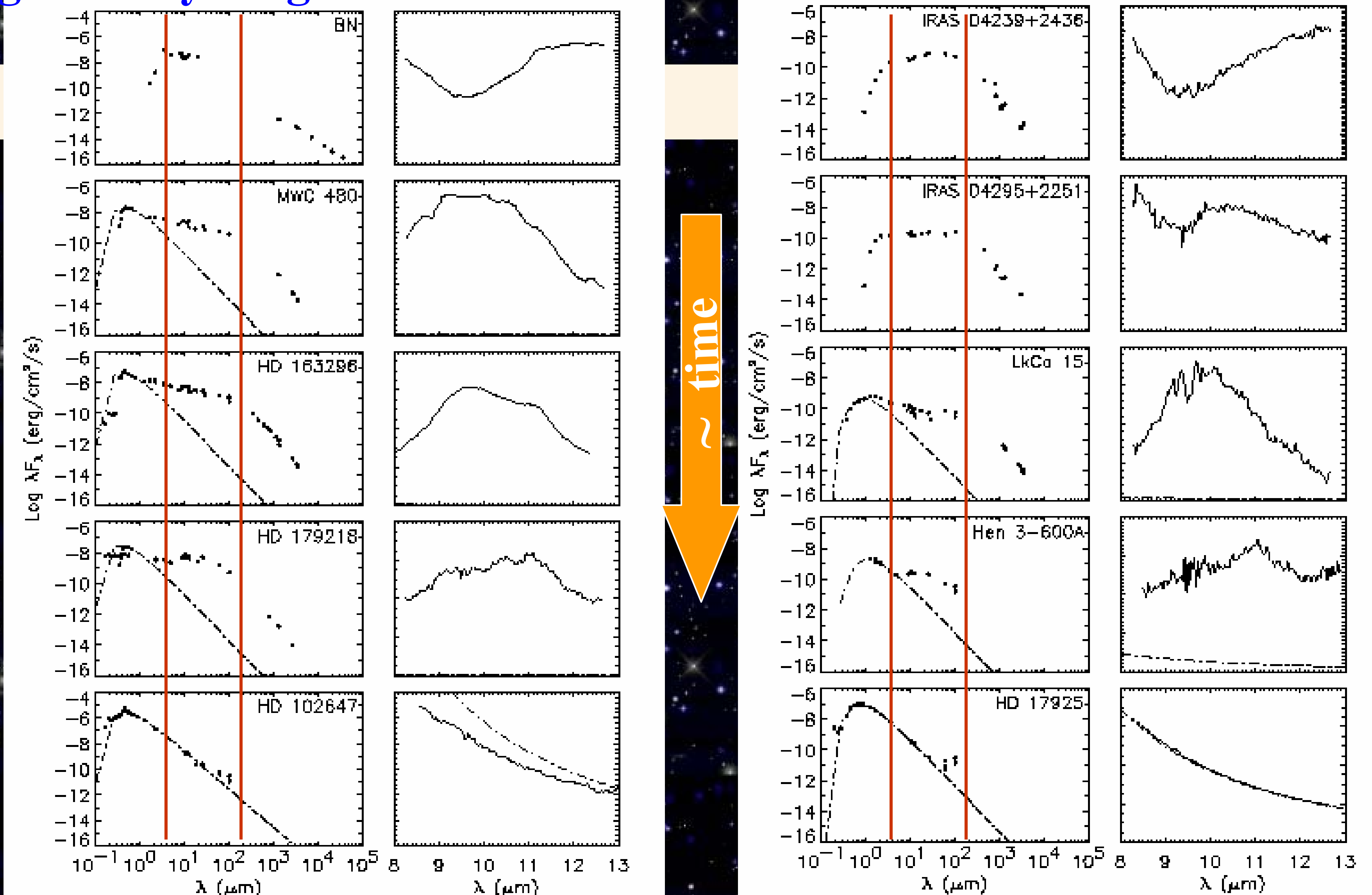


Kessler-Silacci et al. (2004)

SED & Mineralogical Evolution

High mass young stars

Low mass young stars



Jackie Kessler c2d IRS

- silicates/other spectral features in TT disks as diagnostics of evolution first slide
  - Dust coagulation and H2 dissipation time scales
- Change of features with grain size – extrapolate from ISO for HAe stars
- Mix of olivine and graphite -> slightly difft results and get a slightly better fit same for 20 um feature, require larger sizs of grains overall
- Larger grains for sources with cleared out inne disks?
- Want to fit a slew of minerals etc
- Ratio of 10/20 strength means need different poulation of grains – difft sizes
- Statistical trends indicatin grain growth do not appear to be related to sp type, age but maybe to Halpha I'e' clearing of inner disk?