DIGIT (Dust, Ice, and Gas in Time)

Neal Evans (Univ. Texas at Austin and ESO-Chile)

DIGIT (Dust, Ice, and Gas in Time) Open Time Key Project

- 250 hrs + followup
- 31 embedded protostars (full spectral scans)
- 63 disk sources ranging from B to M in spectral type (intermediate and low mass), selected from nearby (a few x 100 pc) molecular clouds (Tau, Oph, Cha, Per, Ser, Lup)
- PACS spectroscopy (52-210 um), PACS photometry (WTTS only; 70, 100, 160 um)
- SPIRE photometry (WTTS only)
- HIFI spectroscopy on 557 GHz H_2O
- Focus on evolution of chemical state during SF
- Spectral features of dust, ice, and gas
- OT2 Followup: CO in Protostars (COPS)
  - SPIRE spec. of protostars (PI: J. Green)
  - HIFI on CO J=16-15 (PI: L. Kristensen)
- Serpens CO Line Map (PI: O. Dionatos)

The DIGIT Team:

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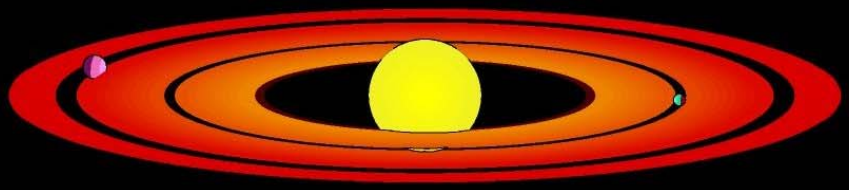
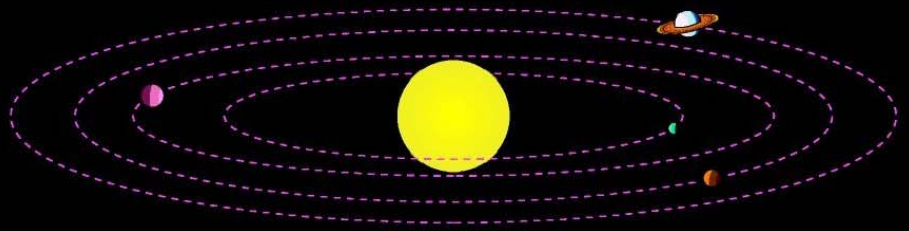
Hyo-Jeong Kim
Johan Olofsson
Bernhard Sturm
Ke Zhang
Gijs Mulders

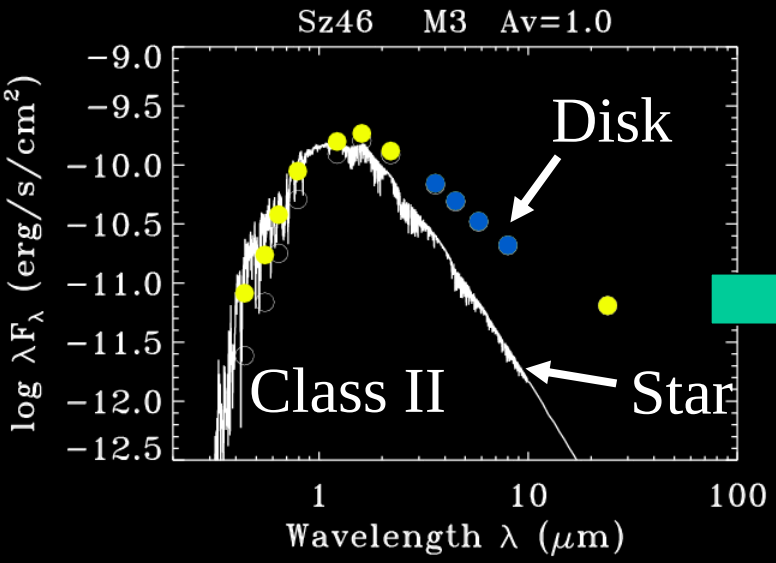
Scenario for star- and planet formation

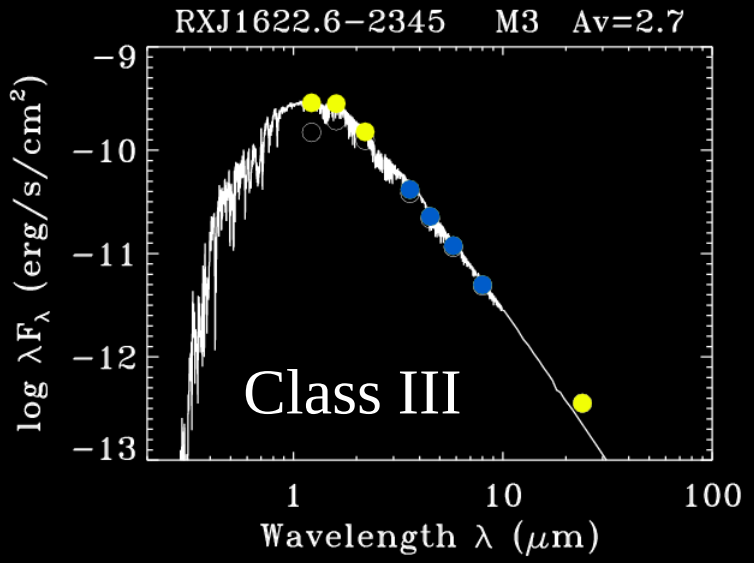




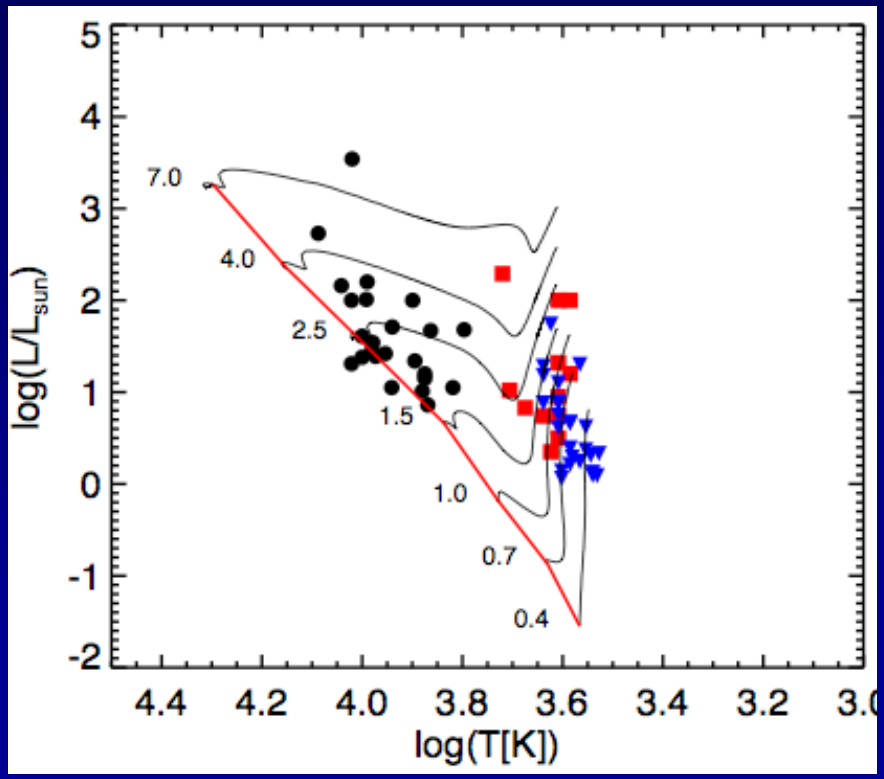
Formation planets $t=10^6$-10^7 yr

Solar system $t>10^8$ yr (?)

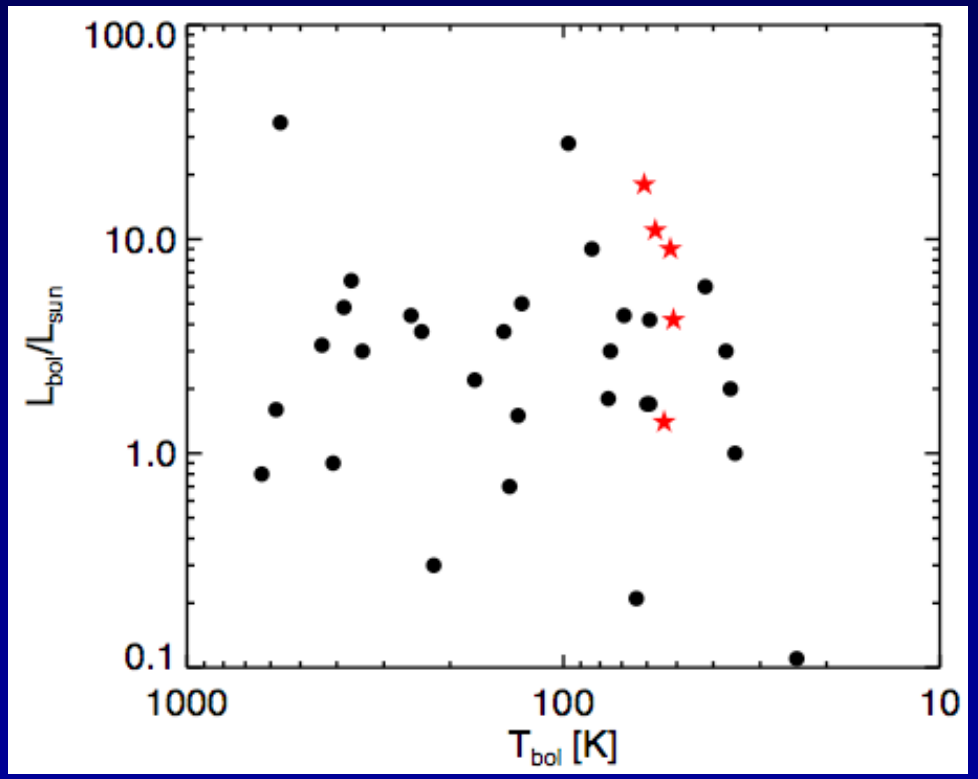




Distribution of Sources in L-T



Disk Sample

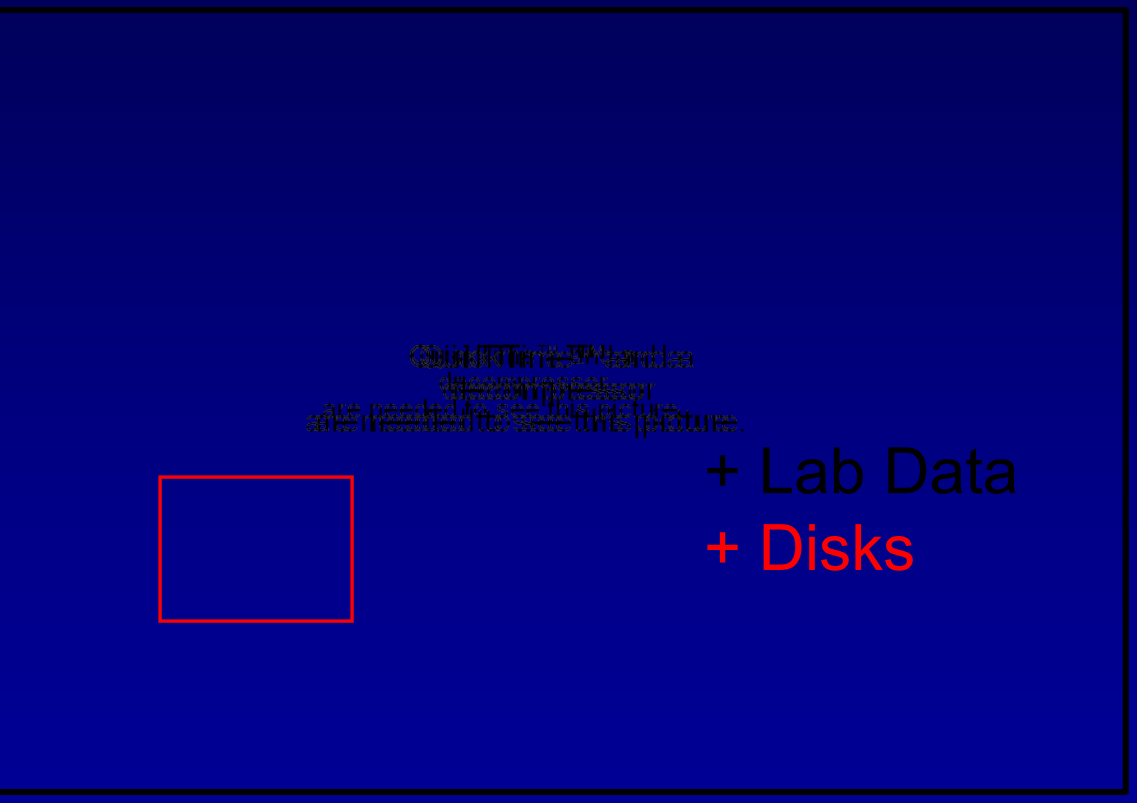


Embedded Sample

Dust Mineralogy

- Six out of 34 Herbig Ae/Be and T Tauri stars show 69 micron forsterite emission
  - Sturm et al. in prep.
  - All but one (AB Aur) have iron content <4%
  - Mostly emitted by 100-200 K dust
  - Comparison to Spitzer forsterite features indicates optical depth effects are important

Iron-free



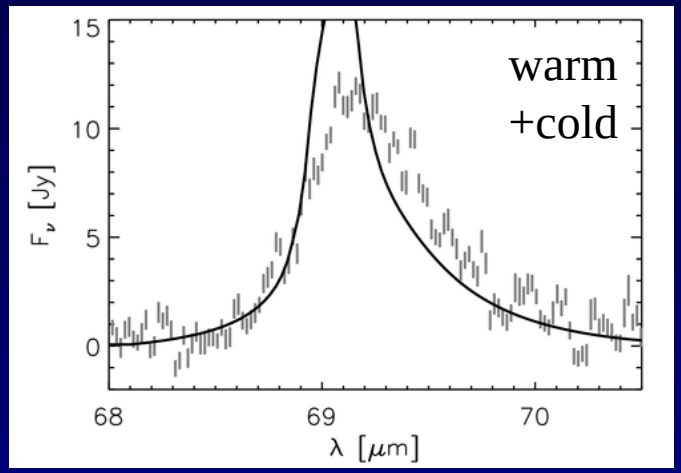
The center wavelength depends on T_d and Iron content.
Location of peak constrains iron content to be very low.

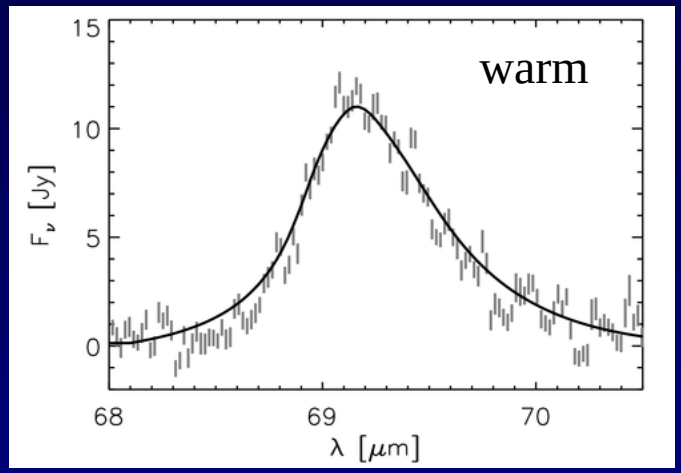
Sturm et al. in prep.

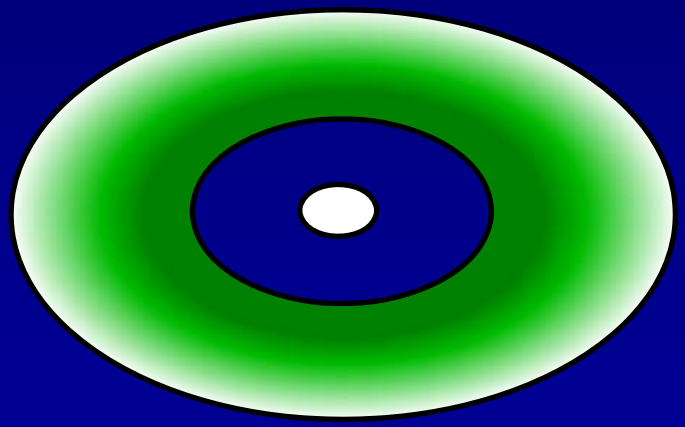
HD100546 Detailed Analysis

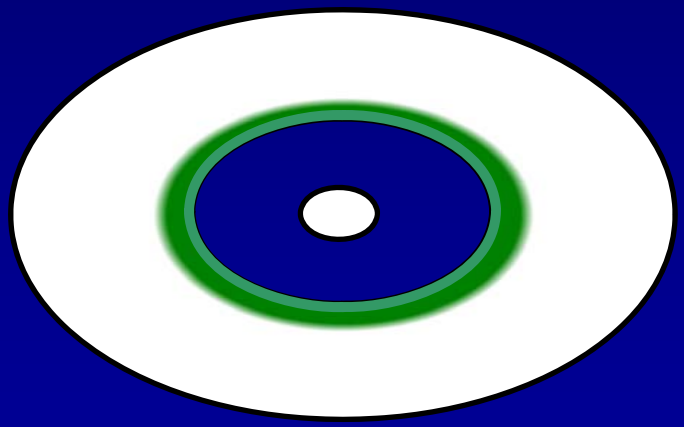
Forsterite is located near inner rim of outer disk.
Only 0.5-0.8% of total dust mass, but location makes it appear to be more.
But, higher temperatures (> 1000 K) needed to make it.
Radial transport, stellar outburst, shocks, planetesimal collisions all possible, but all related to disk gap.
(Mulders et al. 2011)

HD100546: forsterite location





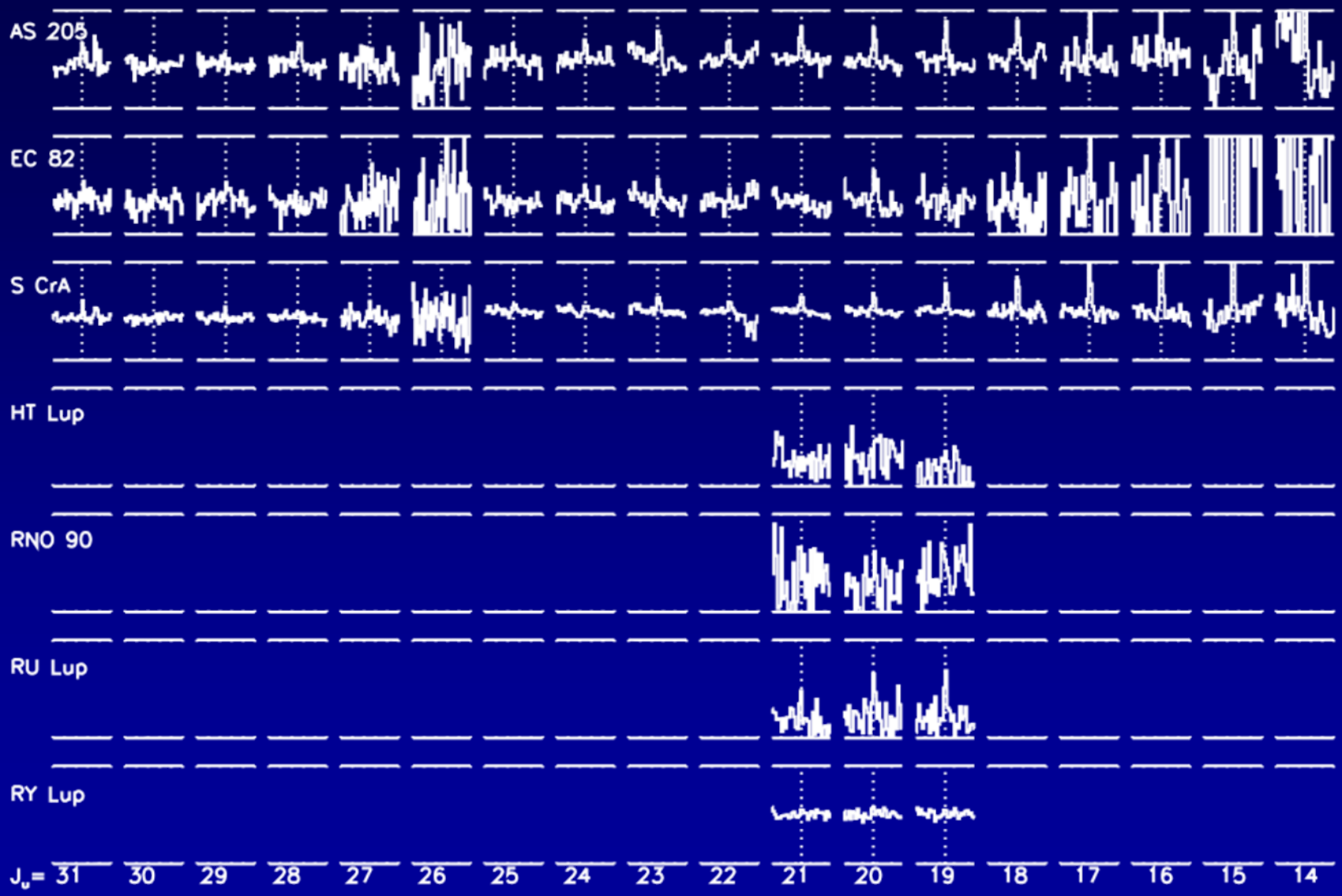




2D RT: forsterite located close to disk wall (13-20 AU)
Low total mass (0.5-0.8%), but strong features
Origin related to disk gap

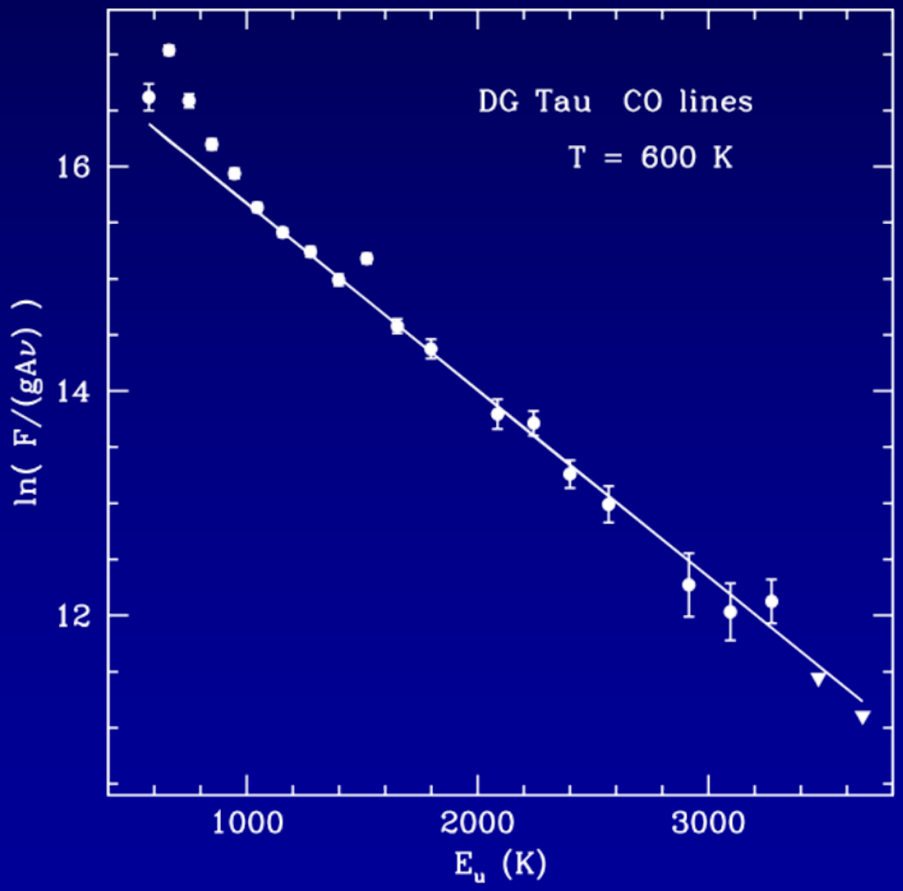
Mulders et al. 2011

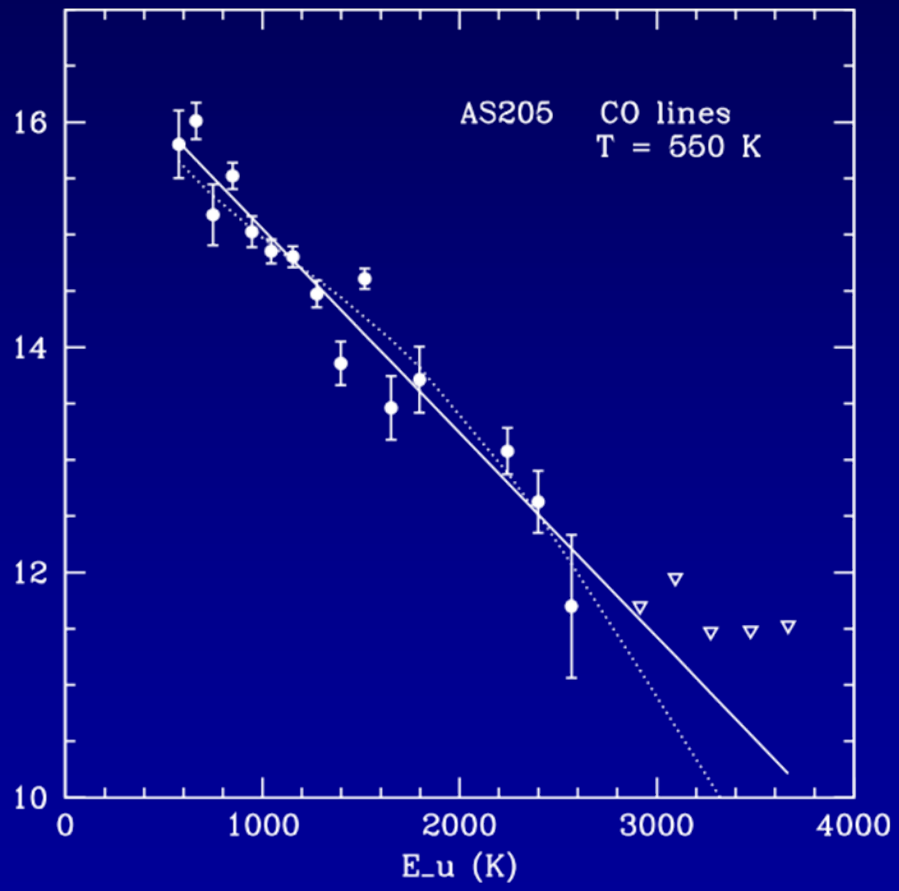
CO in T Tauri Stars



J. Carr, C. Salyk

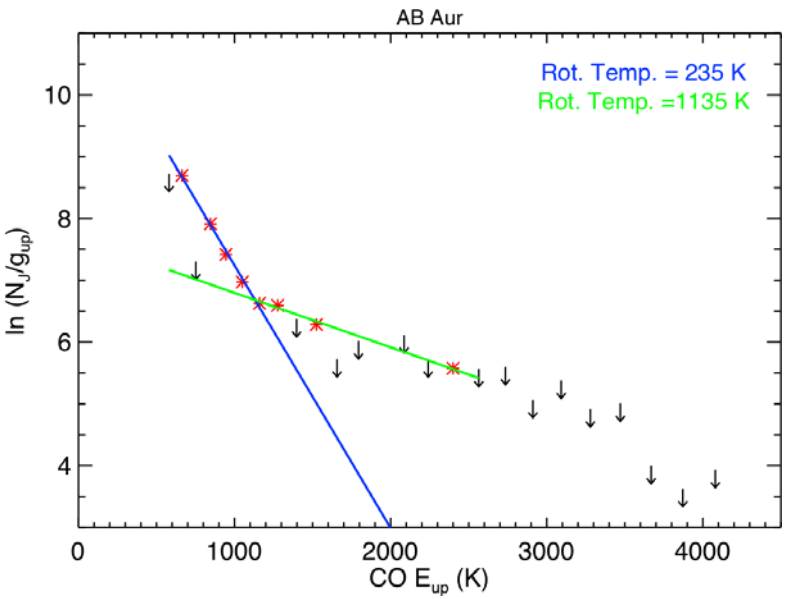
T Tauri: Preliminary Analysis

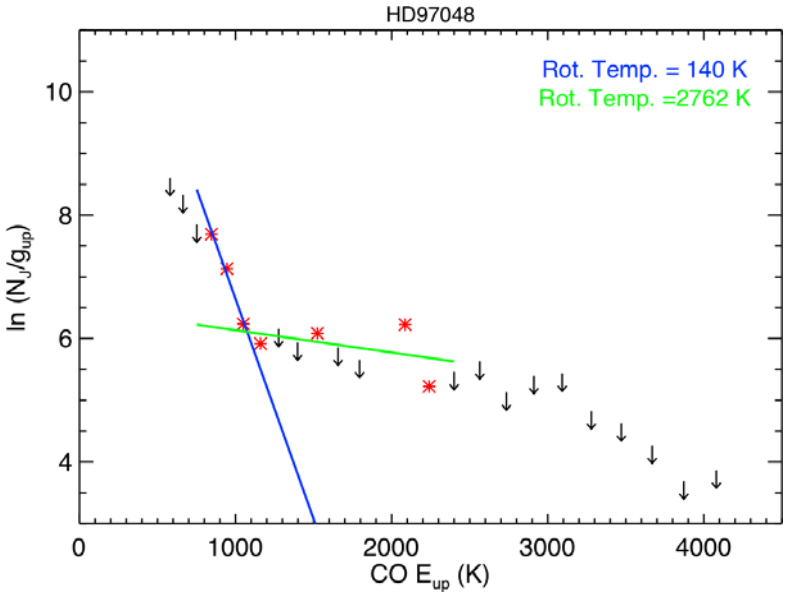


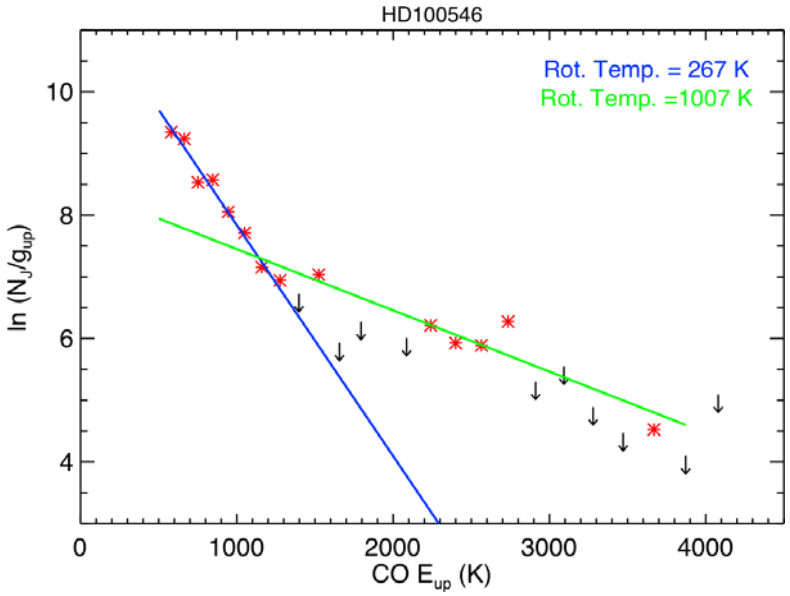


J. Carr

Herbig Ae/Be: both warm and hot components

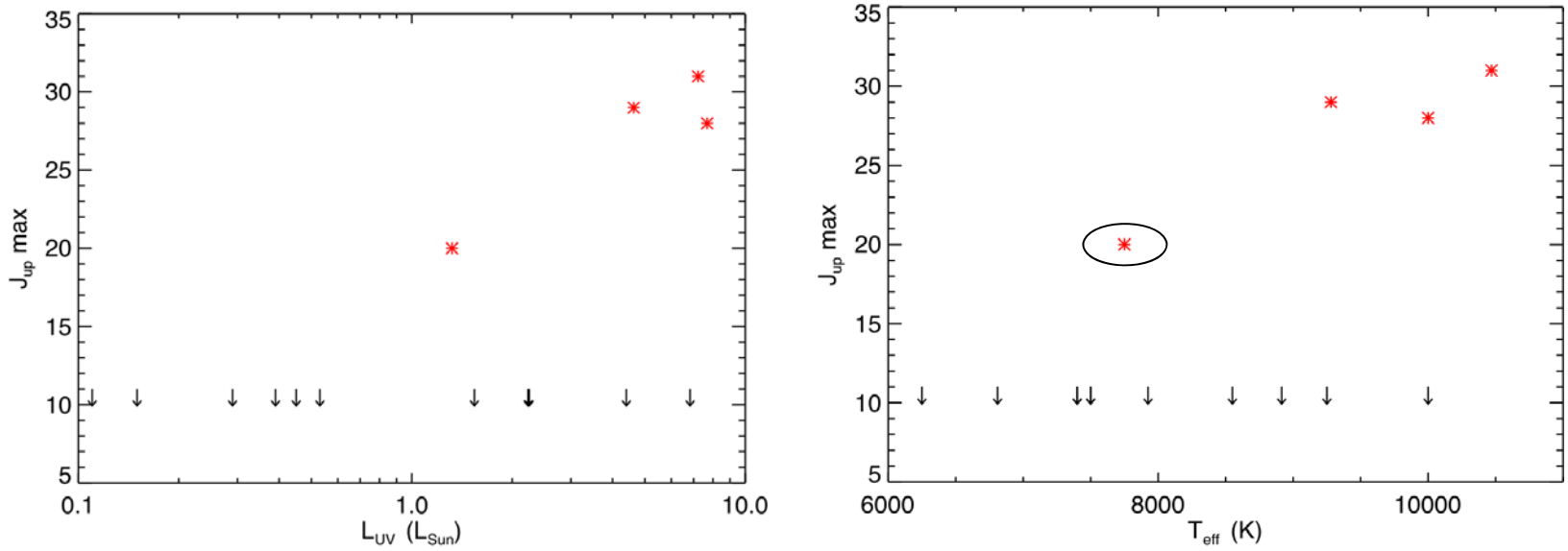






G. Meeus

Highest J versus L_{UV} and T_{eff}



Detections of higher J CO lines in stronger UV sources, but not all high L_{UV} sources have high-J. Ditto for T_{eff}.

G. Meeus

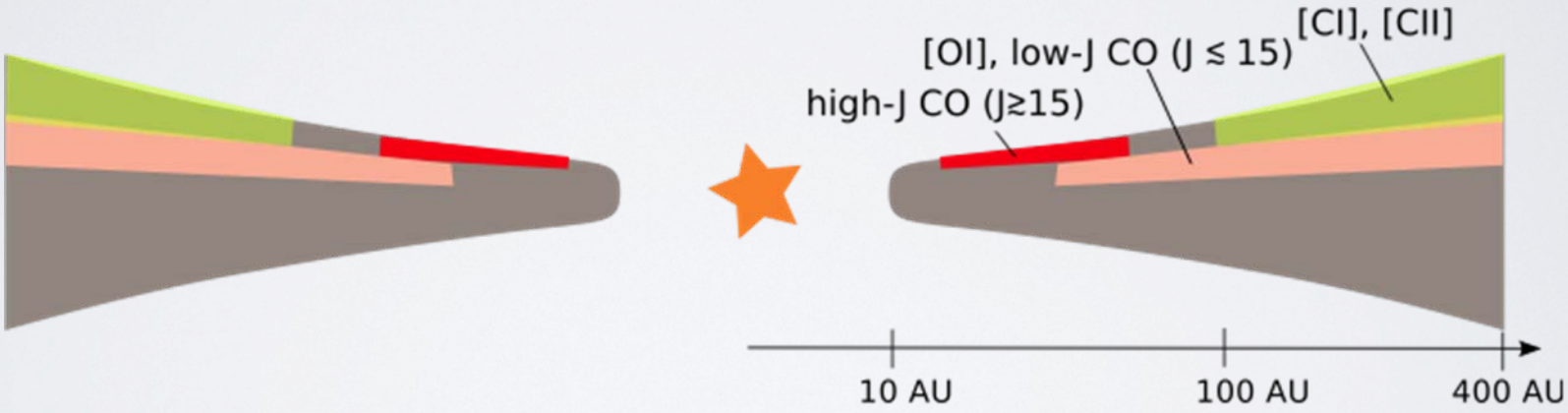
CO in Herbig Ae/Be discs: summary

- **CO mid to high J detections:**
- **flared discs: 4 (out of 11 sources)**
- **flat discs: no detection (out of 9 sources)**
- **Highest J found in HD100546, has hot inner wall, source with highest UV flux**
- **Sources with mid-J CO detections have high UV fluxes (= sources with high T_{eff})**
- **Sources with mid-J CO detections have PAH bands**

- **CO and [OI]63 line fluxes tend to be correlated**

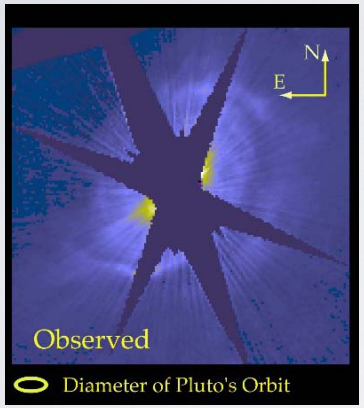
Origin of the lines

- Origin of the far-infrared/submillimeter line emission in HD 100546

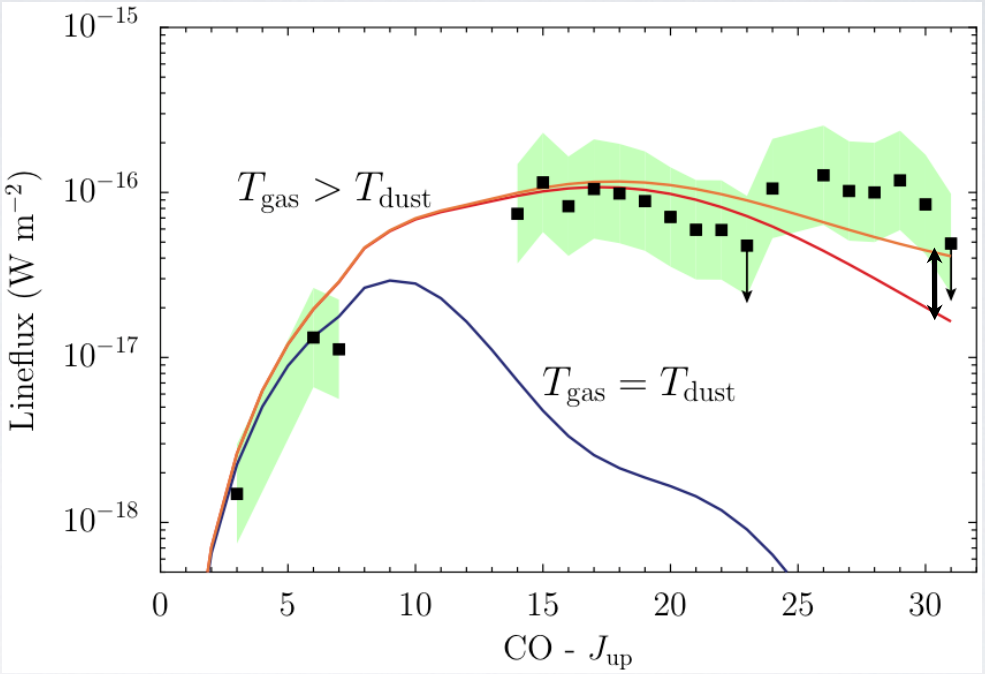


S. Bruderer

HD 100546 : Detailed Model



HST: Grady et al. 2001



Different H_2 formation rates

Bruderer et al. 2012

Evidence that gas- and dust temperatures are decoupled in atmosphere

S. Bruderer

The Herschel DIGIT Survey of Weak-line T Tauri Stars

Sample: 31 WTTSs in nearby star-forming regions and young associations (13 with known Spitzer excesses, 18 with no previous disk detections)

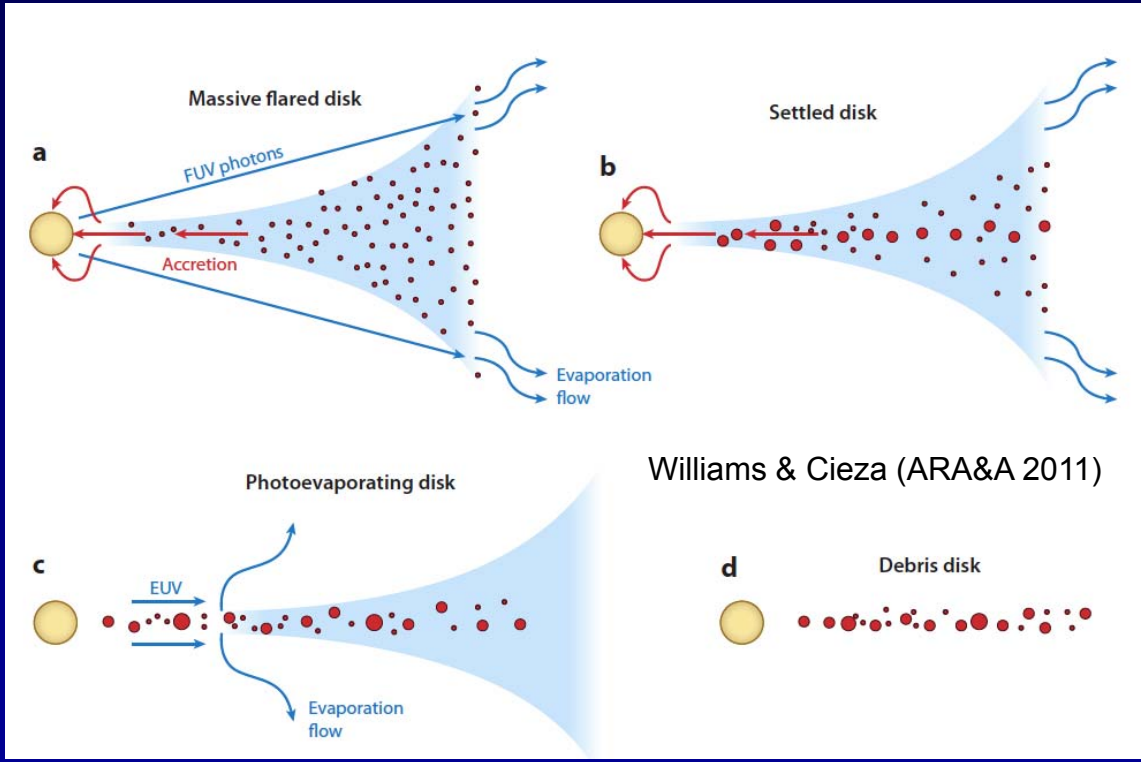
Observations: deep PACS (70/160 μm) and SPIRE (250-500 μm) targeted photometry

Results:

- 15 objects detected at 1 or more Herschel wavelengths (all previously known disks and 2 new disks).
- 2 have SEDs similar to CTTS (borderline objects)
- 4 “evolved” primordial disks (settled disks/inner holes)
- 6 “warm” debris disks (excess at 24 and 70 μm)
- 2 “cold” debris disks (new objects with 70 μm excess)
- 1 massive primordial disk with intriguing properties (T Cha)
- 16 targets have no evidence for a disk at all

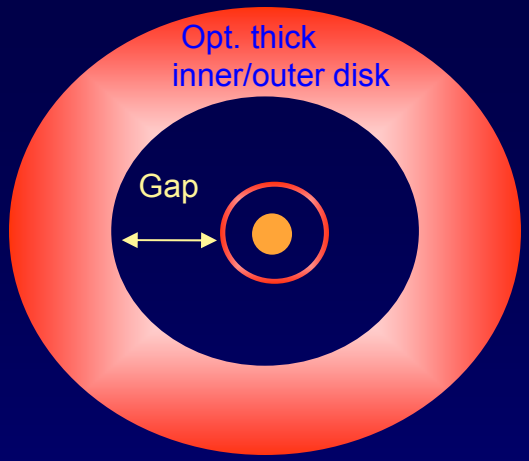
WTTSs in the disk evolution context

• **WTTSs trace the dissipation of the primordial disk and the transition to the debris disk (or diskless) stage**



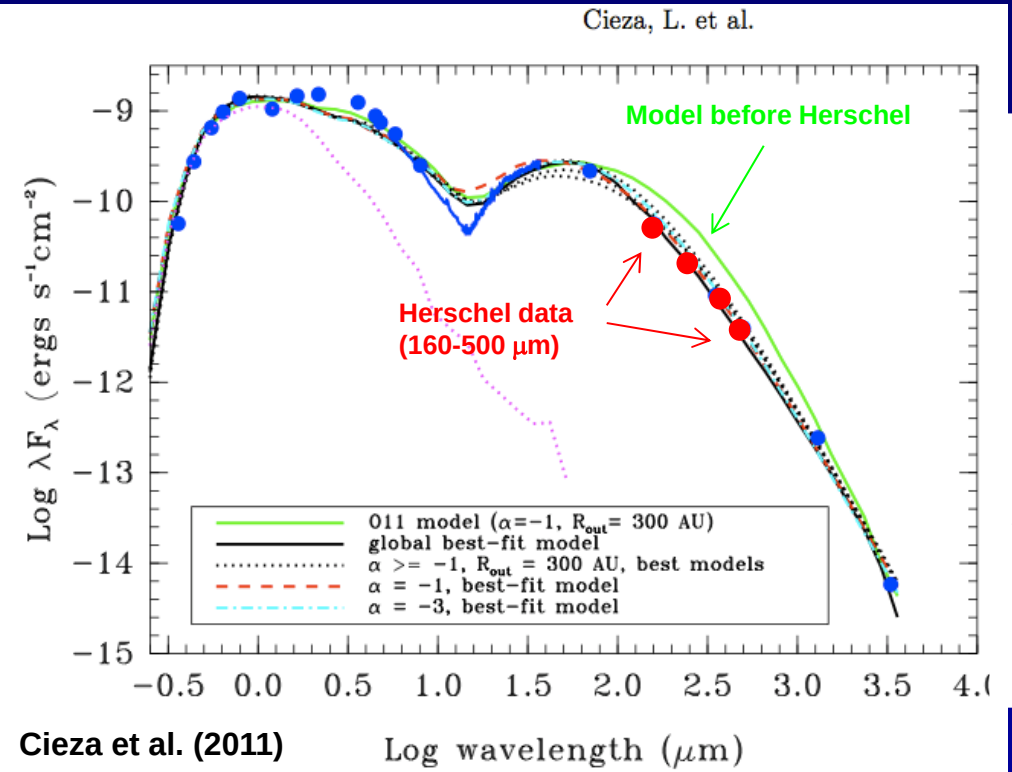
Williams & Cieza (ARA&A 2011)

L. Cieza



T Cha

- WTTS with massive outer disk
- "Transition" disk with wide gap
- Planet candidate detected within gap (Huelamo et al. 2011)
- Herschel fluxes don't match previous models

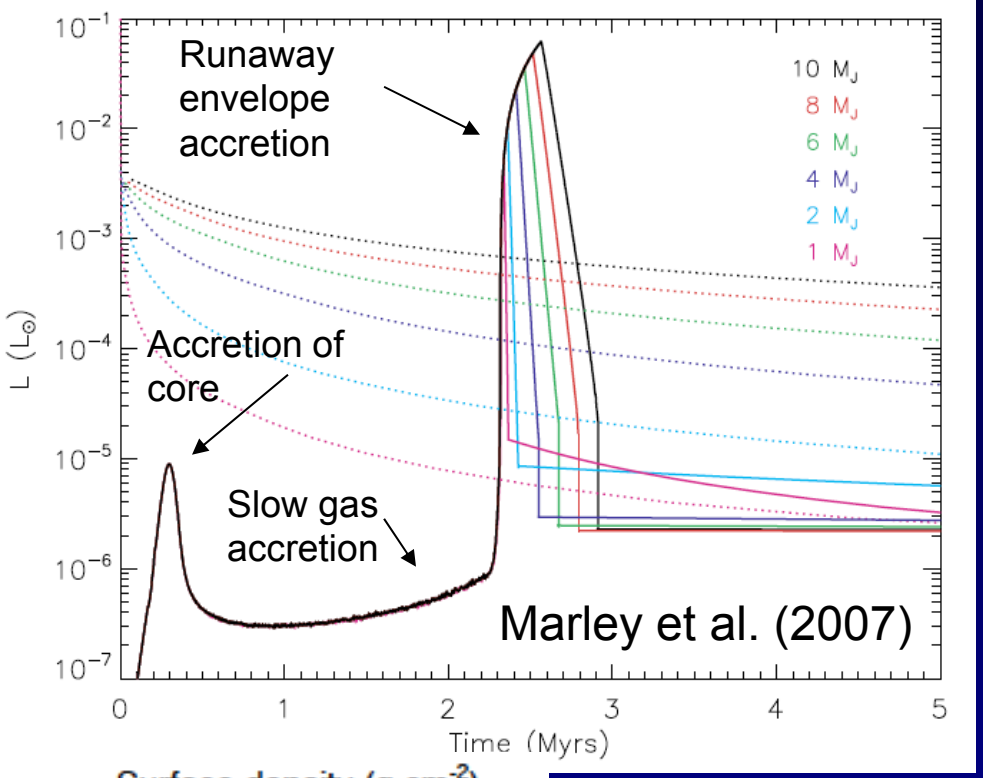


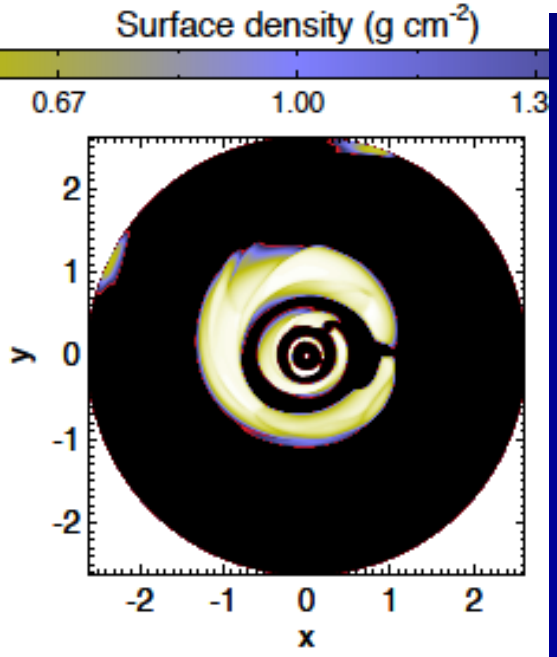
Cieza et al. (2011)

Herschel fluxes imply most of the mass is within 30-40 AU from star:

1) Disk is very small (dynamically truncated by outer planet?)

2) Steep surface density profile (due to dynamical interaction of embedded planet?)





T Cha properties are best explained by runaway envelope accretion (Cieza et al. 2012):

A massive planet explains gap in the disk

- Accretion onto planet explains low accretion onto star despite large disk mass
- Accretion luminosity explains brightness of planet candidate

Hydrodynamic models suggest multiple giant planets might be needed to explain SED!

Dodson-Robinson & Salyk (2011)

Summary

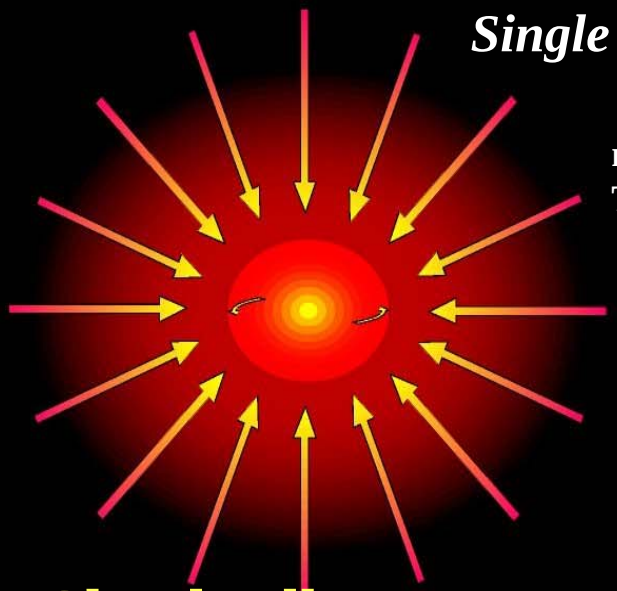
- Forsterite at 69 microns is tracer of past events
- CO seen in small fraction of sample
  - Indicates $T_{gas} > T_{dust}$
- Cold dust seen around some wTTs
  - May be entering debris phase
  - T Cha has evidence for dynamical effects of massive protoplanet

Backup Slides

Standard Evolutionary Scenario

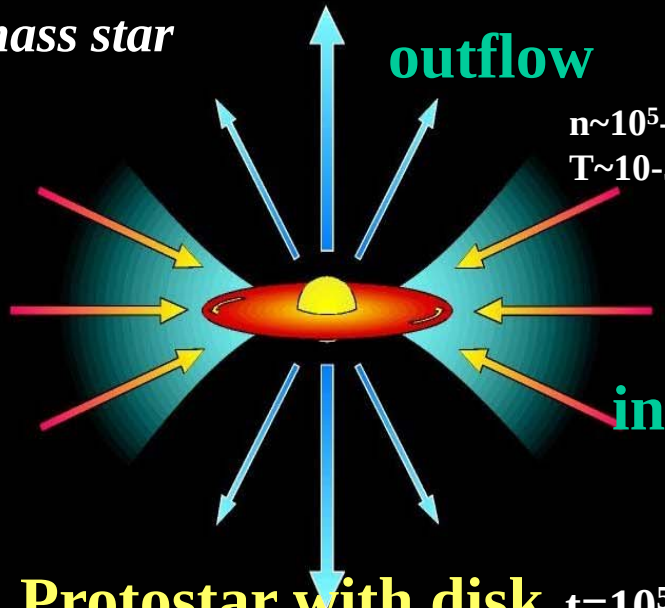
Stages

Single isolated low-mass star



$n \sim 10^4$-10^5 cm^{-3}
T~10 K

Factor 1000 smaller



outflow

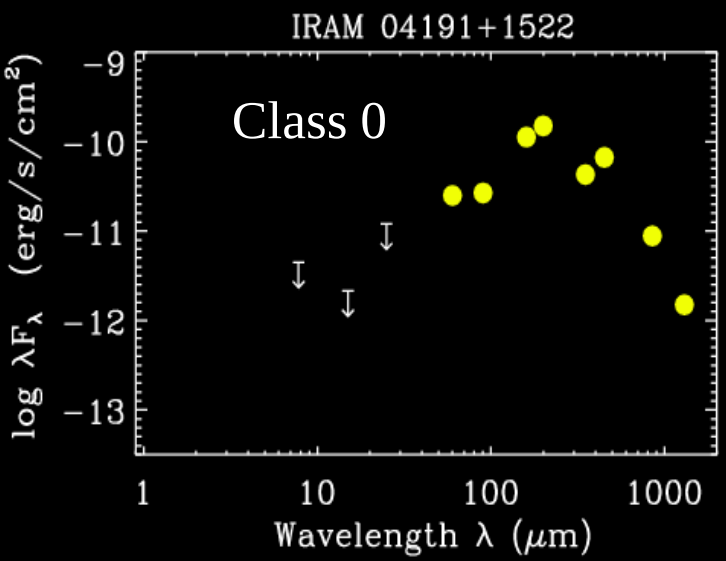
$n \sim 10^5$-10^8 cm^{-3}
T~10-300 K

infall

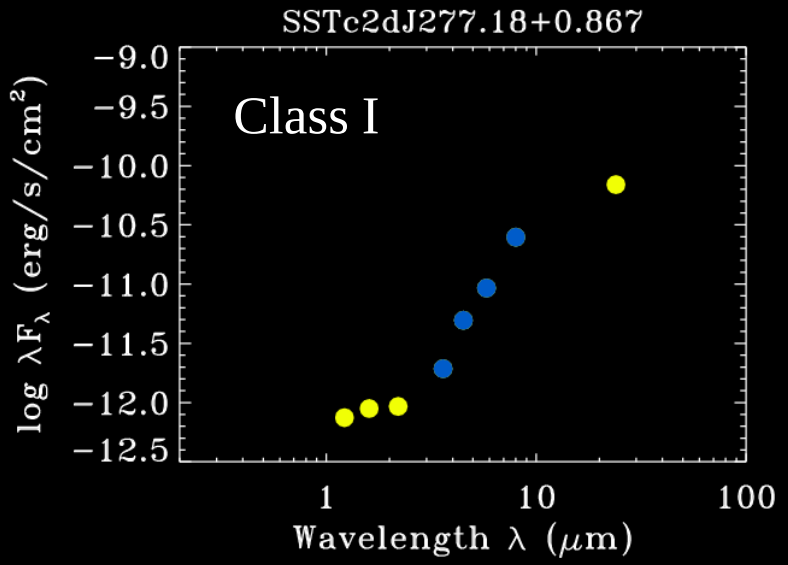
Cloud collapse t=0

Protostar with disk $t=10^5$ yr

Classes

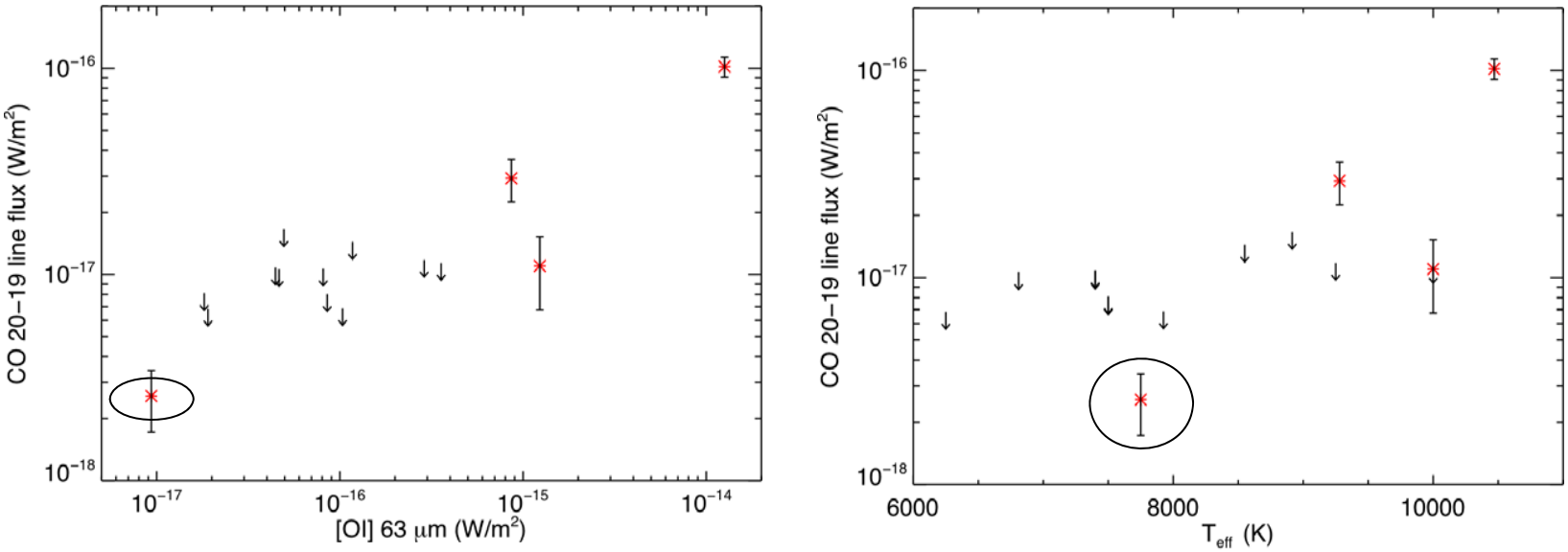


Between stages!



Note axis change!

CO J=20-19 flux vs. [OI] 63 μm and T_{eff}



With the exception of HD36112, CO line flux correlates with strong [OI]
Hottest sources have highest CO line flux