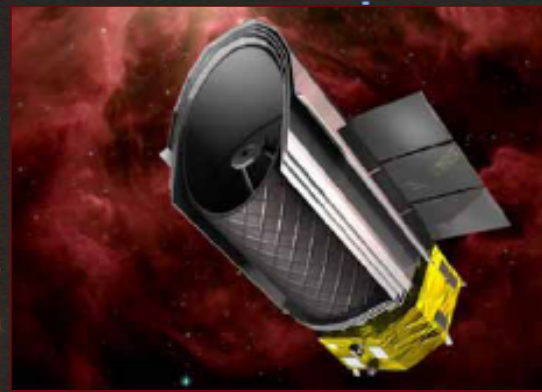
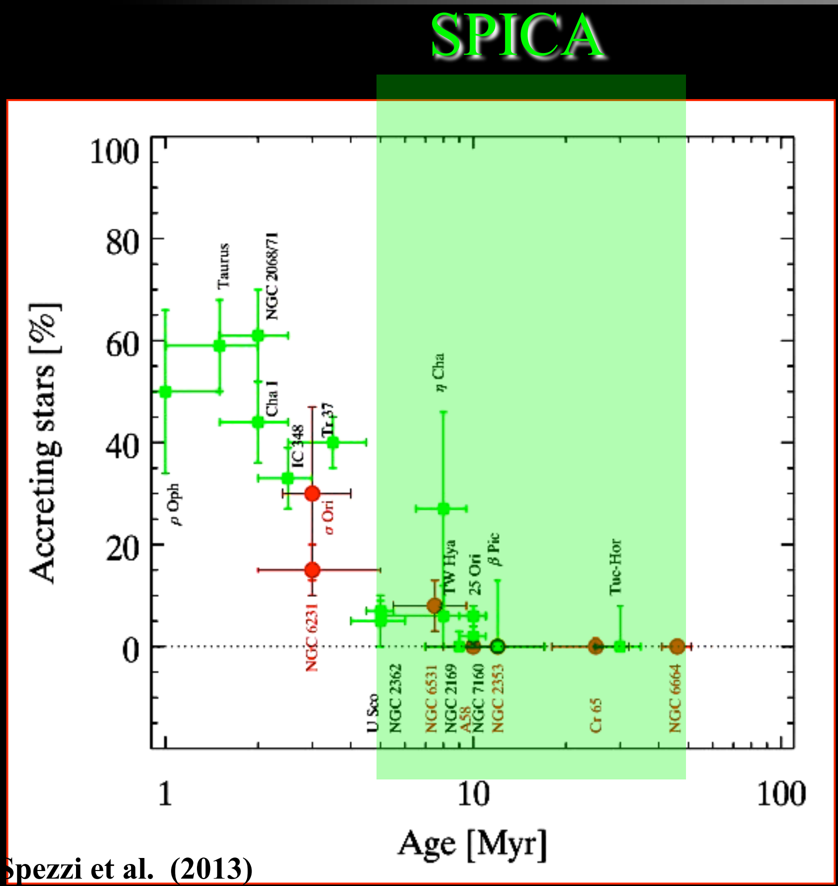
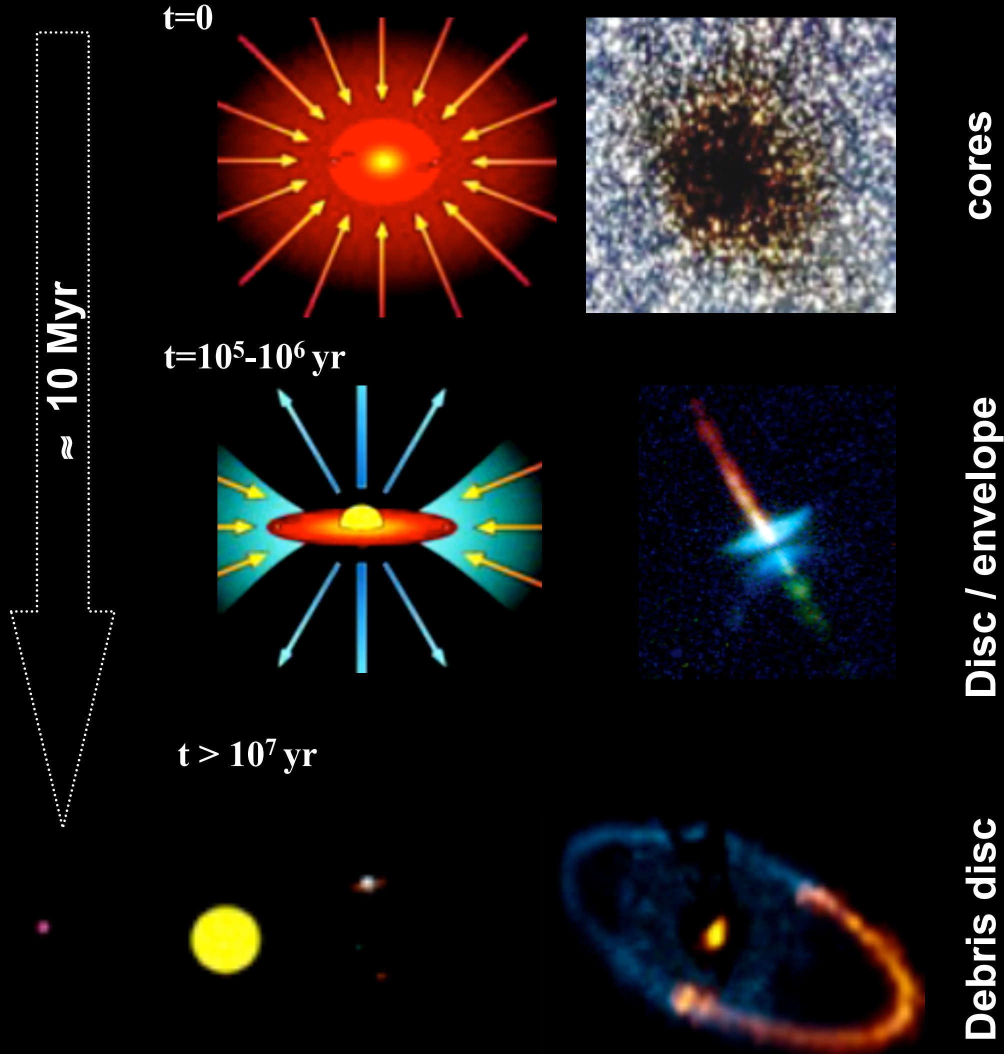
Protoplanetary disks
From Spitzer to SPICA



Juan Manuel Alcalá
INAF- Napoli

Disc/Envelope evolution

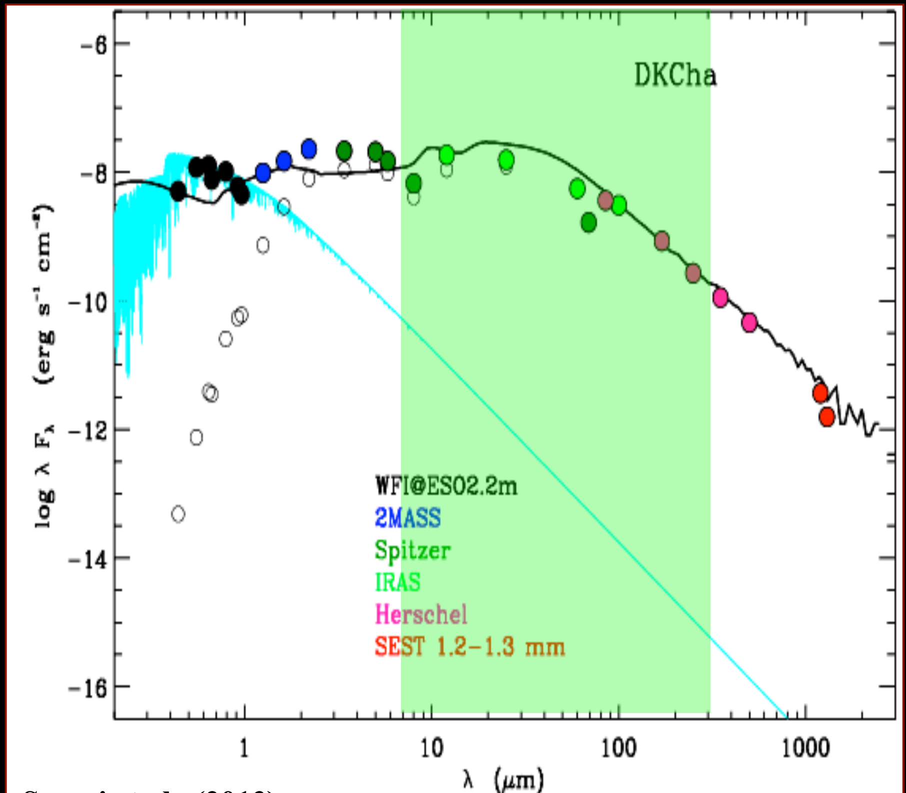




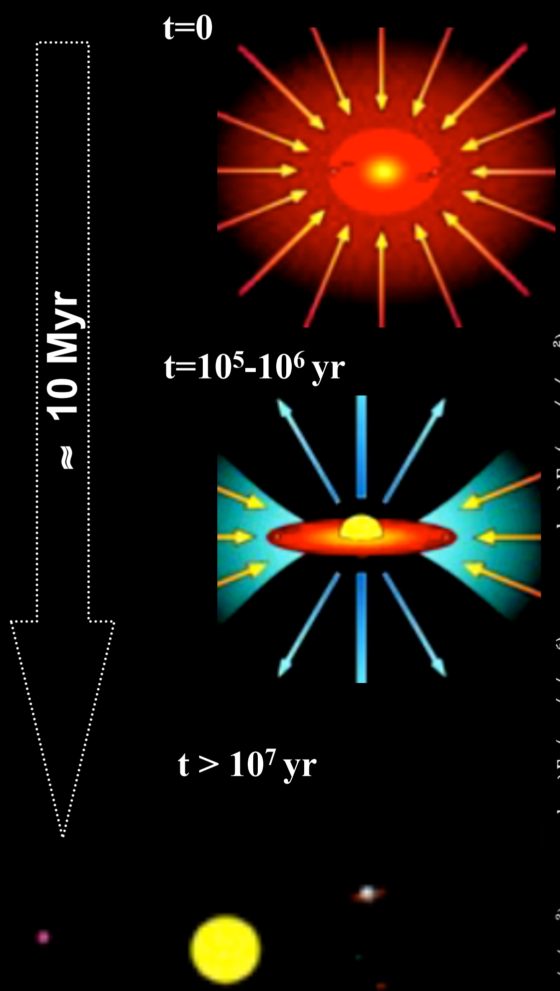
- IR luminosity decrease with age
- the L_{IR} / L_{star} ratio is a good proxi for disk evolution
- evolution of spectral diagnostics

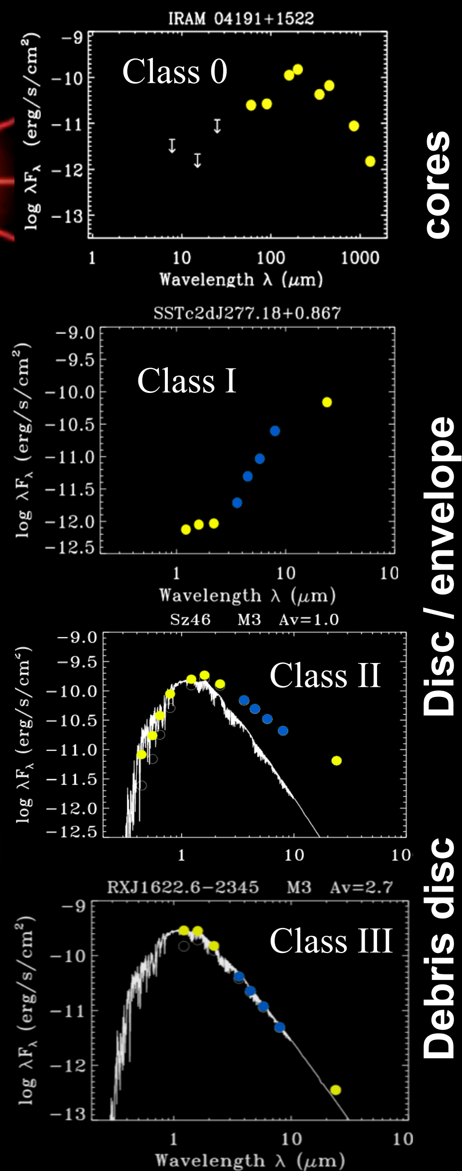
Disc/Envelope evolution

SPICA



Spezzi et al. (2013)





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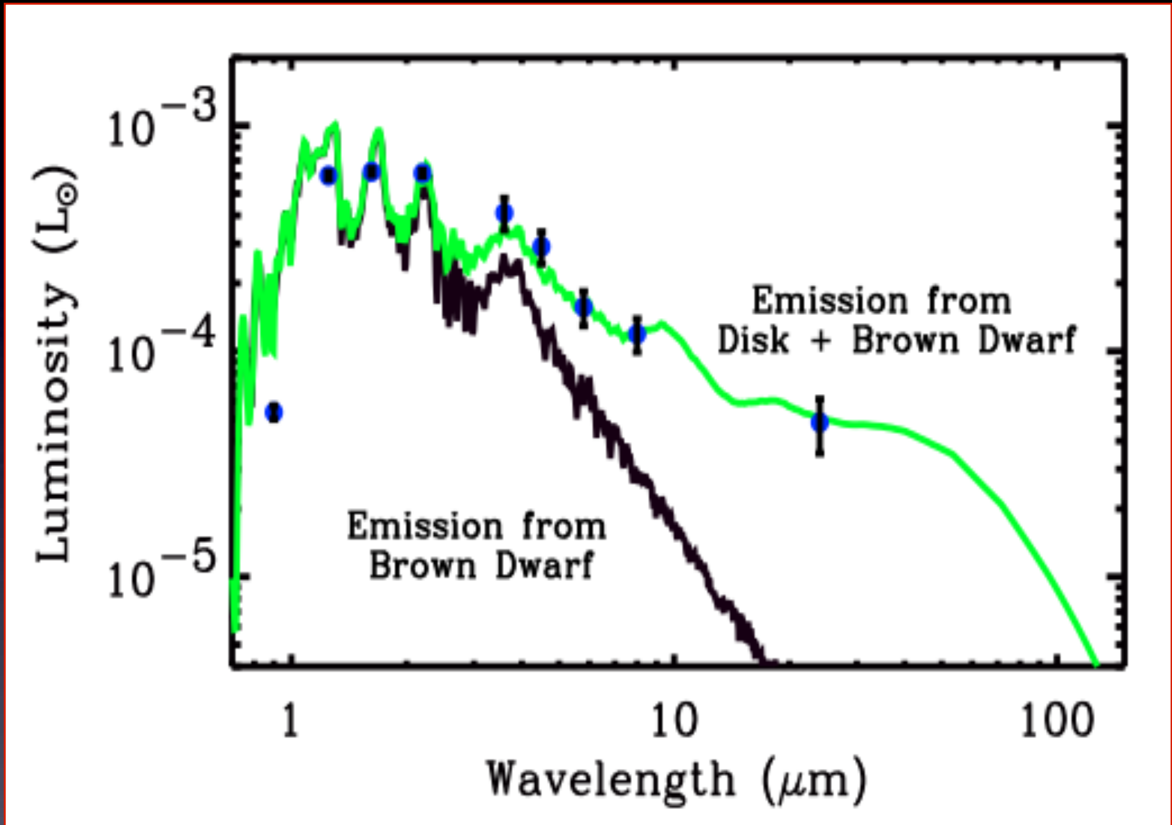
What have we learned from Spitzer ?

Discs throughout the entire mass spectrum, down to brown-dwarf regime



Allers et al. (2006)

NIR fits model atmosphere of 3 Myr old brown dwarf:

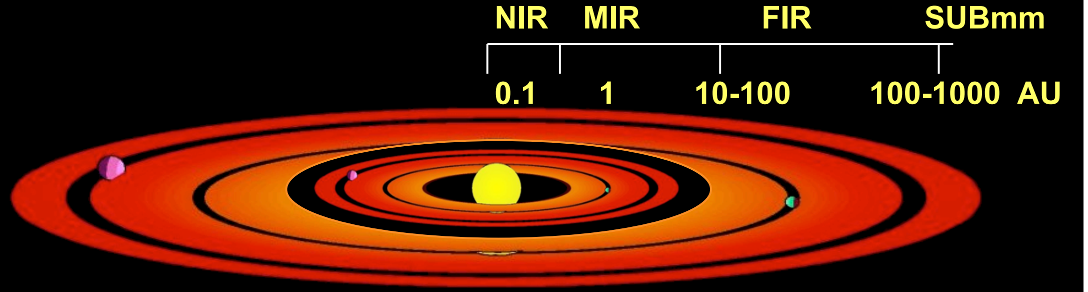
- T_{eff} = 2100 K
- M~10 M_{jup}

Fits model of disk:

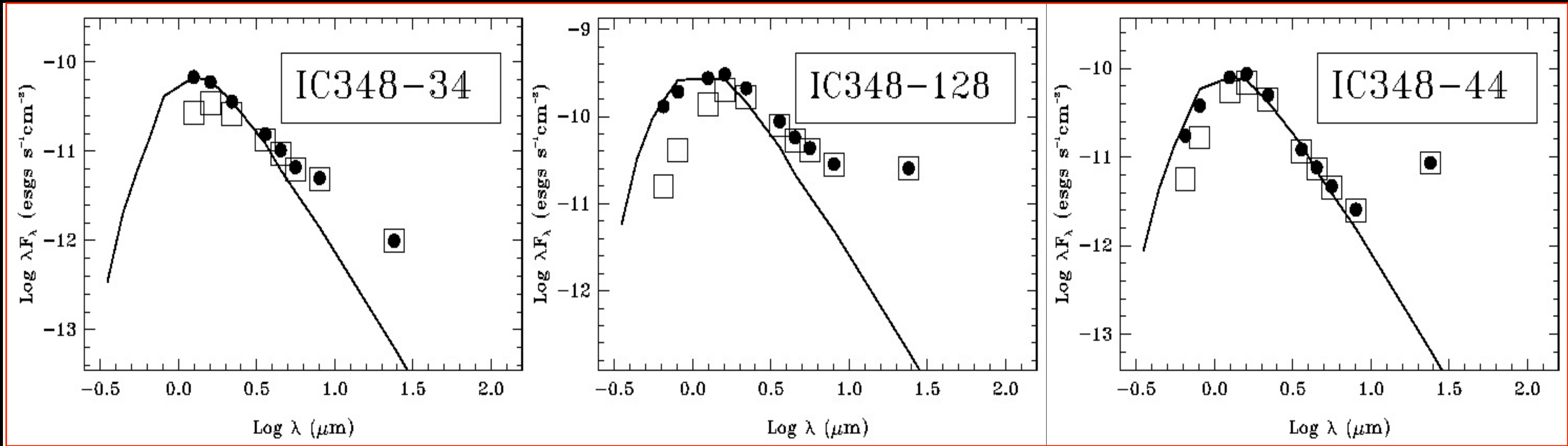
- M_d = 0.03 M_{BD}
- R_d = 5 AU
- i = 40 deg

Spitzer: Transitional discs

$$r_{probe} = 0.01 \cdot \lambda^2 \cdot L_{star}^{0.5}\ \text{AU}$$

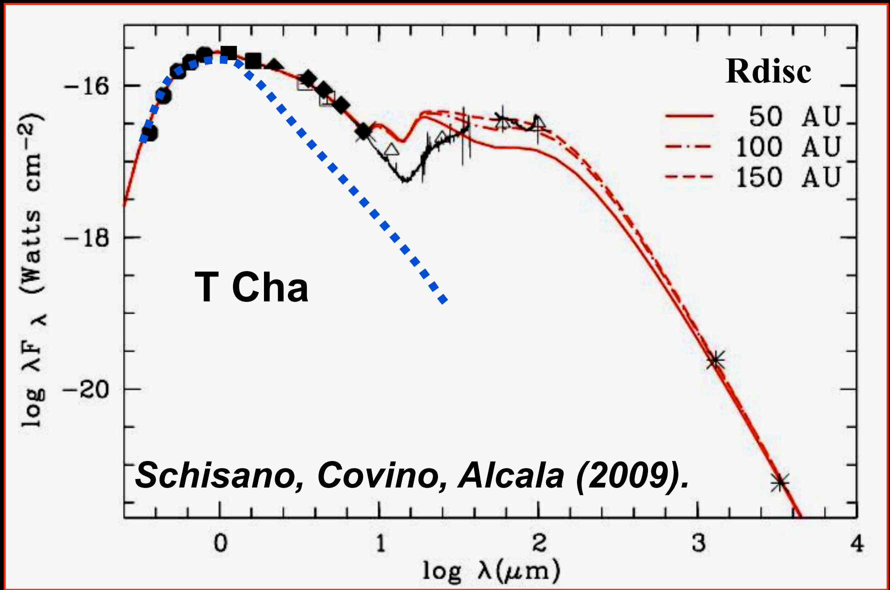


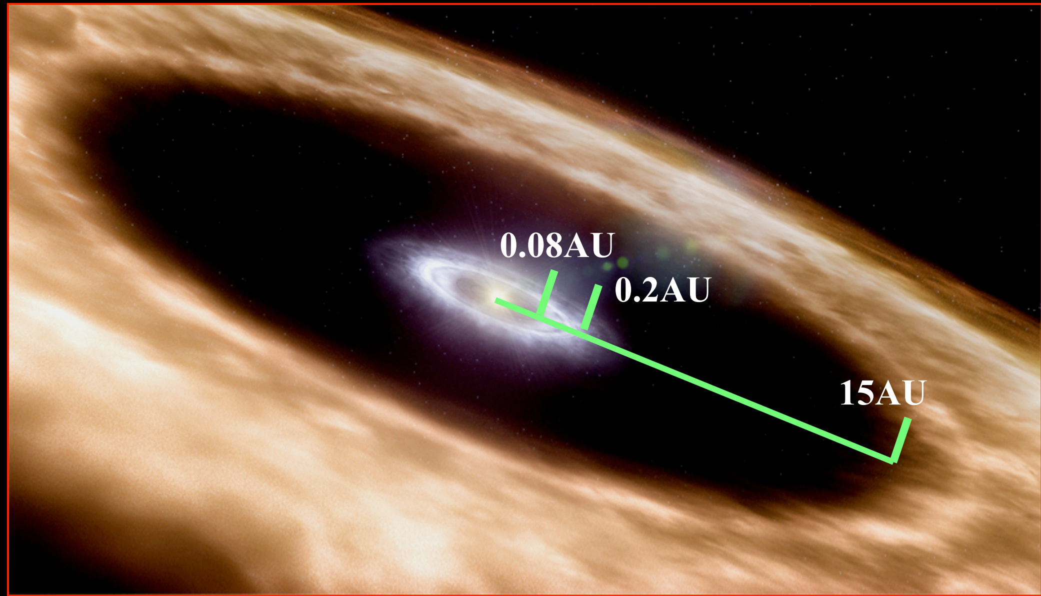
- Different wavelengths probe different locations in the disk
- NIR: ~0.1 AU ; MIR: ~1AU ; FIR: ~30 AU ; SUBmm: ~1000 AU



- some excesses start only at long wavelengths but are substantial: cold disks.
- *traditional* transition from II to III does not capture the diversity seen in disk SEDs.

Transitional discs with gaps

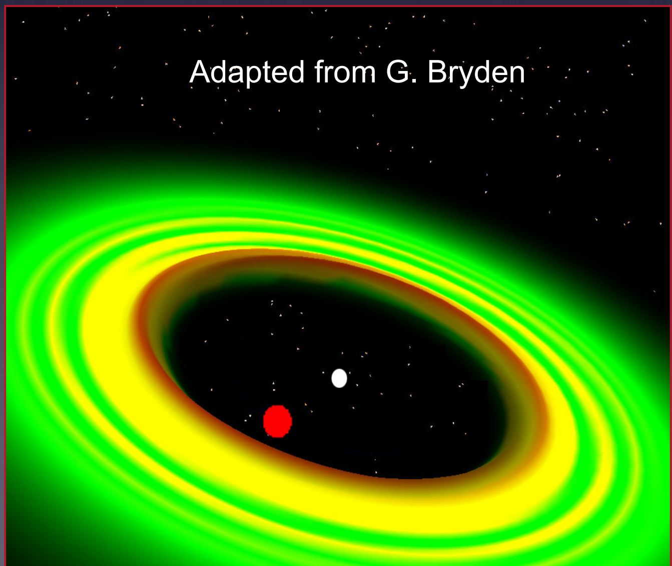




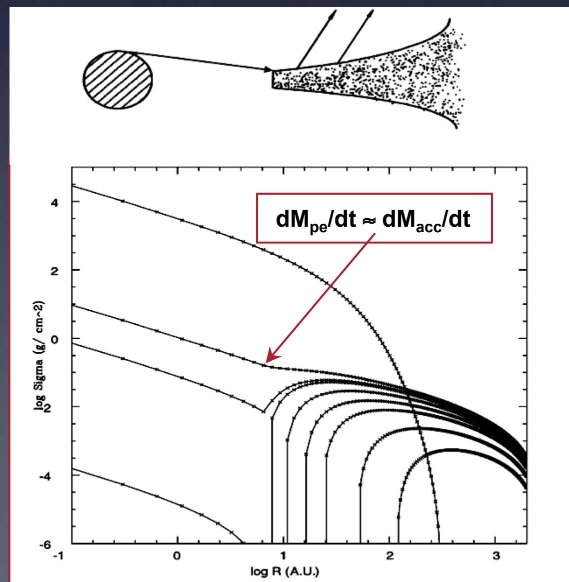
Spitzer results on transitonal disks

- Transition objects are a diverse class
  - Variable inner hole sizes, ranging from 1-25 AU (so far!)
- The diversity of these objects probably reflects
  - diversity among their presumed precursors, the T Tauri stars, and
  - consequent multiple paths to forming planetary systems
- Production of an inner hole by

a) giant planet: rapid draining from inner disc

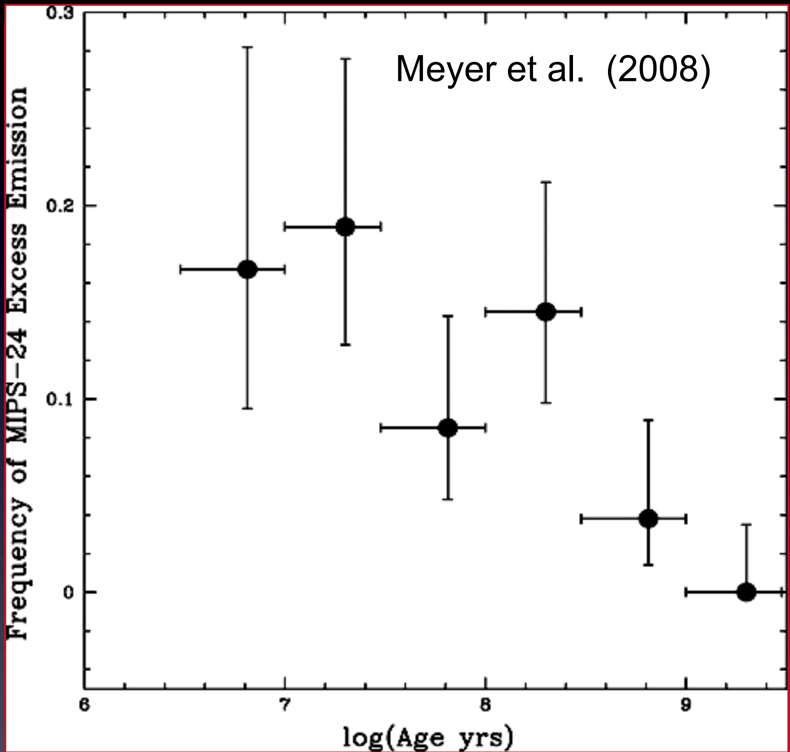


b) photoevaporation ≈ accretion



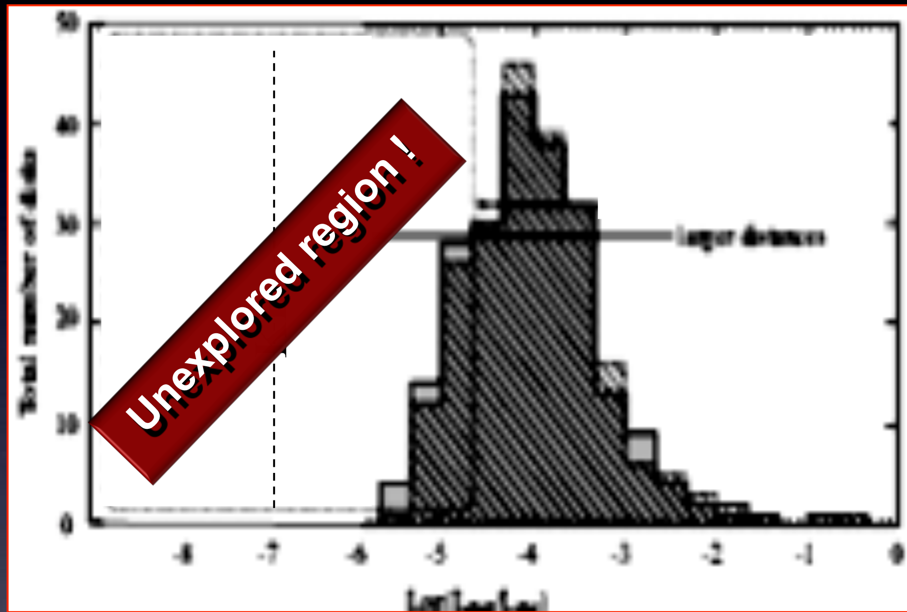
Spitzer results on debris discs

Spitzer FEPS legacy survey



- 309 stars $(0.7 < M/M_\odot < 2.2)$
- 8.5% - 19% at age < 300 Myr
- < 4% for older stars

- $\langle L_{IR}/L_{Star} \rangle \approx 10^{-4}$



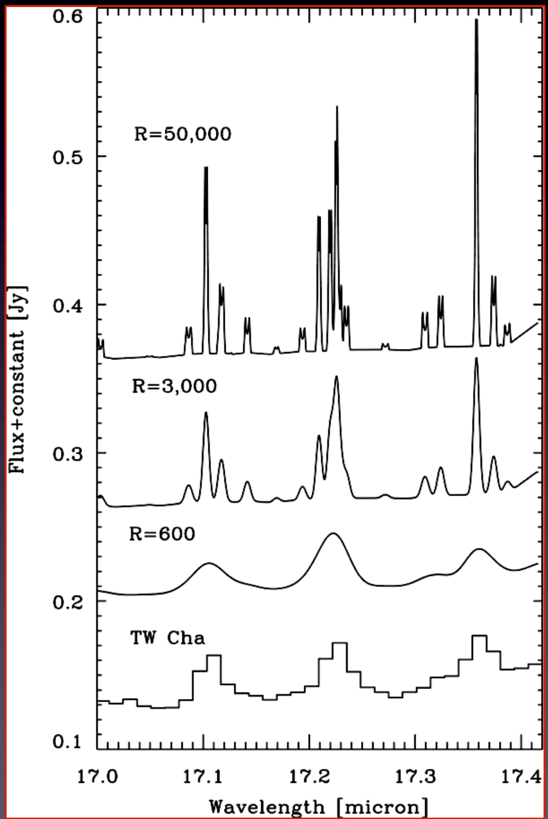
Kuiper belt-like structures still to be investigated

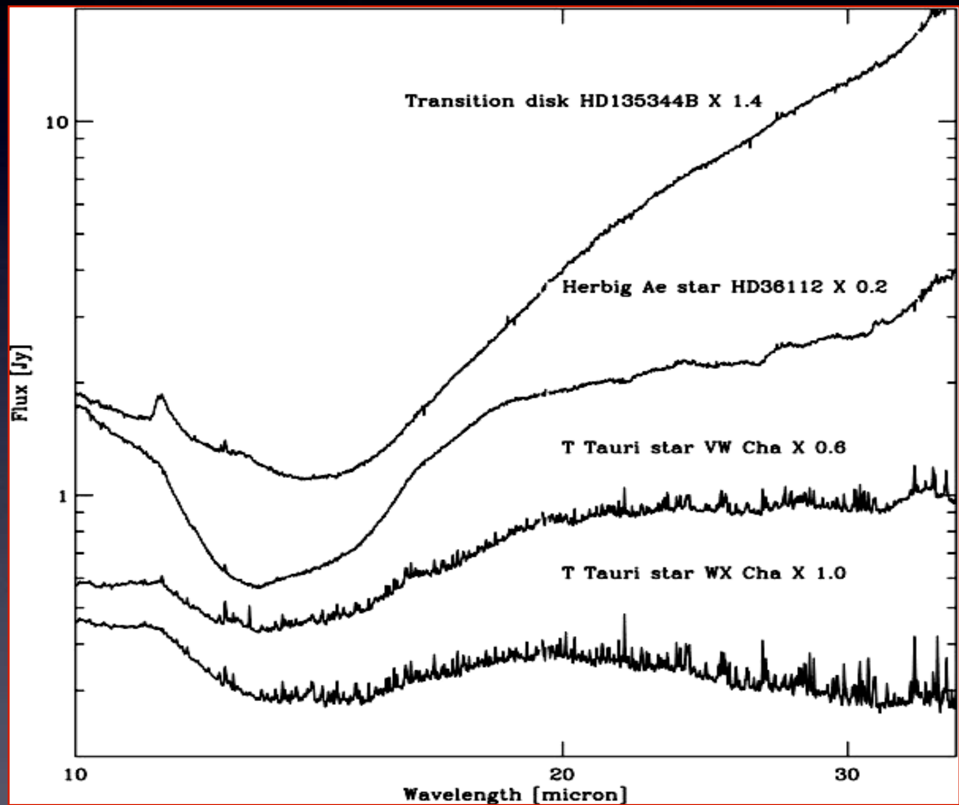
A variety of atomic and molecular emission with Spitzer

- [Ne II] , [Fe II], H_2, H_2O, OH, HCN, C_2H_2, & CO_2, PAHs

H_2O line complex at 17.22μm

Pontoppidan et al. (2010)





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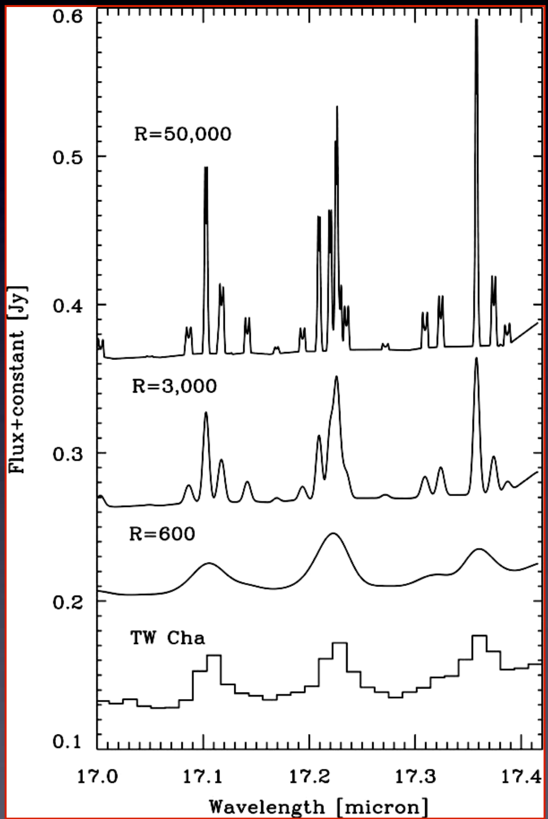

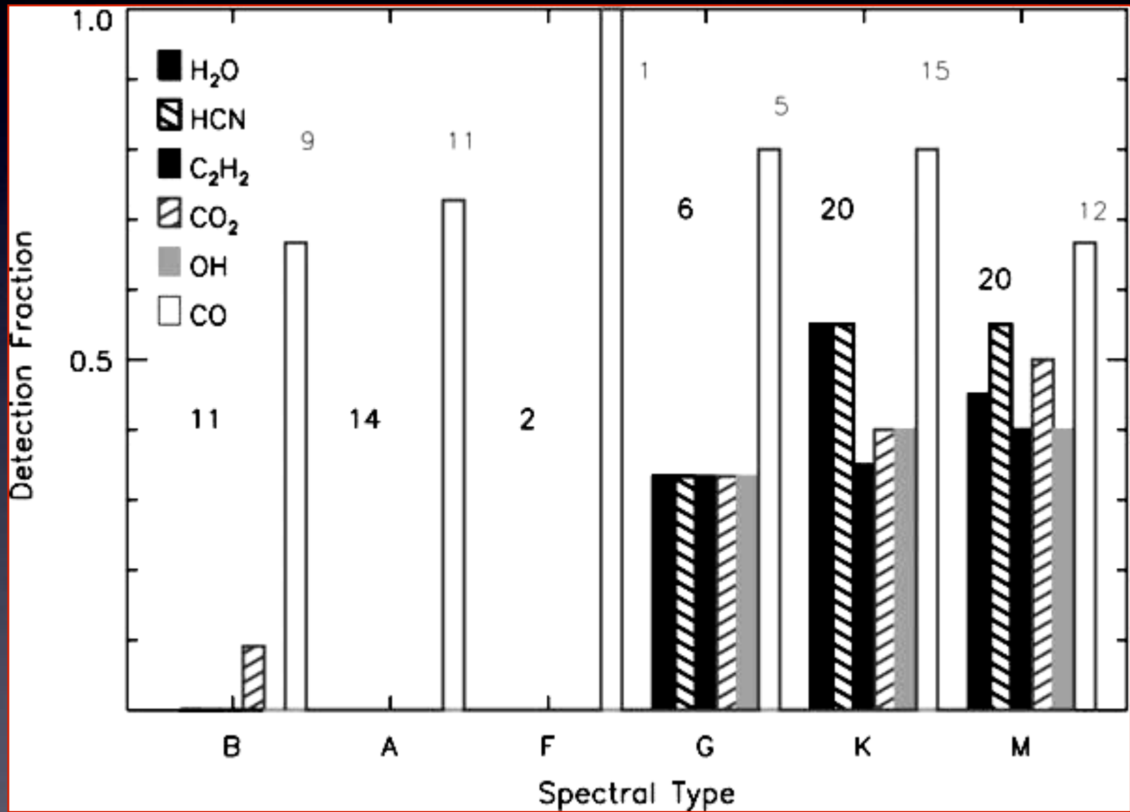

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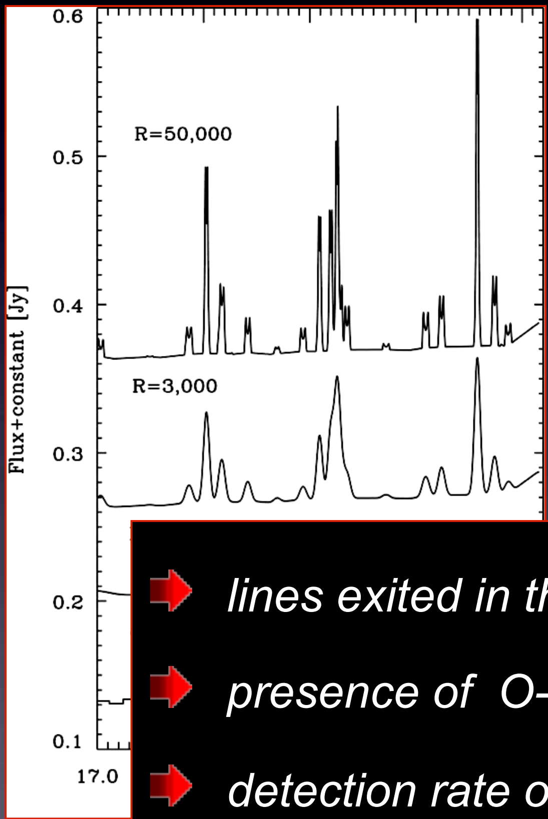
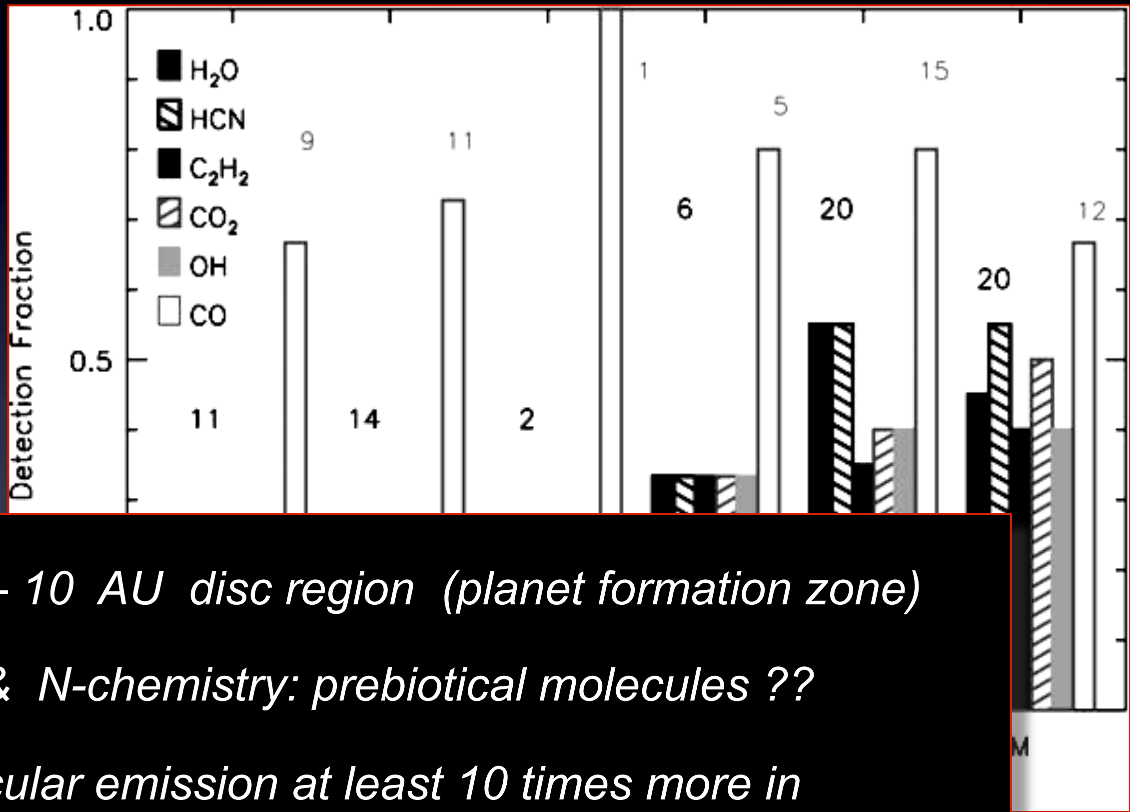
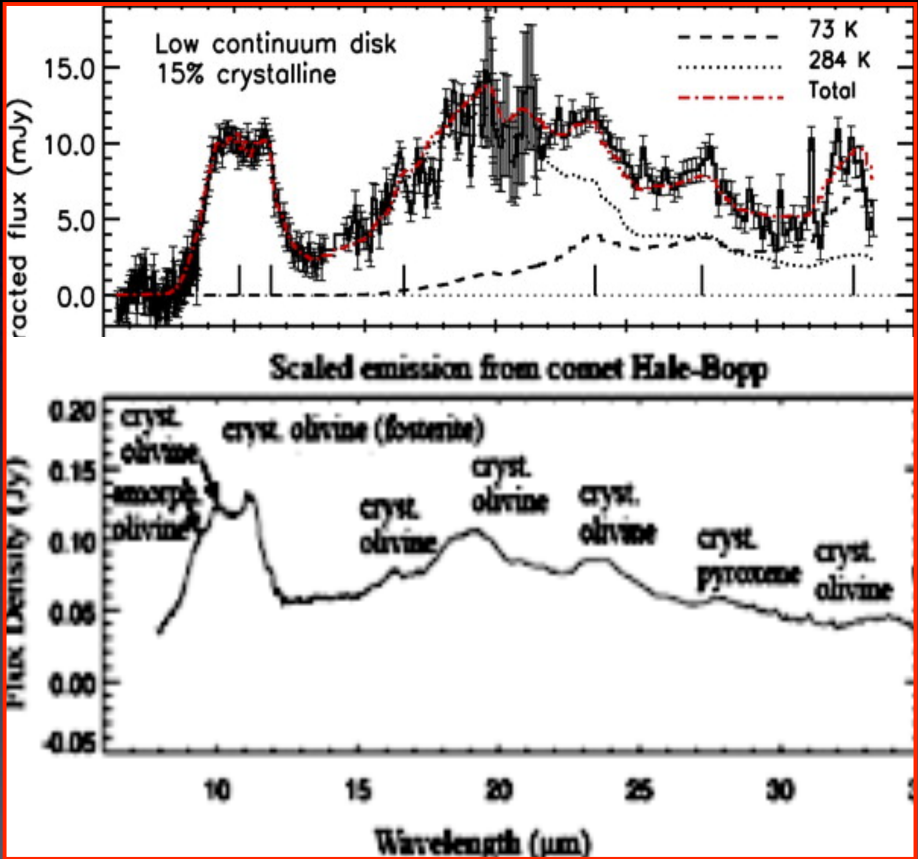




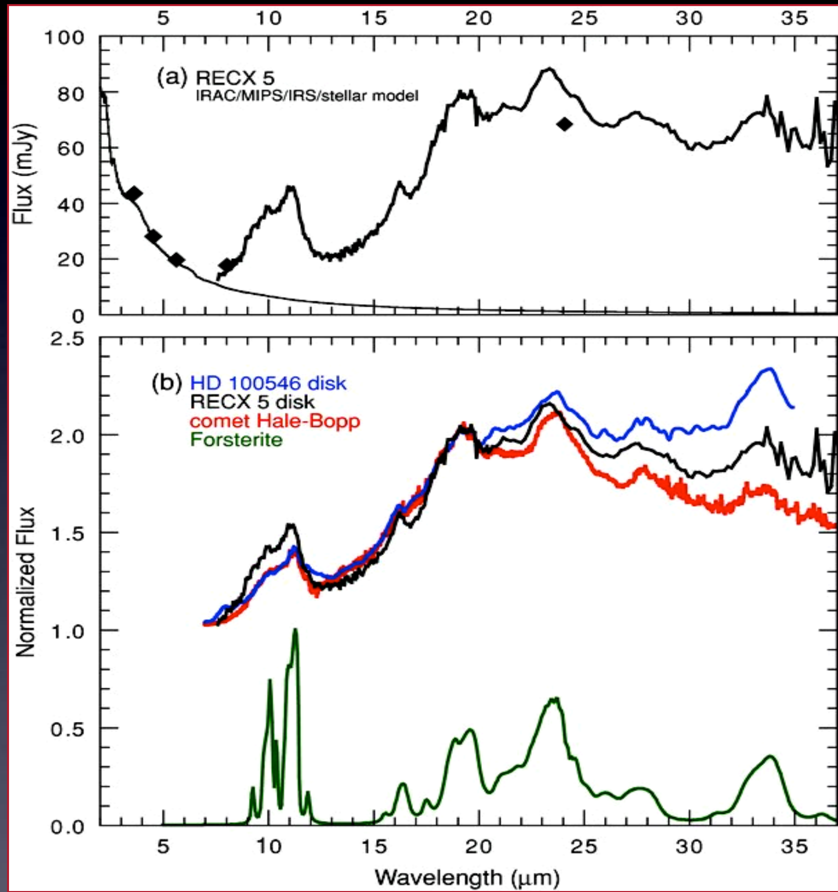
- *lines exited in the 0.1 – 10 AU disc region (planet formation zone)*
- *presence of O-, C- & N-chemistry: prebiotical molecules ??*
- *detection rate of molecular emission at least 10 times more in solar-type stars than in massive stars (photodestruction in AB stars?)*

Abundant crystalline silicates with Spitzer and planet formation

SST-Lup3-1 (Merin et al. 2007):
YSO discovered in the c2d
M = 0.1 $M_{\odot}$

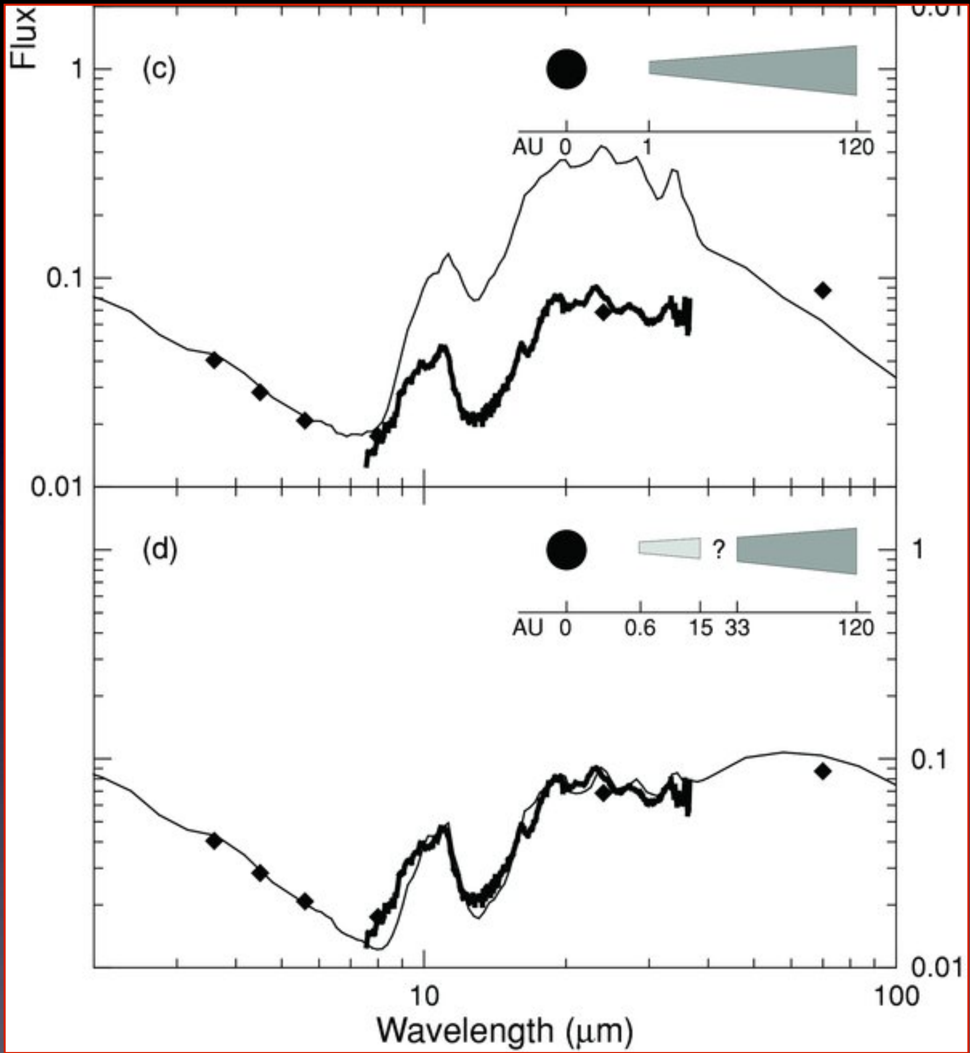


RECX 5 (Bouwman et al. 2010):
YSO in the η-Cha cluster
M = 0.26 $M_{\odot}$



- *giant planet at a distance of ≈ 0.6 AU*
- *Saturn-mass planet orbiting at ≈ 24 AU*

Abundant crystalline silicates with Spitzer and planet formation



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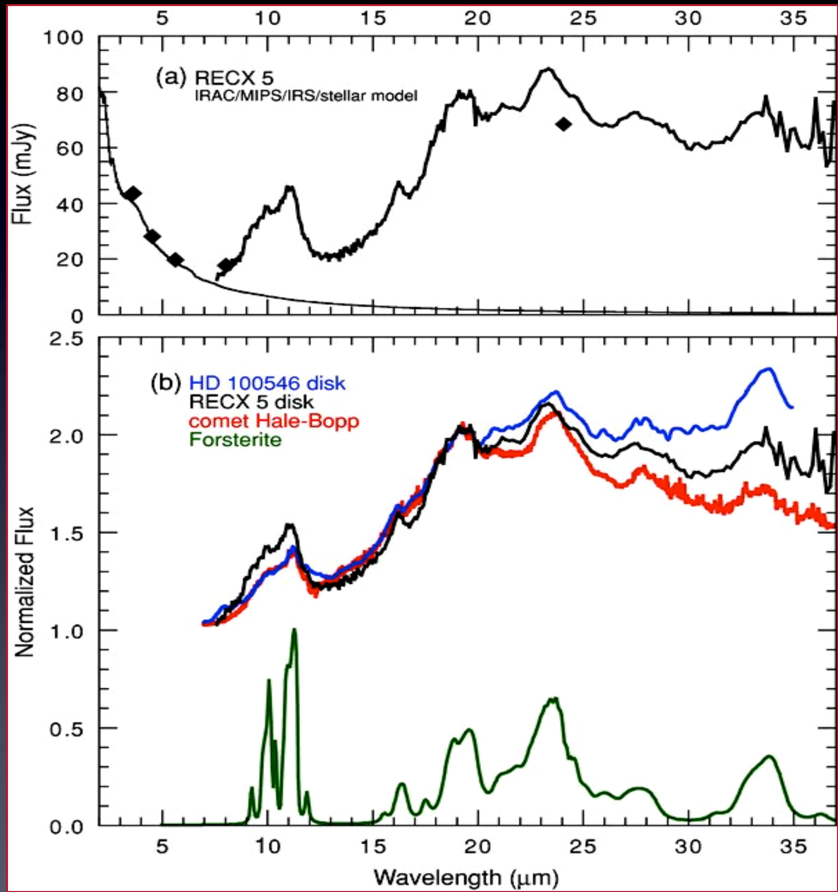

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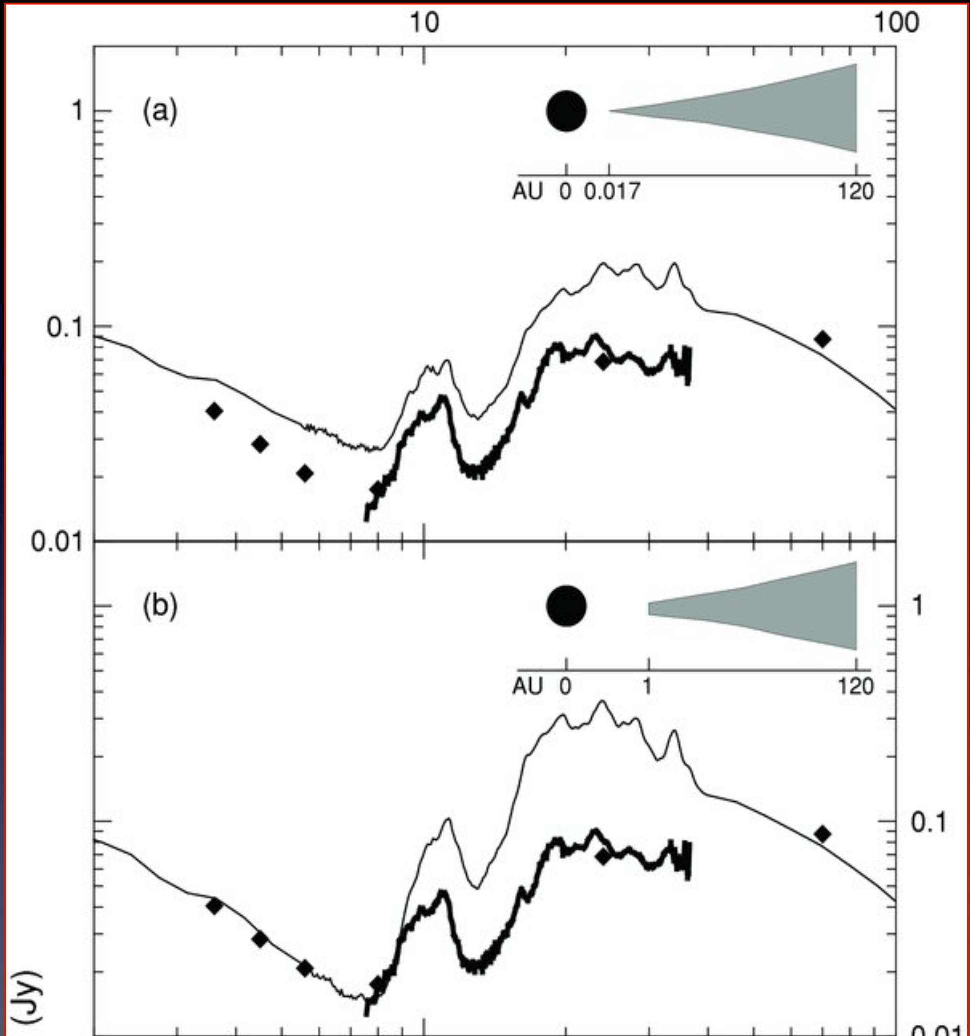

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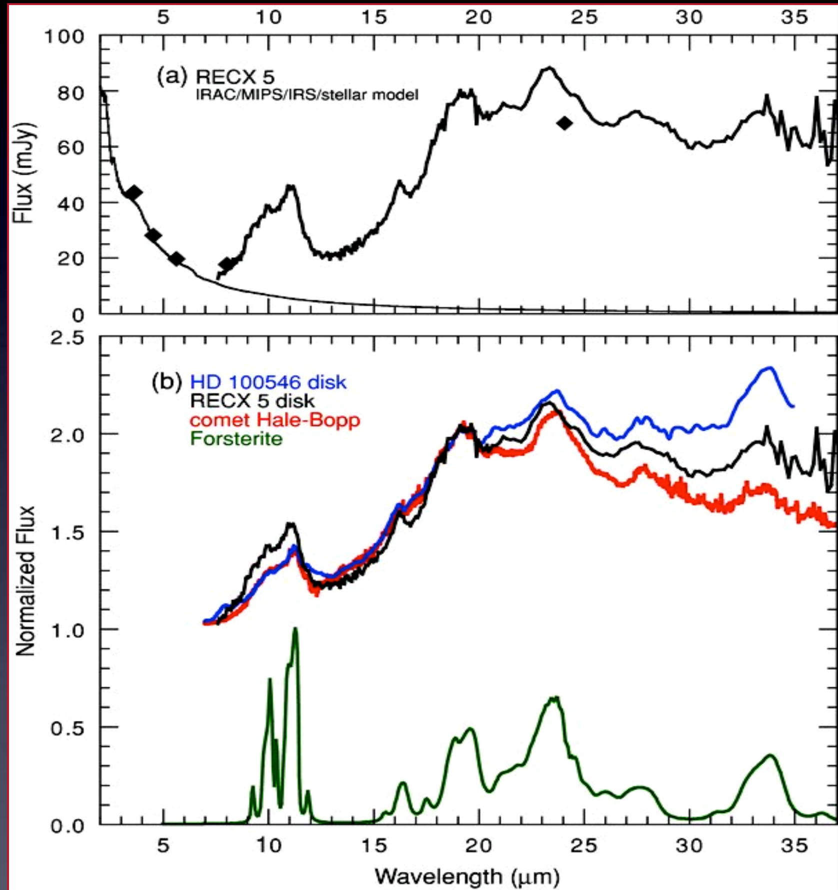


- *giant planet at a distance of ≈ 0.6 AU*
- *Saturn-mass planet orbiting at ≈ 24 AU*

What have we learned from Spitzer ?

Photometry (IRAC & MIPS)

- diversity of SEDs
- different types of proto-planetary discs → disc evolution
- discs at all mass regimes, down to planetary mass objects
- SED modelling → disc parameters
- results on transitional discs: planet formation
- debris disk still to be explored

What have we learned from Spitzer ?

Spectroscopy (IRS)

- a large variety of atomic and molecular emission in thick discs
- differences between high and low-mass regimes ?
- little emission in transitional discs, but very low statistics
- abundant crystalline silicates down to the DB domain
- structure and composition of transitional discs not yet explored
- debris discs still unexplored

What can we learn from SPICA ?

What can we learn from SPICA ?

I. Young optically thick discs

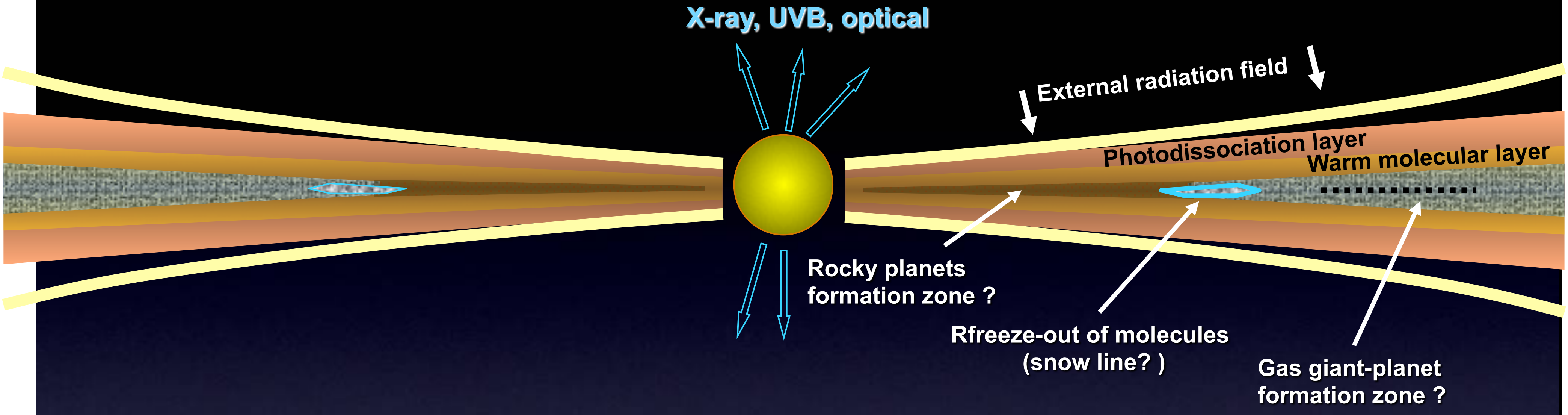
II. Transitional discs

III. Debris discs

Optically thick discs with SPICA

- more precise SED modeling, down to planetary-mass YSOs
- better estimates of disc/envelope parameters and link with star physical parameters down to BD-mass regime
- chemistry of proto-planetary discs: effects of UVB radiation
- study of pre-biotical species: NH_3, CH_4, H_2O
- outflows throughout the mass spectrum (Nisini's talk)
- studies at low metallicity environment
- more in talks by Nisini & Podio

Planet formation in transitional discs



- accretion of gas onto rocky / icy cores of few M_{earth}
- grav. instability: overdense clumps ⇒ quick gas dissipation (< 10Myr)

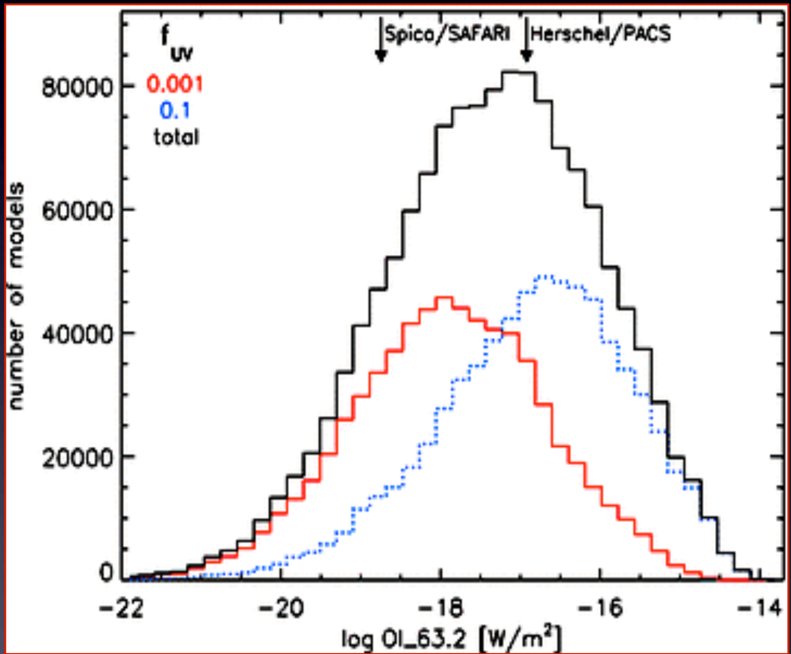
⇒ Amount of gas in TDs ?

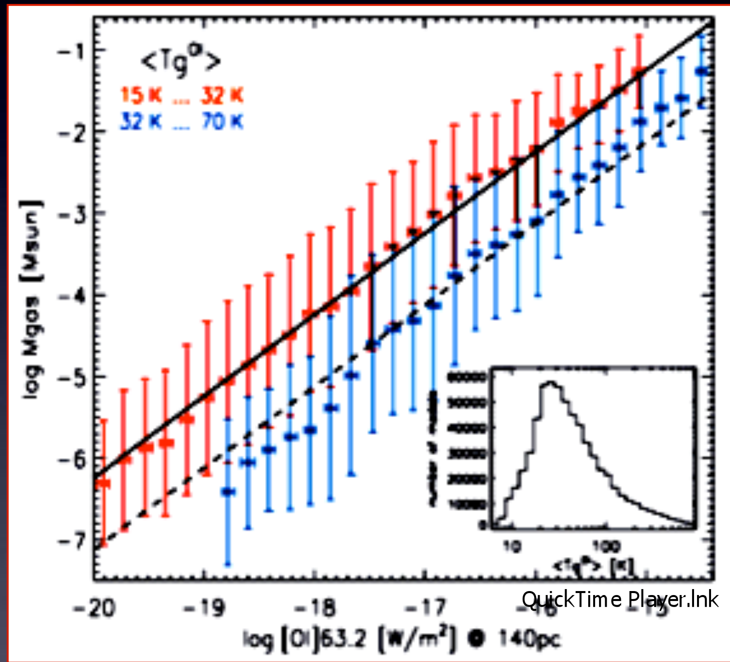
Continuum and line modelling of discs

Woitke et al. (2010, MNRAS 405, L26): Radiative transfer in transition discs

- 300,000 models
- disc mass, flaring & dust and gas parameters
- [OI] (63μm), [OI] (145μm), [SI] (56μm), H_2O, OH, CO

@ 140 pc





- strong dependence on UVB radiation field and disc flaring
- less flaring → less UVB irradiation → fainter lines
- strong dependence on disc mass

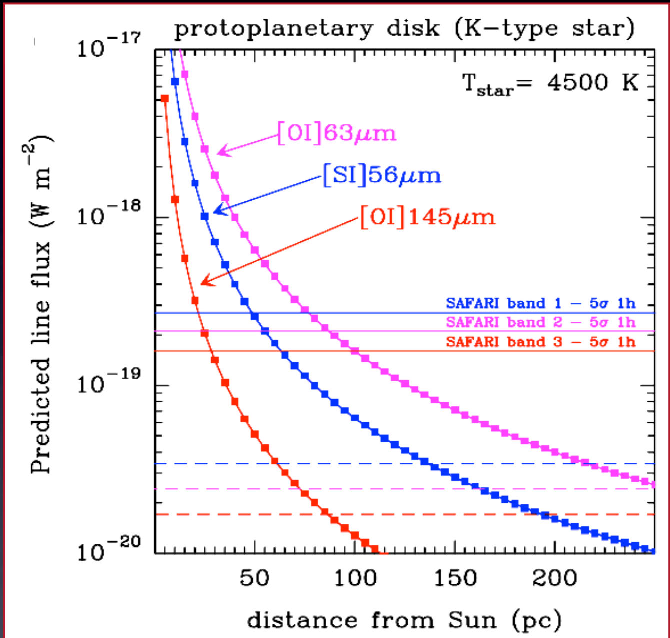
Gas traces in transitional discs

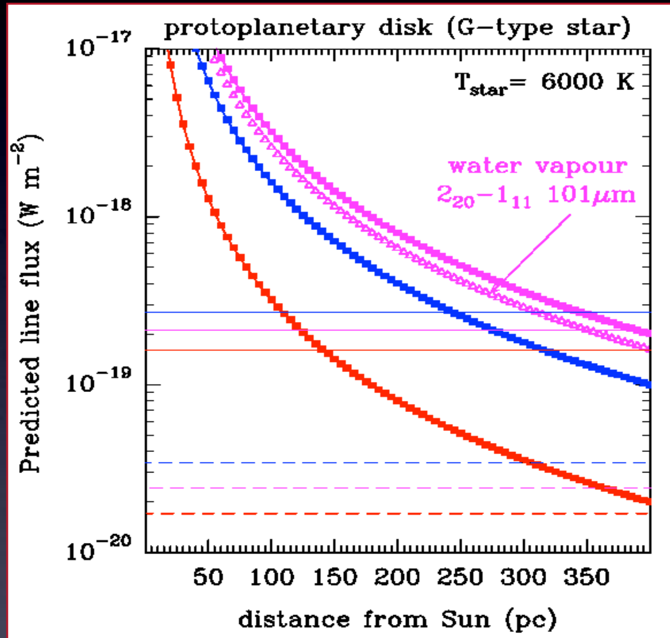
Transition disc models ($M_{gas} \approx 0.001\ M_{jup}$) predict:

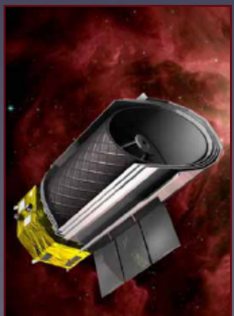
- $L \approx 10^{-8}\ L_{\odot}$: [OI] (145μm), [SI] (56μm), H_2O, OH, CO
- $L \approx 10^{-6} - 10^{-7}$: [OI] (63μm)

F_l (50pc) $\approx 10^{-11}$ (L_{line}/ $L_{\odot}$) Watt m^{-2}

F_l (150pc) $\approx 10^{-12}$ (L_{line}/ $L_{\odot}$) Watt m^{-2}







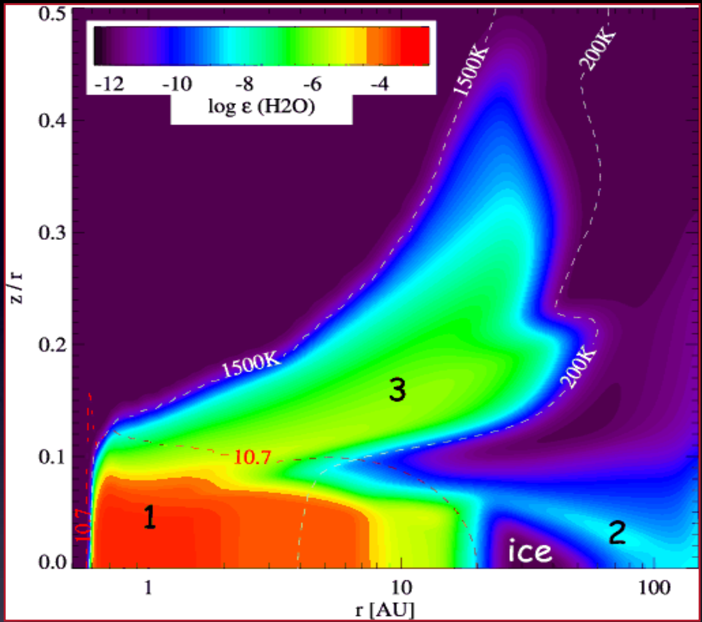
SPICA

- detection of small amount of gas in TDs
- statistically significant samples in nearby (≤ 150pc) SFRs
- Taurus, Upper Sco, TW Hya, Tuc Hor, Beta Pic, Eta Cha
- Disentangle mechanisms for giant planet formation

Water ice in protoplanetary discs

Woitke et al. (2009, A&A 501, L5): Hot and cool water in Herbig Ae protoplanetary discs

- H_2O emission lines from Herbig Ae type protoplanetary disks beyond 70 µm



- *big water reservoir in midplane, behind the inner rim*
- *belt of cold water around the distant icy midplane beyond the "snow-line" r > 20 AU*
- *layer of irradiated hot water at high altitudes, from about 1 AU to 30 AU (200 K < Tgas < 1500 K)*
- *snow-line (T < 150 K)*
- *Solar System: snow-line at about 2.7 AU*

SPICA

- detection of water ice in significant sample of different stellar types
- exact location of the snow line
- diagnostic tools:
  - *44µm crystalline and amorphous water ice*
  - *62µm crystalline water ice*
- ***water in inner disc regions: where rocky planets***

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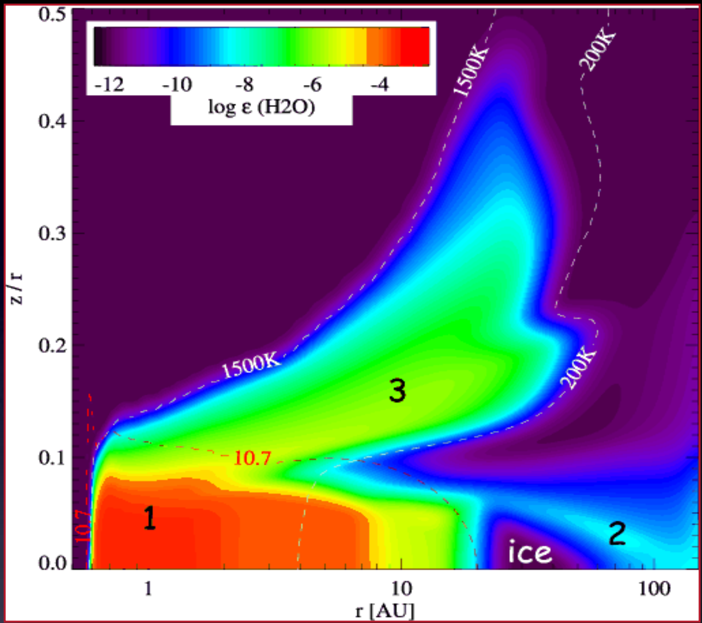

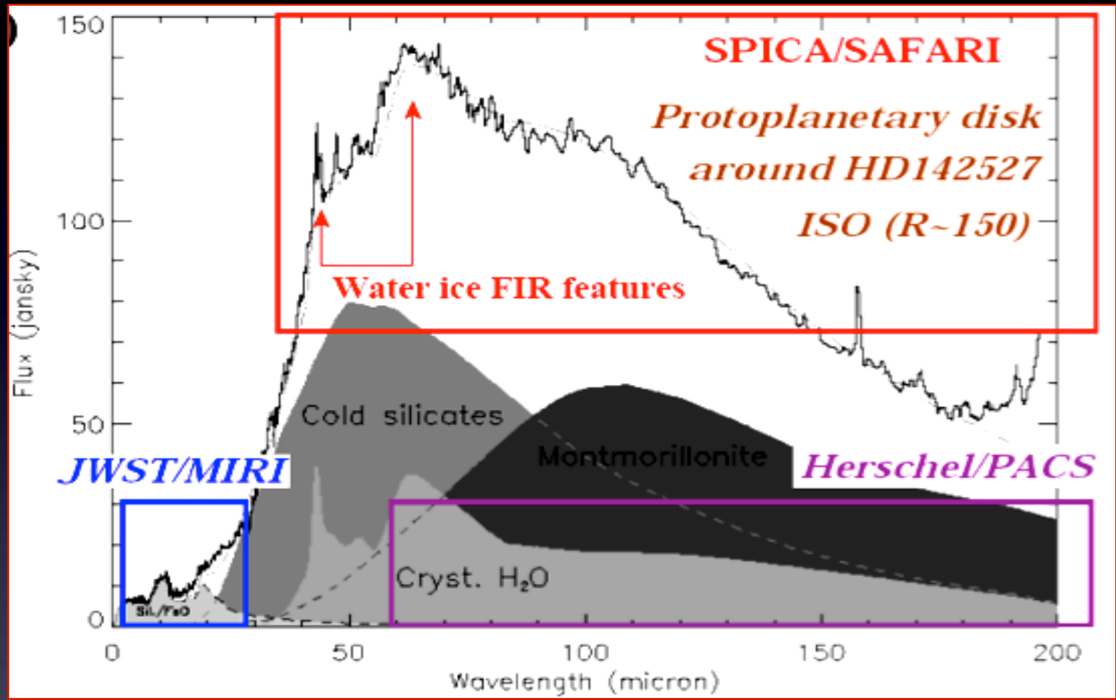

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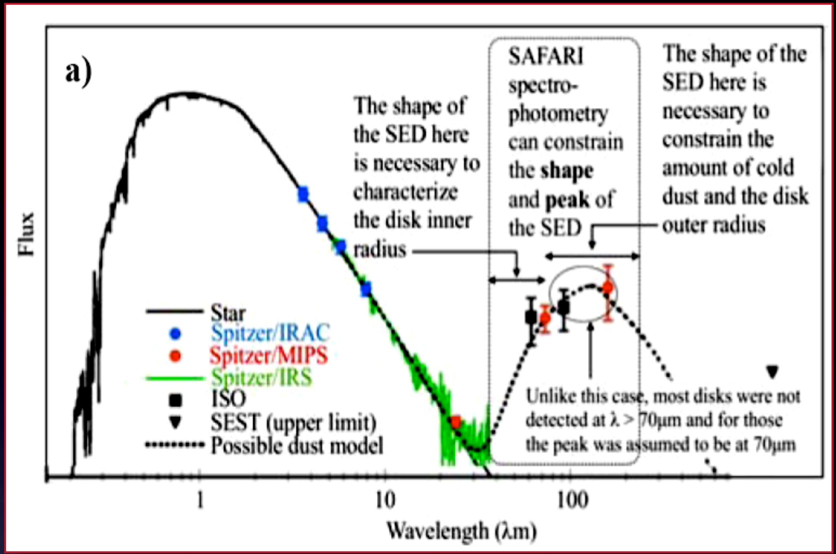
Surveys for debris discs



- debris discs may survive billions of years
  - almost gas-free,
  - collisions of planetesimals: 2nd generation debris disc
- detecting debris discs
  - strong signature of enmerging planetary system
  - 10% of solar-type stars surrounded by debris discs
  - analogous asteroid and Kuiper belts
- nearly 300 debris discs with ISO & Spitzer
  - but most in early type (< K -type) stars
  - bias due to sensitivity ?
  - debris discs till to be explored in low-mass stars

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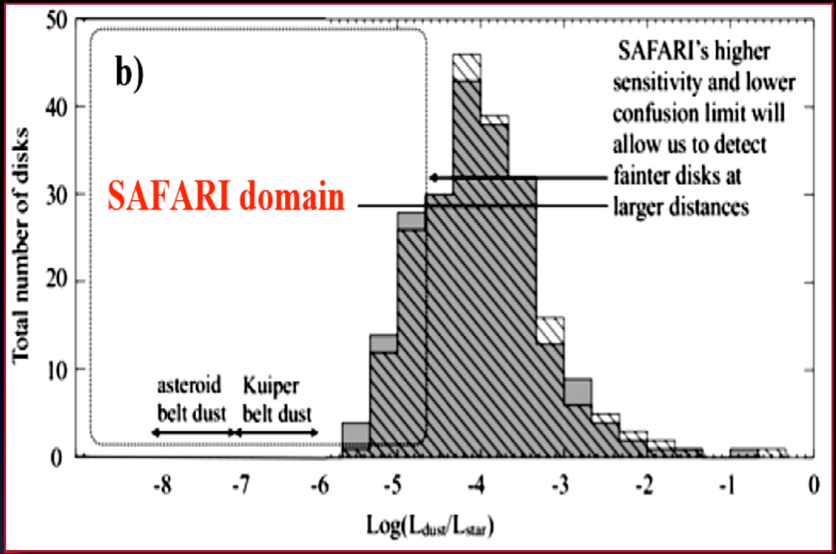

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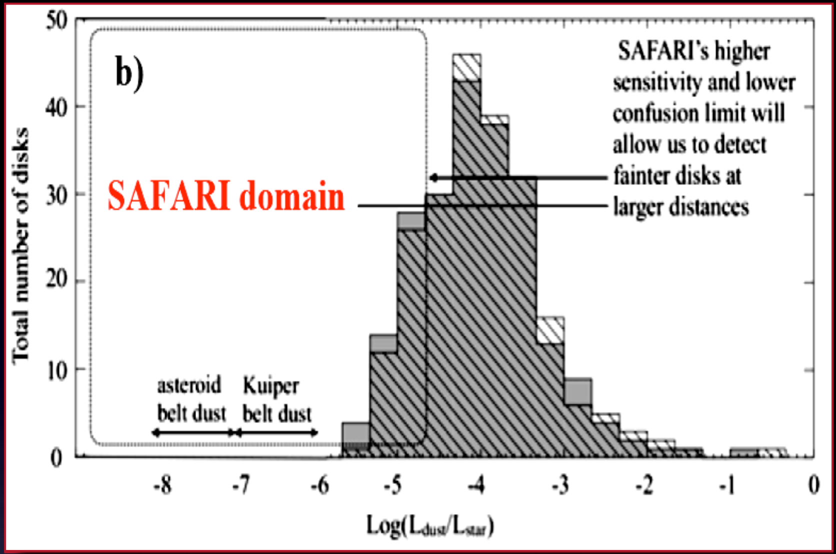

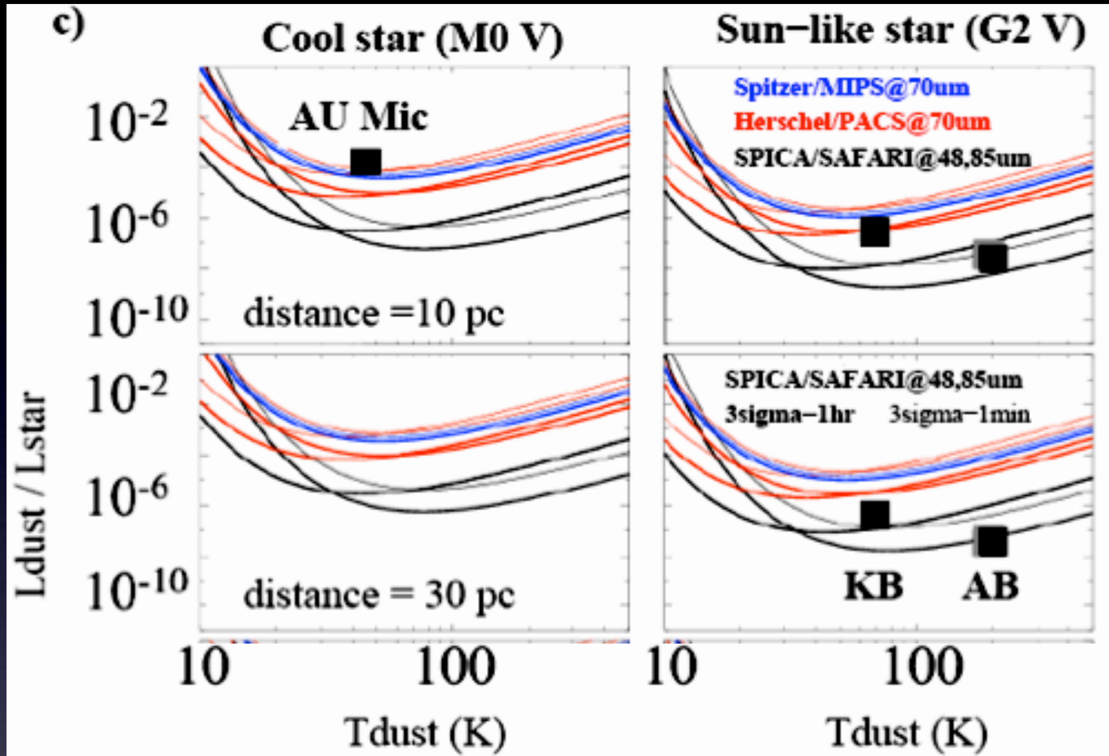

- fast sensitive photometry @ 48μm, 85μm, & 160μm
- spectroscopy (R≈100) in the 30-300μm range (1mJy: 5σ in 1hour)
- some 10^5 F0-K2 stars within 150pc:
  will increas the No. of debris discs by about 3 orders of magnitude
  discs characteristics as function of spectral type
- statistics of debris discs in M-type stars (some 150 within 10 pc)

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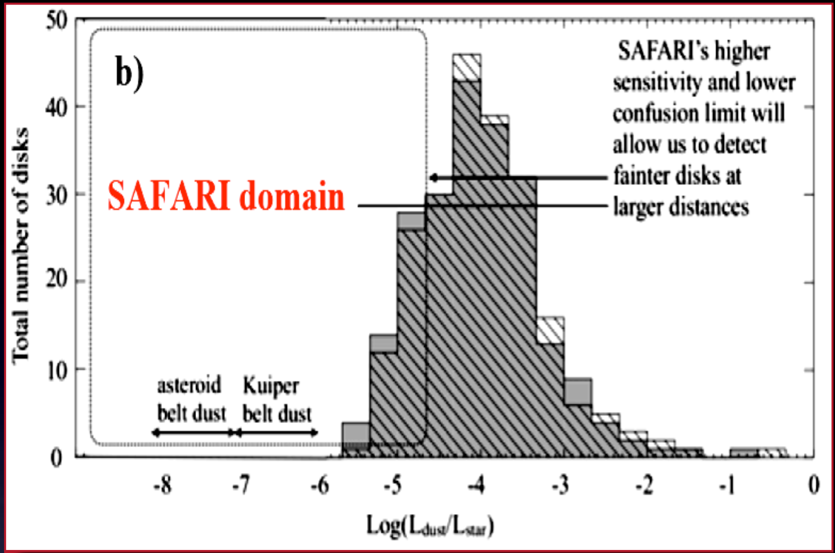

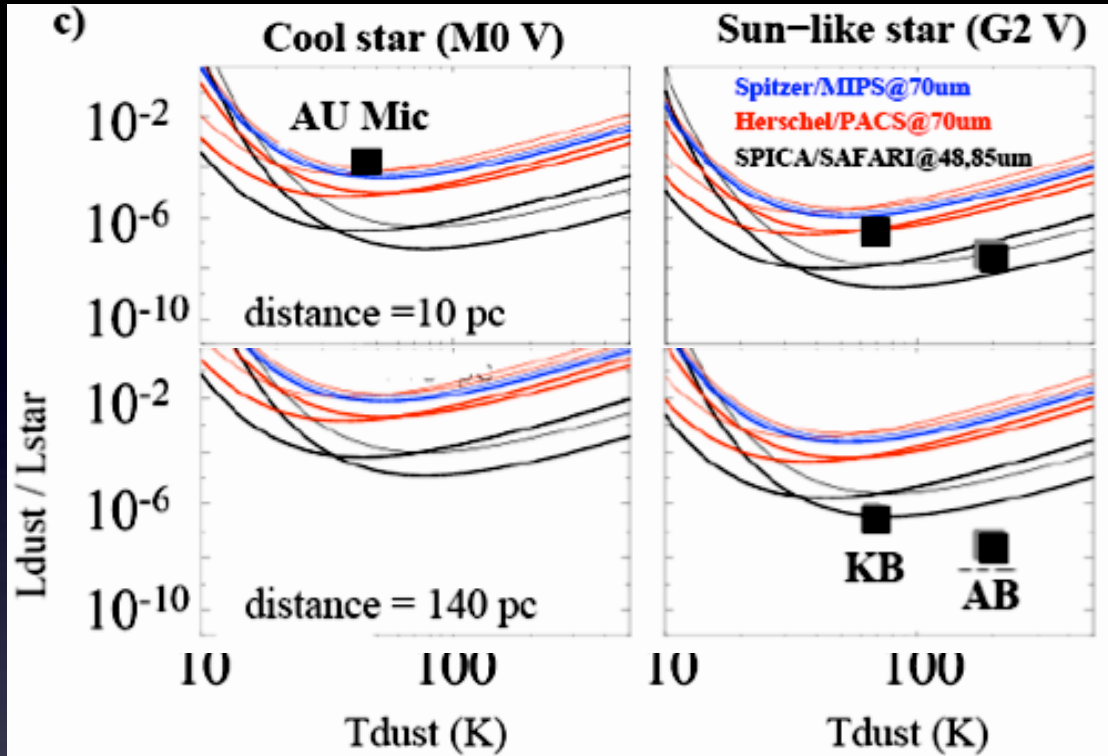

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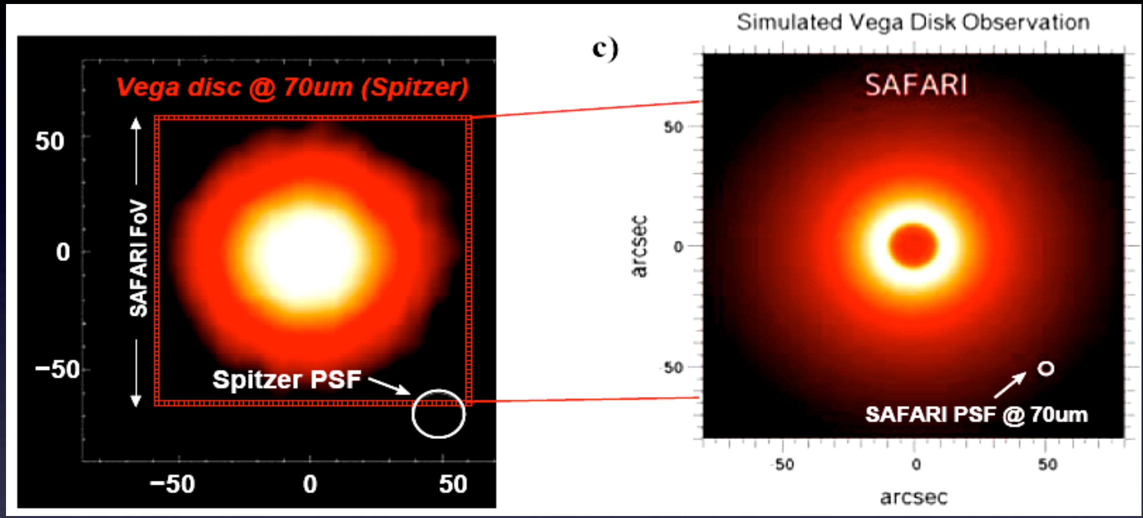
Spatially resolved discs

- @ 50 μm a resolution of 3.5 arc-sec: a 100 AU disk resolved if d < 30 pc
- stars closer than that: ***200 A-type ; 1000 F0-K2 type ; 3500 K2-M-type***



- Objects closer than 10 pc (about 100 A-type):
  - ➡ snow-line expected to be between 20 and 50 AU
  - ➡ distribution of water ice & snow-line

- Disentangle mechanisms for giant planet formation
- water in the inner parts of planetary systems: late heavy bombardment ?