Evolution of Gas and Dust in Planet-Forming Discs: results from the Herschel observations

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DiscAnalysis DIANA
SEVENTH FRAMEWORK PROGRAMME

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GASPS-related talks: Linda Podio & Jessica Donalson

GAS in *P*rotoplanetary *S*ystems

Herschel Open time large program 400 hrs P.I. Dent (2013, PASP 125, 477)
http://www.laeff.inta.es/projects/herschel/

Aim of the project:

1. Trace gas and dust in the planet formation region across an extensive multivariate parameter space.
2. First direct measurement of the warm 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 observed 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 63.3 & 78 micron + photometry

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

Protoplanetary discs gas emissions

Every wavelength range and line probes a different part of the disc.
Gas lines are much more difficult to detect than continuum emission.

The [OI] 63 micron line probes
the 1-100 AU disc region

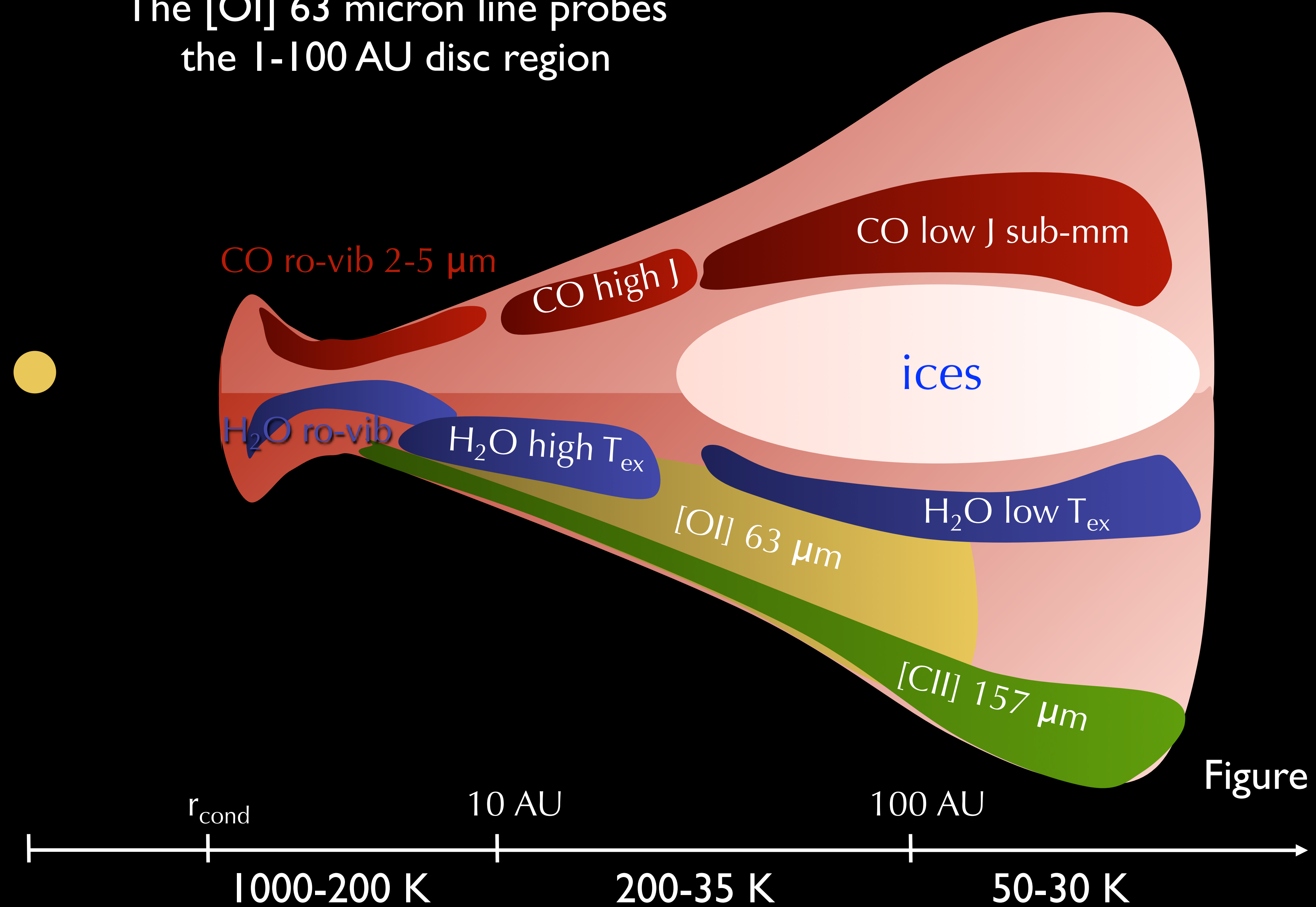


Figure courtesy Inga Kamp

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	

+ Cham II 2 Myrs (PI J Williams)

from continuum studies

Dent et al. 2013, PASP 125, 477

Detection statistics

PACS line spectroscopy: lines are unresolved spatially and spectrally

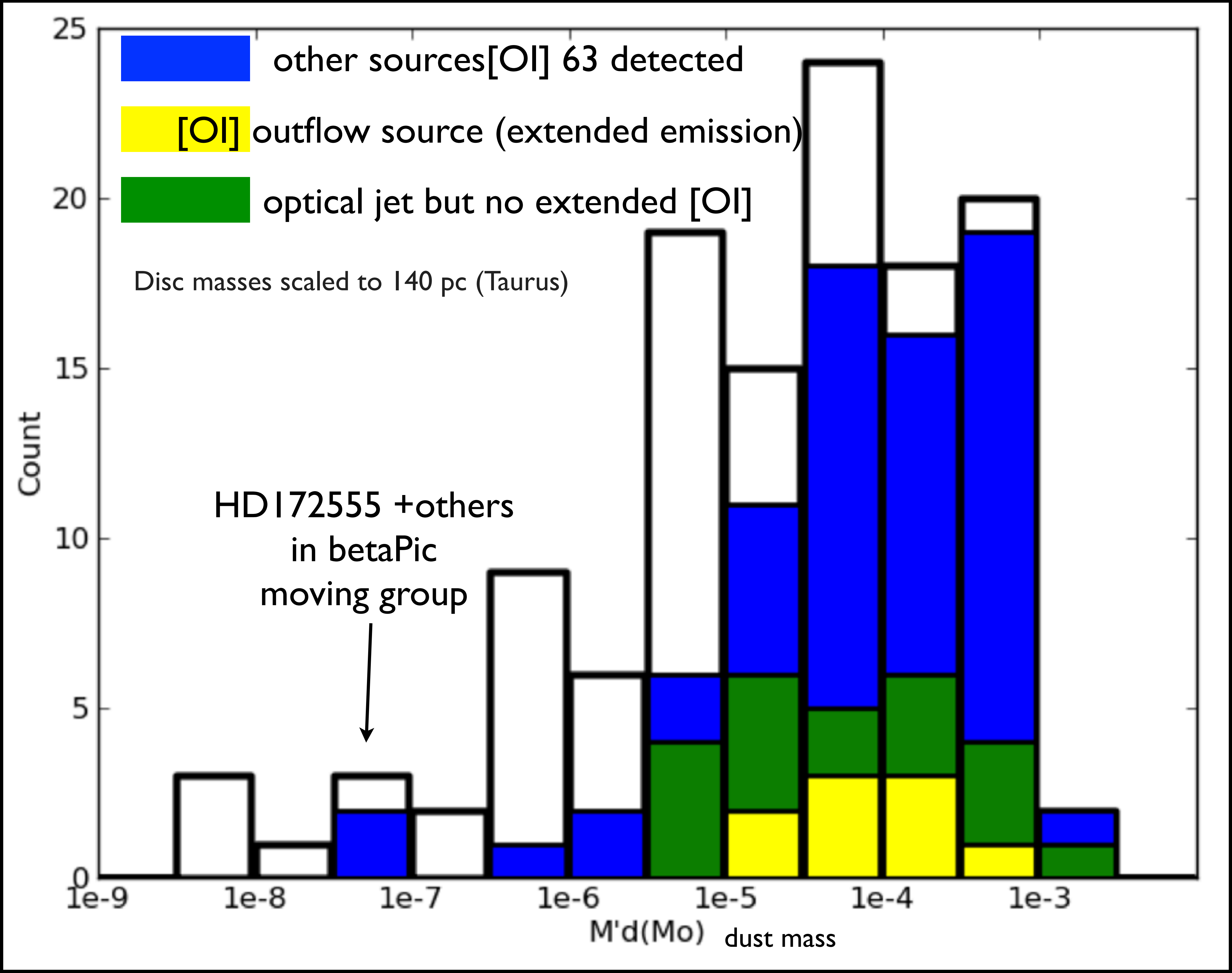
	[OI]63	[OI]145	[CII]157	H_2O63	CO 18-17	Notes
Total	80/163	23/60	17/69	11/58	22/55	
HAeBe stars	20/20	5/20	6/20	1-2/20	10/20	not including 5 debris disks
T Tauri stars	60/138	18/37	11/44	9/138	12/31	

strongest line: [OI] at 63 micron

[CII] line: weak

Dent, Thi, Kamp et al. 2013: Publications of the Astronomical Society of the Pacific, Volume 125, issue 927, pp.477-505

[OI] 63 micron detection rate vs disc dust mass

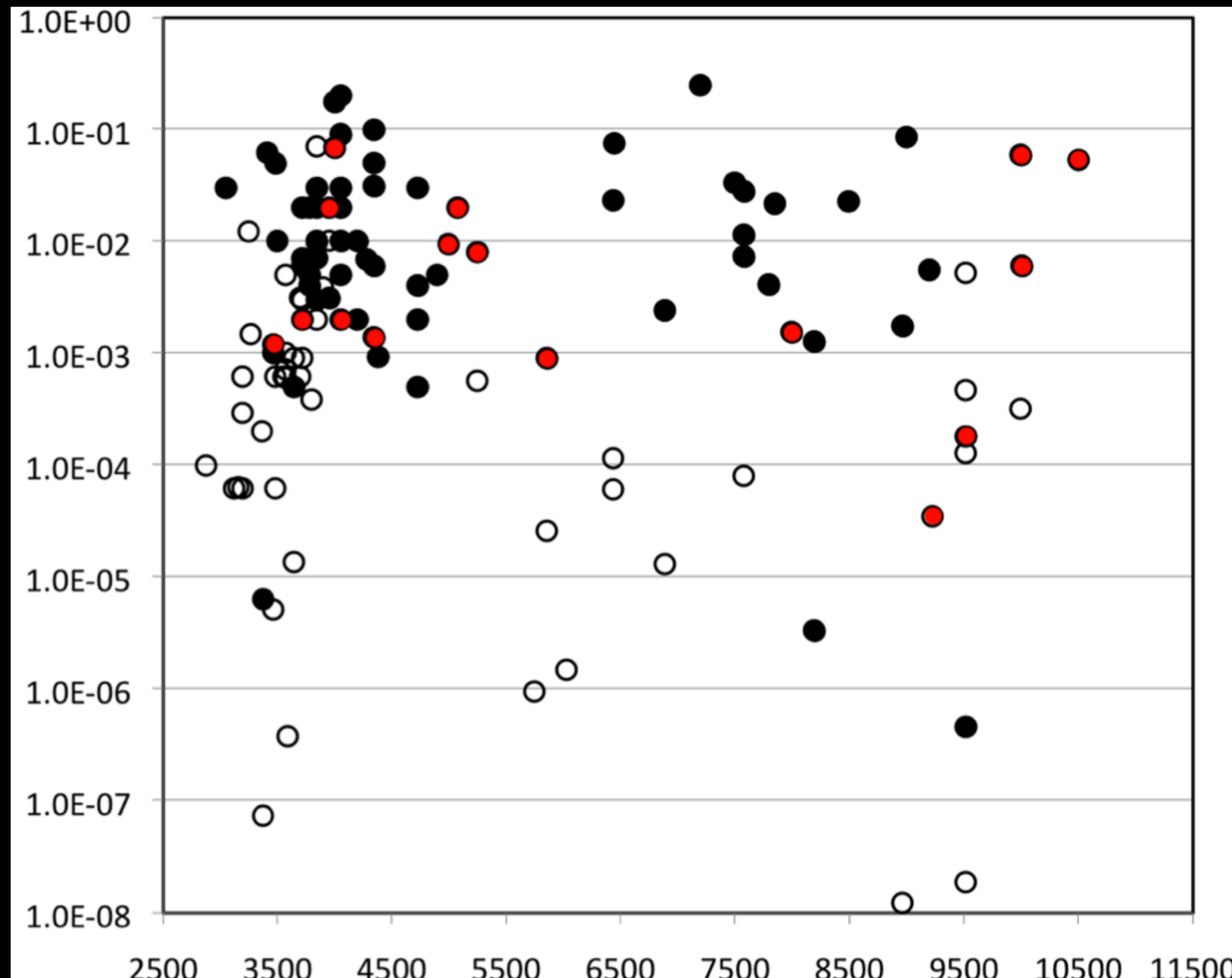


derived from (sub)mm continuum emissions

Dent et al. 2013, PASP 125, 477

[OI] 63 micron vs T_{eff}

Expected disc gas mass from dust mass x 100



[OI] 63 detected

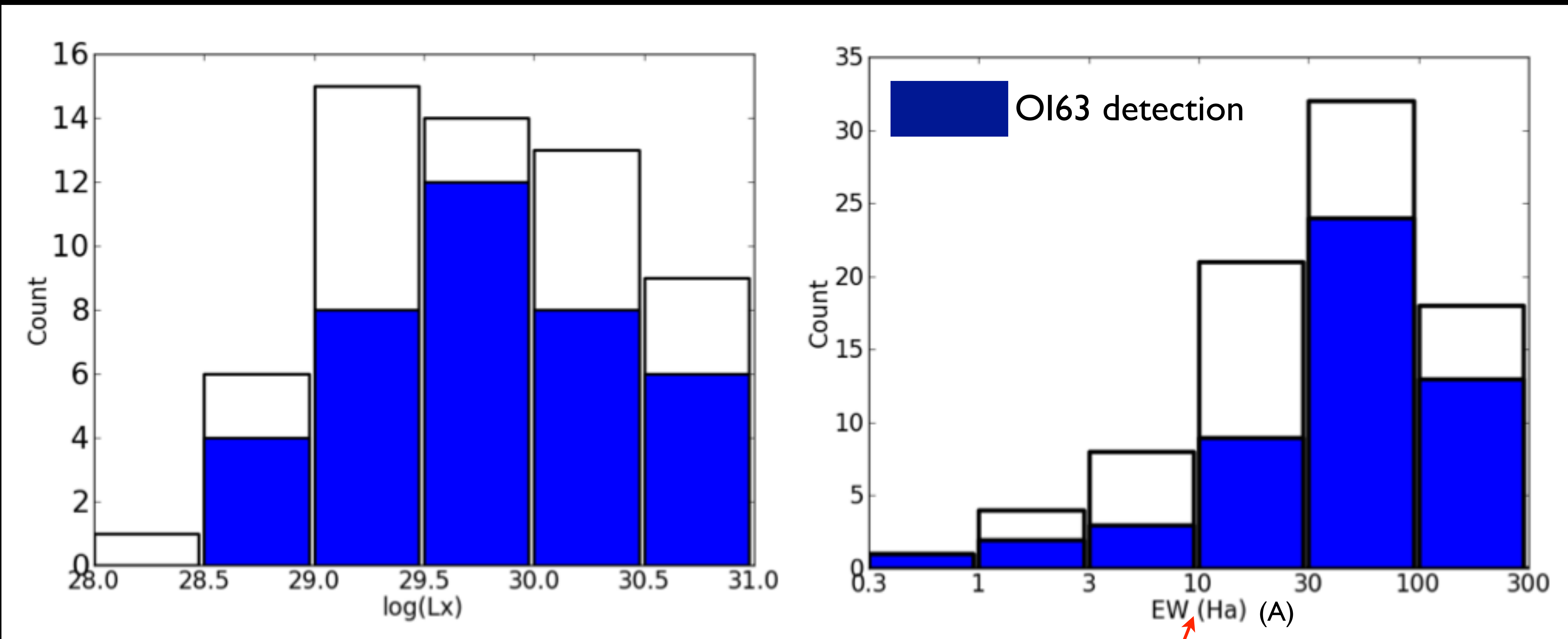
[OI] 63 + [CII] detected

no detection ([OI] 63)

Teff (K)

Dent et al. 2013, PASP 125, 477

[OI] 63 micron vs X-ray luminosity and H alpha

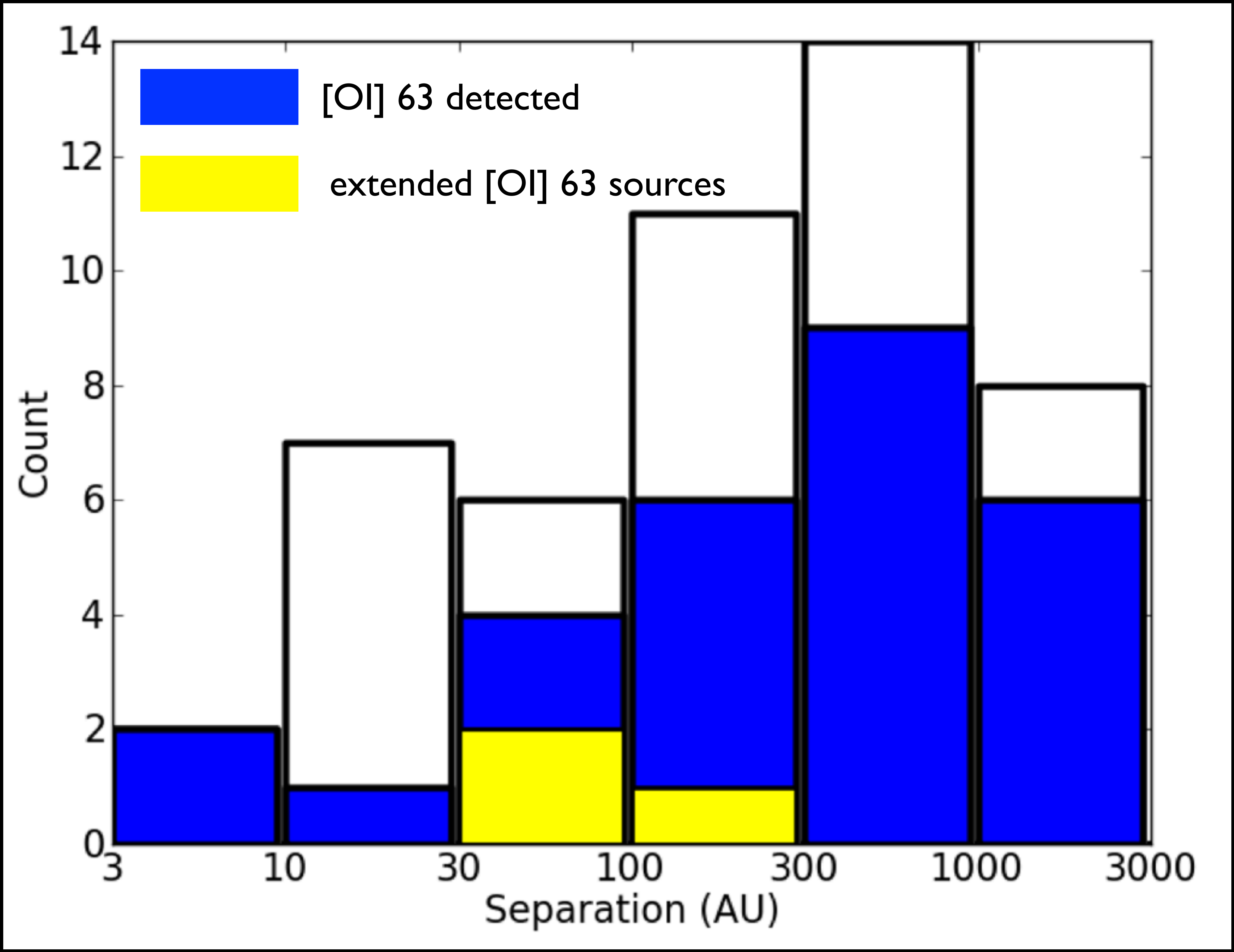


gas accretion tracer (not perfect)

need to include studies
with line profiles

Dent et al. 2013, PASP 125, 477

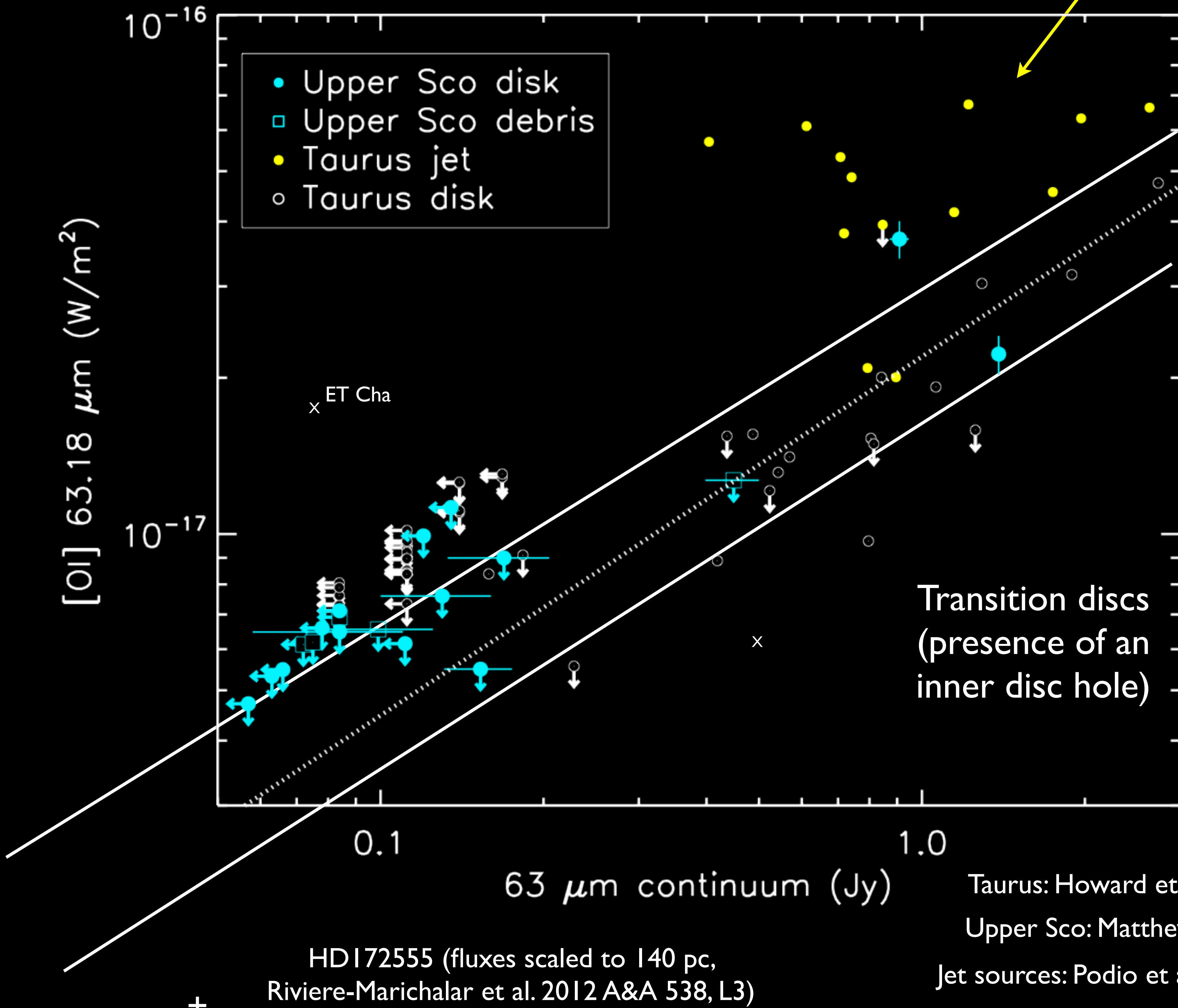
[OI] 63 micron vs binary separation



Dent et al. 2013, PASP 125, 477

Gas versus dust emission: 3-4 classes of objects

Podio et al. 2012: OI63 emission is extended along the optical jet axis



classical TTauri stars: OI emission at the central spaxel

Transition discs (presence of an inner disc hole)

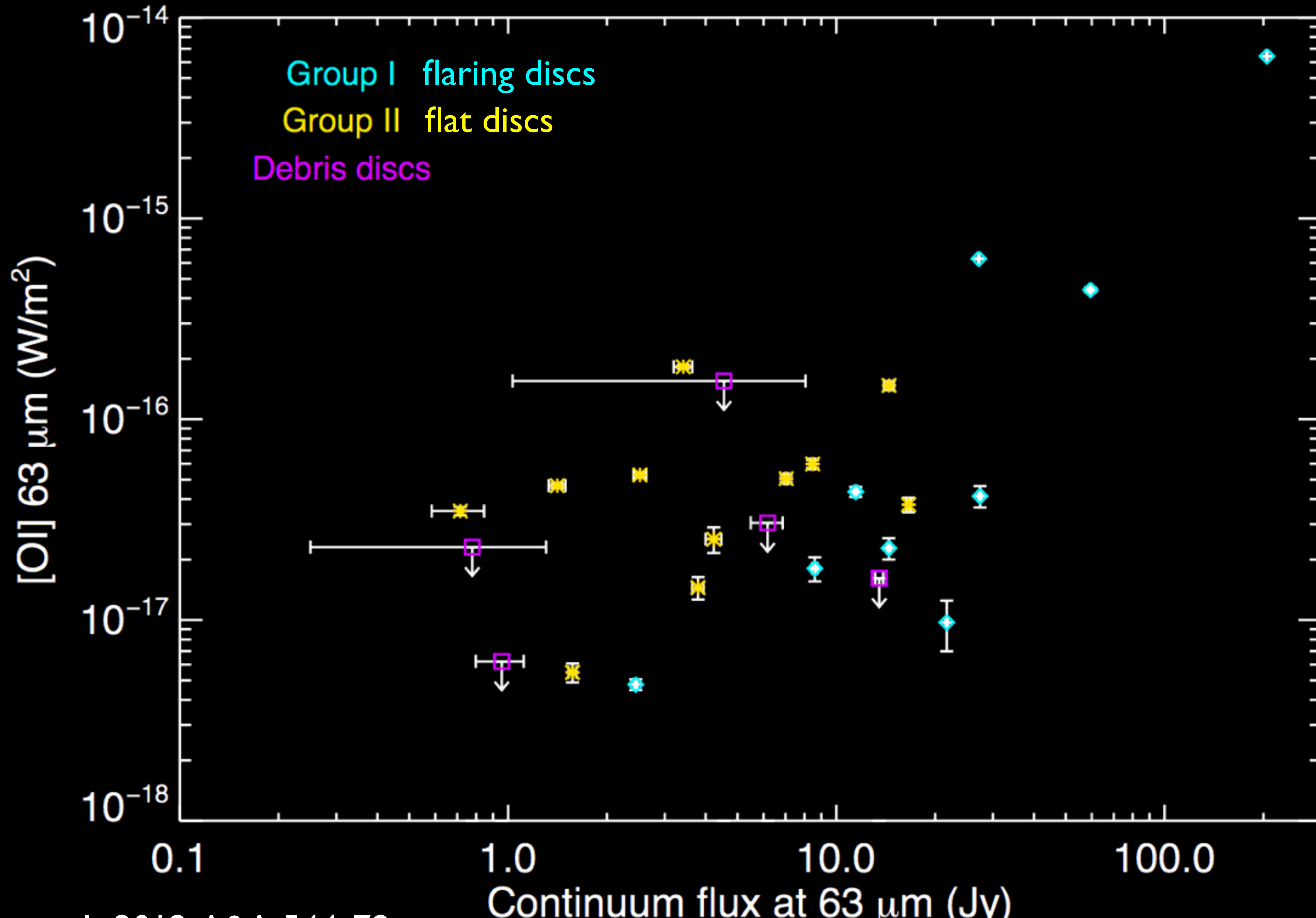
HD172555 (fluxes scaled to 140 pc, Riviere-Marichalar et al. 2012 A&A 538, L3)

Taurus: Howard et al. 2013 ApJ 776, 21

Upper Sco: Matthews et al. 2013 A&A 558, 66

Jet sources: Podio et al. 2012 A&A 545, 44 +talk

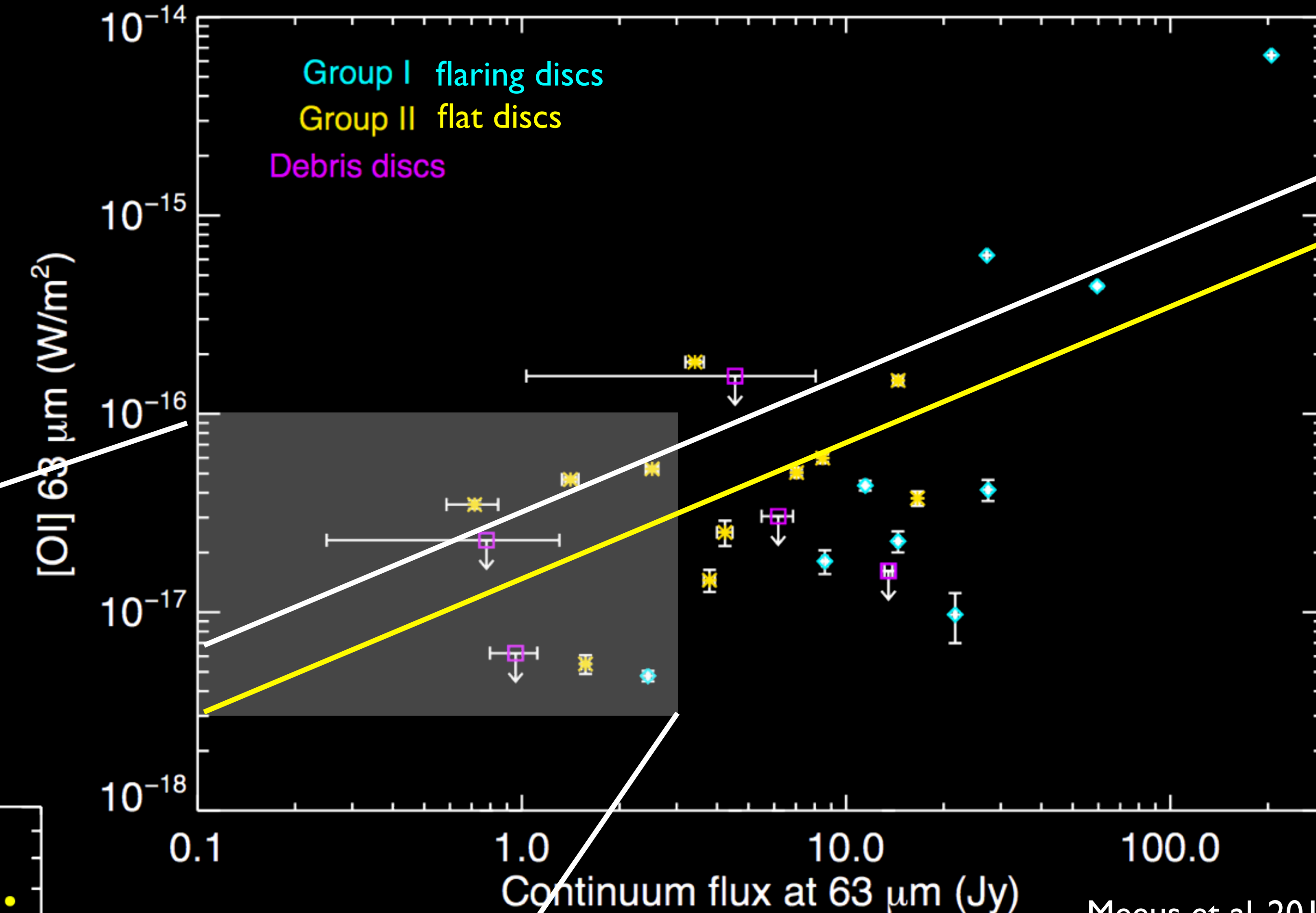
Disks around HerbigAe stars: OI63 line vs 63 micron continuum emission



Meeus et al., 2012, A&A 544, 78

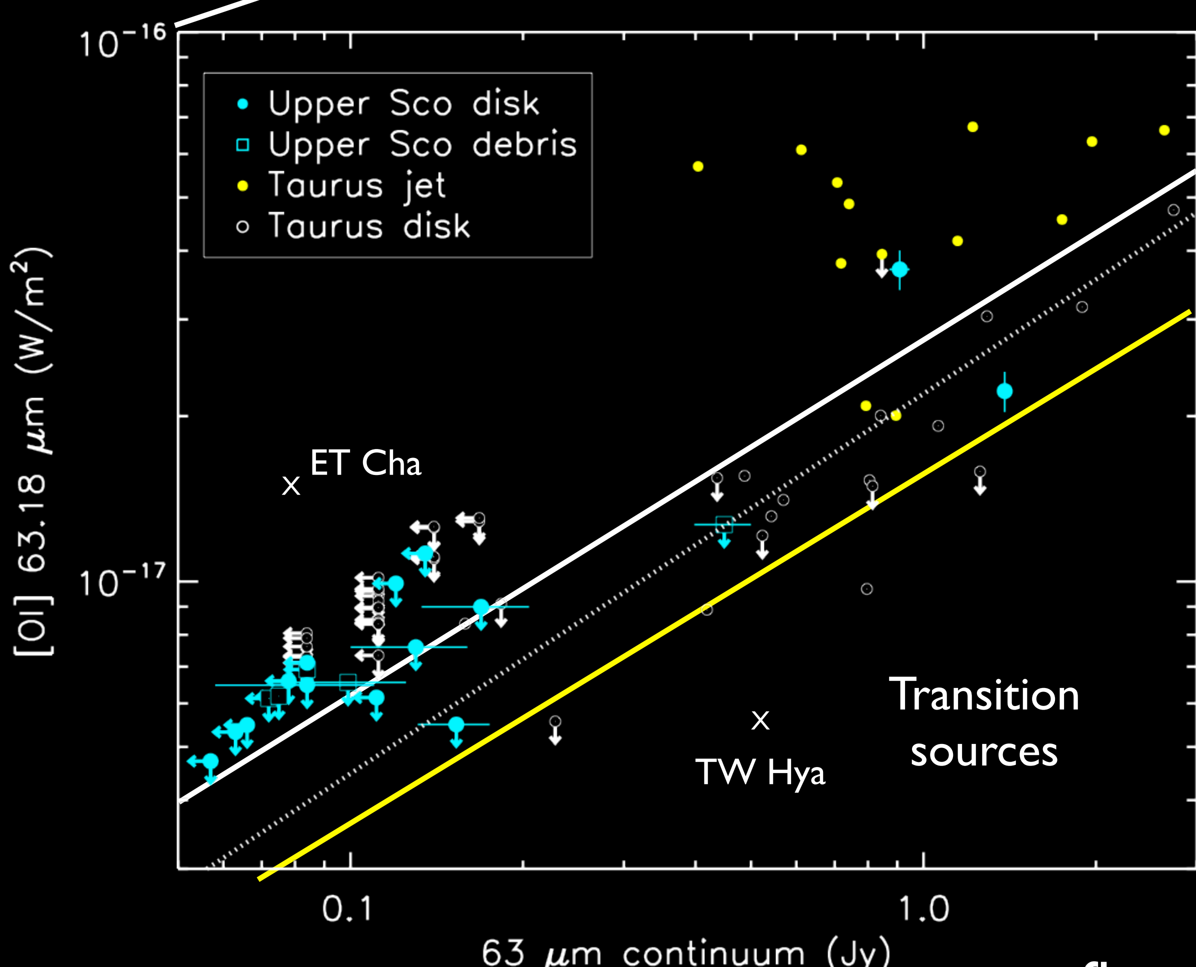
[OI] 63 vs continuum: tracing the gas heating mechanism and/or the gas-to-dust ratio?

HerbigAe stars + A-type star debris discs



Meeus et al. 2012

TTauri stars



to guide the eye

Taurus obs.: Howard et al. 2013

Taurus jet sources: Podio et al. 2012

Upper Sco sources: Matthews et al. 2013

see also Mathews et al. 2010 A&A 518, L126

fluxes scaled to 140 pc

+ HD172555 (fluxes scaled to 140 pc)

Statistical analysis of GASPS data with the DENT grid of disk models

Compare observations to a large grid of protoplanetary disk models

300,000 models: statistical theoretical study of gas (lines) and dust (continuum emission) in protoplanetary discs:

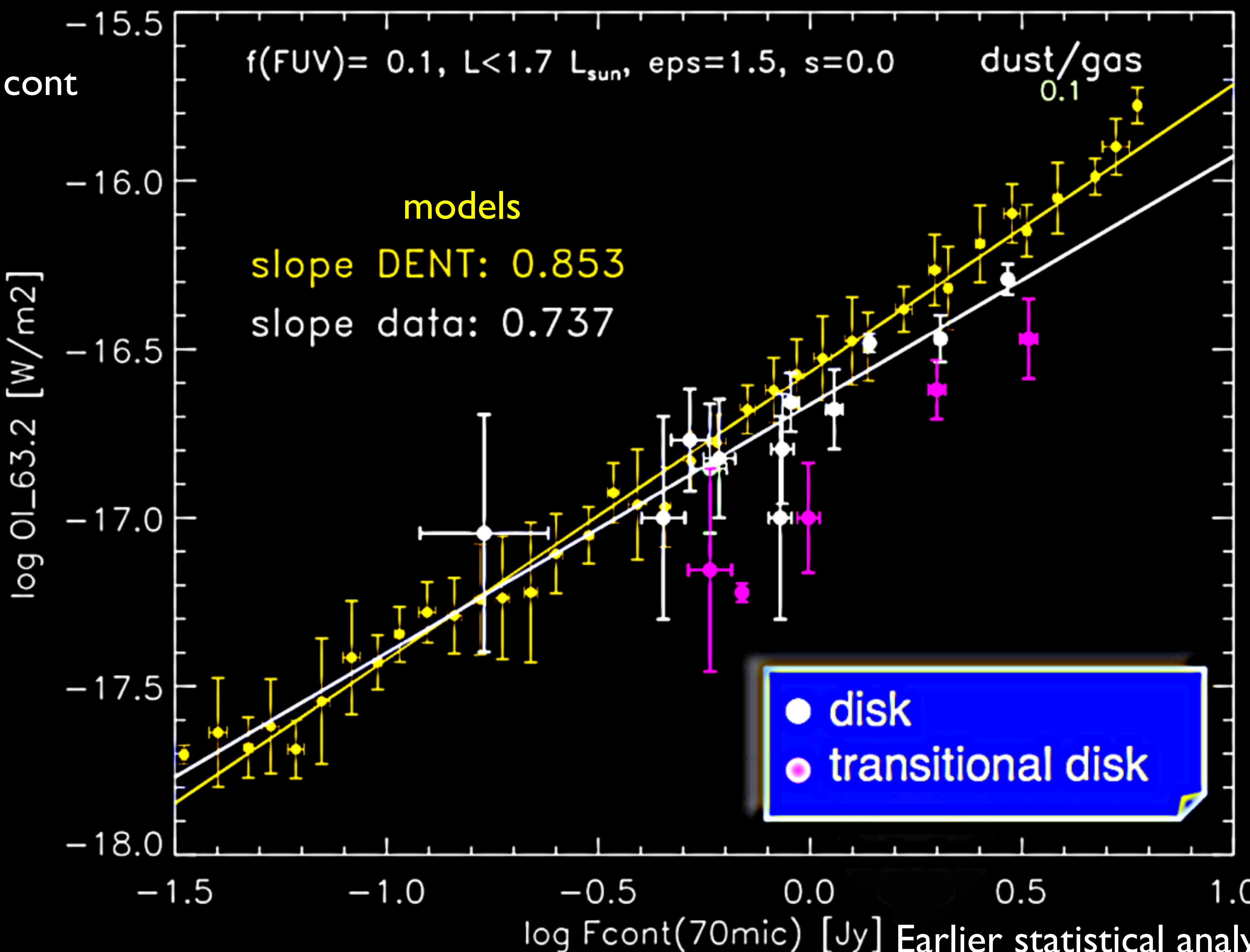
T_{eff}, M_{star}, M_{dust}, M_{gas}, R_{in}, R_{out},, flaring index, scale height H_0, a_{min}, a_{max}, settling

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

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

Statistical analysis of GASPS data with the DENT grid of disk models

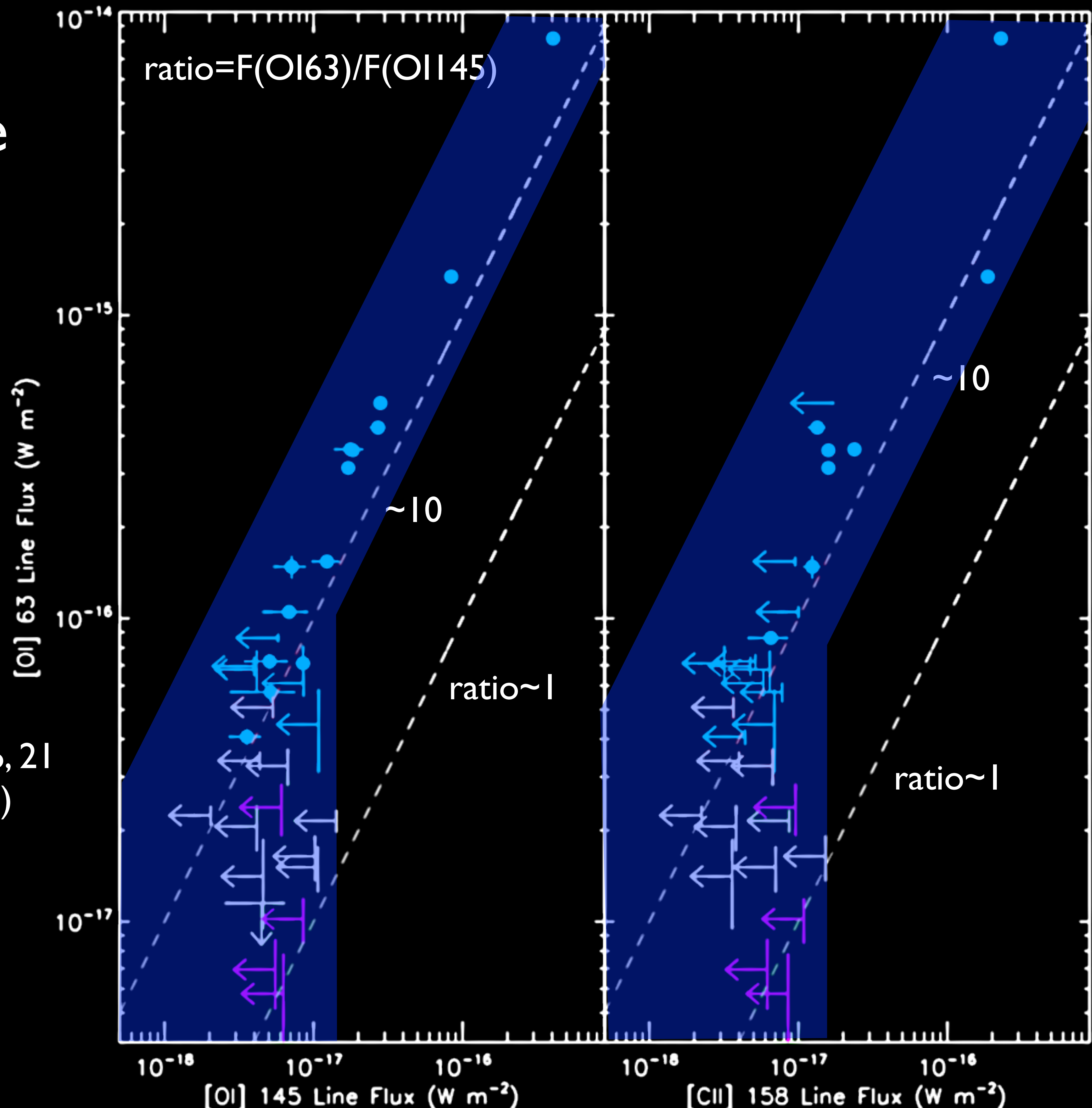
OI63 vs 63 cont



Earlier statistical analysis: Pinte et al. 2010, A&A 518, L126

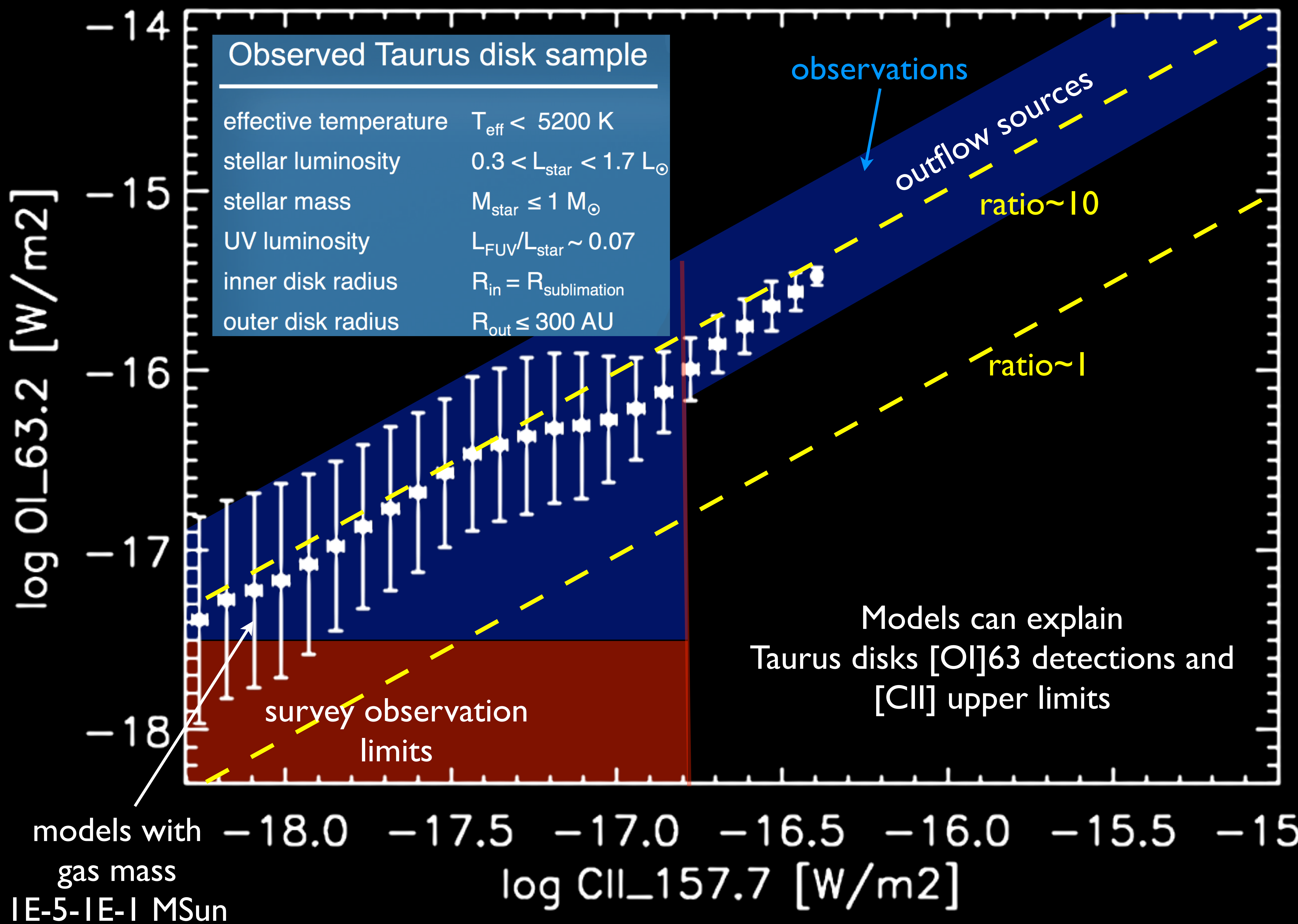
See poster by Silvia Vicente & Inga Kamp

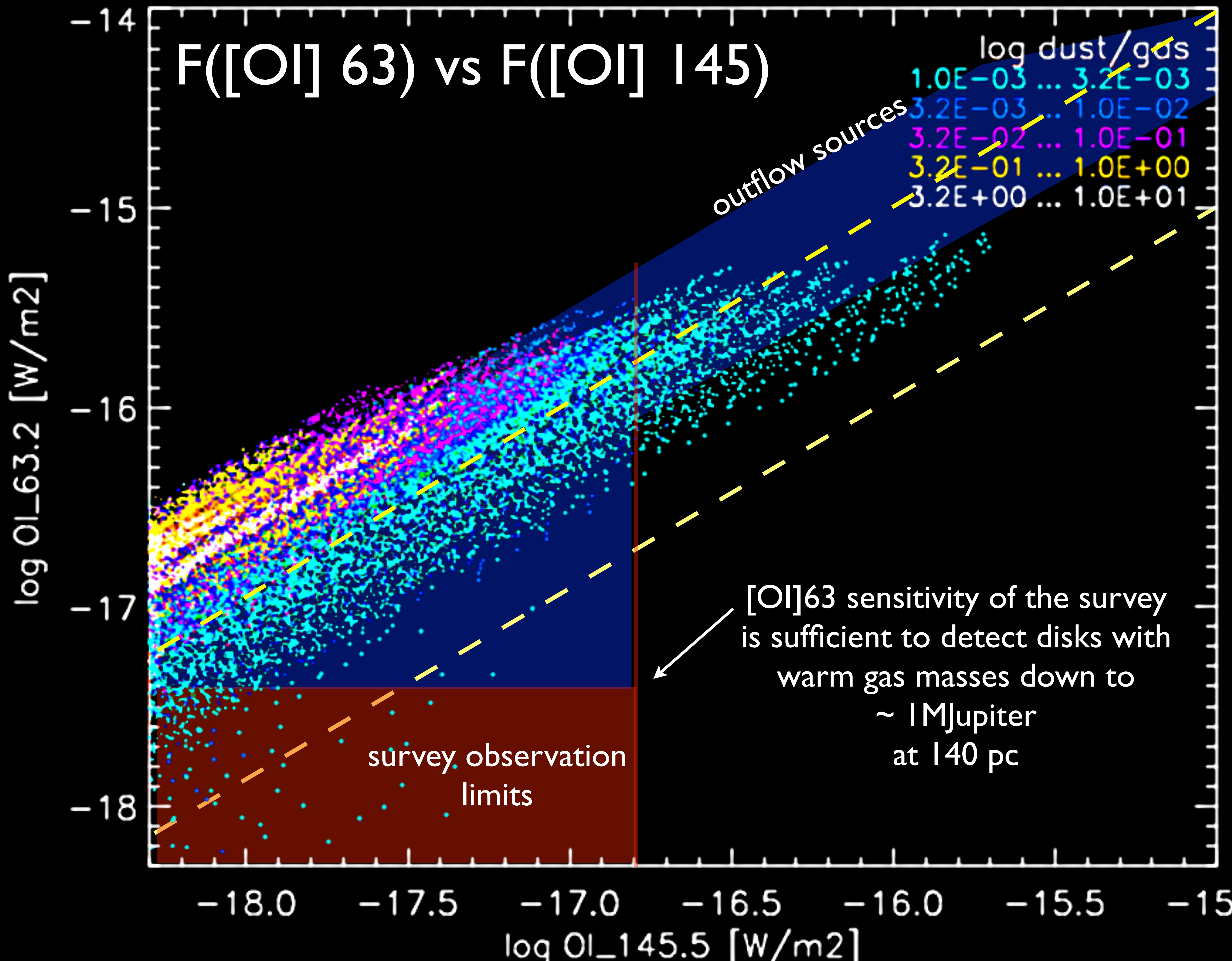
Taurus sample



Howard et al. 2013 ApJ 776, 21
+ poster (Goran Sandell)

Explaining the CII non-detections with the DENT grid of models





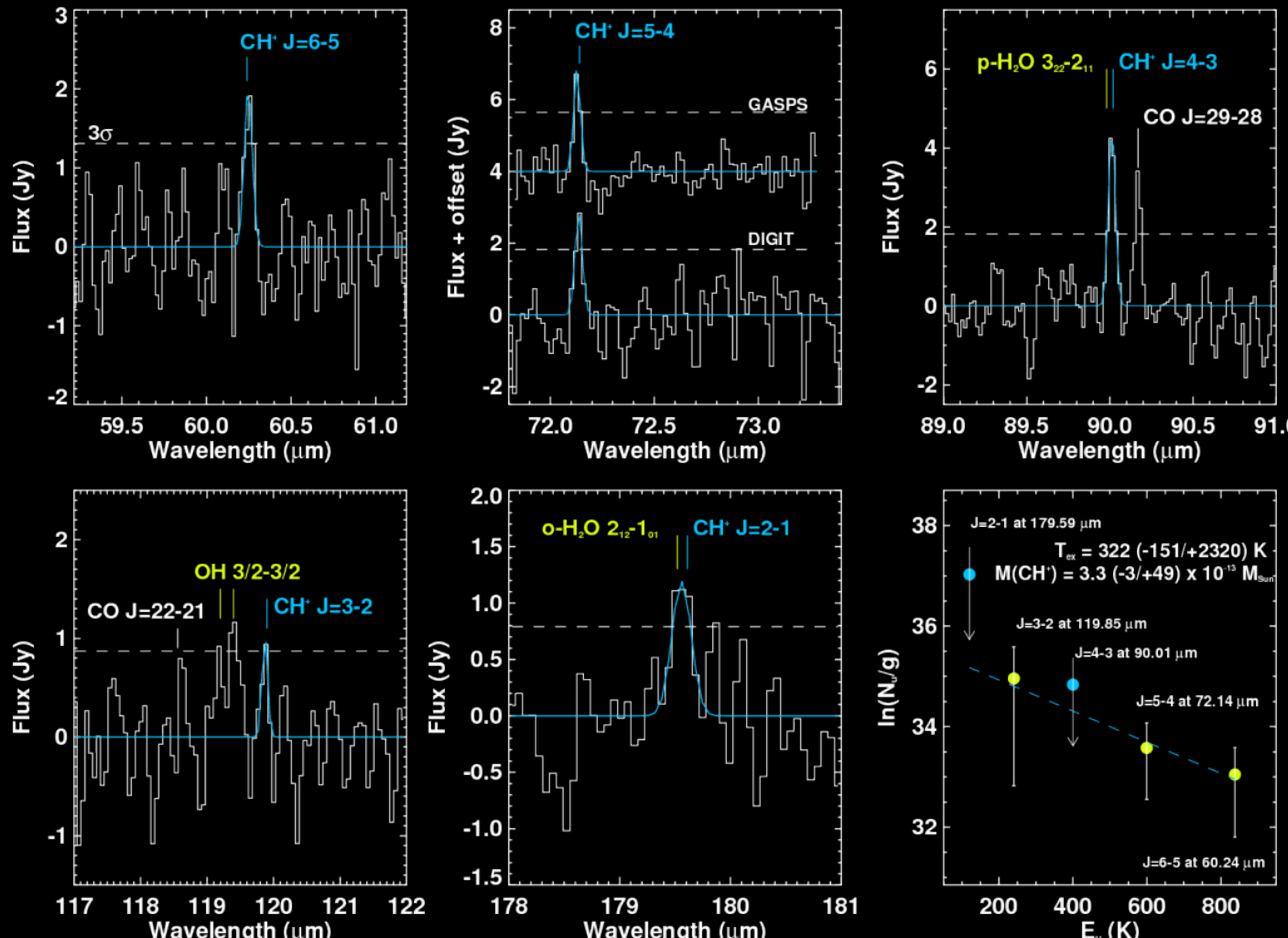
F([OI] 63) vs F([OI] 145)
log dust/gas
1.0E−03 ... 3.2E−03
3.2E−03 ... 1.0E−02
3.2E−02 ... 1.0E−01
3.2E−01 ... 1.0E+00
3.2E+00 ... 1.0E+01
outflow sources
−14
−15
−16
−17
−18
log OI_63.2 [W/m2]
[OI]63 sensitivity of the survey
is sufficient to detect disks with
warm gas masses down to
~ 1MJupiter
at 140 pc
survey observation
limits
−18.0
−17.5
−17.0
−16.5
−16.0
−15.5
log OI_145.5 [W/m2]

Gas and dust modelling

- Sophisticated modelling of all Herschel+complemetntary data is required to derive disc parameters such as disc dust and gas masses:
  - [OI] traces the warm gas in the 10-100 AU of discs (E_u=227K, n_{crit}~5e5 cm^{-3})
  - Total disc gas mass estimates require [OI] and low-*J* CO observations but uncertain O/C abundance, gas excitation, ... Use HD to "calibrate" model assumptions.
  - Knowledge of the stellar properties is essential for accurate modelling
  - modelling water lines is complicated (chemistry, radiative transfer, ...)

HD163296	Tilling et al. 2012 A&A 538, 20
HD161942	Meeus et al. 2010 A&A 518, L124
TW Hya	Thi et al. 2010 A&A 518, L125; Kamp et al. 2013 (water lines)
HD100546	Thi et al. 2011 A&A 530, L2 (CH+ detection)
eta Cha 15	Woitke et al. 2011, A&A 534, 44
HD141569	Thi et al. 2013 astro-ph1309.5098
51 Oph	Thi et al. 2013 A&A, 557,111
HD135344B	Carmona et al., submitted
FT Tau	Garufi et al.. submitted

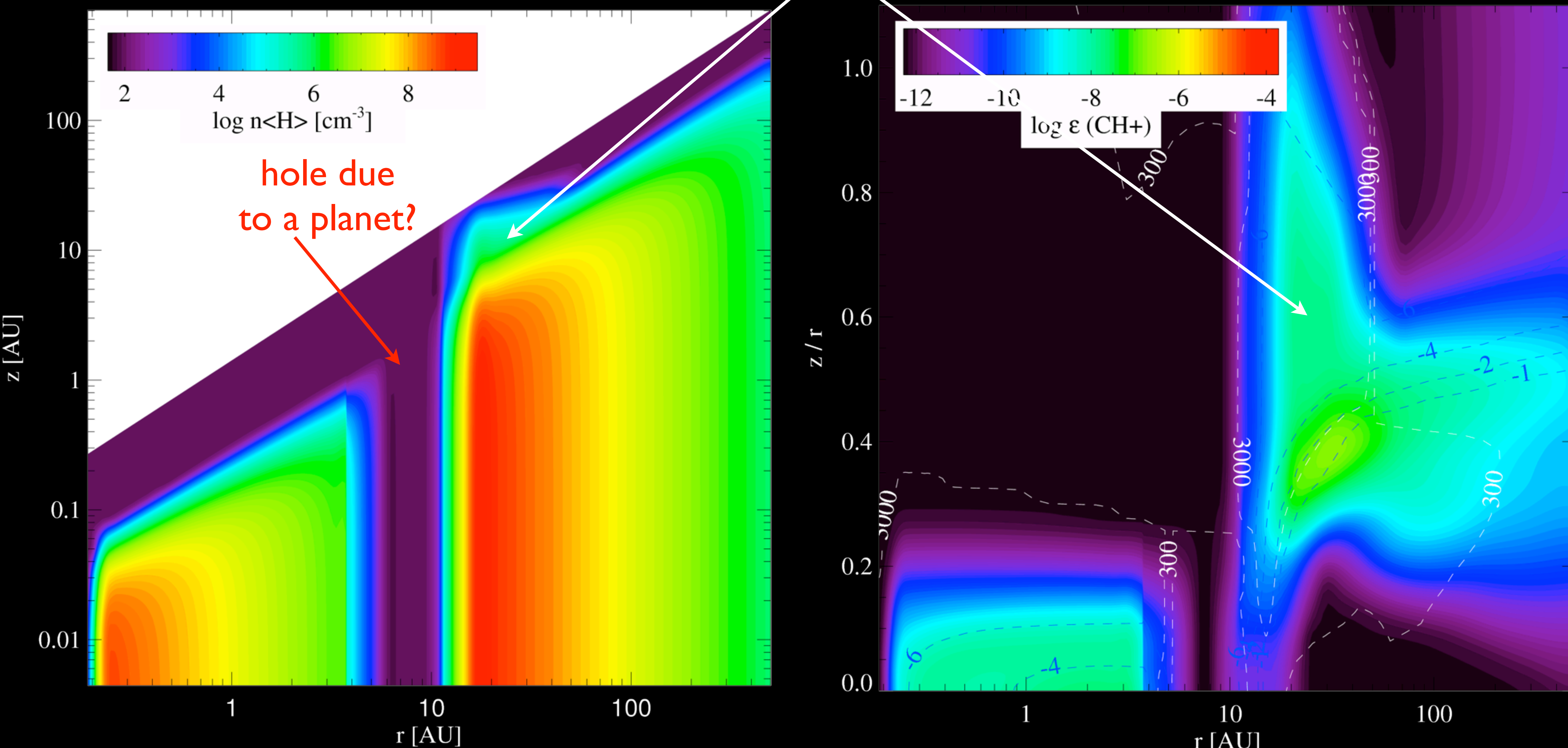
Serendipity detection of CH^+ in the HD100546 disc



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

CH^+ is located at the rim (HD100546)

outer disc rim



inner disc

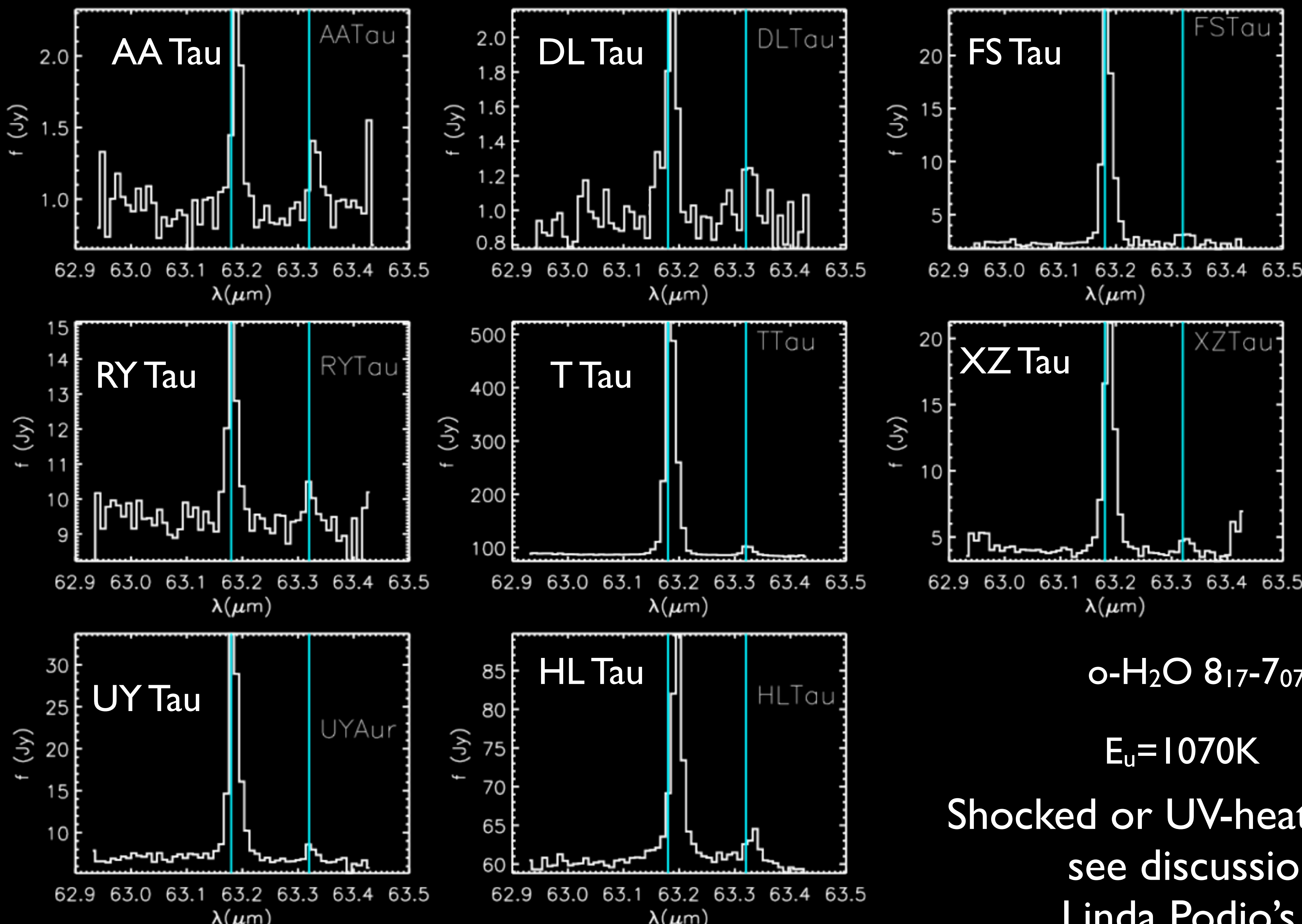
outer disc

Thi et al. 2011 A&A 530, L2

Warm water in disks

OI 63 micron

water @ 63.3 micron



o-H_2O 8_{17}-7_{07}

E_u=1070K

Shocked or UV-heated water?
see discussion in
Linda Podio's talk

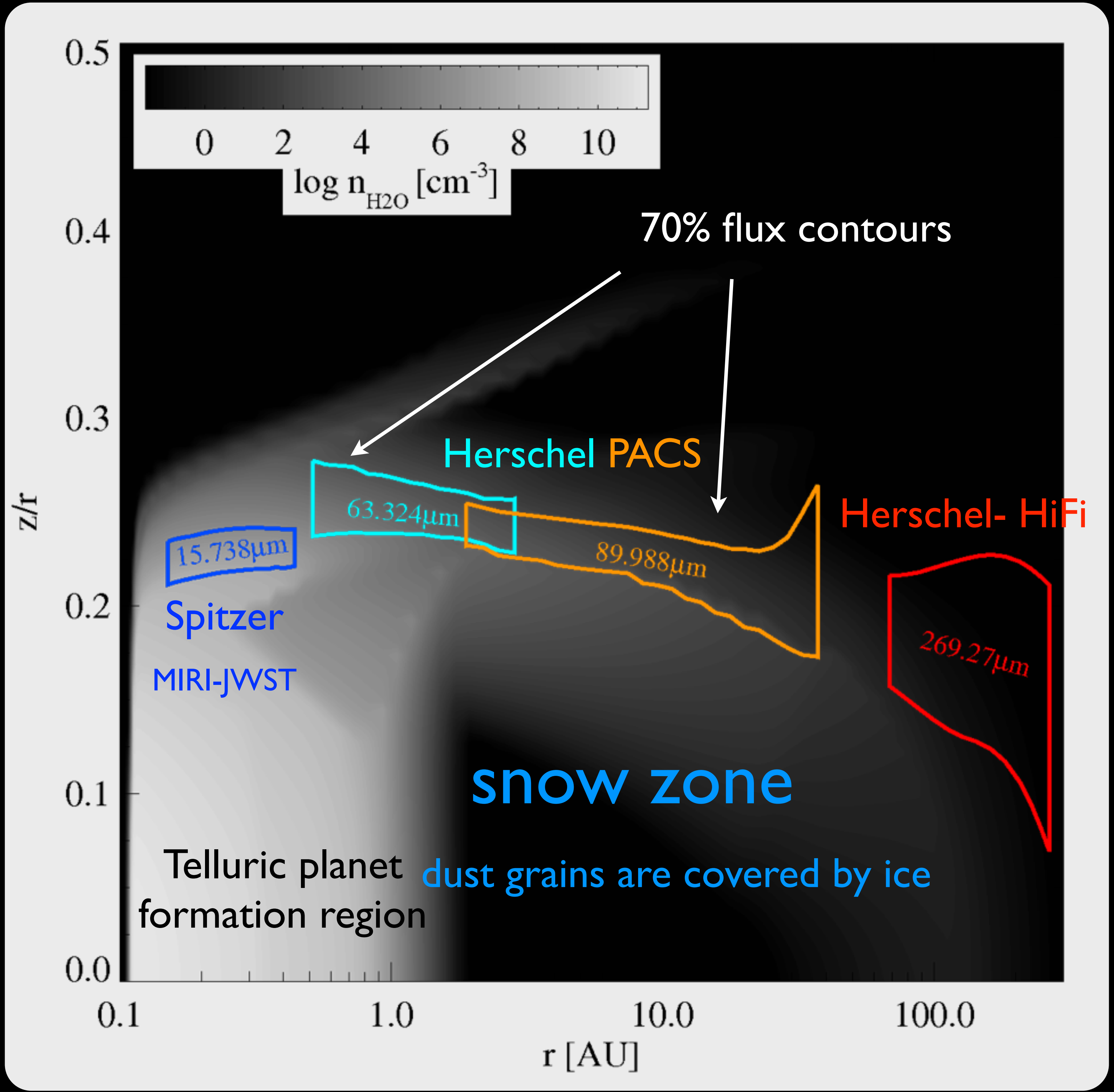
Riviere, Ménard, Thi, Herschel-GASPS team, 2012 A&A 538 L3

The 63.32 micron water line probes the warm gas 1-5 AU region of discs (or outflowing gas)

10^{-2} Msun disk around a TTauri star (model generated by ProDiMo)

water abundance differs for different regions (density, temperature, gas composition for the collision patners)

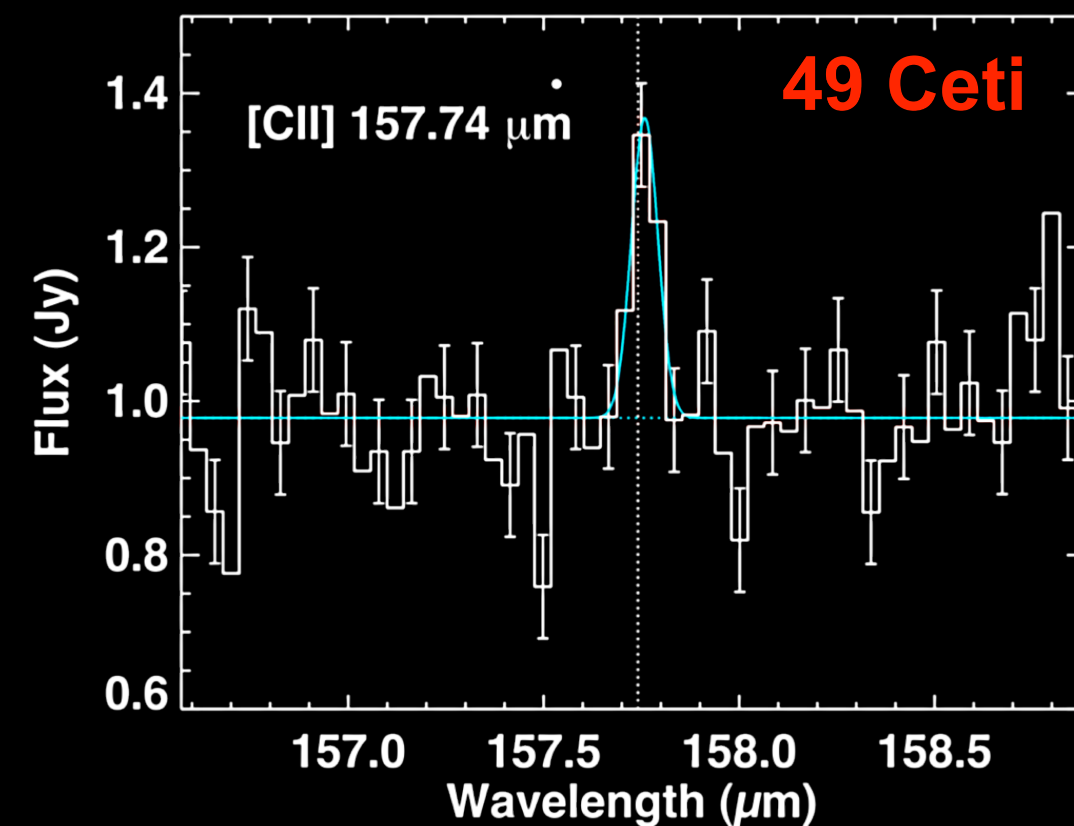
Kamp, Thi, Meeus et al. 2013, A&A, astro-ph1308.1772 (modelling water lines in TW Hya)



"Young" debris discs
with and without gas detection

Gas in Debris Disks

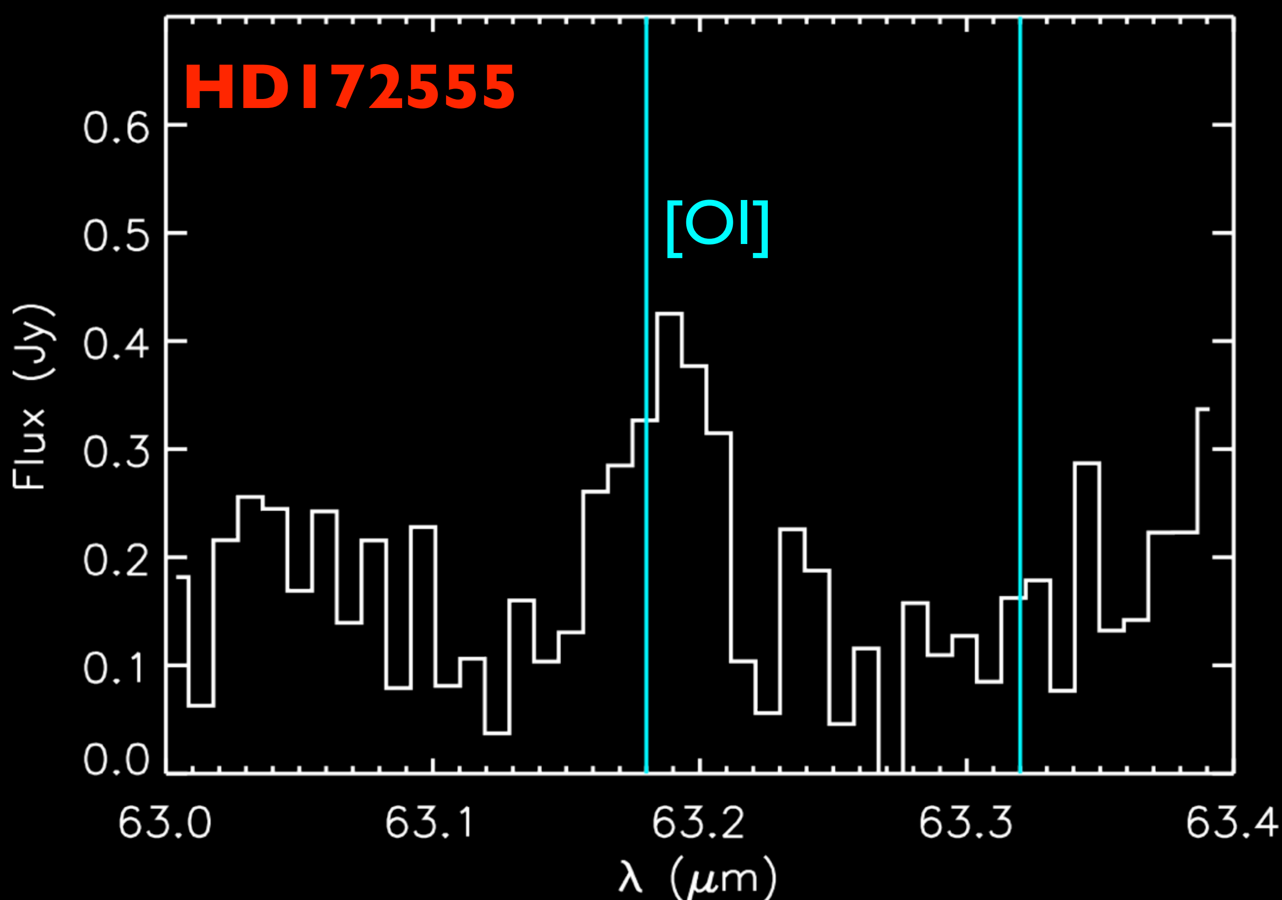
Roberge et al. (2013)



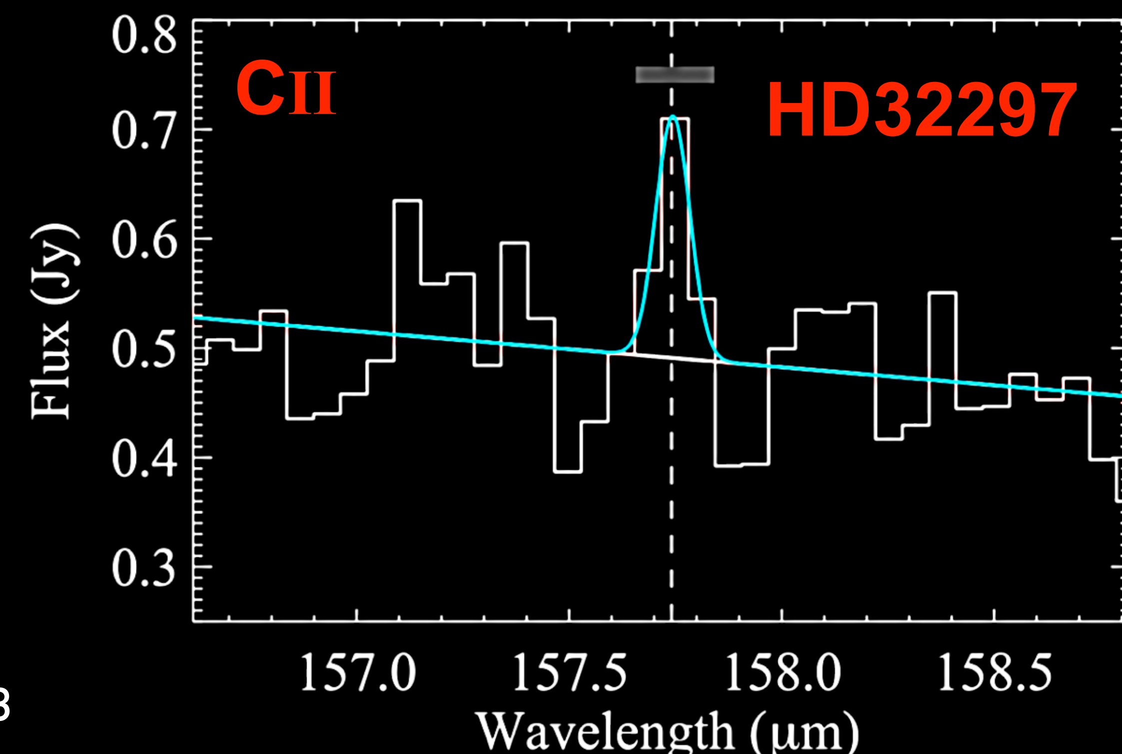
Modest amounts detected in 7 to 10 debris disks, nearly always in absorption

GASPS adds gas emission detections in three disks

Secondary gas from planetesimals?



Donaldson et al. (2013)

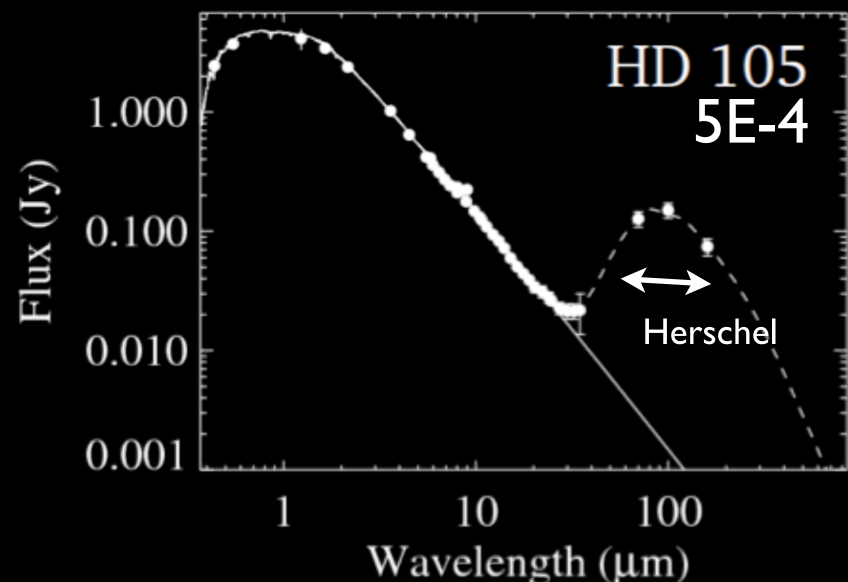


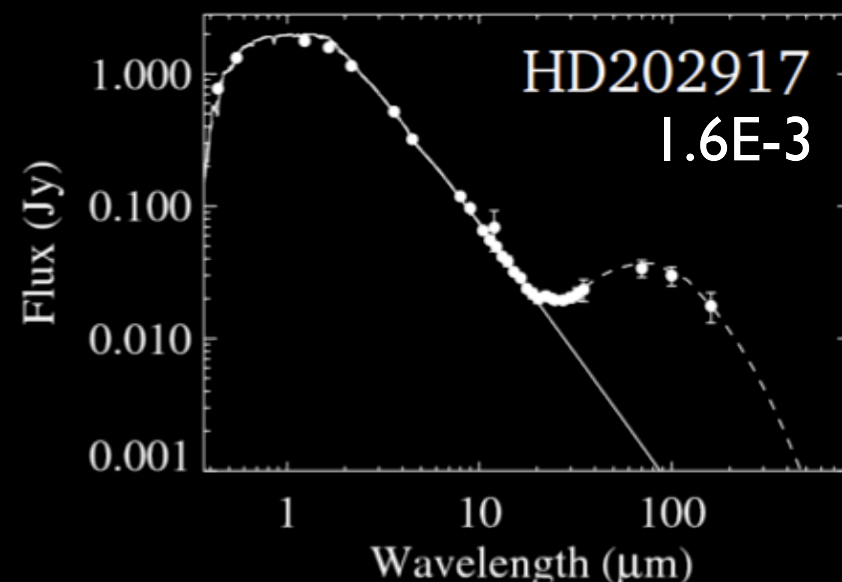
see poster Roberge et al.

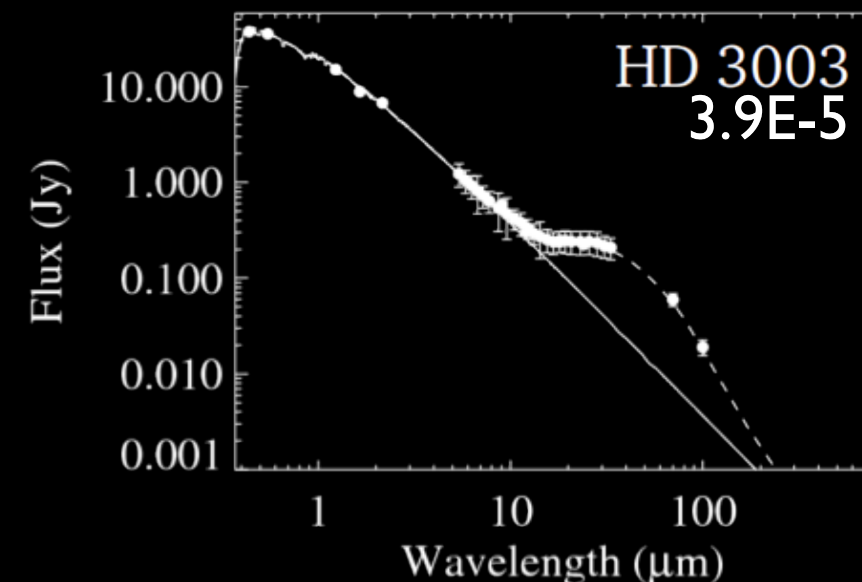
Riviere-Marichalar et al. 2012 A&A 538, L3

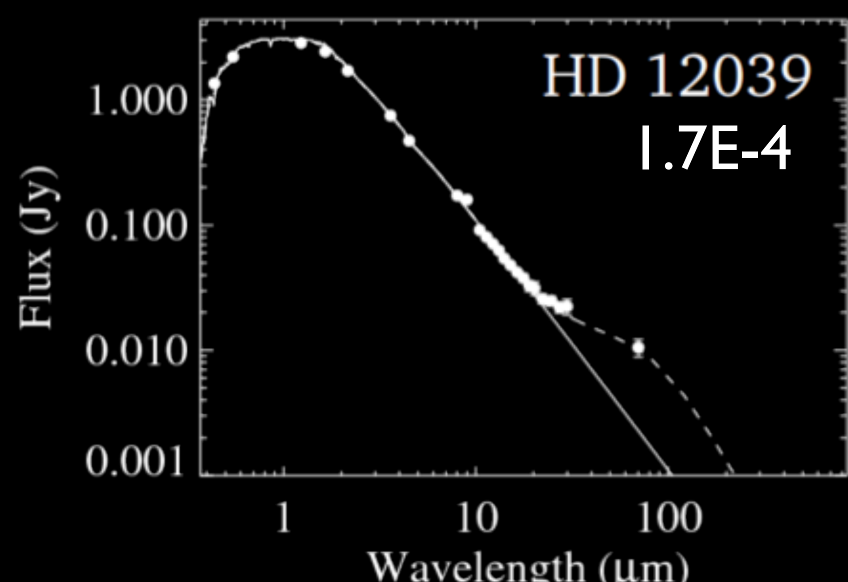
Debris discs in Tuc-Hor (~30 Myrs): no gas detection

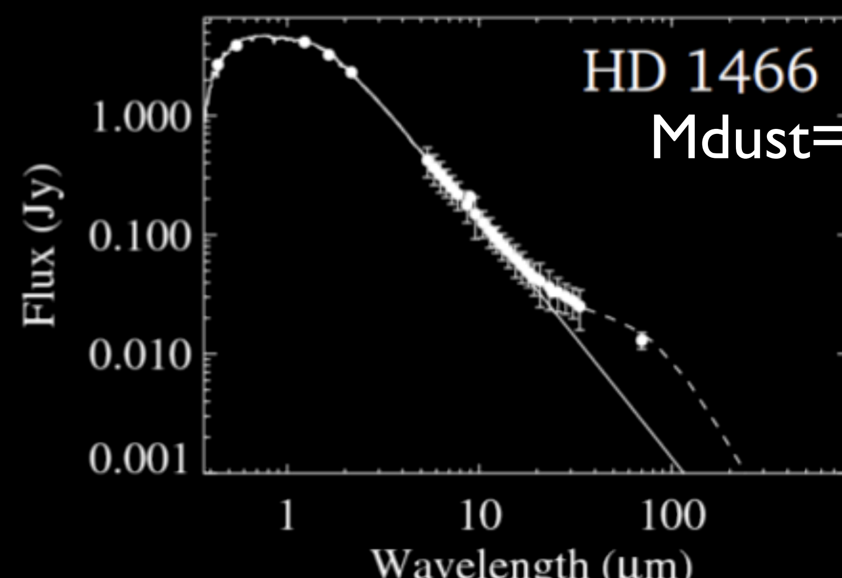
d=24-64 pc











Mdust=1.1E-4 MEarth

M_{Earth}=3e-6 M_{Sun}

Hint of cool/cold discs from *Spitzer*: confirmed by *Herschel*

Donaldson et al. 2012, ApJ 753, 147 GASPS data

talk by Jessica Donaldson

HD181327: Lebreton, Augereau, Thi + GASPS A&A 539, 17

[OI]63 (warm gas) and continuum detection rate vs time

GASPS survey disc gas mass sensitivity : 1-3 $M_{Jupiter}$

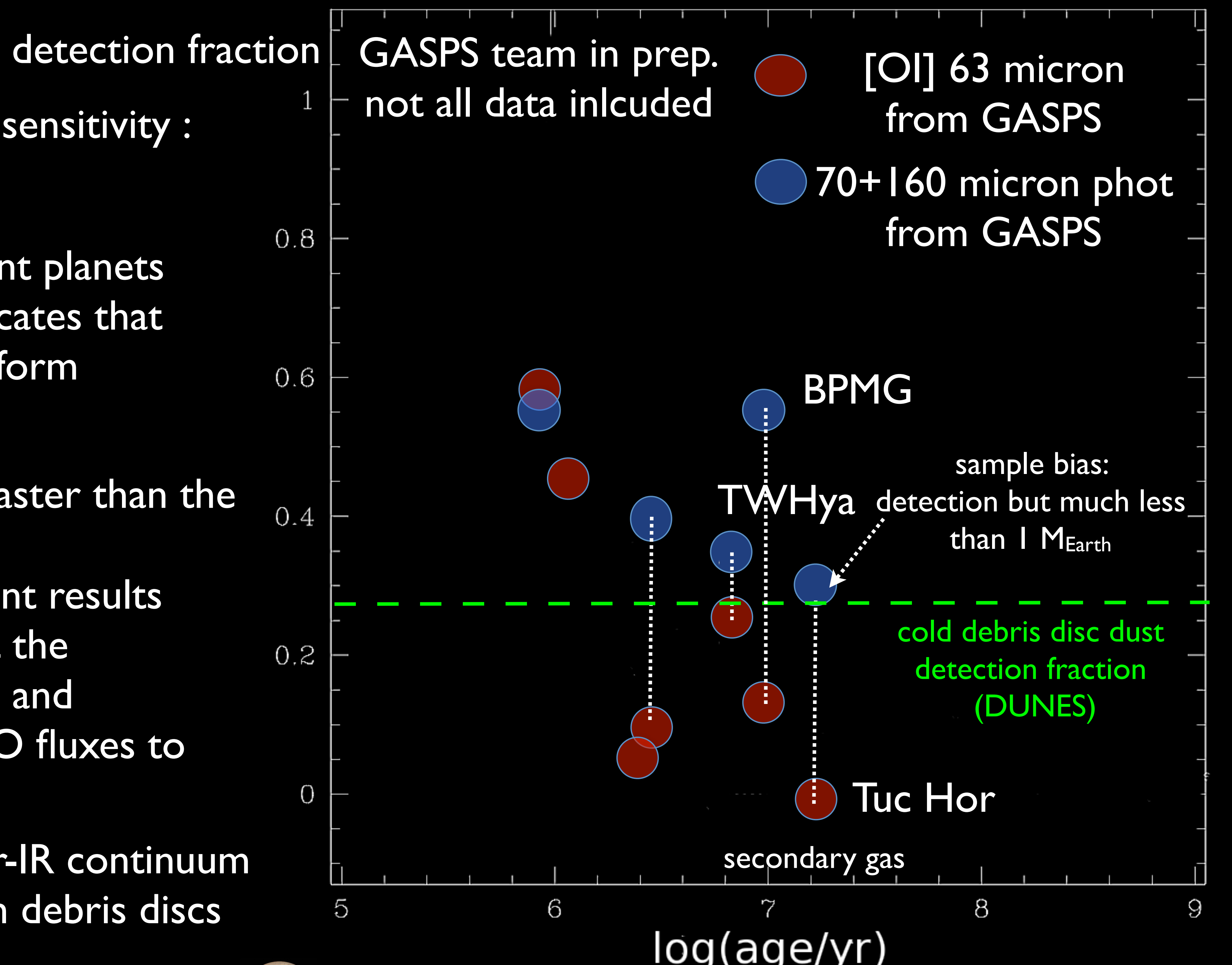
If there is in average >~1 giant planets per star, then our survey indicates that Jupiter-mass planets need to form quickly.

The gas seems to disappear faster than the dust but :

1) Preliminary results! Current results are based on our sample not the population (selection biased) and conversion from [OI] and CO fluxes to H_2 masses

2) Sample chosen to show far-IR continuum excess: bias towards dust-rich debris discs

3) Age determination issues



TWHya association: Richiere-Marichalar et al. 2013 A&A 555, 67

Alibert et al. 2005

Conclusions & Prospects

The Herschel-GASPS protoplanetary disc programs have reached (or is about to reach) his aims:

Measurement of the disc warm gas lifetime: The warm gas dissipates after 5-6 Myrs or (10-12 Myrs). This supports fast giant formation scenarios (core-accretion with migration or direct collapse models). Warm dust (70 micron photometry) dissipates after 10 Myrs (or 20 Myrs). This is supported by other studies (Geers et al. 2012, Keane et al., in prep.)

Better understanding of disc gas and dust structures: the GASPS team has modelled precisely a couple of young to debris discs using the codes ProDiMo+MCFOST/GraTer. A few discs may have gas-to-dust mass ratio may <100.

Warm water has been detected: preliminary modelling suggests that we are probing the telluric planet formation region. Can this warm water be the source of oceans for planets in the Habitable Zone? (Comets being another possible source of water)

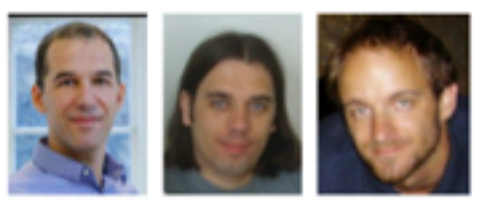
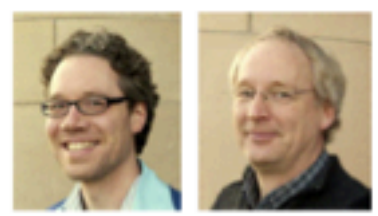
(HIFI water observations trace a large reservoir of icy grains (see talk Hogerheijde))

ProDiMo and other codes are now being used to predict continuum and disc line fluxes from near-IR (JWST, VLT) to the radio (ALMA, eVLA). A large modelling effort is being carried out within the European project DIANA (PI P. Woitke).

DiscAnalysis DIANA

FP7-SPACE 2011 collaboration

Analysis and Modelling of Multi-wavelength Observational Data from Protoplanetary Discs

St Andrews	**Vienna**	**Amsterdam**	**Grenoble**	**Groningen**
				
P. Woitke	*M. Güdel*	*R. Waters*	*F. Ménard*	*I. Kamp*
				
Greaves Ilee Rigon	*Dionatos Rab Liebhart*	*Min Dominik*	*Thi Pinte Carmona Anthonioz*	*Antonellini*
sub-mm to cm	**X-rays**	**near-mid IR**	**near-far IR**	**near IR - mm**
coordination	obs./mod.	mod./obs.	obs./mod.	mod./obs.
JCMT, eMERLIN	XMM, Herschel	VLT, JWST	HST, Herschel	Herschel, JWST
astrobiology	high energy	dust mod.	interferometry	gas mod.

multi-λ data collection X-ray to cm (archival and proprietary)

coherent, detailed modelling of gas & dust throughout the disc

using disk modelling software ProDiMo, MCMax, MCFOST

aim: disc shape, temperatures, dust properties, chemistry in the birth-places of exoplanets

Summer School on Protoplanetary Disks: Theory and Modeling meet Observations

16.-20. June 2014

on the Dutch island of Ameland

http://www.diana-project.com/summer-school/

SEVENTH FRAMEWORK PROGRAMME

university of groningen

faculty of mathematics and natural sciences

kapteyn astronomical institute

DiscAnalysis DIANA

- A few GASPS team-members are looking for jobs:
  - A. Carmona: post-doc, fellowship
  - W.-F. Thi: senior position
  - J. Donalson: post-doc, fellowship