Modelling the gas and the dust of protoplanetary discs in the Herschel-GASP sample

W.-F. Thi [1] and The GASPS team [2]

[1] UJF-Grenoble 1 / CNRS-INSU, Institut de Planétologie et dAstrophysique (IPAG) UMR 5274, Grenoble, F-38041, France

[2] J. M. Alacid, S. Andrews, D.R. Ardila, G. Aresu, J.-C. Augereau, D. Barrado, S. Brittain, D. R. Ciardi, W. Danchi, J. Donaldson, I. de Gregorio-Monsalvo, W. R. F. Dent, G. Duchêne, C. Eiroa, D. Fedele, C. A. Grady, A. Heras, C. D. Howard, N. Huelamo, I. Kamp, A. Krivov, J. Lebreton, R. Liseau, C. Martin-Zaïdi, G. Mathews, G. Meeus, F. Ménard, I. Mendigutía, B. Montesinos, A. Mora, M. Morales-Calderon, H. Nomura, E. Pantin, I. Pascucci, N. Phillips, C. Pinte, L. Podio, D. R. Poelman, S. Ramsay, B. Riaz, K. Rice, P. Riviere-Marichalar, A. Roberge, G. Sandell, E. Solano, I. Tilling, B. Vandenbussche, H. Walker, G. J. White, J. P. Williams, P. Woitke, G. Wright

GAS in *P*rotoplanetary *S*ystems

Herschel Open time large program P.I. Dent (PASP to be submitted)
http://www.laeff.inta.es/projects/herschel/

Aim:

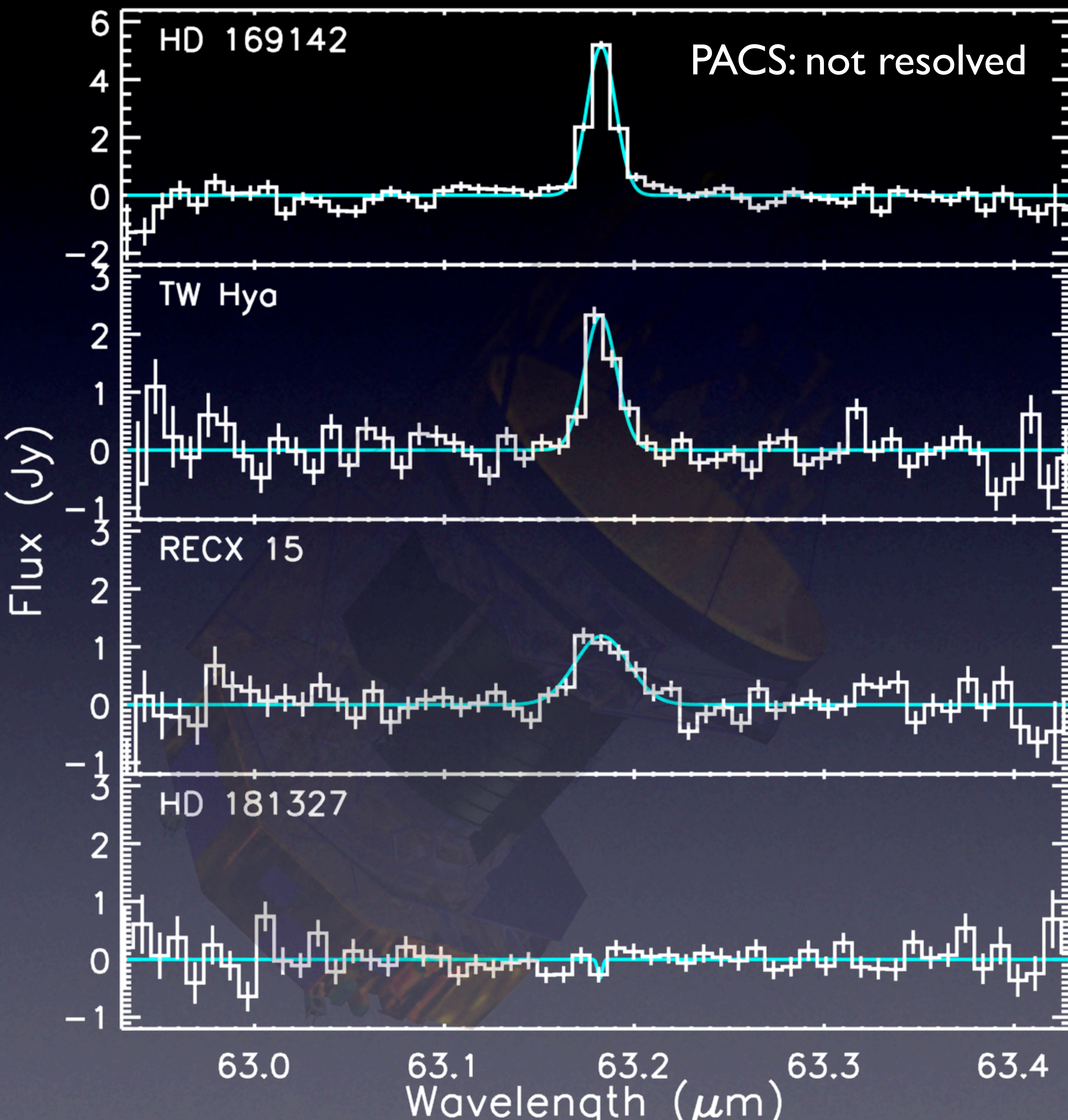
1. Trace gas and dust in the planet formation region across an extensive multivariate parameter space.
2. Direct measurement of the gas dissipation timescale.
3. Study the evolutionary link between protoplanetary and debris discs.
4. Investigate the extent of warm water in planet-forming regions of discs.
5. Provide an extensive database of disc observations for future observations (ALMA, JWST, …).

GASPS project will observe nearby clusters (~250 pre-main-sequence stars) in the age range 1-30 Myr disc masse range of $10^{-5} – 10^{-2}$ M_{sun}

1st phase[CII] 157 micron, [OI] 63 micron, water 78 micron + photometry

2nd phase: [OI] 145 micron + extra water lines

First results: [OI] 63 micron, [CII] not detected



HerbigAe star (Meeus et al. 2010)

see poster Meeus et al. for more Herbig star disc obs.

'Classical' TTauri star (Thi et al. 2010)

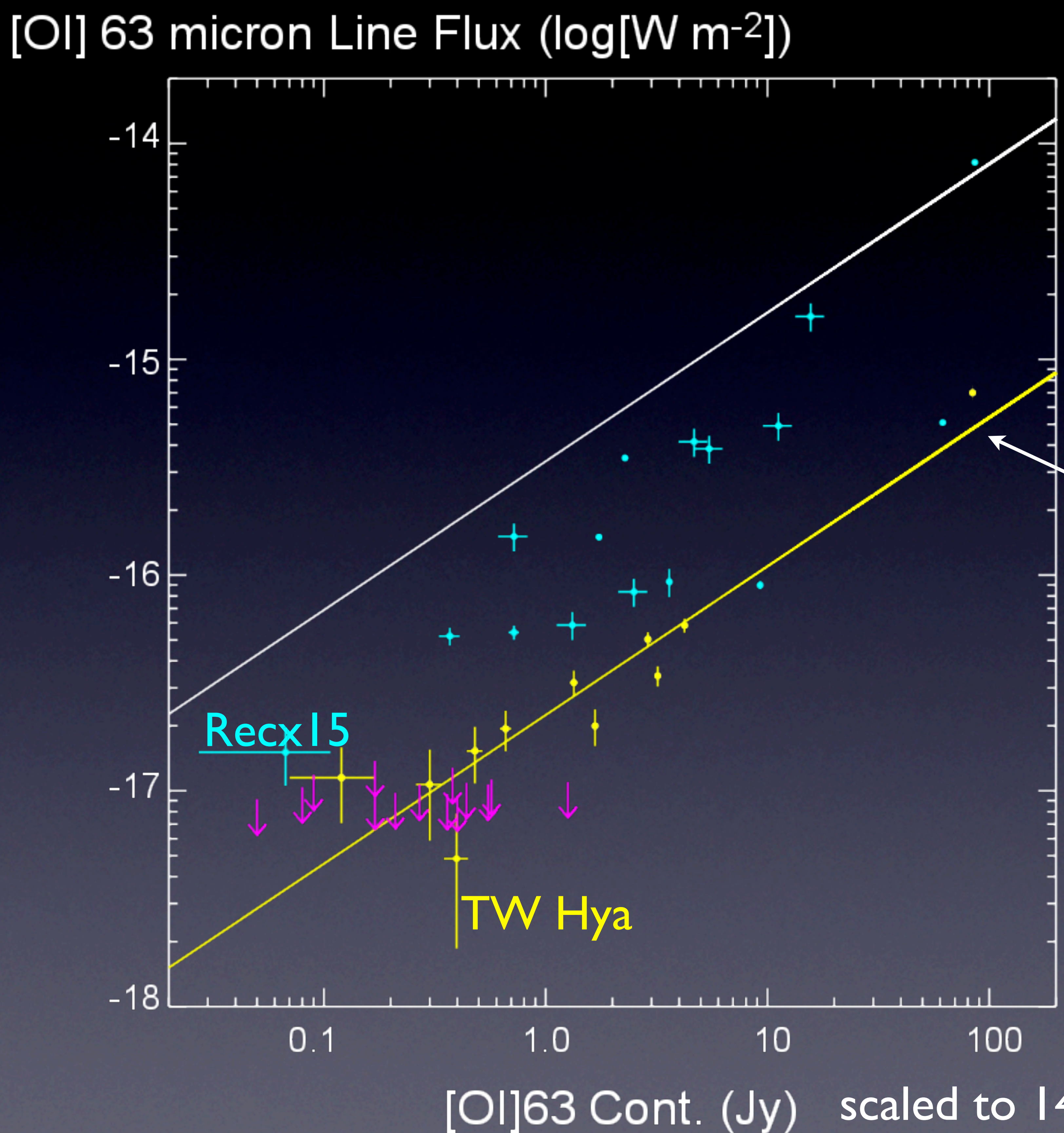
see poster (Kamp et al.)

TTauri star with a small compact disc (Woitke et al. 2011)

Debris disc (Lebreton et al., in prep.)

Mathews et al. 2010 A&A 518, L127, Pinte et al. 2010 A&A 518, L 126

TTauri stars: Disc, outflow, and envelope



scaled to 140 pc

● Sources with known jet and/ or outflow

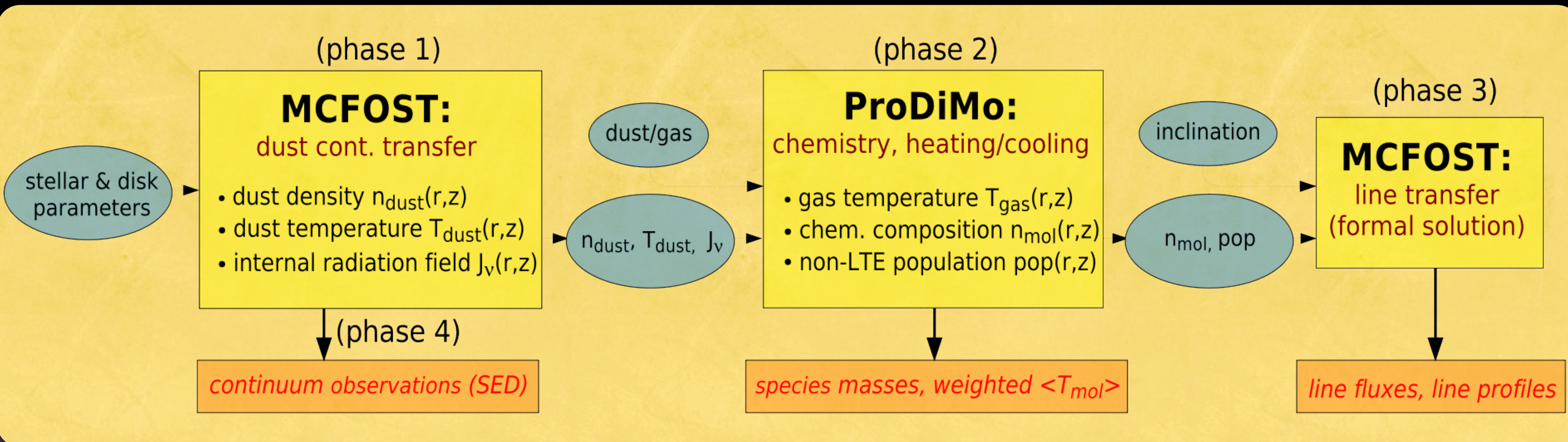
● Sources with disc only

Massive disc or envelope emission

Not the complete survey

Howard et al. in prep. see also Podio et al. poster

The DENT grid: 3D Monte-Carlo radiative transfer code MCFOST + gas code ProDiMo

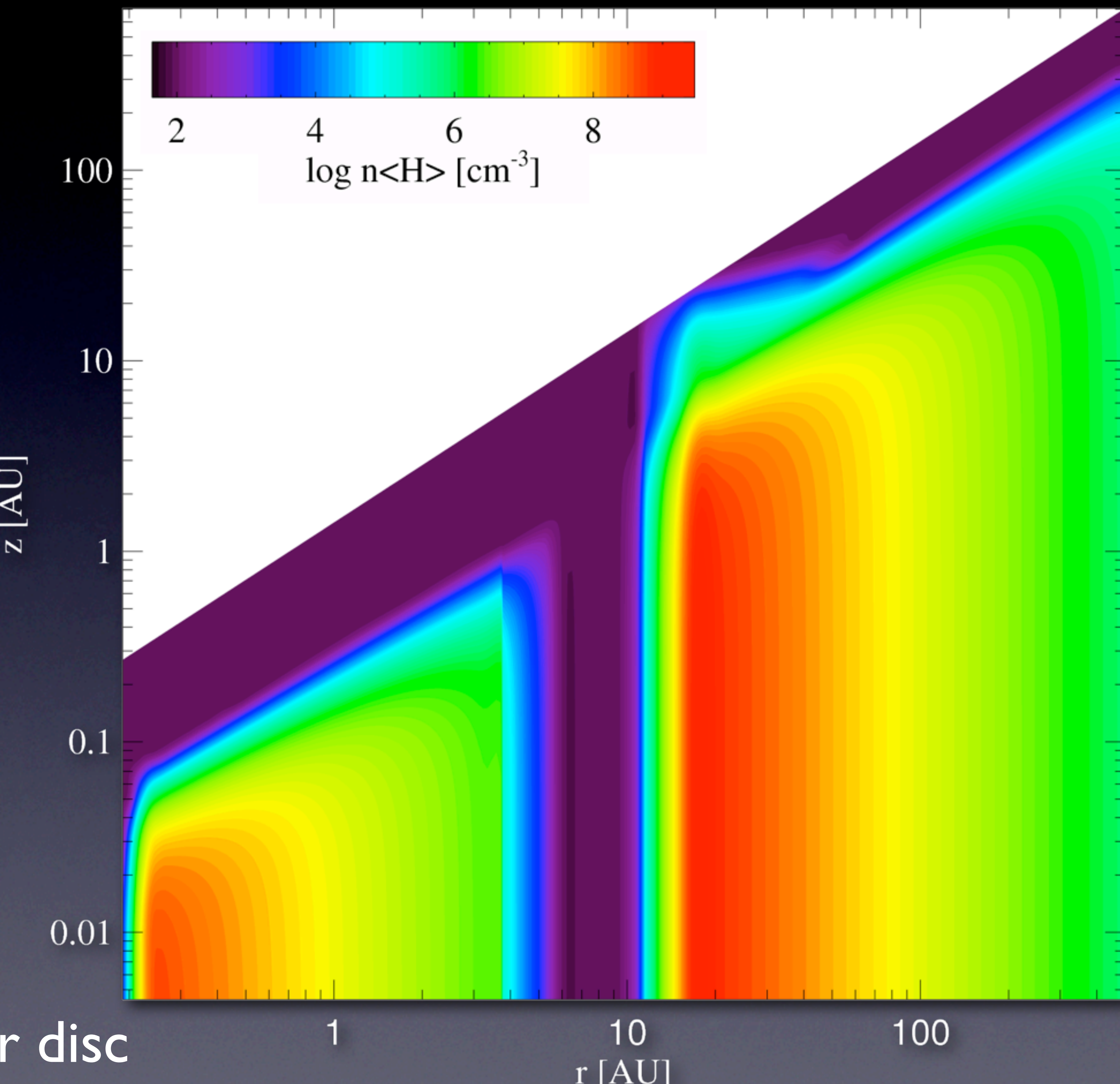


Grid of 300,000 models: 1st statistical theoretical study of gas and dust in protoplanetary discs (T_{eff}, M_{star}, M_{dust}, M_{gas}, R_{in}, R_{out},, flaring index, scale height H_0, a_{min}, a_{max}, settling)

Woitke et al. 2010 MNRAS 405, L26 and Kamp et al. (2011, arXiv 1103.5763K)

ProDiMo: Woitke et al. 2009a, 2009b; Kamp et al. 2009; Thi et al. 2010a, 2011, Aresu et al. 2011 (see poster Aresu et al., Chapparo et al.) MCFOST: Pinte et al. 2006 A&A 459, 797

Disc density structure



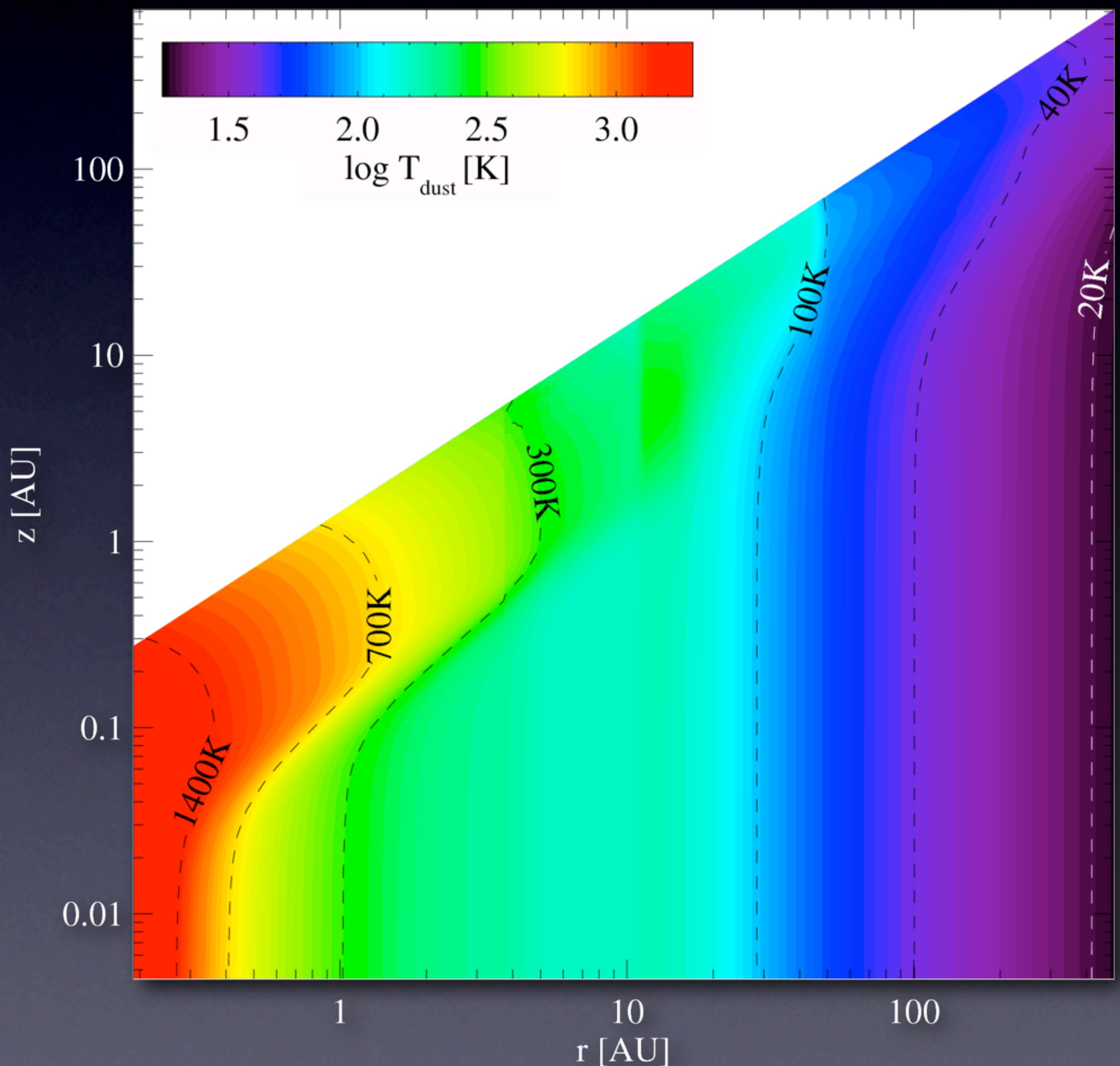
disc height

inner disc

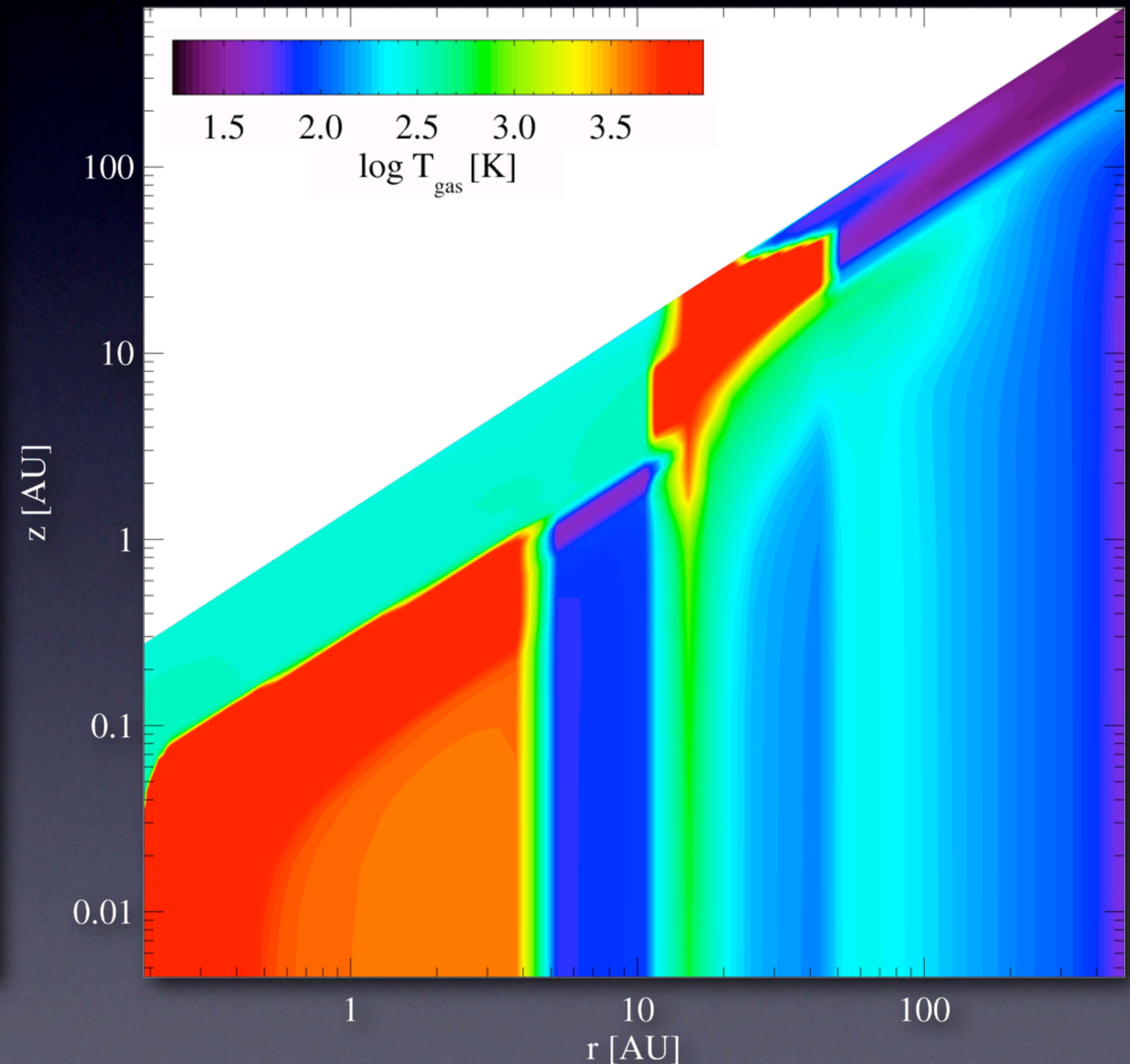
outer disc

Dust and gas temperature

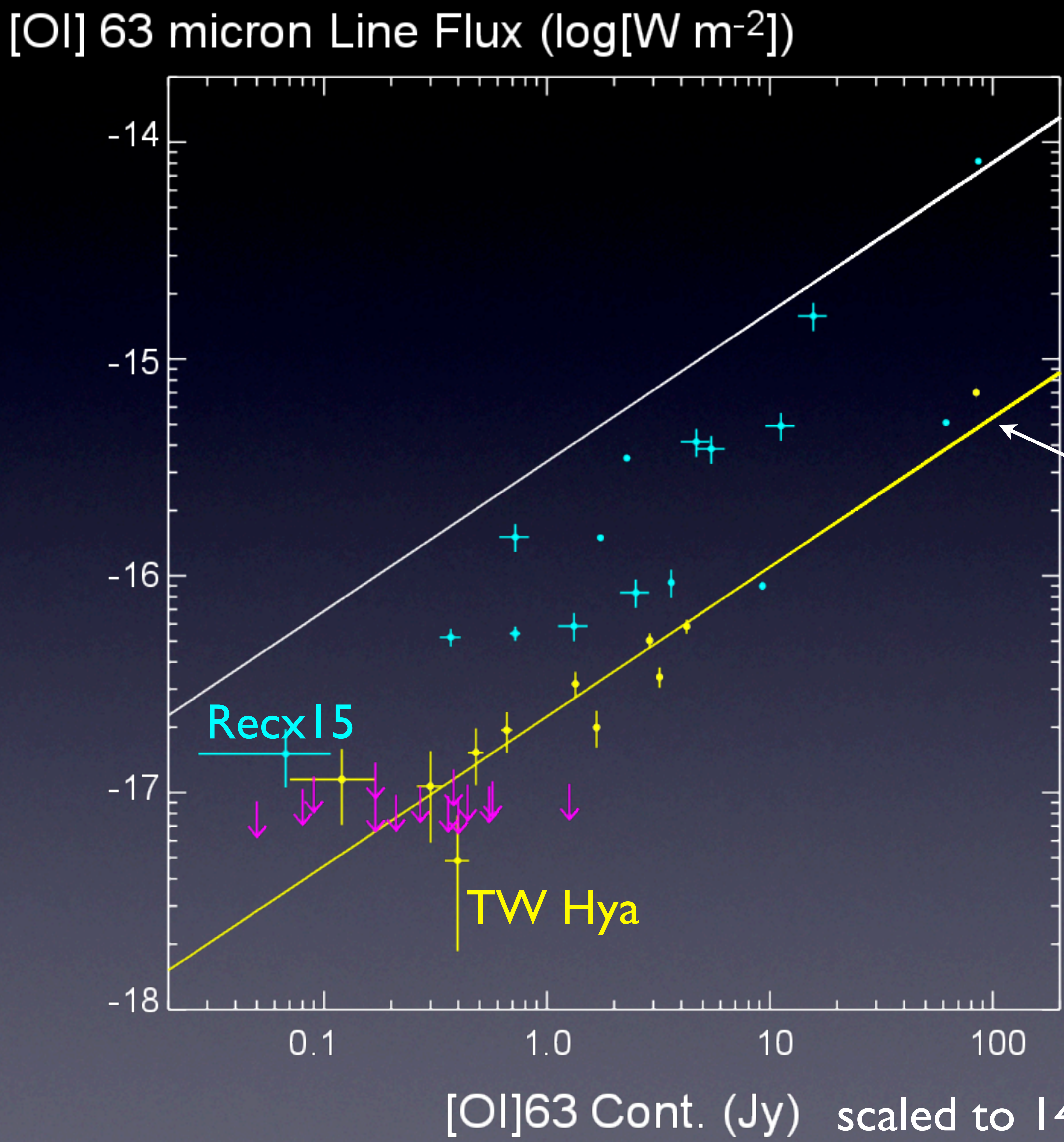
T_{dust}



T_{gas}



TTauri stars: Disc, outflow, and envelope



scaled to 140 pc

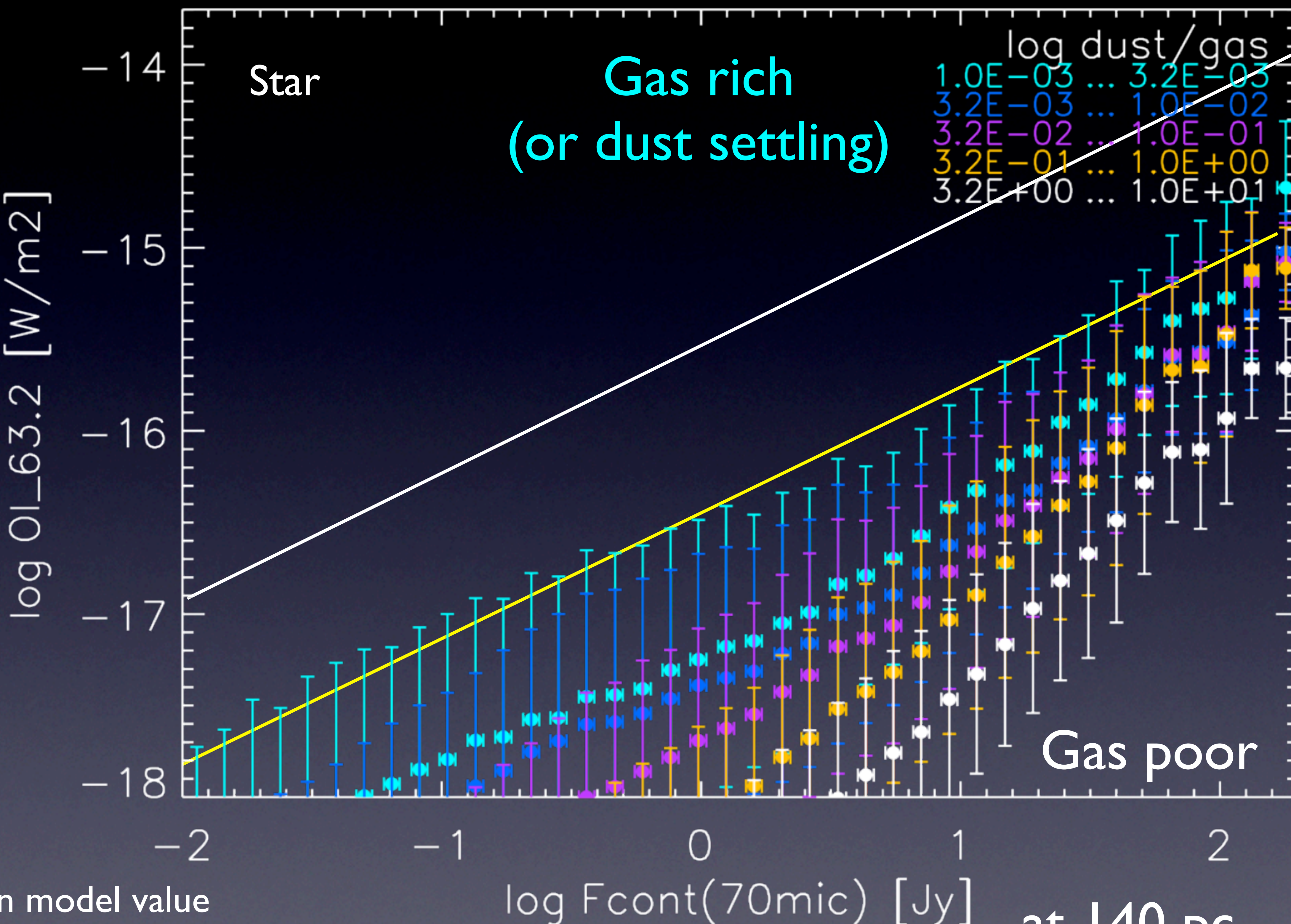
● Sources with known jet and/or outflow

● Sources with disc only

Massive disc or envelope emission

Howard et al. in prep.
see also Podio et al. poster

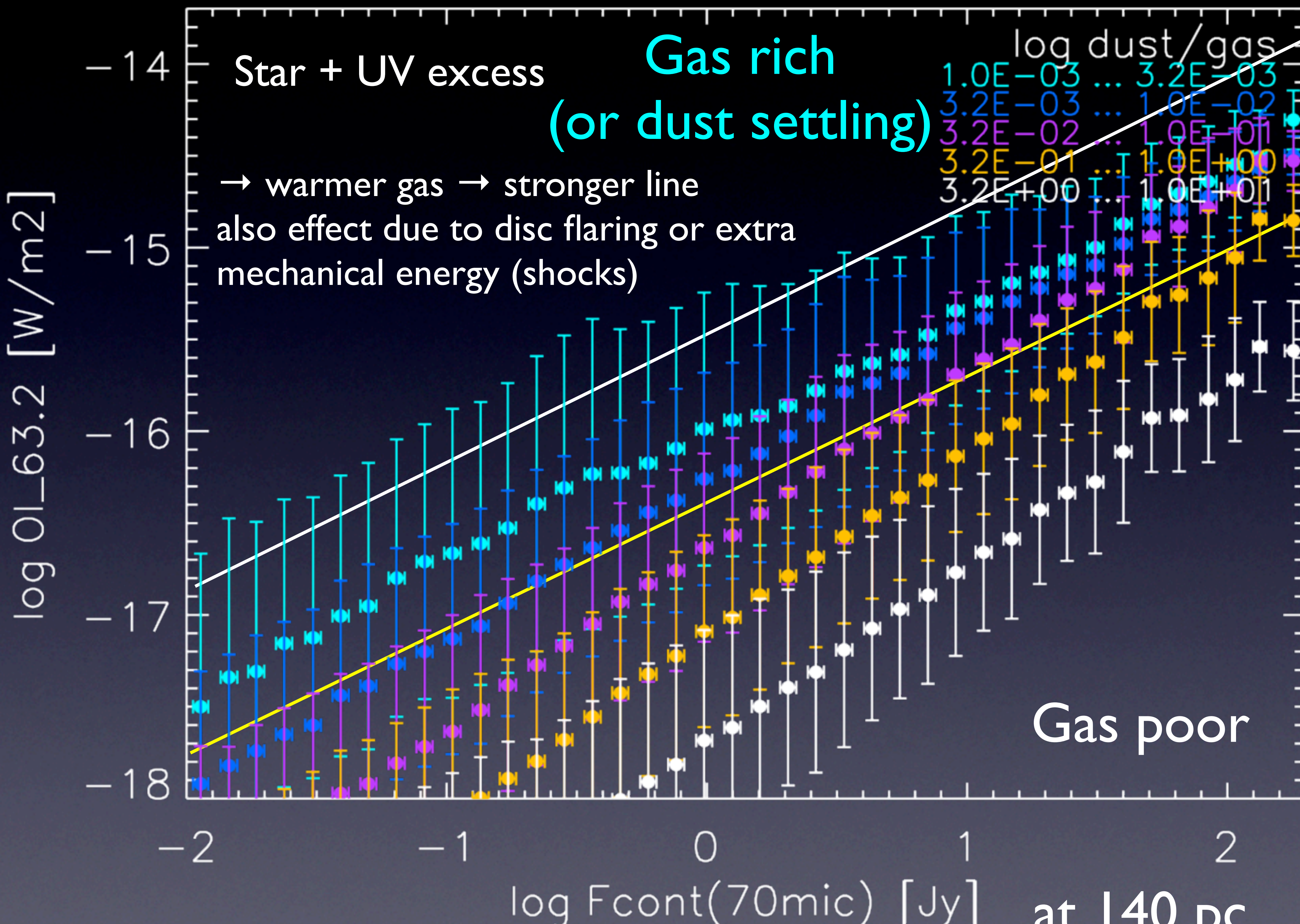
Preliminary statistical qualitative analysis



Median model value
+ dispersion

at 140 pc

Influence of the excess UV flux

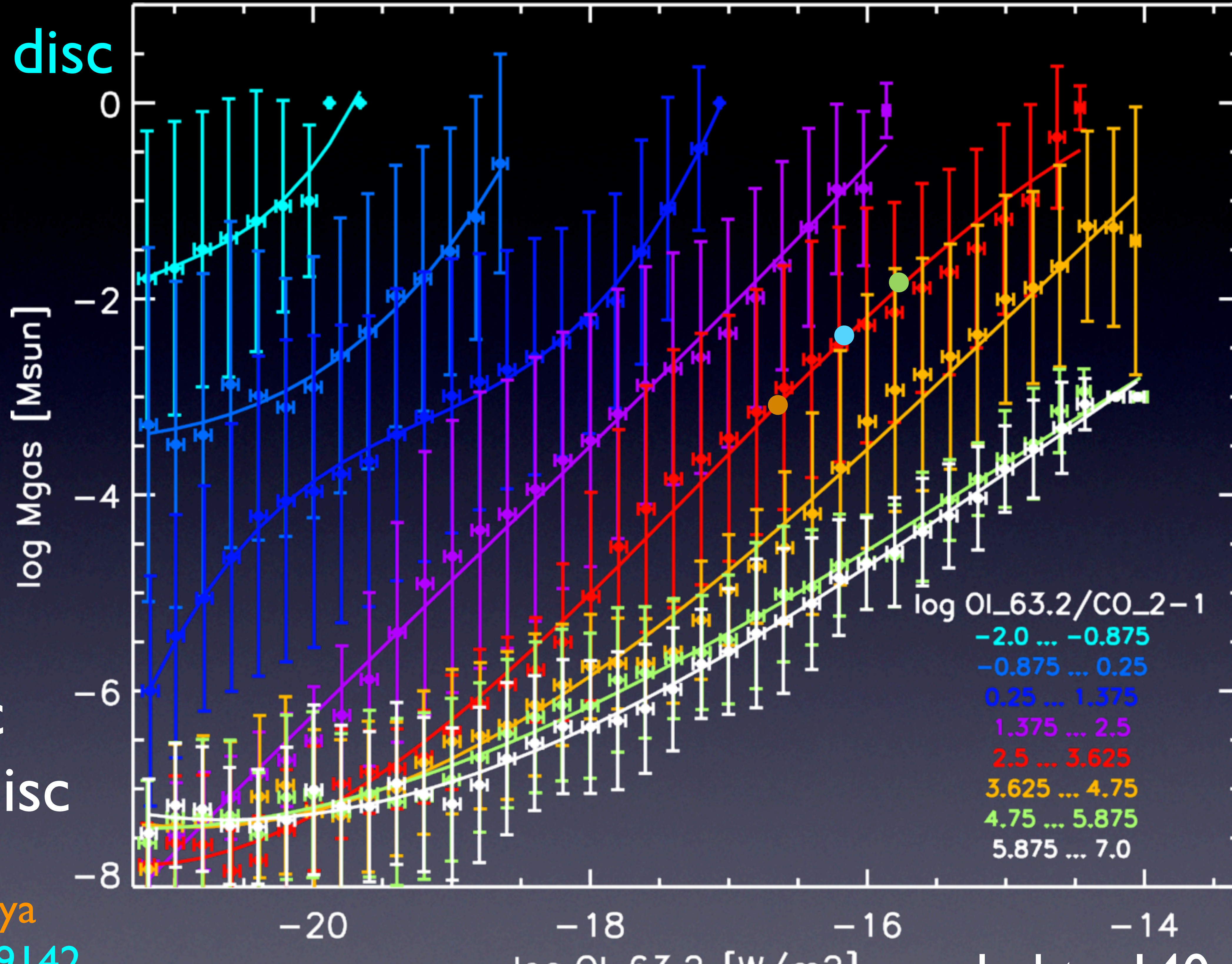


at 140 pc

outlow ↔ accretion → UV excess

Estimating the gas mass using the DENT grid

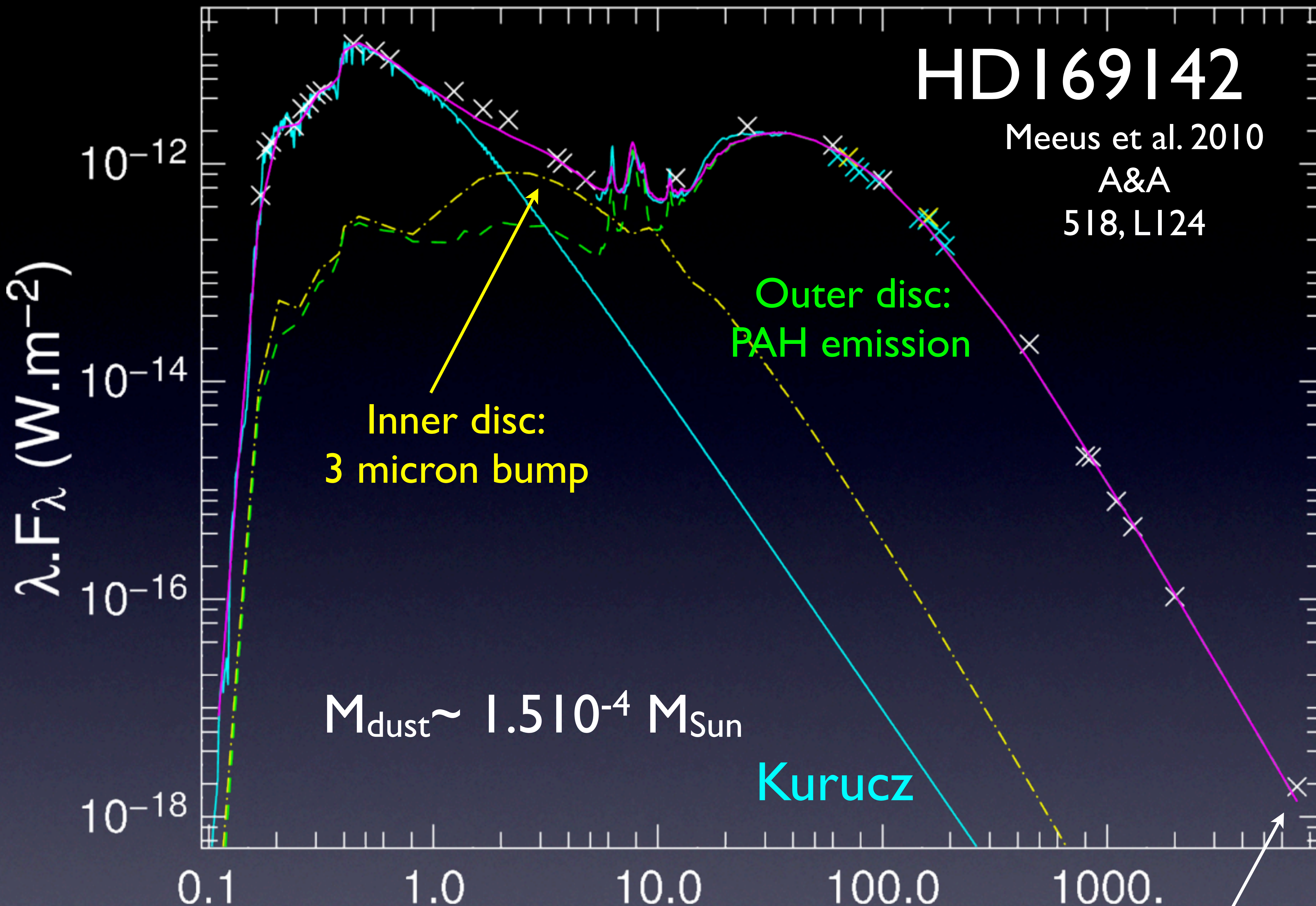
Molecular disc



Atomic (debris) disc

- TW Hya
- HD169142
- HD163296 (Tilling et al. submitted)

scaled to 140 pc



Simultaneous fit with MCFOST:

- SED including PAH features
- 1.1micron image (Grady et al. 2007) → gap
- 1.3 mm visibilities (Pañic et al. 2008)

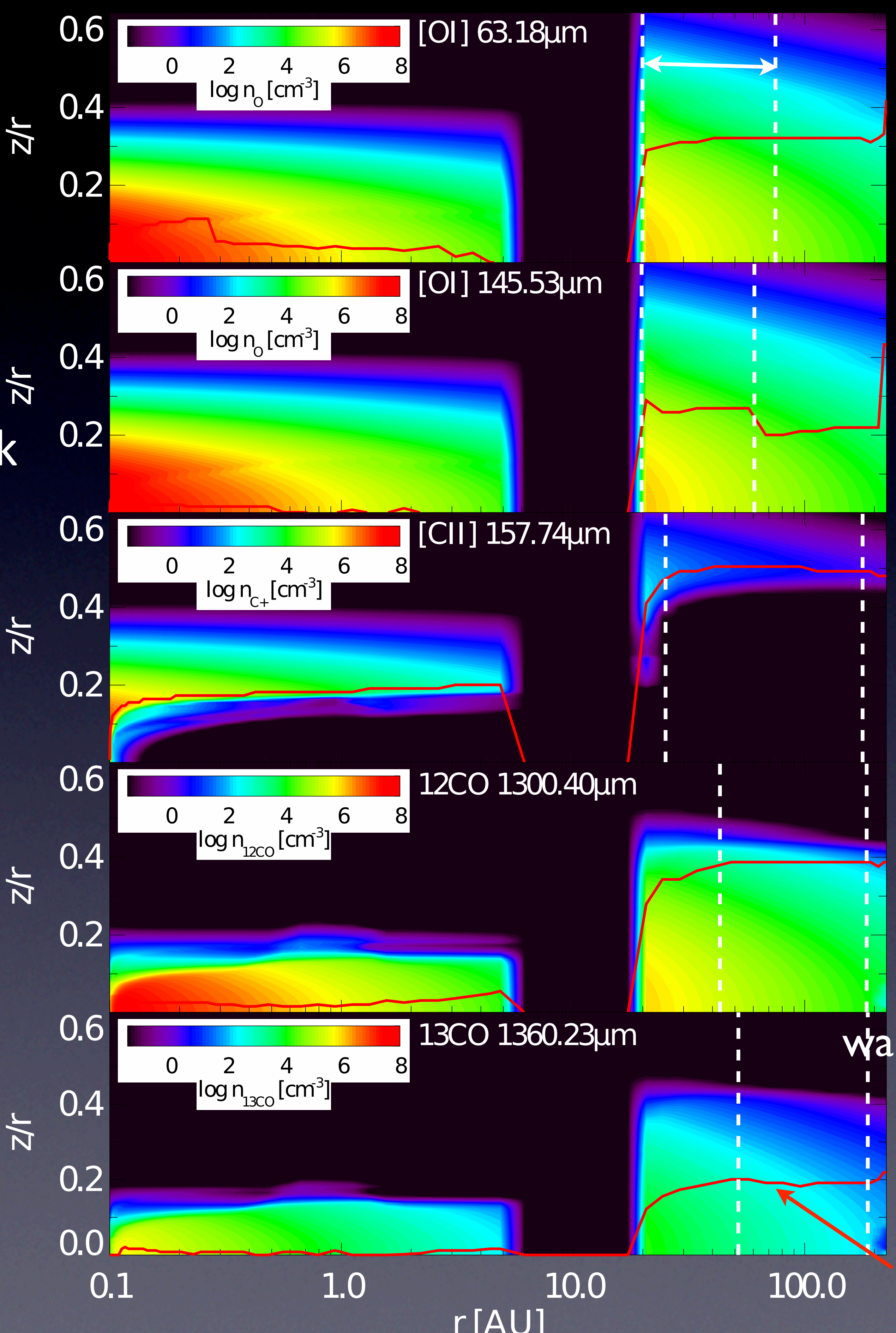
large grains emission
(+ free-free)

Different lines probe different disc regions

- **Dust modelling** (SED + images) to constrain the disk structure and dust properties
  → geometry, gap 5-20 AU
  → amount of PAHs: f_{PAH}=0.03
- **Input for gas modelling**
  → low UV excess
  → PAH = main gas heating source
  → gas dust ratio ≈ 20-50

M_{gas}~ (3-6.5)10^{-3} M_{Sun}

70% emission area



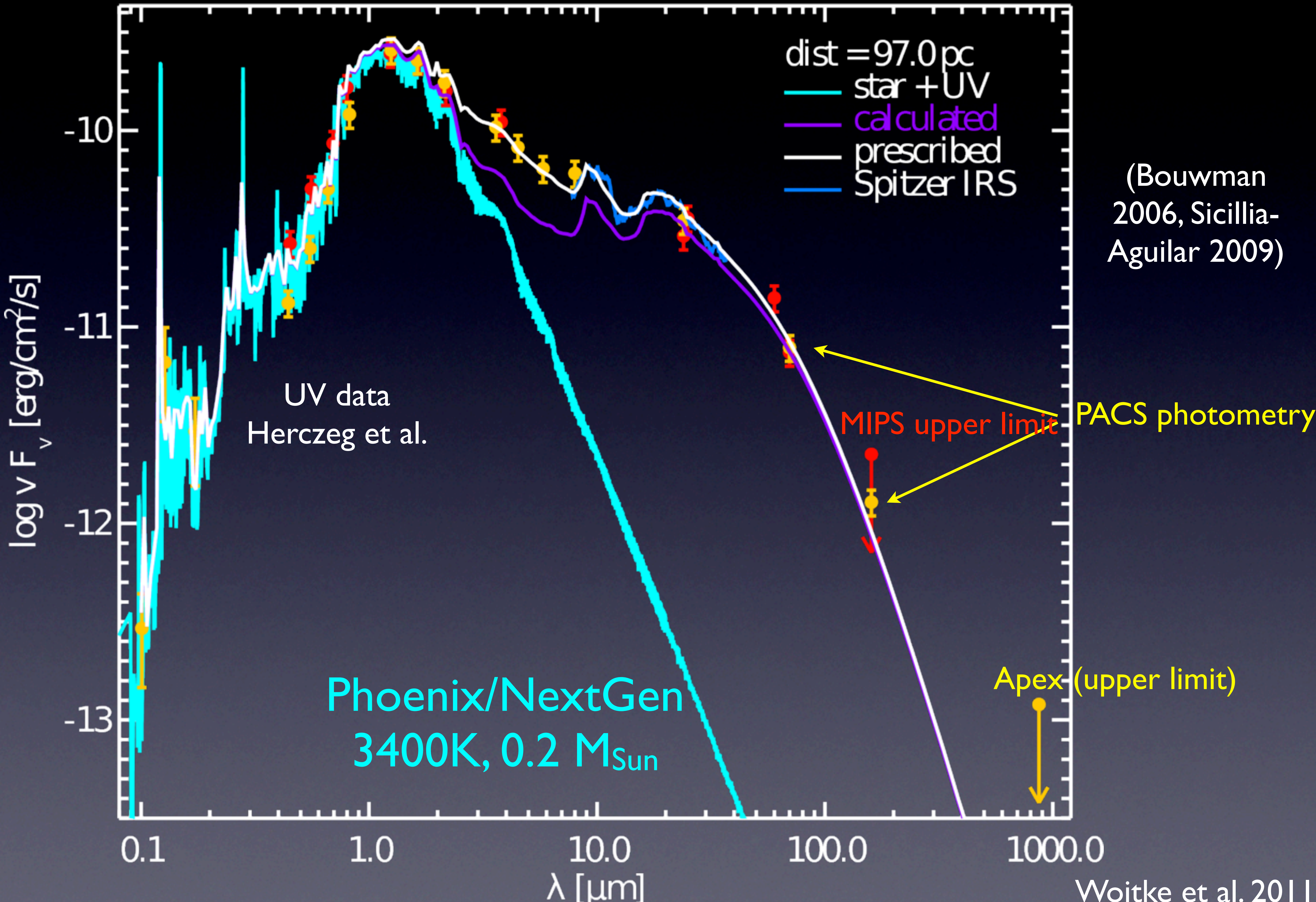
intermediate layer

atomic/ion surface

warm molecular layer

contour of highest emissivity

RECX15



(Bouwman 2006, Sicillia-Aguilar 2009)

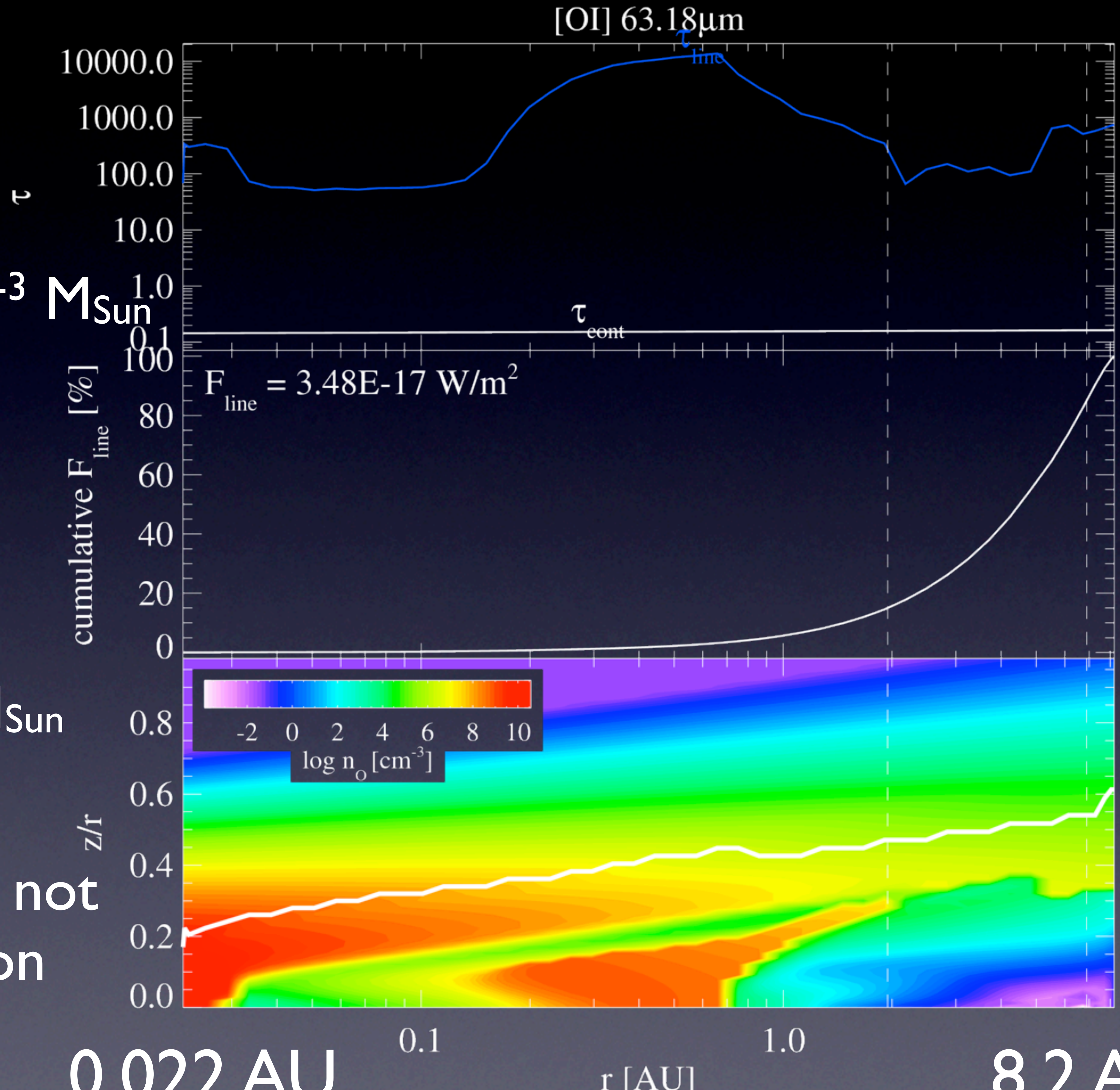
Woitke et al. 2011

Recx15: a compact gas-rich disc

$M_{gas} \sim 5\ 10^{-5} - 3\ 10^{-3}\ M_{Sun}$

$M_{dust} \sim (2\text{-}5)\ 10^{-8}\ M_{Sun}$

The most likely, but not the unique solution



0.022 AU

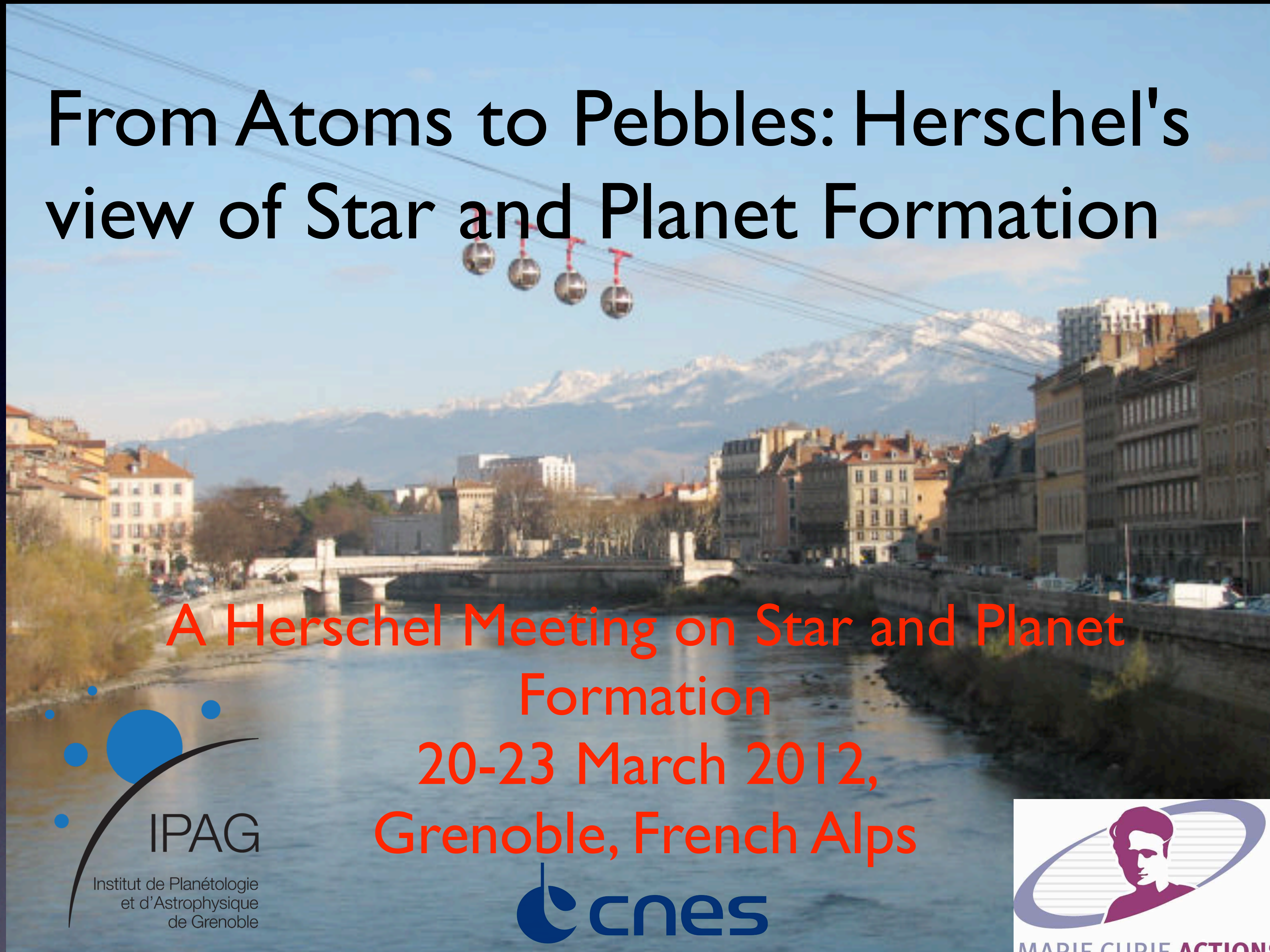
8.2 AU

Woitke et al. 2011

- GASPS-survey: 80% observations performed
- [OI] 63 micron is the strongest GASPS-line
- [CII] non-detection may be due to extended emission
- A statistical picture starts to emerge (see poster Meeus et al.)
- The DENT grid of models is valuable to understand the data
- The detailed modelling confirms the dust and gas mass estimates from the grid:
  - variety of gas and dust masses from gas-rich discs (RECX 15 gas-to-dust>100) to gas-poor discs (TW Hya gas-to-dust<10)
  - we are also modelling the molecular emissions (CH^+), H_2O (see poster Kamp et al.)
  - other sources modelled individually (papers submitted or in preparation): HD181327 (Lebreton et al.), HD163296 (Tilling et al.), HD141569A(Thi et al.), 49Cet (Roberge et al.), HD135344 (Martin-Zaïdi et al.), GGTau (Duchêne et al.), HD9672 (Meeus et al.), ABAur, 51Oph, FT Tau, IRAS04158+2805 (Pinte et al.), LKCa15, GM Aur, ...

GASPS/ProDiMo-related posters

- Kamp et al. "The disk around TW Hya water and signs of evolution" (see also the talk by Hogerheijde on water in TWHya)
- Meeus et al. "Herschel's view on the gas in Herbig Ae/Be stars"
- Podio et al. "Herschel/PACS observations of young sources in Taurus: the far-infrared counterparts of optical jets"
- Aresu et al. "X-rays in protoplanetary disks: their impact on the thermal and chemical structure, a grid of models"
- Chaparro et al. "The role of OH in the chemical evolution of protoplanetary disks"
- Lahuis et al. "Epic changes in the IRS 46 mid-infrared spectrum, an inner disk chemistry study
- Thi et al. poster on CH^+ in the disc around HD100546



Contact: augereau@obs.ujf-grenoble.fr

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MARIE CURIE ACTIONS

Summary of Clusters and associations in GASPS

Group	Distance (pc)	Age (Myr)	Disk fraction (total)	GASPS targets	Notes
Taurus	140	0.3-4	90%	106	Class I-III T Tauri stars
Upper Sco	145	5	20%	44	Class II-III T Tauri stars
η Cha	97	5-9	56%	17	T Tauri and debris disks
TWHya	~50	8-10	≥30%	13	T Tauri and debris disks
βPic	10-50	10-20	≥ 37%	18	Debris disks
Tuc Hor	40-50	30	≥26%	16	Debris disks
HAeBe stars	50-200	~0.5-30	100%	24	

↑ from continuum studies

Dust modelling of HD169142: constraining the disc structure

Parameter	Inner Disc	Outer Disc
r_{in} (AU)	0.1	20
r_{out} (AU)	5	235
surface dens. exp o	–1.0	–1.0
flaring exponent β	1.05	1.00
ref. scale height h_0	0.07 AU @ 1 AU	12.5 AU @ 100 AU
M_{dust} (M_o)	2×10^{-9}	1.5×10^{-4}
f_{PAH}	0	0.03 (3% ISM value)

1. tenuous inner disc
2. gap between 5 and 20 AU (sign of a planet?)
3. small amount of PAH (f_{PAH}=1 means abundance of 3 10^{-7})

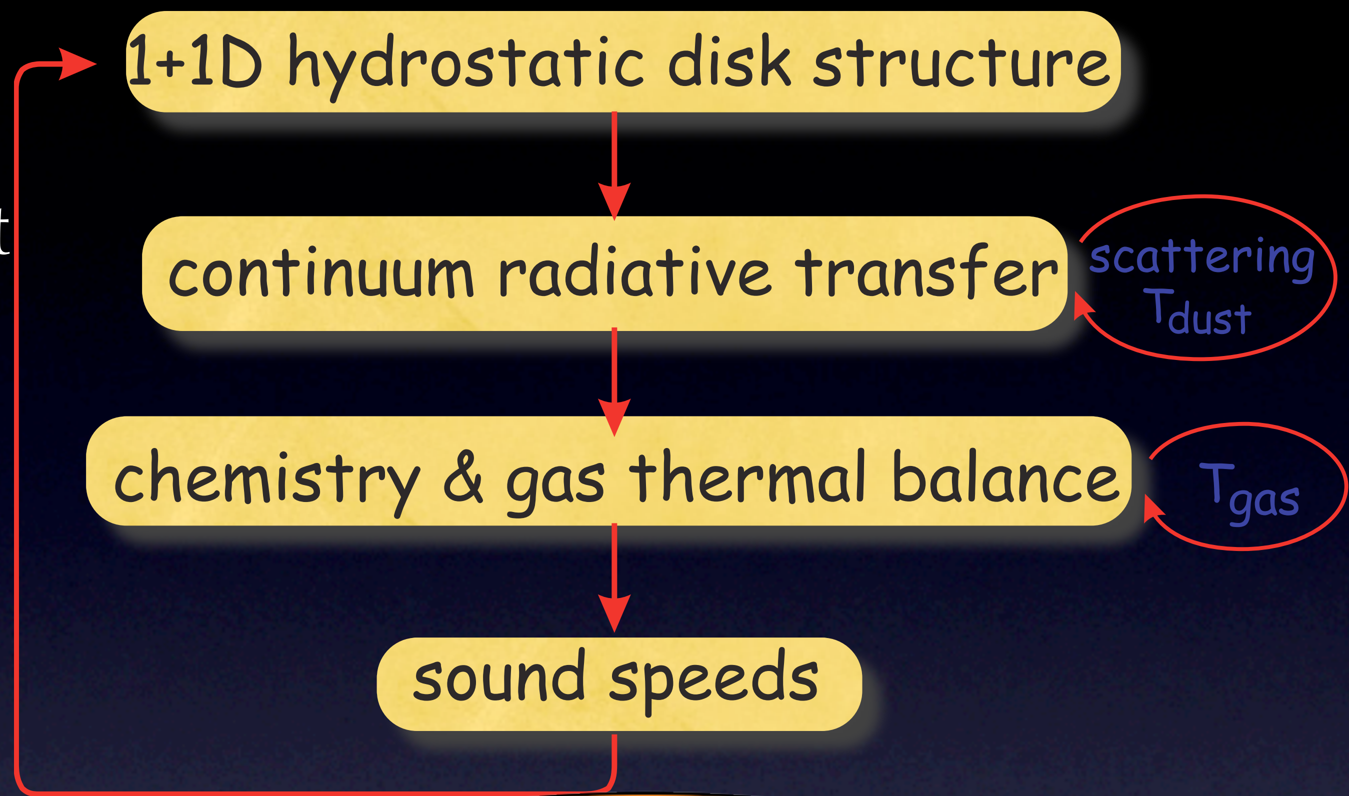
Modelling the gas in discs with ProDiMo

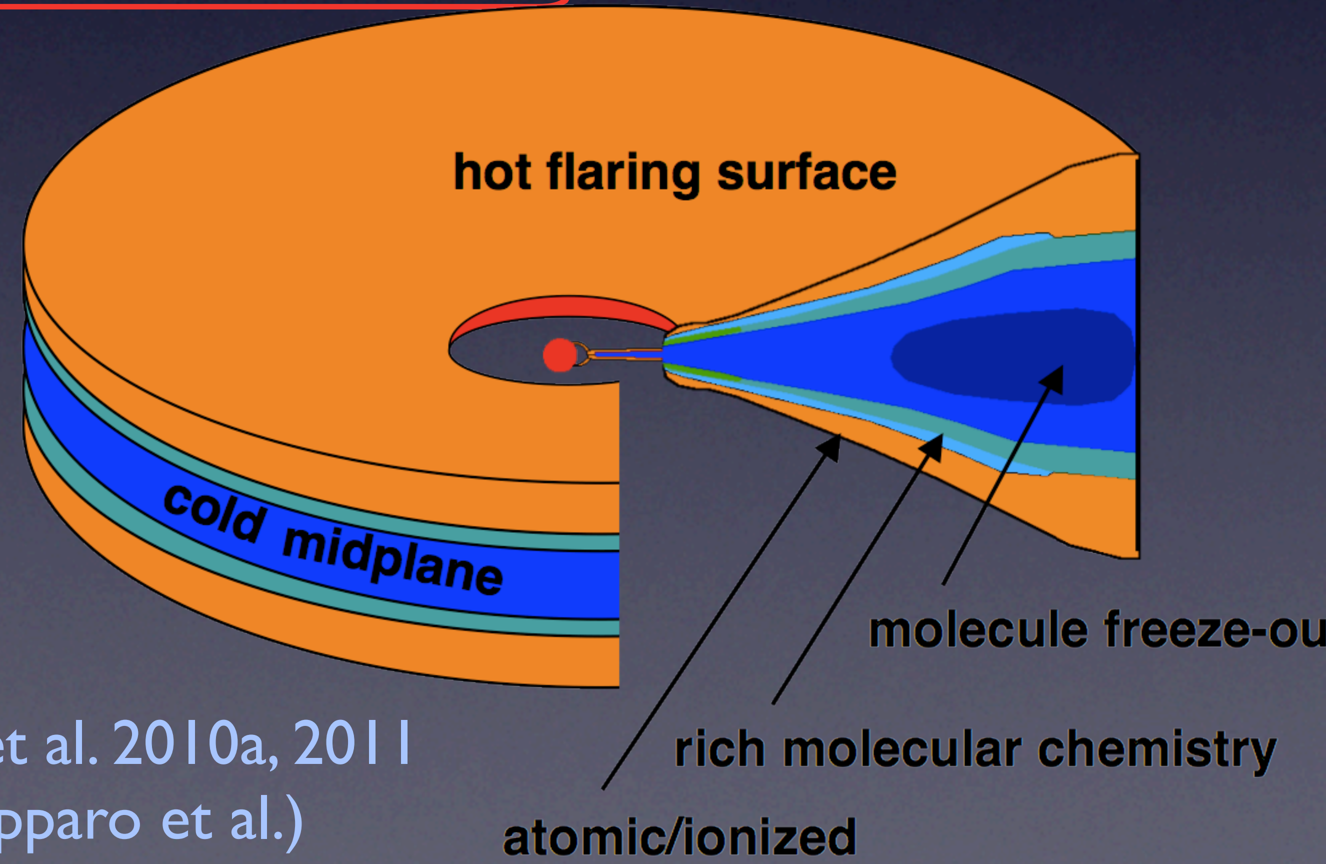
1. 2D dust radiative transfer: grain thermal balance (can also take input from MCFOST or GRaTer)

2. 1+1D for the gas cooling using escape probability (checked against 3D Monte-Carlo): atomic and ro-vibrational cooling lines

3. Over 71 gas and solid species (including deuteratred species) steady-state+time-dependent. Xray and UV chemistry

4. Hydrostatic equilibirum





Woitke et al. 2009a, 2009b; Kamp et al. 2009; Thi et al. 2010a, 2011
Aresu et al. 2011 (see poster Aresu et al., Chapparo et al.)

RECX15: compact hot gas only seen in [OI] and H_2

line	λ [µm]	observed (10^{-18} W m^{-2})	model (10^{-18} W m^{-2})
[OI] $^3P_1 \rightarrow {}^3P_2$	63.18	30.5 ± 3.2	34.5
[OI] $^3P_0 \rightarrow {}^3P_1$	145.52	< 6.0	2.6
[OI] $^1D_2 \rightarrow {}^3P_2$ (HVC)	0.6300	73 ± 25	–
[OI] $^1D_2 \rightarrow {}^3P_2$ (LVC)	0.6300	65 ± 25	69.6
[CII] $^2P_{3/2} \rightarrow {}^2P_{1/2}$	157.74	< 9.0	0.11
CO $J = 3 \rightarrow 2$	866.96	< 0.05	0.014
CO $J = 29 \rightarrow 28$	90.16	< 9.6	4.9
CO $J = 33 \rightarrow 32$	79.36	< 24	3.3
CO $J = 36 \rightarrow 35$	72.84	< 8.0	2.6
o-H_2 v=1→0 S(1)	2.122	2.5 ± 0.1	2.4
o-H_2O $2_{21} \rightarrow 2_{12}$	180.49	< 5.2	1.1
o-H_2O $2_{12} \rightarrow 1_{01}$	179.53	< 5.0	1.4
o-H_2O $4_{32} \rightarrow 3_{12}$	78.74	< 30	11.1
p-H_2O $3_{22} \rightarrow 2_{11}$	89.99	< 9.6	

[OI] detected in the optical and Far-IR

← atomic jet emission

← disc emission

← CO J=3-2 non-detection by Apex

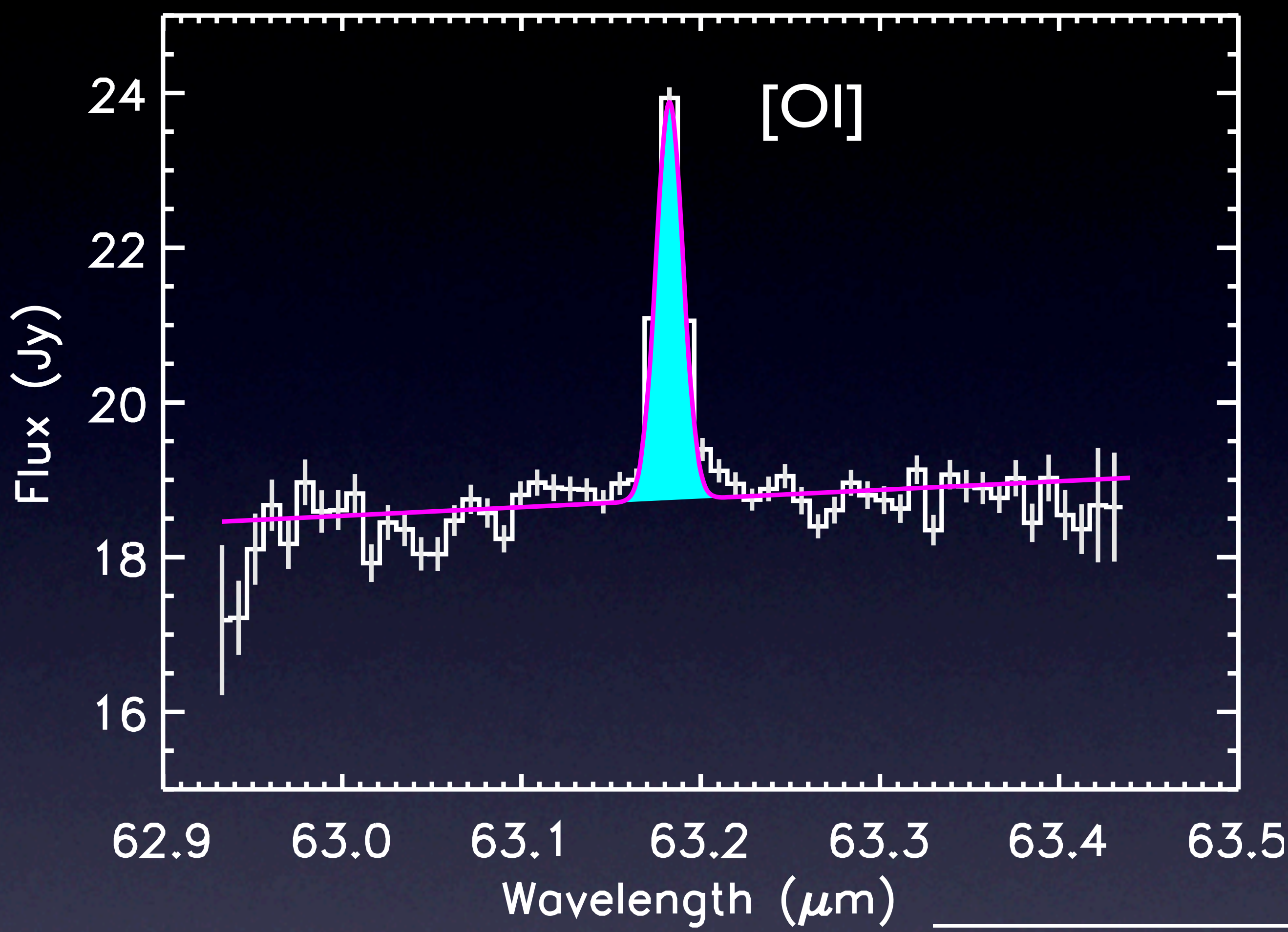
Caution: not unique solution

Woitke et al. 2011

H_2 modelling

- H_2 formation: Jura, Cazaux & Tielens
- H_2 formation pumping
- H_2 fluorescence and self-shielding: simple analytical formula or 1+1D NLTE radiative transfer
- most recent H_2 collision rates with H^+, e, H, He, H_2

Gas modelling HD169142 with ProDiMo



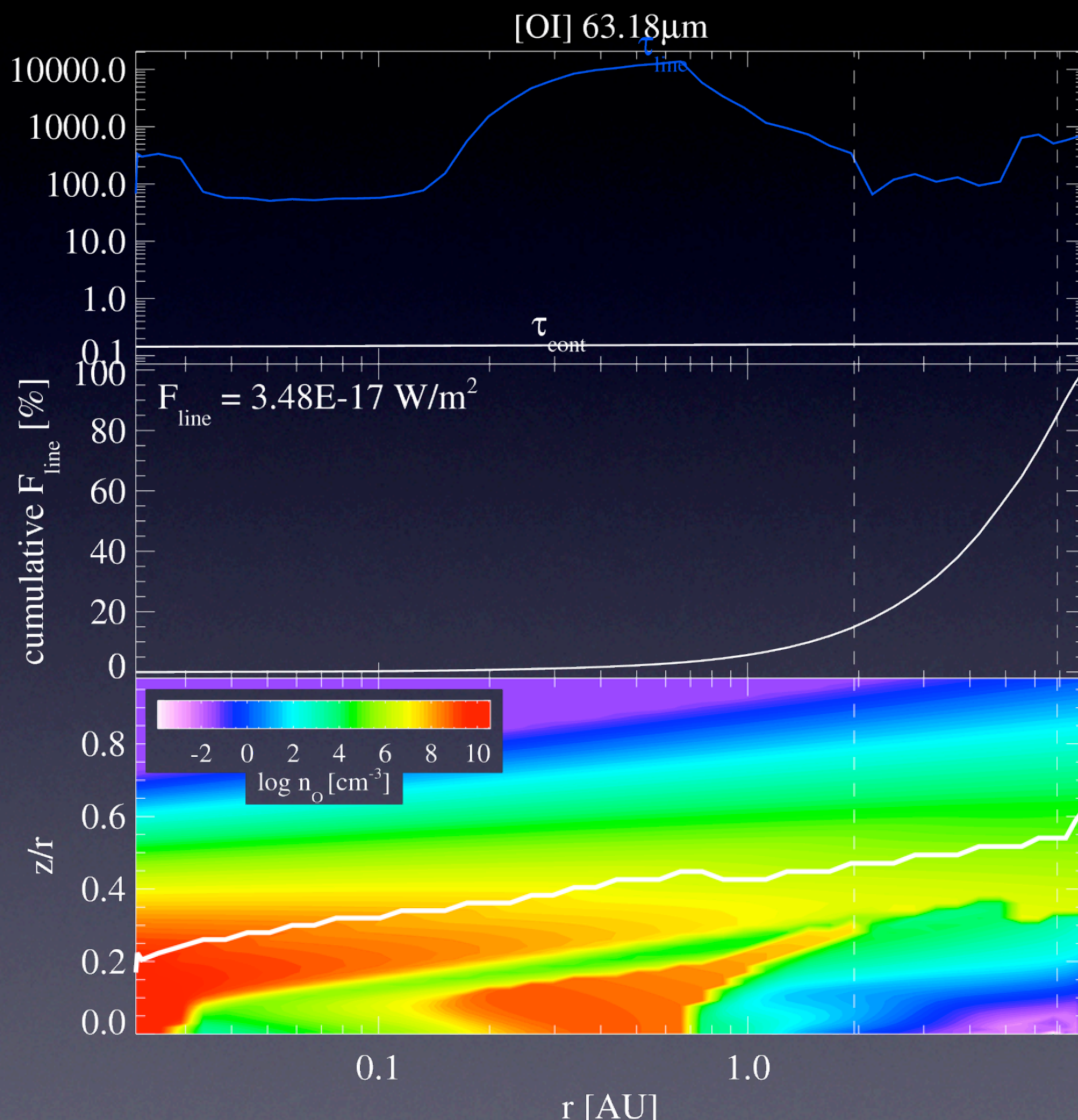
	Model 1	Model 2	Model 3	Observed
gas/dust	1	10	33	–
f_{PAH}	0.01	0.0055	0.0087	–
f_{UV}	0.005	0.0	0.0	–

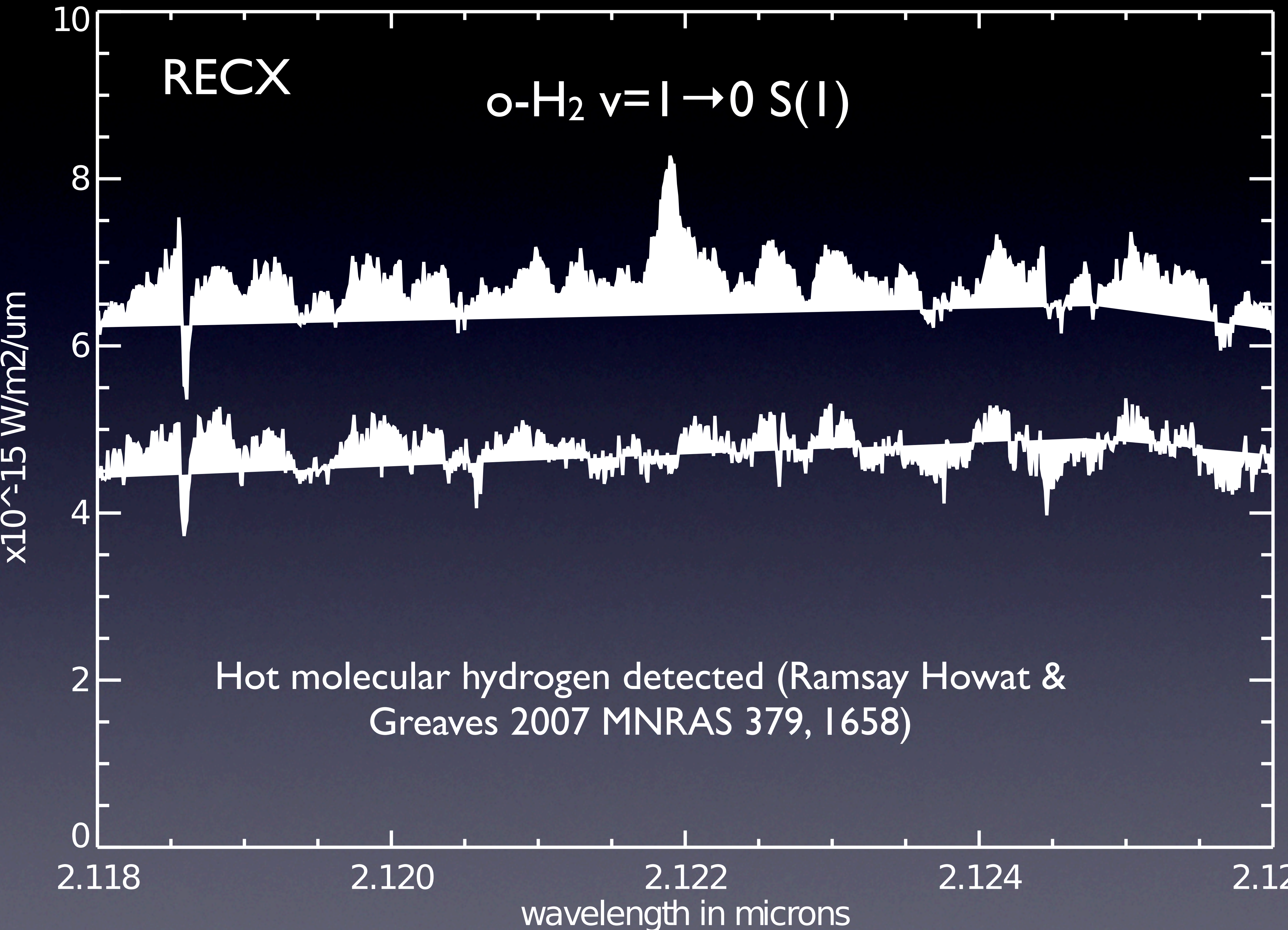
Line	Line Fluxes [10^{-18} W/m^2]			
[OI] 63.2 μm	154	71.6	71.6	71.7
[OI] 145.5 μm	5.17	10.1	7.01	<10.4
[CII] 157.7 μm	4.58	0.04	0.06	<6.4
o-H_2O 179.5 μm	5.66	5.15	1.76	<8.8
^{12}CO 2 → 1	0.060	0.092	0.093	0.093
^{13}CO 2 → 1	0.011	0.059	0.048	0.048
$^{12}CO/^{13}CO$	5.69	1.55	1.92	1.94

Parameter	Inner Disc	Outer Disc
r_{in} (AU)	0.1	20
r_{out} (AU)	5	235
surface dens. exp o	–1.0	–1.0
flaring exponent β	1.05	1.00
ref. scale height h_0	0.07 AU @ 1 AU	12.5 AU @ 100 AU
M_{dust} ($M_\odot$)	2×10^{-9}	1.5×10^{-4}
f_{PAH}	0	0.03

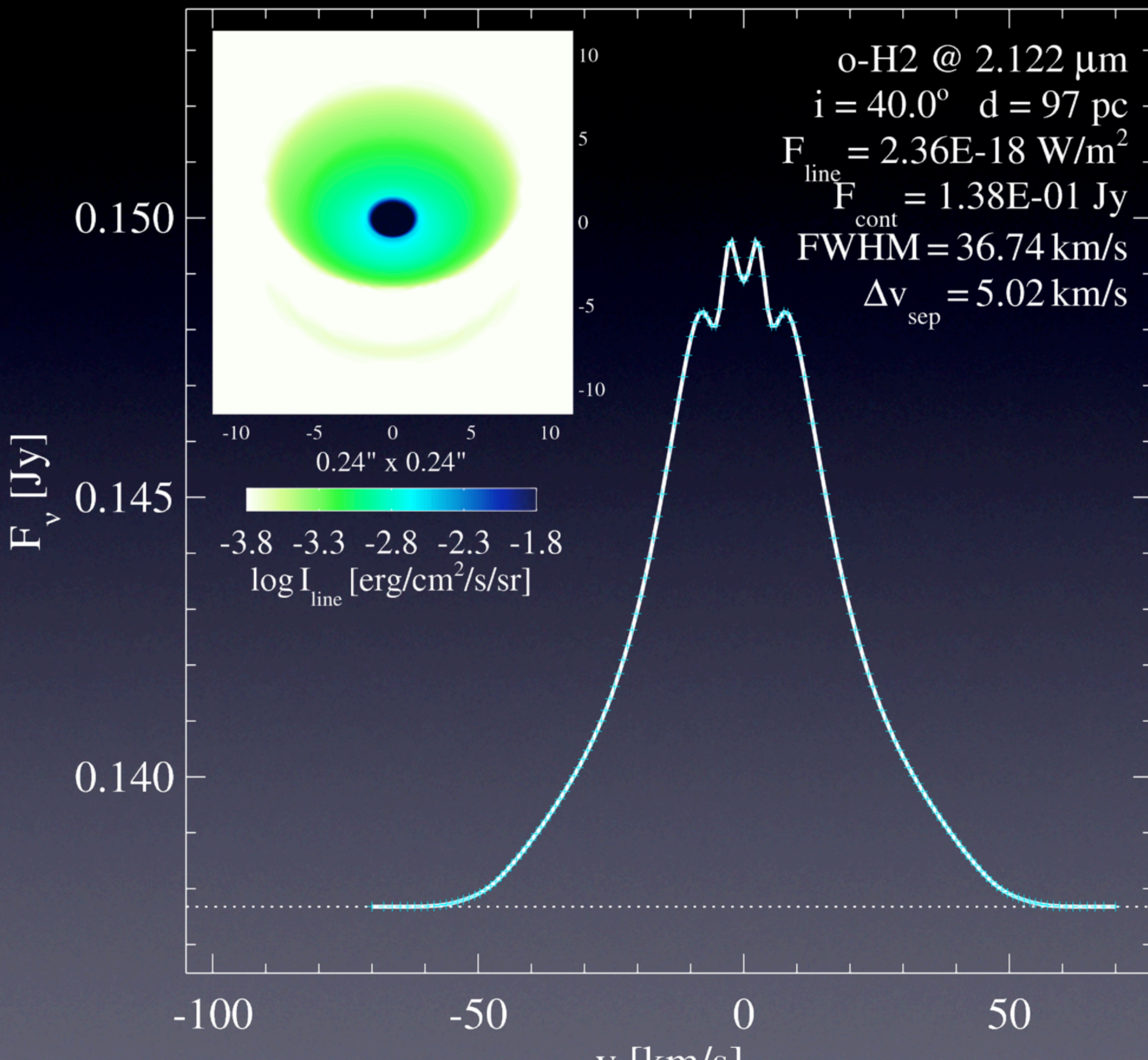
Recx15: a compact gas-rich disc

quantity	symbol	value
stellar mass	$M_\star$	$0.2\,M_\odot$
effective temperature	$T_{\rm eff}$	3400 K
stellar luminosity	$L_\star$	$0.085\,L_\odot$
disk gas mass*	$M_{\rm gas}$	$6.1\times10^{-4}\,M_\odot$
inner disk radius	$R_{\rm in}$	0.022 AU
outer disk radius*	$R_{\rm out}$	8.2 AU
column density power index*	ϵ	-0.020
reference scale height*	H_0	0.011 AU
reference radius	r_0	0.1 AU
flaring power index*	β	1.09
disk dust mass*	$M_{\rm dust}$	$2.6\times10^{-8}\,M_\odot$
minimum dust particle radius	$a_{\rm min}$	0.05 µm
maximum dust particle radius	$a_{\rm max}$	1 mm
dust size dist. power index	p	4.1
minimum settling particle size	a_s	0
dust settling power index	s	0
dust material mass density	$\rho_{\rm gr}$	$3\,{\rm g\,cm^{-3}}$
dust composition	Mg_2SiO_4	32.9%
(volume fractions)	amorph. carbon	24.4%
	$MgFeSiO_4$	23.0%
	SiO_2	8.8%
	$MgSiO_3$	7.6%
	cryst. silicate	3.3%
strength of incident ISM UV	$\chi^{\rm ISM}$	1
cosmic ray H_2 ionisation rate	$\zeta_{\rm CR}$	$5\times10^{-17}\,{\rm s^{-1}}$
PAH abundance rel. to ISM*	$f_{\rm PAH}$	0.081
chemical heating efficiency*	$\gamma^{\rm chem}$	0.55
α viscosity parameter	α	0
disk inclination	i	40°
distance	d	97 pc



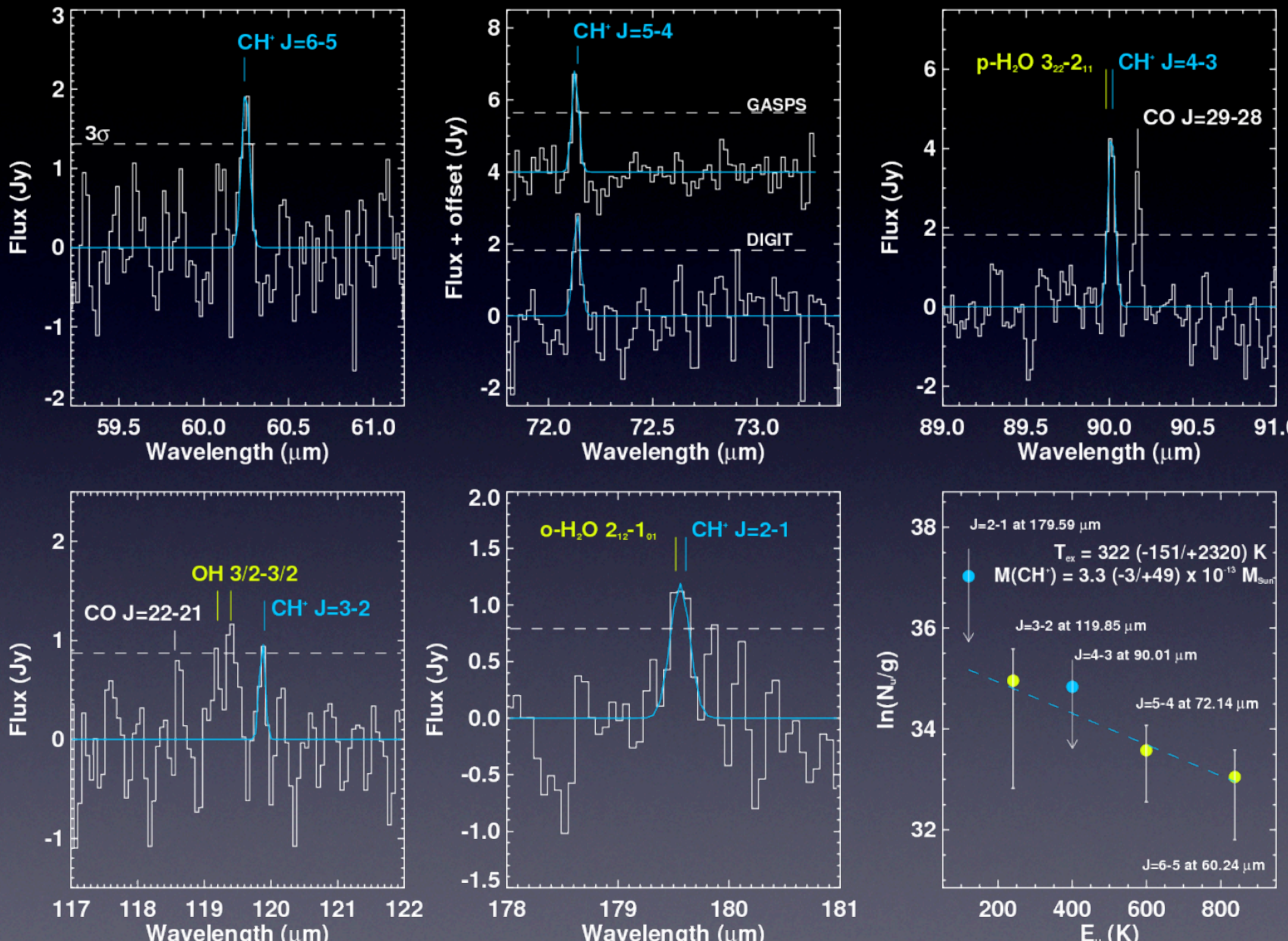

RECX
o-H2 v=1→0 S(1)
x10^-15 W/m2/um
10
8
6
4
2
0
2.118
2.120
2.122
2.124
2.126
wavelength in microns
Hot molecular hydrogen detected (Ramsay Howat & Greaves 2007 MNRAS 379, 1658)

H_2 modelled by ProDiMo



H_2 levels:
rovibrational+
electronic

CH^+ in HD100546: Herschel-PACS



Thi et al. 2011 A&A 530, L2 continuum subtracted archival data (Sturm et al. 2010 A&A 518 L129)