Debris Discs around Stars

Marie Jourdain de Muizon

Observatoire de Paris & Sterrewacht Leiden

muizon@strw.leidenuniv.nl

Sigüenza, 24-27 June 2002

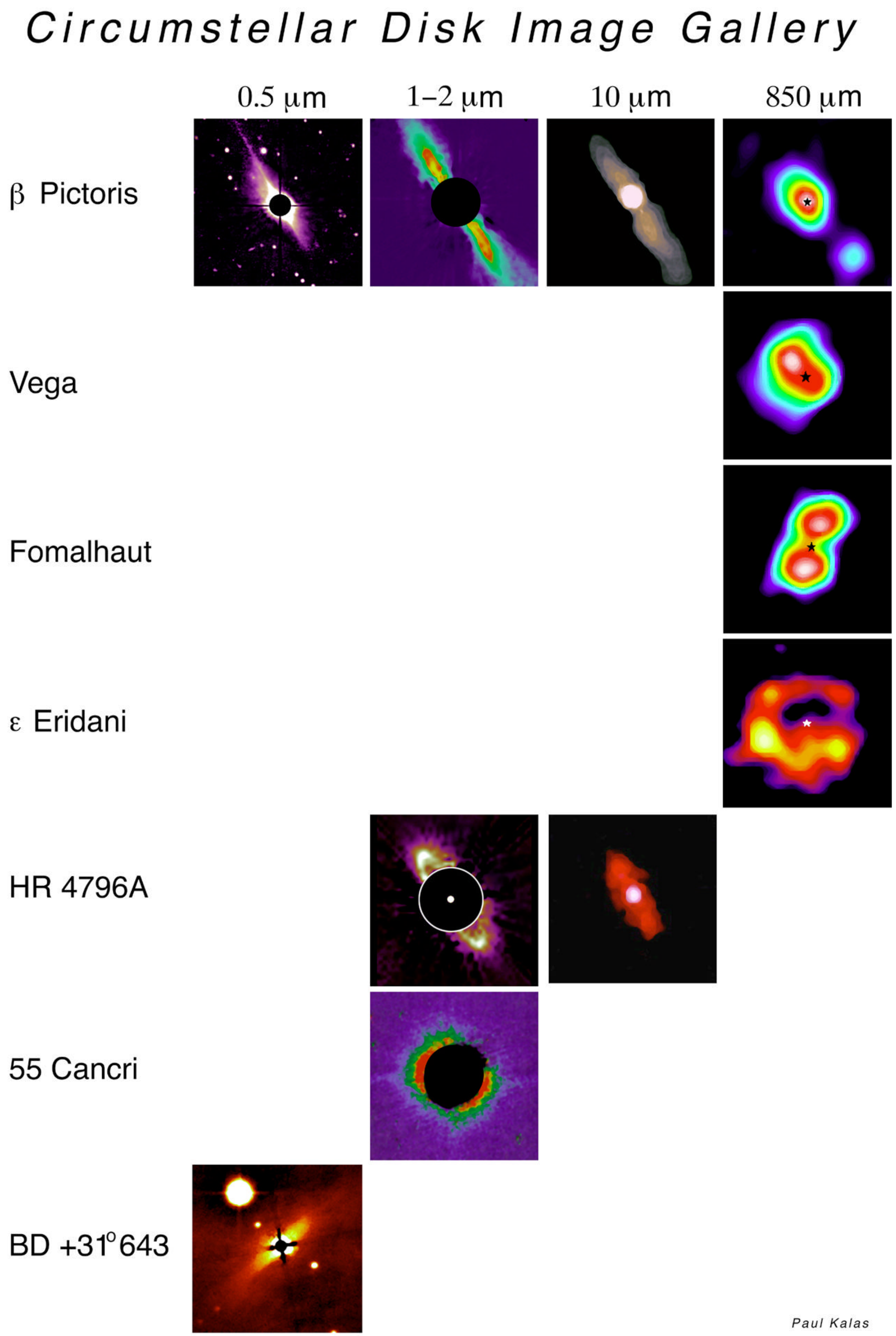
Debris discs around stars

1. Introduction: various discs, various observing methods
2. ISO Vega-type disc surveys:
   - *Habing et al. 1999, 2001*: general statistics 84 MS stars
   - *Decin et al. 2000*: 30 G dwarfs
   - *Spangler et al. 2001*: 150 stars in open clusters
   - *Robberto et al. 1999*: 97 T Tauri stars in clusters
   - *Fajardo-Acosta et al. 1997,1999*: 38 MS stars
3. Case studies:
   - *Heinrichsen & Walker 1998, 99*: Vega, βPic
   - *Dominik et al. 1998*: 55 Cnc
   - *Jourdain de Muizon et al. 1999*: HD207129
   - *Fajardo-Acosta et al. 1997*: 5 Vega-type systems
4. ISO spectroscopy of discs:
   - Amorphous silicates, crystalline silicates, fosterite, PAHs,
   - H_2 gas

Debris disc around stars

Age	Various kind of disc	Observational methods
< 10Myr	Dusty discs around PMS stars: Original interstellar dust Optically thick. Extending to a few AU T Tauri, He Ae/Be, ZAMS	Scattered near-IR light Coronographic optics NICMOS, STIS on HST Adaptiv optics/imaging Submm: SCUBA at JCMT (cool dust, molecular spect.) Radio: CO
10Myr <age < 1Gyr	Debris discs around MS stars: mainly interplane-tary dust resulting from collisions. Optically thin. Extending to a few 100 AU (αLyr,αPsA,εEri,βPic)	IRAS/ISO: FIR excess above photospheric flux traces the presence of a disc. Possible confusion with distant galaxies. ISO spectroscopy: dust & gas composition

Kalas disc gallery



2. ISO surveys: 2.1 General statistics

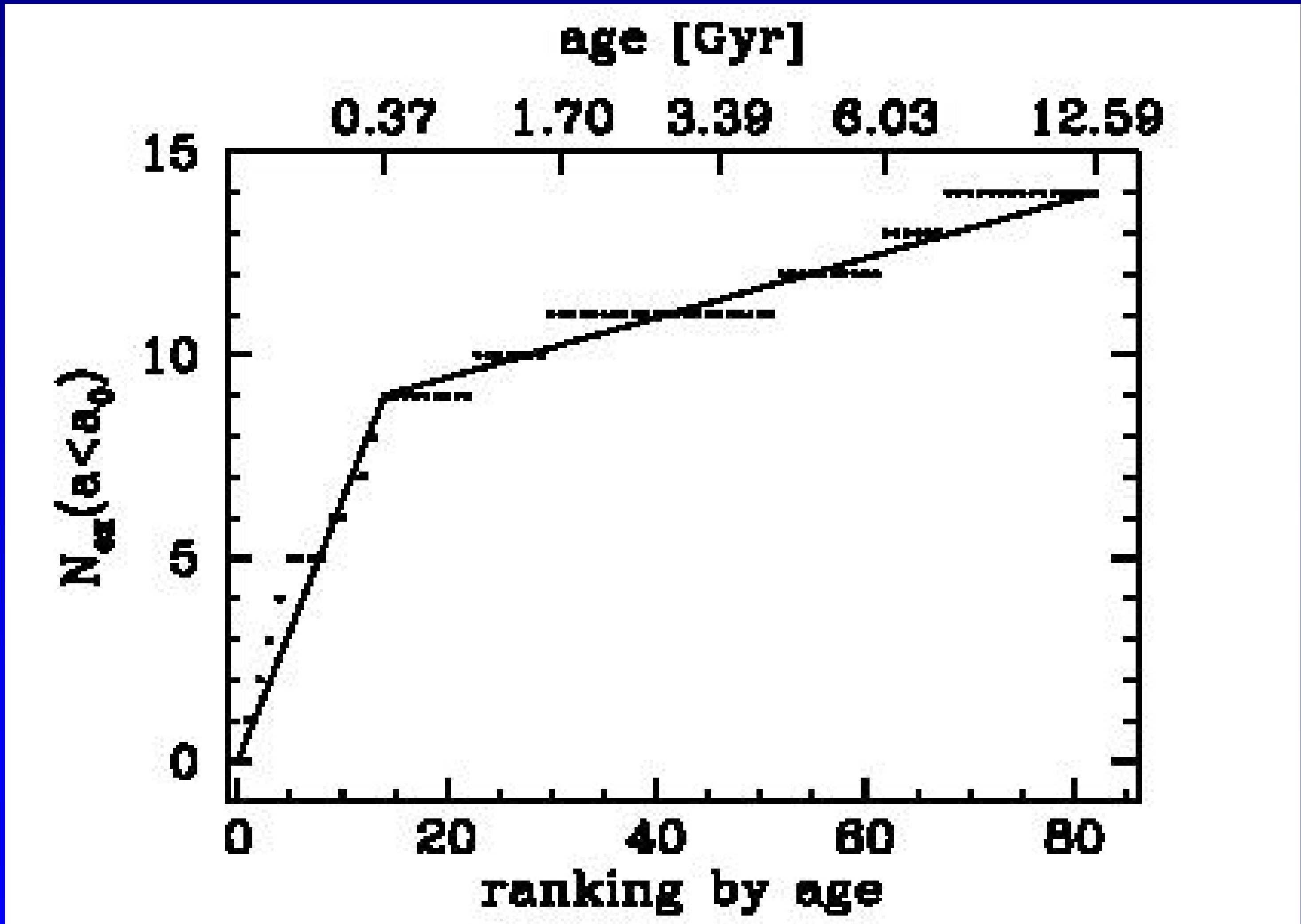
- *Habing et al. 1999, 2001* ISO proposal: HJHVEGA
- Goal: define the incidence of Vega-type discs in a distance limited sample (< 25 pc from the Sun) of main-sequence stars
- 84 MS stars, spectral type A-F-G-K
- ISOPHOT observations at 25, 60, 90 and 170 µm (65 hrs)

Main results (based on 60µm C100 minimaps):

- 17% of all stars do have a disc
- All stars younger than 300 Myr have a disc
- 70% of the stars younger than 400 Myr have a disc
- 8% of the stars older than 1 Gyr have a disc

Discs around MS stars disappear after 400 Myr

Cumulative distribution of excess stars as a function of index, sorted by age



Habing et al. 2001

2. ISO surveys: 2.1 General statistics

- ? <u>Warm discs</u> (based on 25µm): *Laureijs et al. 2002*
  - – 81 stars: 5 discs detected (6% of the stars; all < 400Myr)
  - – $50<T_{dust}<120K$
- ? **<u>Comparison with our solar system</u>**:
  - – Discs need continuous replenishment of dust
  - – Possible reservoirs: collisions between asteroids and planetesimals, evaporation of comets
  - – Vega-type disc mass similar to mass in the Kuiper belt
  - – The timesscale of disc decay corresponds to the end of the late heavy bombardment on the Moon; it may trace the significant decrease of planetesimals number and the final touches of planet surface modelling

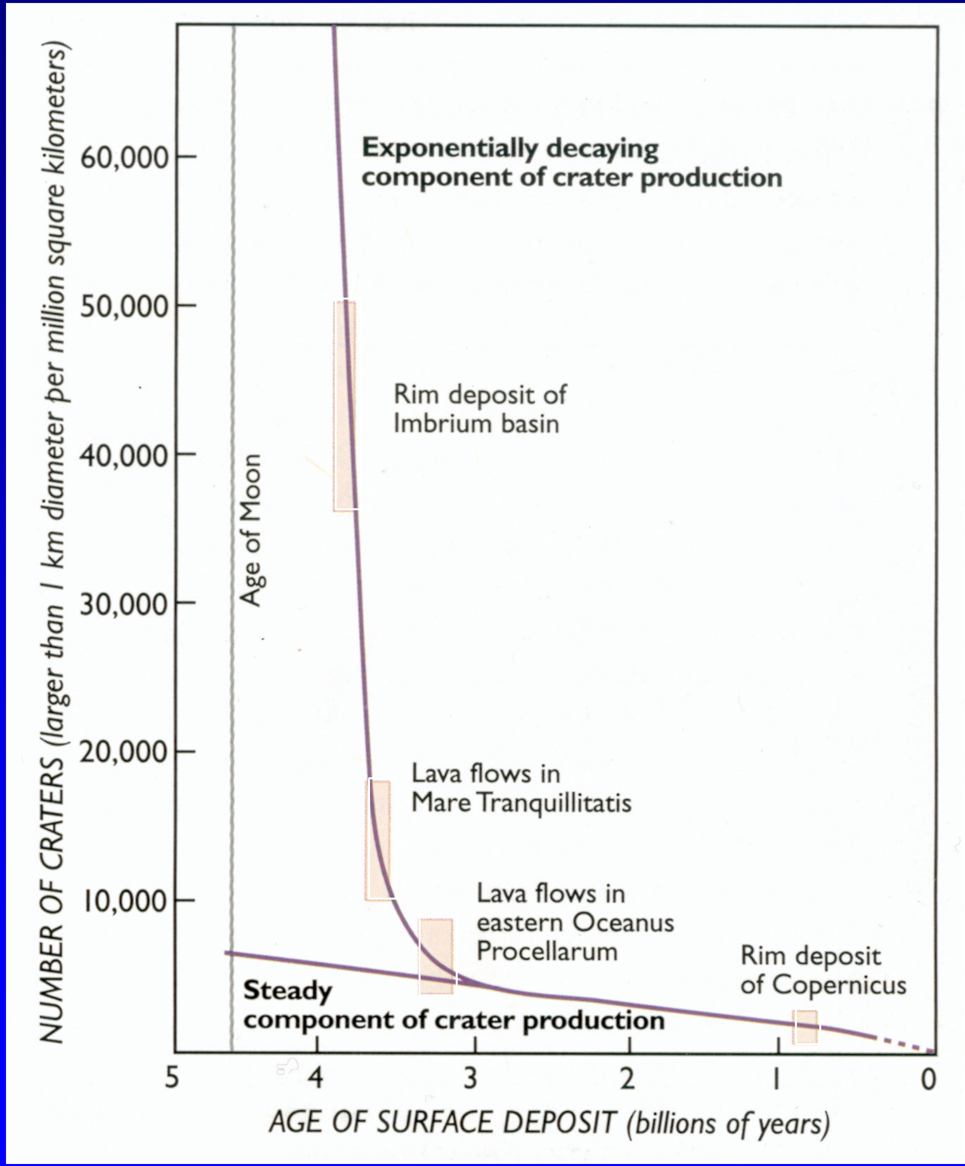
Impact rate versus age

The variation of crater density on lunar surfaces with different ages

Each pink rectangle corresponds to an Apollo landing site.

The high cratering rate during the late heavy bombardment dropped rapidly between 3.9 and 3.3 billion years ago, giving way to a slower, steady rate of crater production.

From: Shoemaker & Shoemaker, 1999 in "The New Solar System"



2. ISO surveys: 2.2 G stars

- *Decin et al. 2000* proposal: Waelkens
- ISO observations: ISOPHOT (PHT37) C100 3x3 minimaps at 60µm of 30 G dwarfs
- Main results:
  - 5 stars have an IR excess and are likely older than 3Gyr
  - 2 of them have a very high fractional disc luminosity (L_{dust}/L_{star})which is similar to βPic
  - Disc incidence: 17% (in Habing et al. 2001, 19% of the G stars have a disk, 3 of them are older than 5Gyr)
- No clear explanation why the discs around cool stars survive longer than among other objects
- Results are compared with recently started CORALIE survey: 9 stars were found double but they have no 60µm excess.
- No correlation between dust disc and planets.

2. ISO surveys: 2.3 Stars in open clusters

- *Spangler et al. 2001* Proposals by Becklin, Sargent
- 150 stars observed:
  - 80 MS stars in nearby (d < 120pc) open clusters

    α Persei, Coma berenice, Hyades, Pleiades, UMa

    Ages 50 – 700 Myr, sp. T: A to K
  - 50 T Tauri stars in Chamaeleon I, Scorpius & Taurus

    (d = 150pc), incl. few field stars
  - 10 nearby stars (d < 60pc)
- ISO observations: ISOPHOT chopped C100 at 60 & 100µm

  or raster C100 at 60 & 90µm
- Results: 36 stars detected (only 34 in their table!), of which 33 show evidence for a far-IR excess,

  i.e. 22% of all observed stars

2. ISO surveys: 2.3 Stars in open clusters

- 1/3 had an IRAS excess
- 2/3 new ISO detections !
  - 60, 90 and 100 µm excess for: 13 cluster stars, 5 young field stars and 1 other field star
  - Mainly F spectral type
- Excess IR luminosity relative to stellar photosphere declines consistently with stellar age with a power-law of index -2

$$\frac{F_{excess}}{F_{phot}} = \frac{L_{dust}}{L_{bol}} = f_d = \frac{L_{IRexcess}}{L_{star}} \qquad f_d \propto (\text{age})^{-1.76}$$

- For collisionally replenished secondary dust disc, one expects $f_d \propto (\text{age})^{-2}$

2. ISO surveys: 2.4 T Tauri stars in clusters

- *Robberto et al. 1999* proposals: Beckwith
- 97 T Tauri stars in 5 young clusters: Chamaeleon I, IC1602, α Persei, Pleiades, NGC 7092
- Distances: 140 – 270 pc
- Ages: 1 – 300 Myr
- ISO observations: ISOPHOT broad-band photometry at 25 and 60µm, C200 maps, PHOT-S spectra
- Main results:
  - At 60µm 15% detections in Cham (age 1– 5Myr)

    0% detection in other clusters

Only preliminary results in ESA–SP427 (Paris ISO conference), no final paper yet.

3. Case studies: 3.1 Vega & bPic

ISOPHOT	**Vega**	b **Pic**
High-resolution scans	60 µm (P32/C100)	25, 60 µm
Disc resolved	Yes: face-on	Yes: edge-on
Distance	7.8 pc	19.3 pc
Disc radius	86 AU at 60µm 140 AU at 90µm	84 AU at 25µm 140 AU at 60µm
Multifilter-Photometry	25,60,80,100,120, 150,170 & 200 µm	4.85,7.3,11.3,12.8,16,20,25 60,80,120,150, &170 µm
Adopted dust emissivity	$Q(\lambda) \propto 1 / \lambda^{1.1}$	$Q(\lambda) \propto 1 / \lambda$
Dust mass in disc	1 – 5 x10^{-3} M "	1.0 – 3.3 x 10^{-2} M "
	(*Habing et al 2001*: M=1.3 – 13 x 10^{-4} M ")	(*Habing et al. 2001*: M=1.2 – 12 x 10^{--2} M ")
Reference	*Heinrichsen et al. 1998* Proposal: Walker	*Heinrichsen et al. 1999* Proposal: Heinrichsen

3. Case studies: 3.2 ρ^1Cnc (55 Cnc)

- G8V star, d=12.5 pc, age=5 Gyr similar to our Sun, found to host a planet (Butler et al 1997) of mass $M=0.84\ M_{JUPITER}$ period=14.65 days Semi-major axis= 0.11 AU
- ISO observations: PHT03 at 25µm, PHT22 minimaps at 60 & 90 µm
- Results: Excess at 60µm

First case of disc + planet !

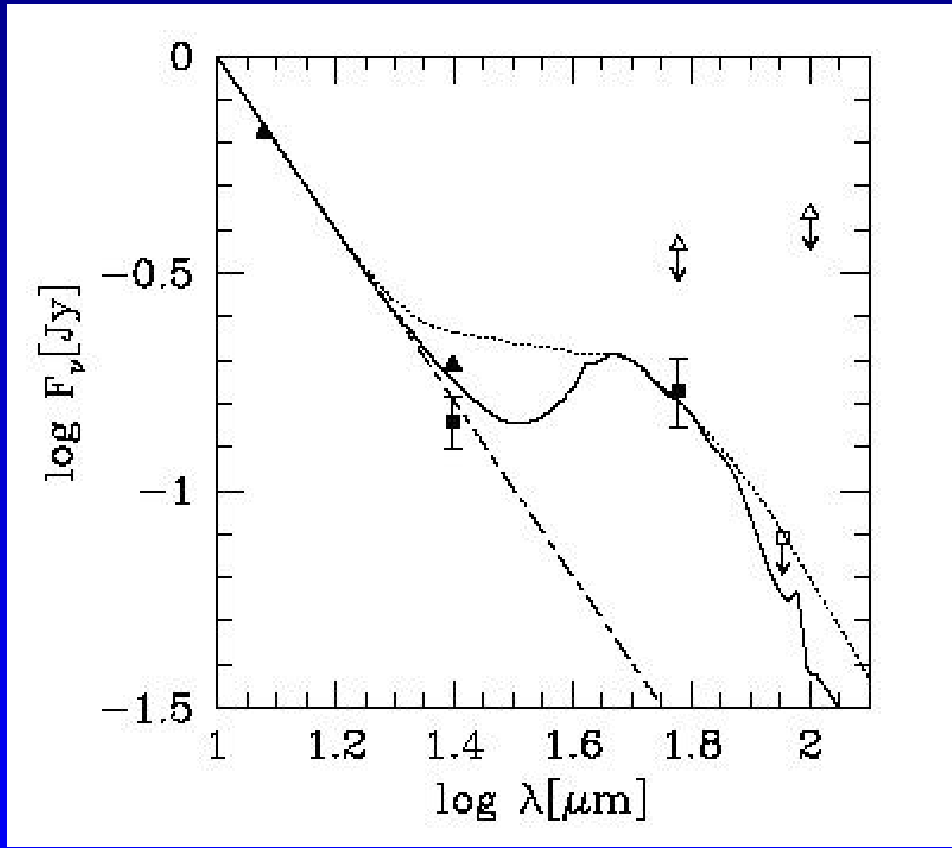
d=50 – 60 AU

$M_{dust}=4\times10^{-5}\ M_{\oplus}$

Radiation pressure from G8V star and Poynting-Robertson effect imply disc must be replenished:

→ existence of larger bodies: comets, planets

Dominik et al. 1998 PI: Habing



3. Case studies: 3.3 HD207129

•G2V star, d=15.6pc, age ª 5 Gyr

•<u>ISO observations</u>: 3.6 to 200µm PHT-S, minimaps, …

•<u>Results</u>:
strong IR excess from 30 to 200µm
Cold disc: T ª 30K
L_{disc}=1.4 x 10^{-4} L_{SUN}

M_{disc} ª 0.01 – 0.1 M ‥

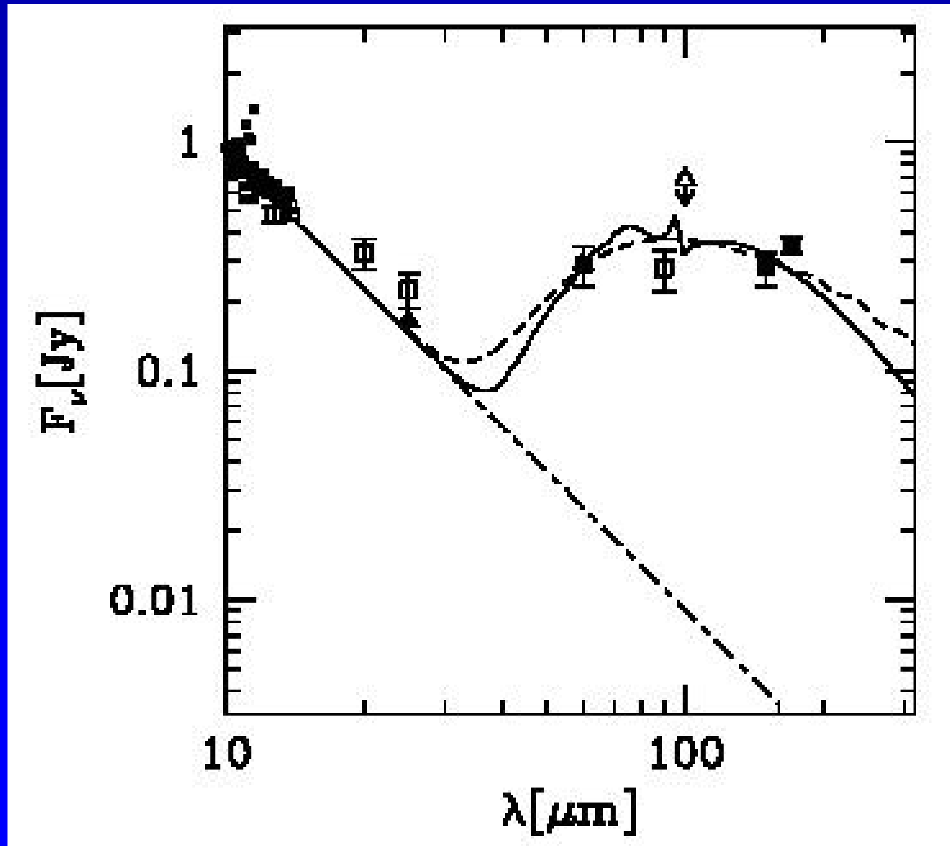
	case A	case B
Grain Material	DL84	LG97
Minimum grain mass	1.1×10^{-11} g	1.1×10^{-11} g
Minimum grain size	1 μm	2.4 μm
Maximum grain mass	9×10^{-6}g	9×10^{-6}g
Maximum grain size	93 μm	227 μm
Size distribution	$f(m) \propto m^{-1.83}$	$f(m) \propto m^{-1.83}$
Surface density	$\sigma(r) \propto r^{-1.7}$	$\sigma(r) \propto r^{-1.7}$
Total mass	$5 \times 10^{-8} M_{\odot}$	$5.7 \times 10^{-8} M_{\odot}$
Inner disc radius	200 AU	400 AU
Outer disc radius	500 AU	1000 AU
Max $T_{\rm dust}$	46 K	37 K
Min $T_{\rm dust}$	12 K	17 K
$L_{\rm IR/L_*}$	1.1×10^{-4}	1.02×10^{-4}

Resolving equation of energy balance of a dust grain + grain model (cometary grains, Mie theory)

Þ 550 < d < 850 AU

and an inner hole within 400 AU

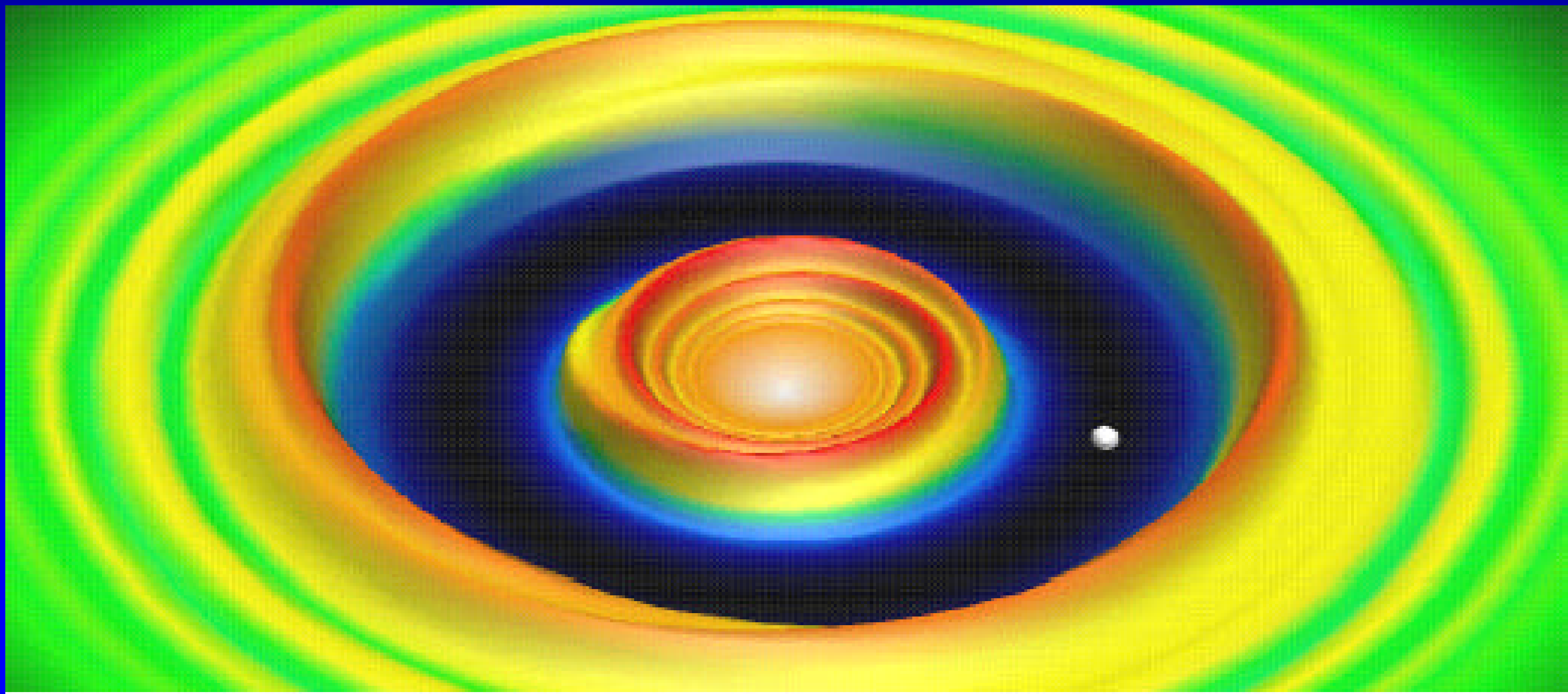
Þ one or more planets



Jourdain de Muizon et al. 1999

3. Case studies: formation of a planetary system

Simulation of the formation of a planetary system
(from *Lin et al. 2000*)



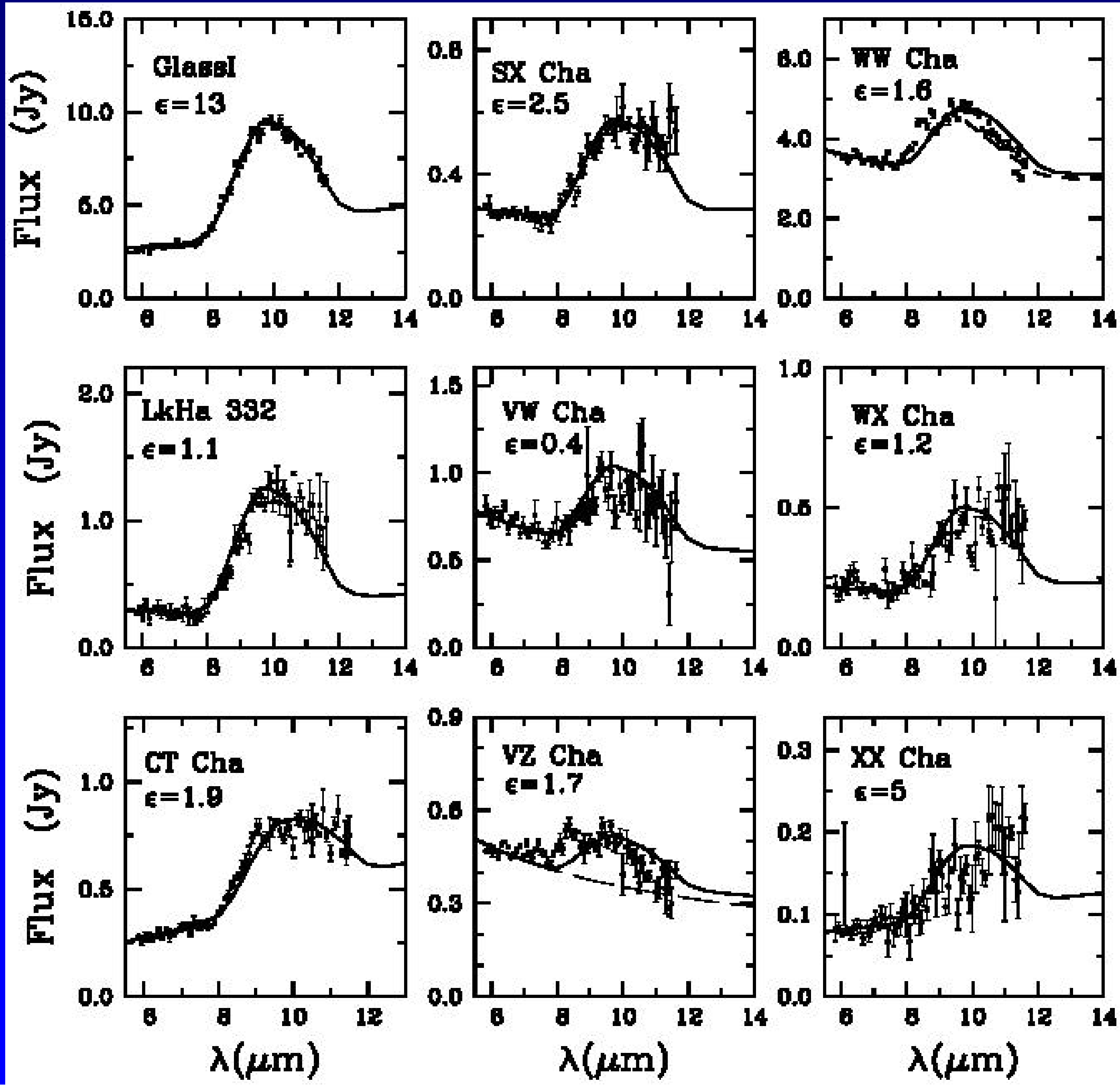
4. Spectroscopy: dust

Spectral signature	Observations/Reference	Interpretation
Amorphous Silicates r<1µm	Phot-S spectra 9 classical T Tauri stars in Cham I dark cloud *Natta et al. 2000*	Disc atmosphere Optically thin surface layer of the disc
Crystalline silicates (recently formed dust) and also hot gas (850K) CO, CO_2, H_2O, NO	SWS01+LWS01 full scan 51Oph bright emission-line star B9.5Ve or A0 II-IIIe *v.d. Ancker et al. 2001*	Features unusual for a young star: recent episode of mass loss from a Be star, or recent destruction of a planet around a young star
Fosterite (Mg_2SiO_4) Present in polar micrometeorites and interplanetary dust of our SS Feature similar to comet Hale-Bopp Also: FeO, H_2O ice, PAHs	SWS01+LWS01 full scan HD100546 He Ae/Be star *Malfait et al. 1998*	Amount of Fosterite equiv. To 10^{13} comets Hale-Bopp ! Þ presence of a massive Oort cloud of comets Crystallisation process occurs during the early phase of disc evolution around young stars

4. Spectroscopy: dust (cont.)

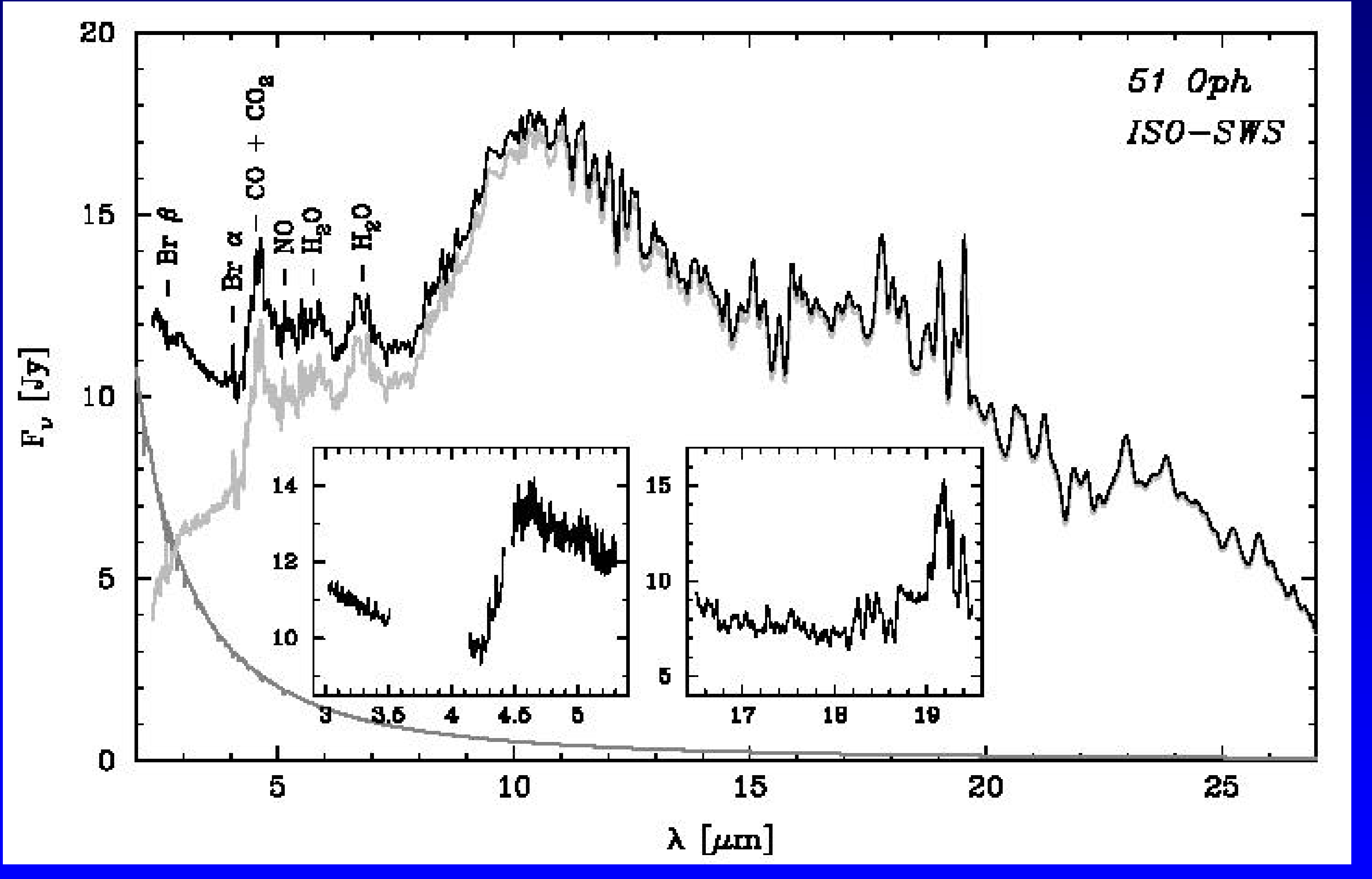
Spectral signature	Observations/Reference	Interpretation
Amorphous and crystalline silicates, PAHs bands (on top of a near-IR + mid-IR excess)	SWS01+LWS01 full scan 14 He Ae/Be stars *Meeus et al. 2001*	Disc modeling: Optically thick/geometrically thin disc → power-law component Optically thin/flared region → BB component
Amorphous silicates and PAHs Aliphatic carbonaceous dust: SiO_2 (silica) Olivine grains (0.1-2µm) Fosterite	Same observations as above but detailed study of the 10µm spectral range HD 162296 *Bouwman et al 2001*	Detailed study of dust composition in each star. Significant variation of the features from star to star → Various phases of dust processing. Crystalisation timescales longer than coagulation No correlation between dust composition and disc geometry

4. Spectroscopy: amorphous silicates



Natta et al. 2000

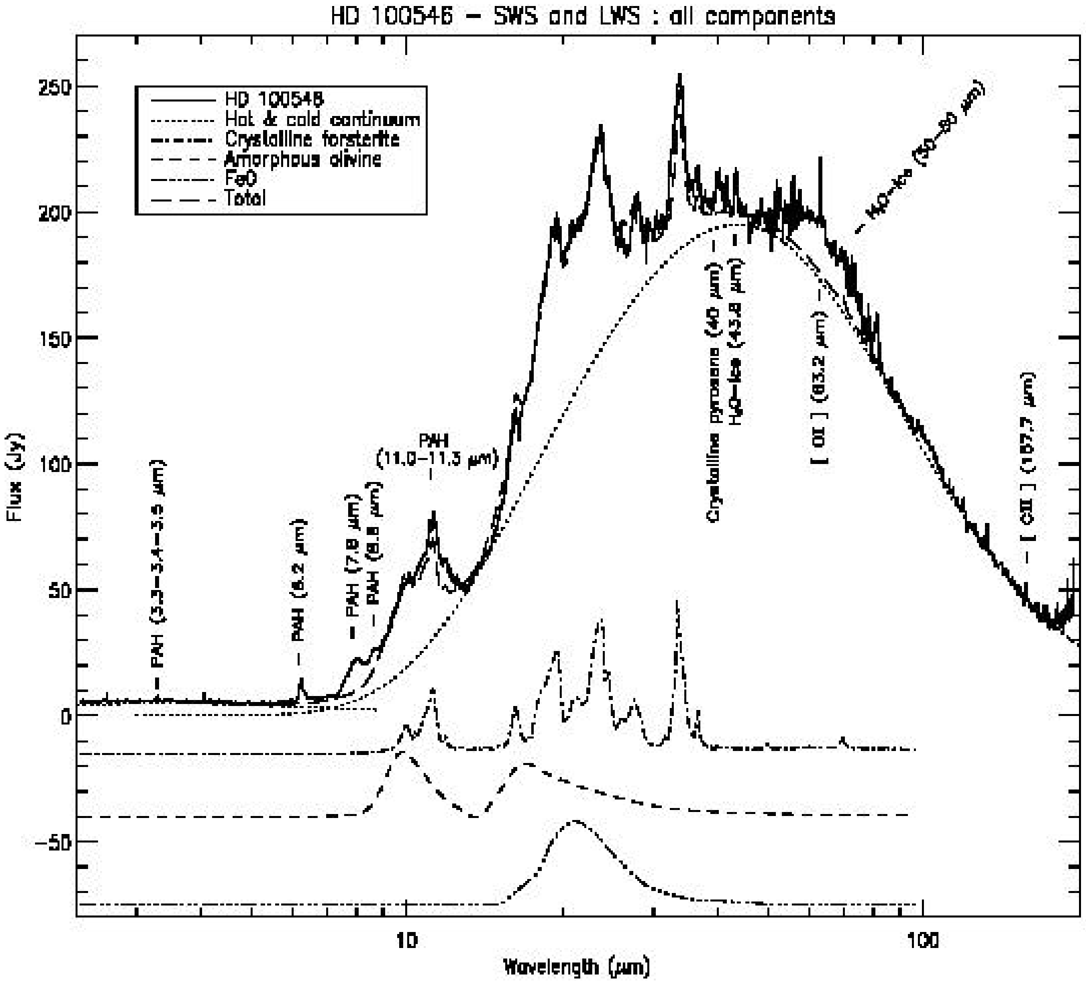
4. Spectroscopy: crystalline silicates



van den Ancker et al. 2001

4. Spectroscopy: Fosterite

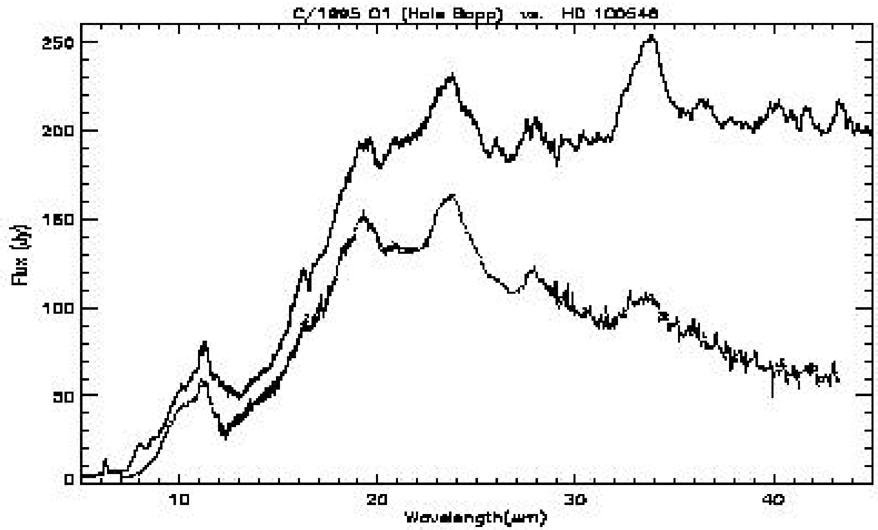
HD 100546 SWS + LWS



Comparison of the ISO-SWS spectrum of HD 100546 with comet C/1995 O1 Hale-Bopp

top: HD 100546

bottom: Hale-Bopp

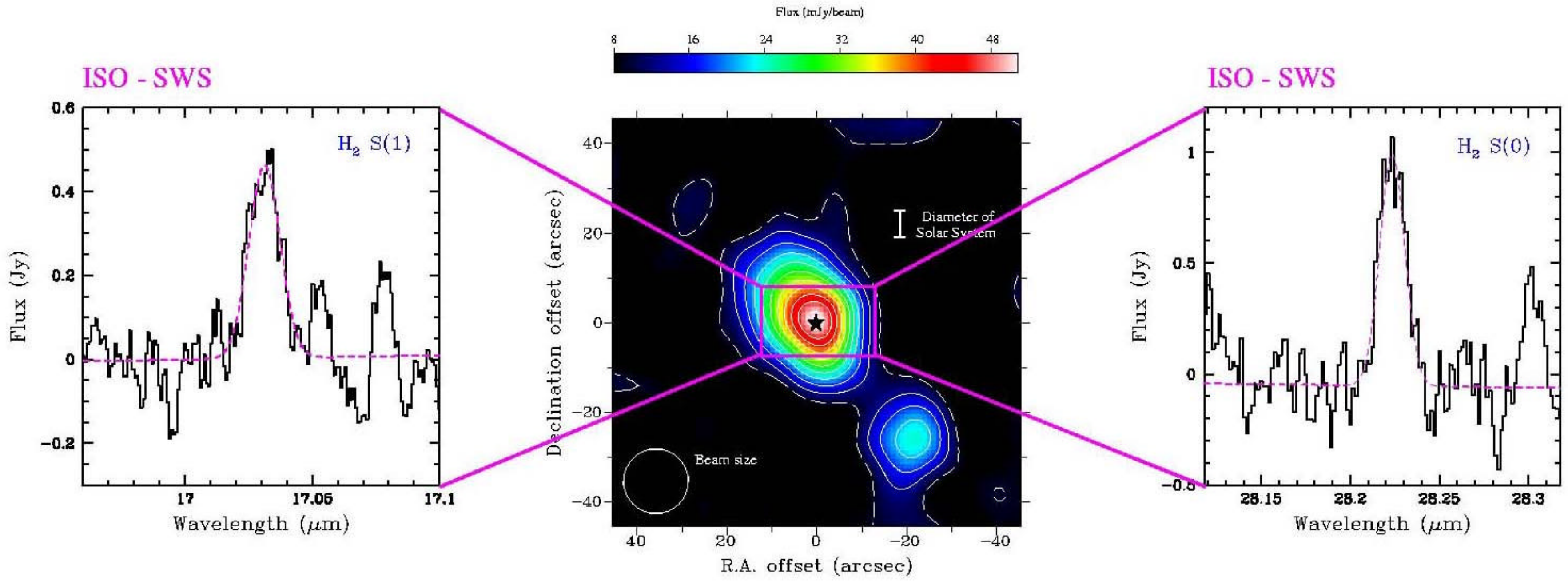


Malfait et al. 1998

4. Spectroscopy: gas

Spectral signature	Observations/Reference	Interpretation
Molecular H_2 at 28.218 µm J=2→0 S(0) & 17.035 µm J=3→1 S(1)	SWS02 GG Tauri *Thi et al. 1999*	H_2 gas at T_{kin}=110K M_{gas} a (3.6 ± 2) x 10^{-3} M_{SUN} Photon & wind-shock heating mechanism
	SWS02 49 Ceti, βPic, HD135344 *Thi et al. 2001* SWS02 8 T Tauri stars 9 He Ae stars 3 Debris-disc stars *Thi et al. 2001*	T a 100 – 200 K H_2 detected toward most stars < 10 Myr + 3 older Vega-like stars M_{gas} = 0.1 – 10 x 10^{-3} M_{SUN} Possible reservoir for Jovian planet formation CO depleted in young objects (bad tracer of the gas mass) Freeze-out onto grain surfaces or photodissociation of CO in disc atmosphere

H_2 emission from β Pictoris disc



SCUBA 850 μm Holland et al. 1999

- d = 19.6 pc, $M_{solid} = 10^{-6}\ M_{sun}$ (Li & Greenberg 1998)
- $\langle T \rangle_{gas} \sim 108$ K, $M_{gas} = 1.3\ 10^{-4}\ M_{sun}$

Thi et al. 2001

What's left in the ISO data archive ?

At least 85 hours of observing time in some 15 proposals using the four ISO instruments, addressing most of the topics presented here

What to expect from future missions ?

SIRTF:

? similar wavelength range as ISO but higher sensitivity

? will be able to probe deeper, i.e. to make the same kind of statistics but on a much bigger volume around the Sun

HERSCHEL:

? will extend the ISO wavelength range to the submm

? will allow to trace the cold component of the discs (cf. dust in the Kuiper belt, Oort cloud and beyond)

Open questions

? Why and how do discs disappear after 400 Myr ?

? Do discs coexist with planets ?

? Is the timesacle of disappearance of the disc related to the spectral type of the star ?

? What physical/chemical processes occur during the evolution of a disc ?