HD 100546: a disk, a gap, and a planet ?

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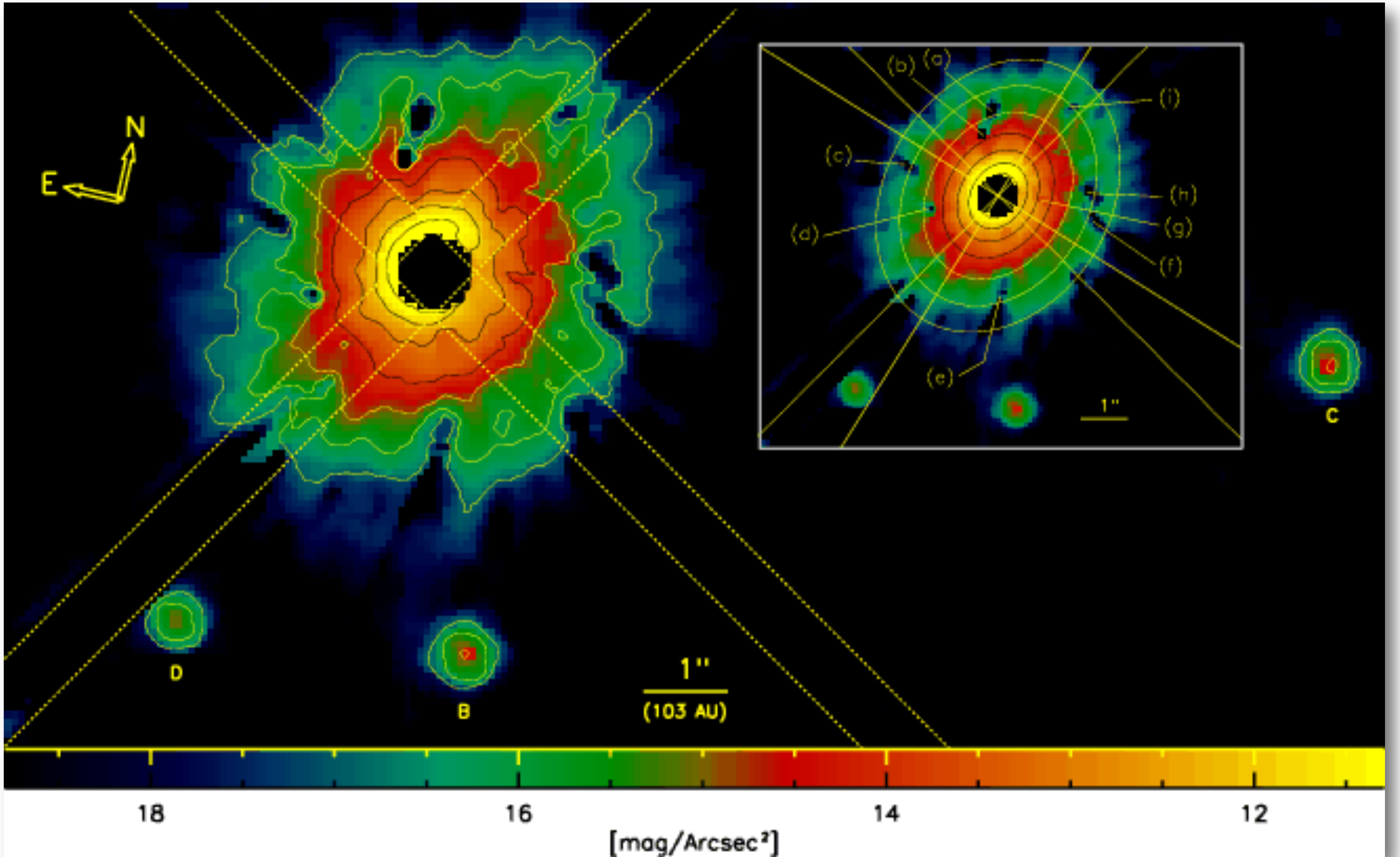
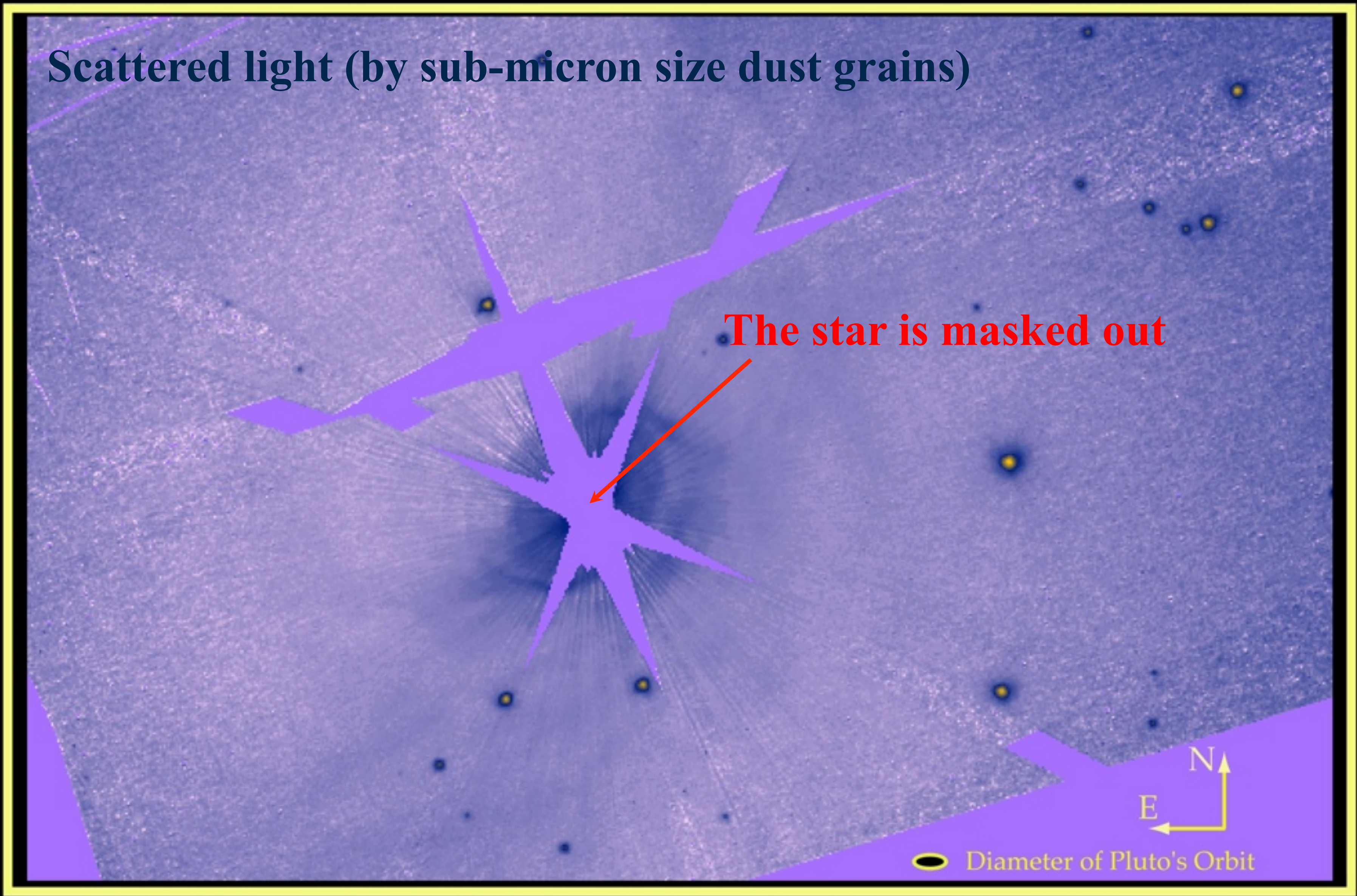
Institut de Planétologie et d'Astrophysique de Grenoble
+ a few others

Near IR image of HD100546



Augereau et al. (2001), HST / NICMOS

Discovered by ground based AO, Pantin et al. (2000)



The Disk and Environment of HD 100546

C.A. Grady (NOAO, GSFC) and the STIS Investigation Definition Team, NASA

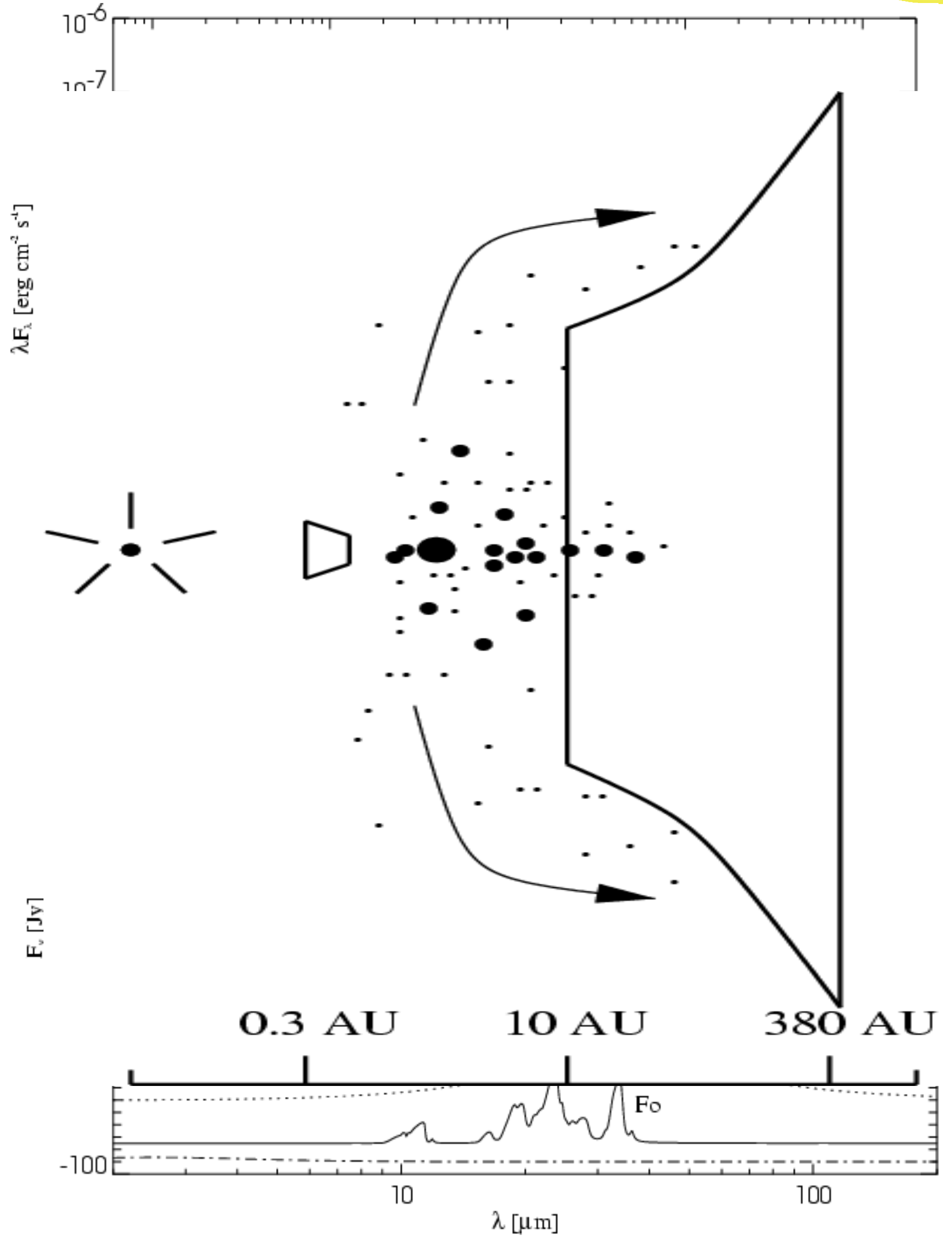
Grady et al. (2001)

Previous disk models

- Bouwman et al. (2003)
  - Disk geometry
  - Dust Mineralogy

HD 100546 is a

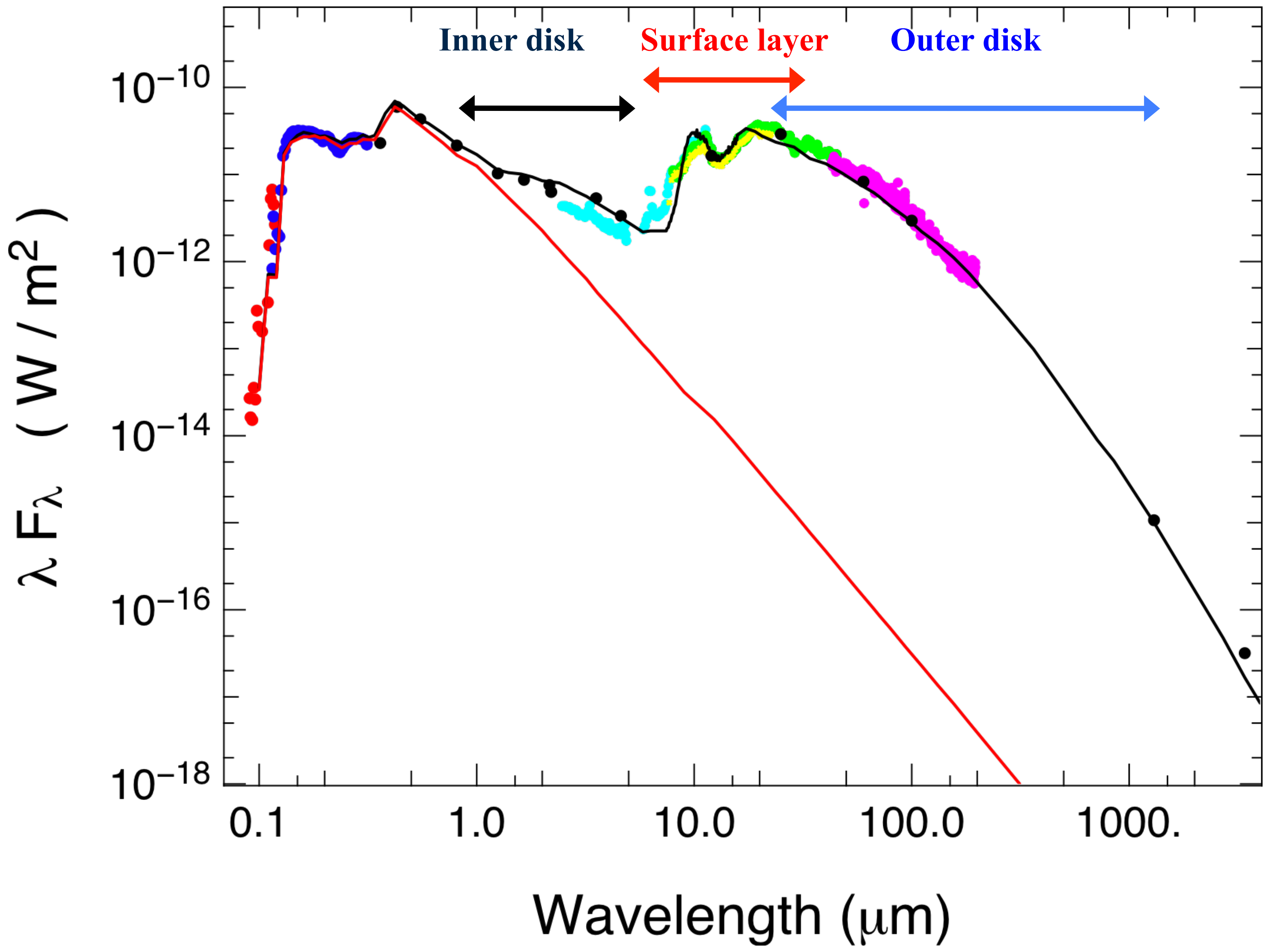
Pre-Transitional Disk



In this talk:

- 1- Fit SED -> get overall disk structure
  - Pre-transition disk (inner disk, gap, outer disk)
- 2- Fit VLTI data -> improve on inner disk
  - set Rin, surface brightness profile of inner disk
  - Where's the planet?
- 3- Fit Herschel lines fluxes -> gas content
  - Discovery of CH+
  - Other lines in GASPS spectra
  - CO rotational diagram
- 4- Future work , concluding remarks

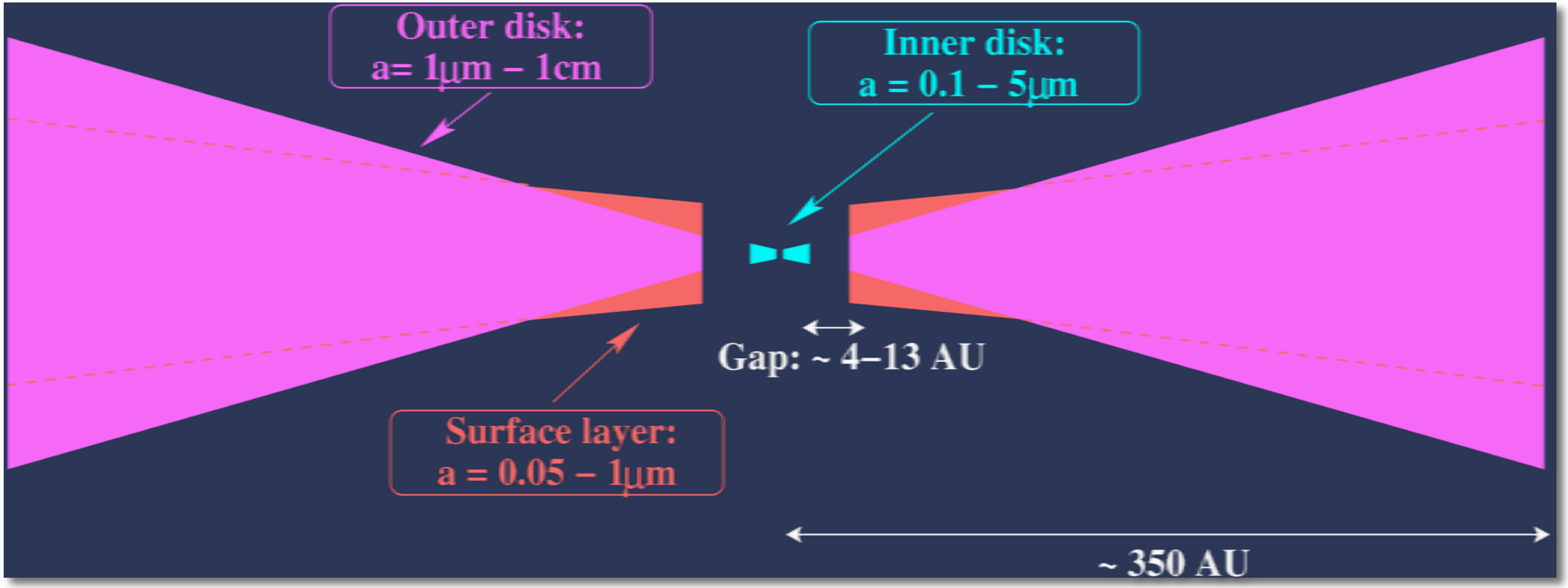
Our disk model, the SED



Calculations made with MCFOST: Pinte et al. (2006, 2009)

HD100546: sketch of the disc structure

Not to scale

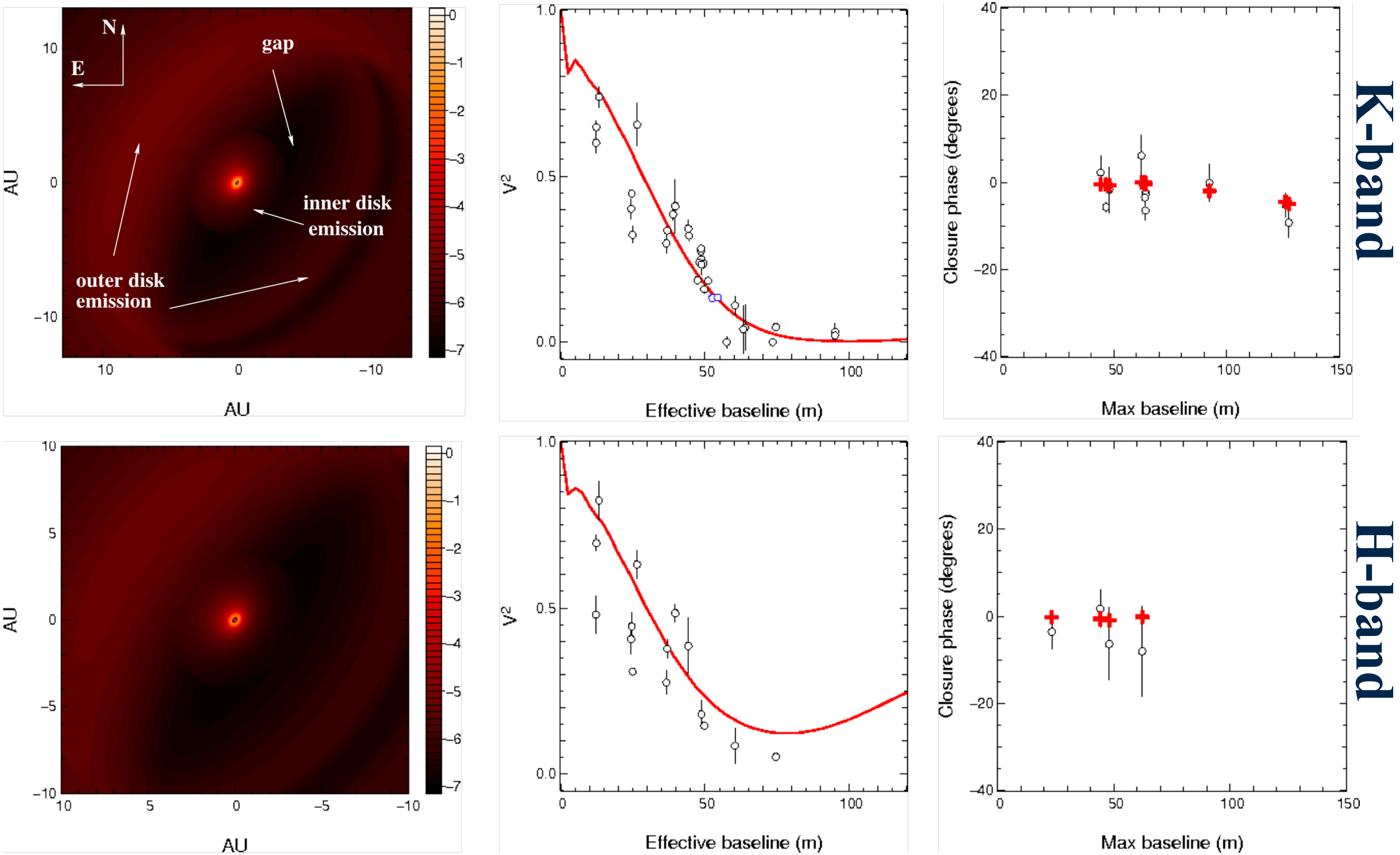


up to 500 AU in CO data (see Panic et al.)

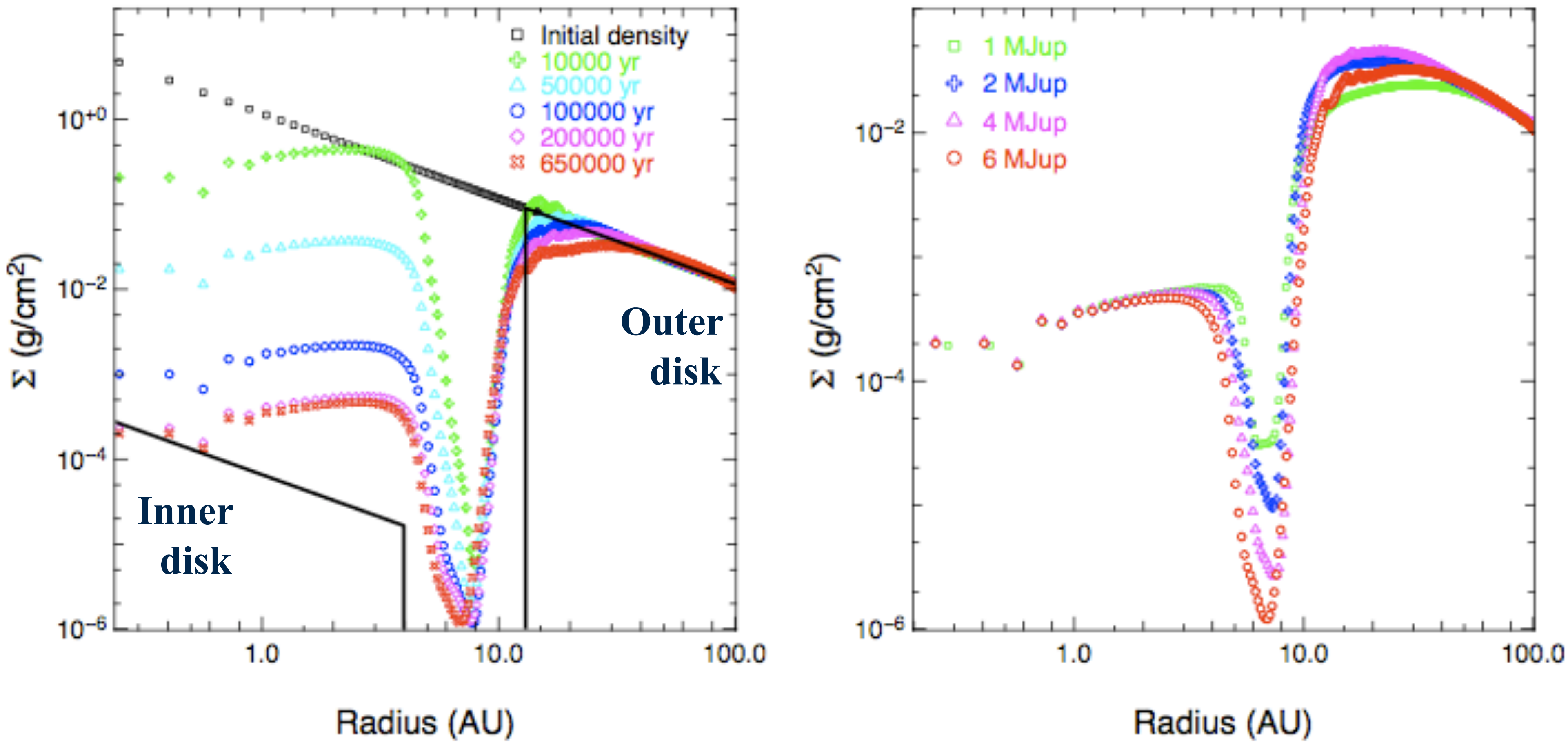
See Poster by Mulders for more on Mineralogy and the surface layer

Benisty et al. 2010; Tatulli et al. 2011

ESO-VLTI data , observing the inner disk



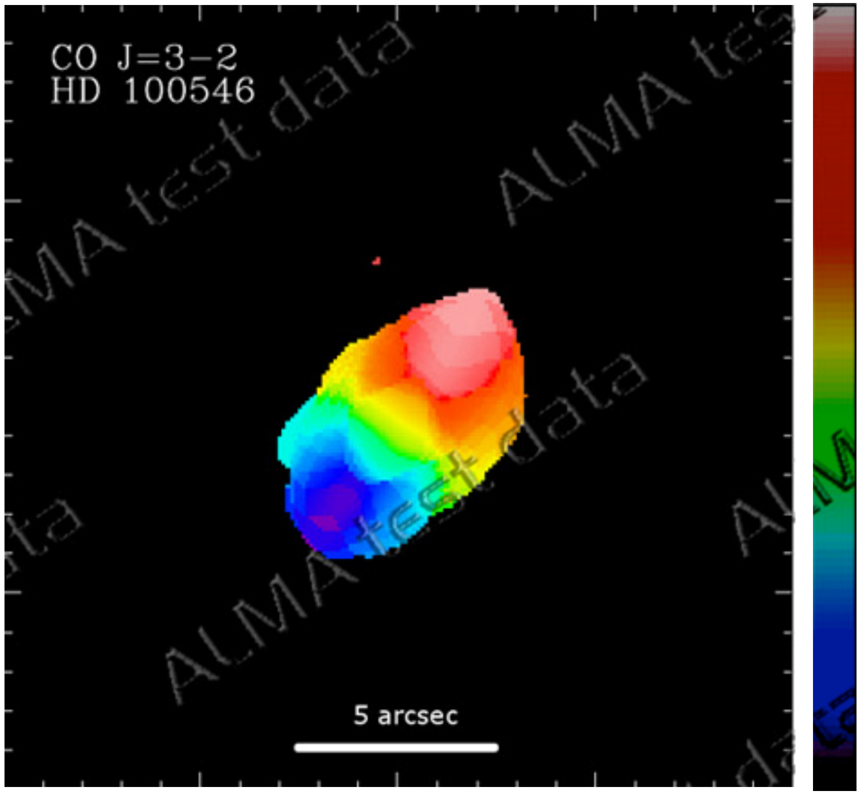
HD100546: a disc with a planet at ~8 AU?

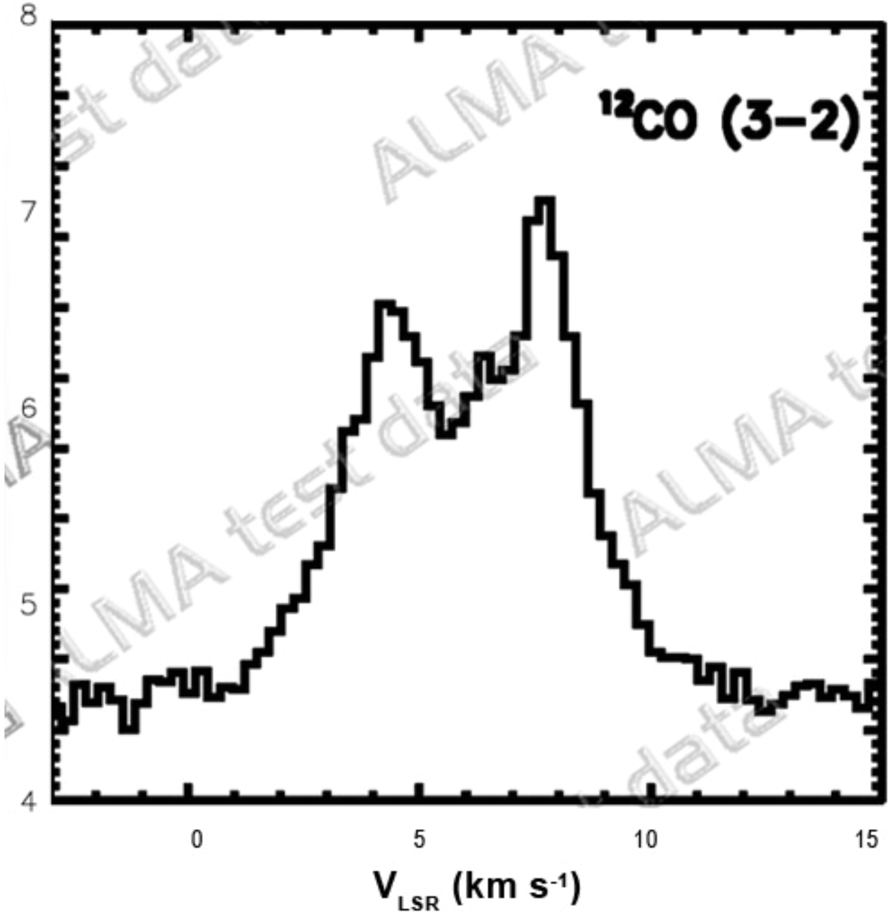


Surface density profile, Σ(r)

Evolution with time **Effect of Planet mass, @ 1Myr**

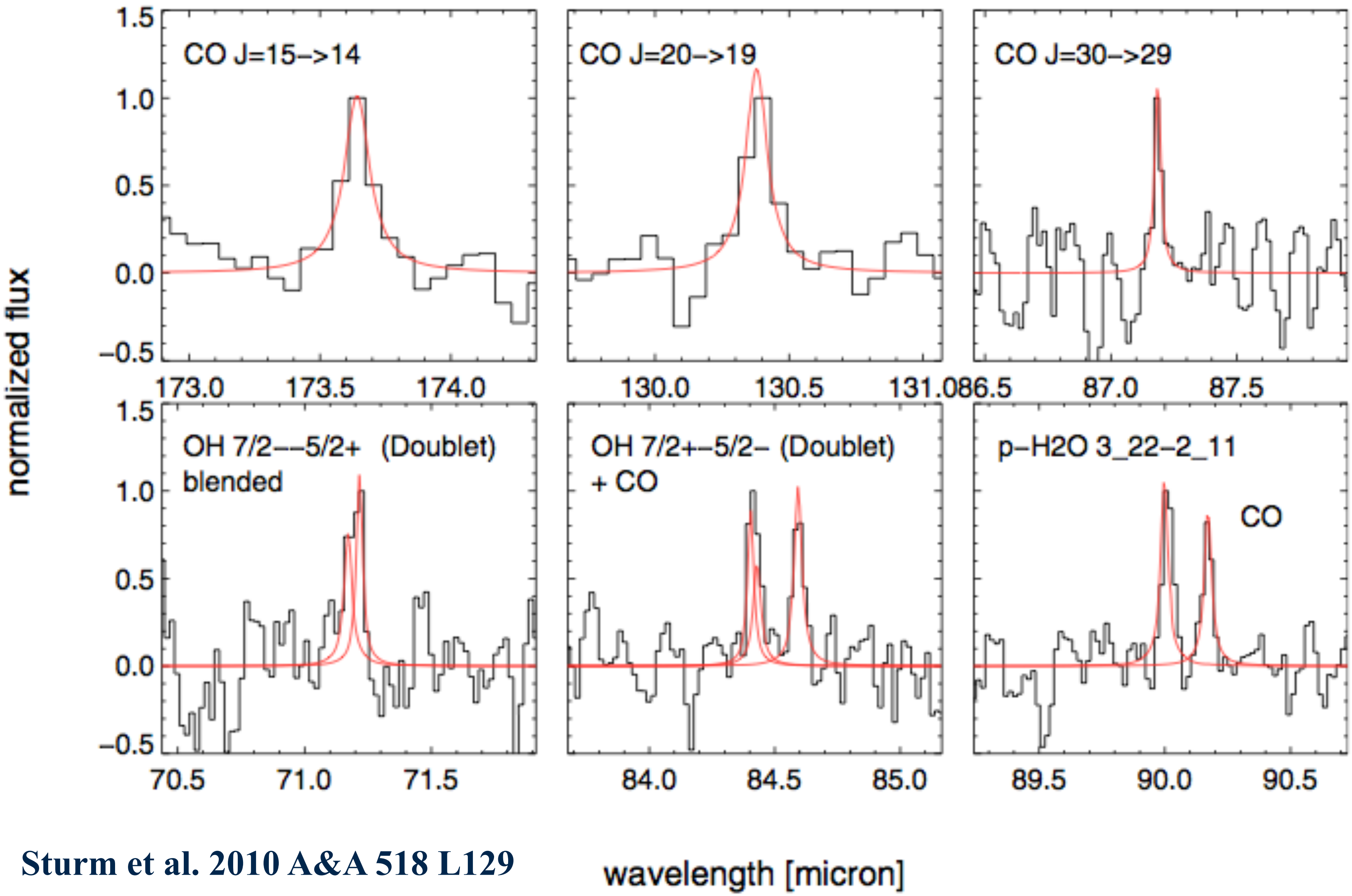
The gas disc around HD100546: an ALMA test-case





See also Panic et al. 2010

The disc is rich in hot gas (atomic and molecular)



Sturm et al. 2010 A&A 518 L129

GASPS : detection of CH+

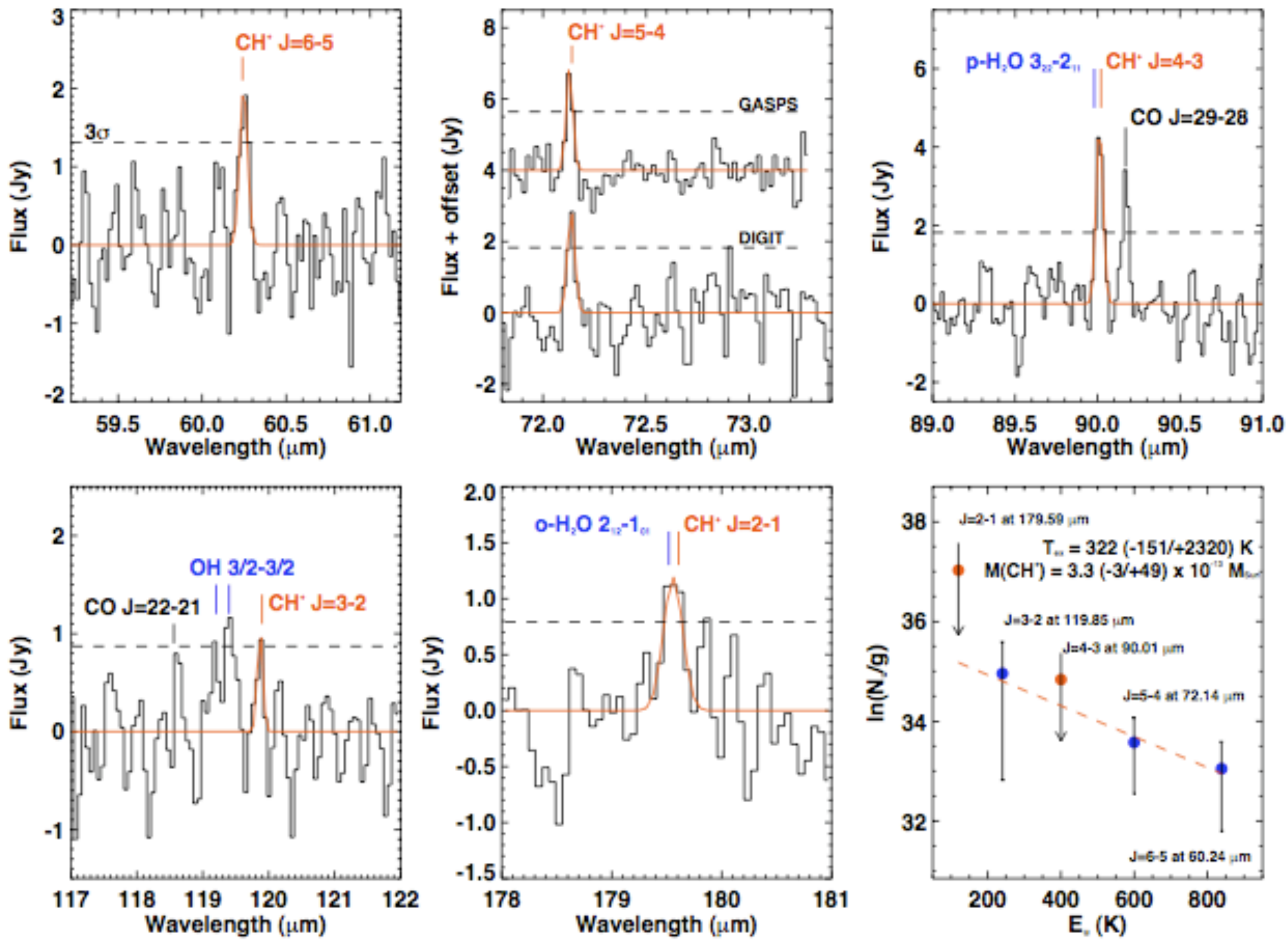
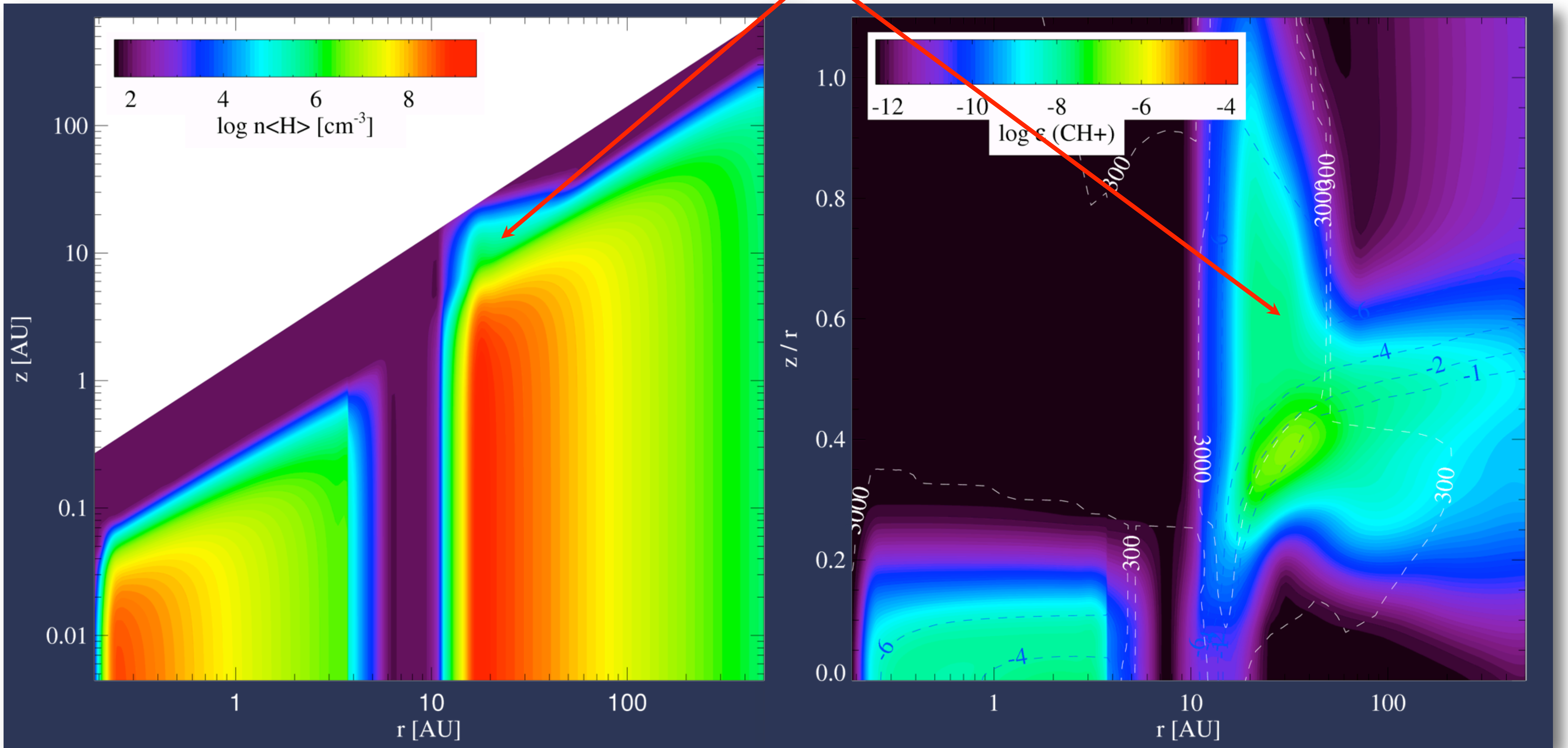


Fig. 1. Continuum subtracted HERSCHEL-PACS spectra of HD 100546 around the CH+ J=6–5, 4–3, 3–2, 2–1 (DIGIT data), and J=5-4 (GASPS and DIGIT data) lines. The 3σ statistical error levels do not include the 30% calibration uncertainty. A rotational diagram using those transitions is plotted in the lower-right panel. The errors in the diagram is the quadratic sum of all the statistical and calibration errors ($err_{tot} = \sqrt{(3\sigma_{stat})^2 + (0.3F_{obs})^2}$). Blended lines are considered as upper limits (red filled dots).

CH^+ is located at the rim

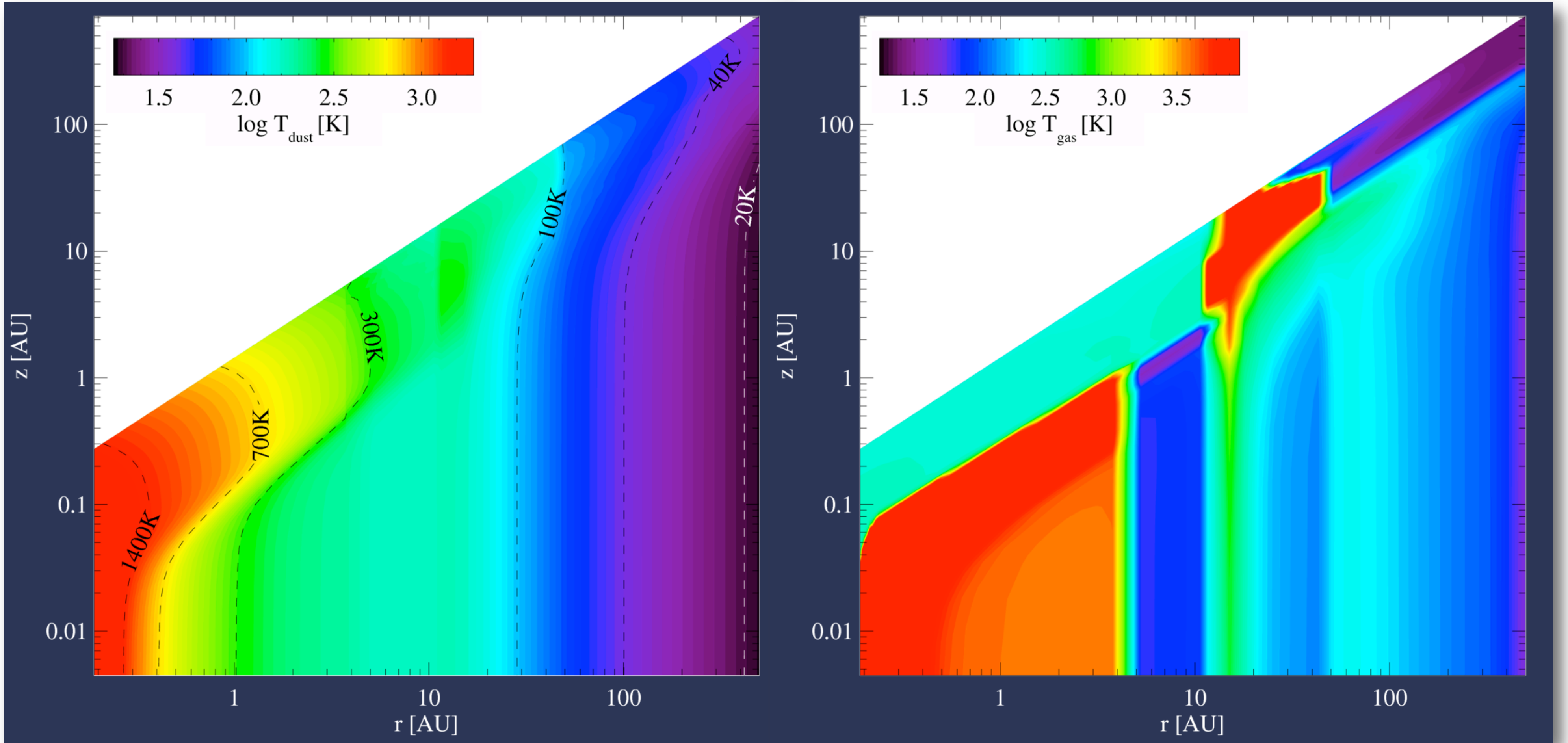
outer disc rim



inner disc **outer disc**

Calculations made with PRODIMO:
See papers by Woitke et al.; Kamp et al.; Thi et al.

Dust and gas temperature



Tgas NOT equal to Tdust

CH+ … and a few others

Table 1. Observed and modelled line fluxes

Transition	λ (μm)	obs.	model 1	model 2
		(10^{-17} W m^{-2})		
[O I] $^3P_1$–$^3P_2$	63.19	554.37 ± 167^a	785	763
[O I] $^3P_0$–$^3P_1$	145.54	35.70 ± 11.4	35.7	42.7
[C II] $^2P_{3/2}$–$^2P_{1/2}$	157.75	31.87 ± 10.0	12.7	17.2
p-H_2O $3_{22} - 2_{11}$	89.90	$\leq 14.32 \pm 1.2^b$	4.6	7.4
CH^+ $J = 4 - 3$	90.02	$\leq 14.32 \pm 1.2^b$	3.7	6.3
CH^+ $J = 6 - 5$	60.25	10.32 ± 5.7	4.2	8.9
CH^+ $J = 5 - 4^c$	72.14	6.86 ± 3.4	3.3	6.7
CH^+ $J = 3 - 2$	119.87	2.16 ± 1.1	1.8	2.9
CO $J = 3 - 2^d$	866.96	0.10 ± 0.03	0.08	0.24

[a] The total (3σ statistical + 30% calibration) errors are given for the PACS observations. [b] The blended H_2O+CH^+ line is detected. [c] The PACS values are from the DIGIT programme (Sturm et al. 2010) except for the CH^+ $J = 5 - 4$ flux (GASPS programme). [d] Data from Panić et al. (2010) with 3σ error.

The model parameters

	Inner disc	Surf. layer	Outer disc
MCFOST[a]			
Inner radius R_{in} (AU)	0.24	13	13
Outer radius R_{out} (AU)	4	50	500
Surf. density exponent q	1	0.5	1.125
Scale height $H_{100\,AU}$ (AU)	6	14[a]	14[a]
Scale height exponent β	1.0	1.0	1.0
Total dust mass M_{dust} ($M_\odot$)	1.75(–10)[b]	3(–7)	4.3(–4)
Dust mass ($a \leq 1$ mm, $M_\odot$)	1.75(–10)	3(–7)	1.3(–4)
Min. grain radius a_{min} (μm)	0.1	0.05	1
Max. grain radius a_{max} (μm)	5	1	10^4
Grain power law index p	3.5	3.5	3.5
Silicate grain density (g cm^{-3})	3.0	3.0	3.0
ProDiMo[c]			
ISM UV field (χ, Habing)		1.0	
viscosity (α)		0.0	
Non-thermal speed (km s^{-1})		0.15	
Disc inclination (°)		42	
UV excess		0.013	
UV power-law index		6.5	
Cosmic ray flux ζ(s^{-1})		1(–17)	
PAH $C_{150}H_{30}$ mass ($M_\odot$)		1.8(–7)	
Gas mass ($M_\odot$)		5(–4) (model 1)	
Gas mass ($M_\odot$)		1(–3) (model 2)	

Notes. [(a)] Values taken from Benisty et al. (2010) and Tatulli et al. (2011) except for the scale height $H_{100\,AU}$ at 100 AU. [(b)] $\alpha(-\beta)$ means $\alpha \times 10^{-\beta}$. [(c)] This work.

- 2 slides removed

Concluding remarks

DUST:

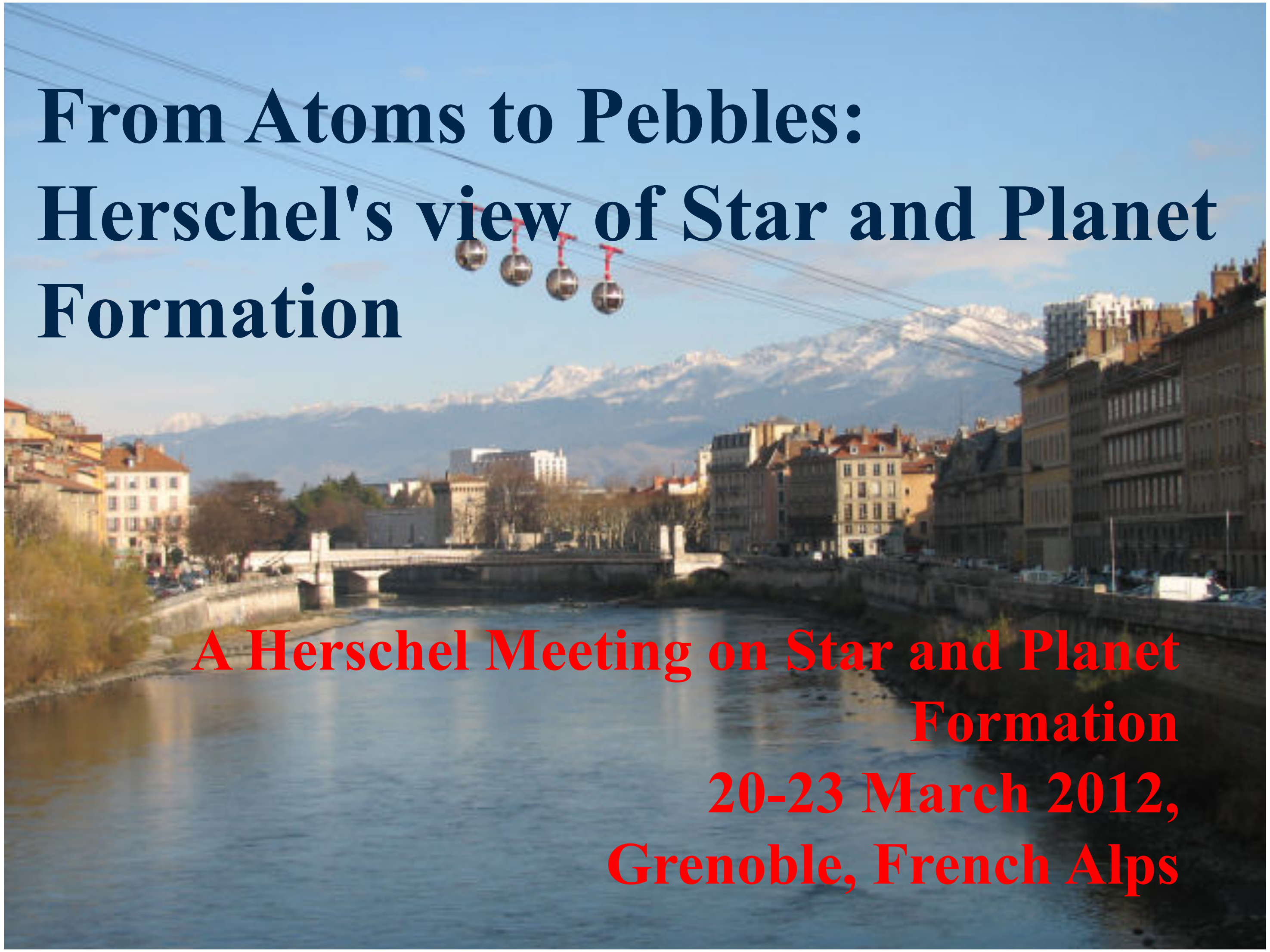
- Pre-Tansitional disk
- There is a gap between ~4 and ~13 AU
  - may be carved by a 6-8 Jupiter mass planet
  - Difficult to detect directly (disk is bright, gap is narrow)
- We find it necessary to deal with scattering properly in the models
- Inner disk may be variable?

GAS:

- Disk rich in gas, both inner and outer.
- I discussed (and modelled) lines for the outer disk so far.
  - Working on inner disk (CO ro-vib…)
- Modelling of several lines provide first estimates of total gas mass.
- CH^+ transitions up to J=6-5, first detection in a disk by Herschel
  - probe the upper rim atmosphere of the outer disc

We developed a unique combination of continuum radiative transfer code and a thermo-chemical code to allow extensive modeling.

- Axisymmetric models remain useful (see also remark by David Wilner)
- Don't explain everything by provide good understanding of disk (structure, temperature , composition…)



Consult: http://www.herschel2012.com