Line Emission from Jets & Disks in CTTSs: results with *Herschel* and the future with SPICA

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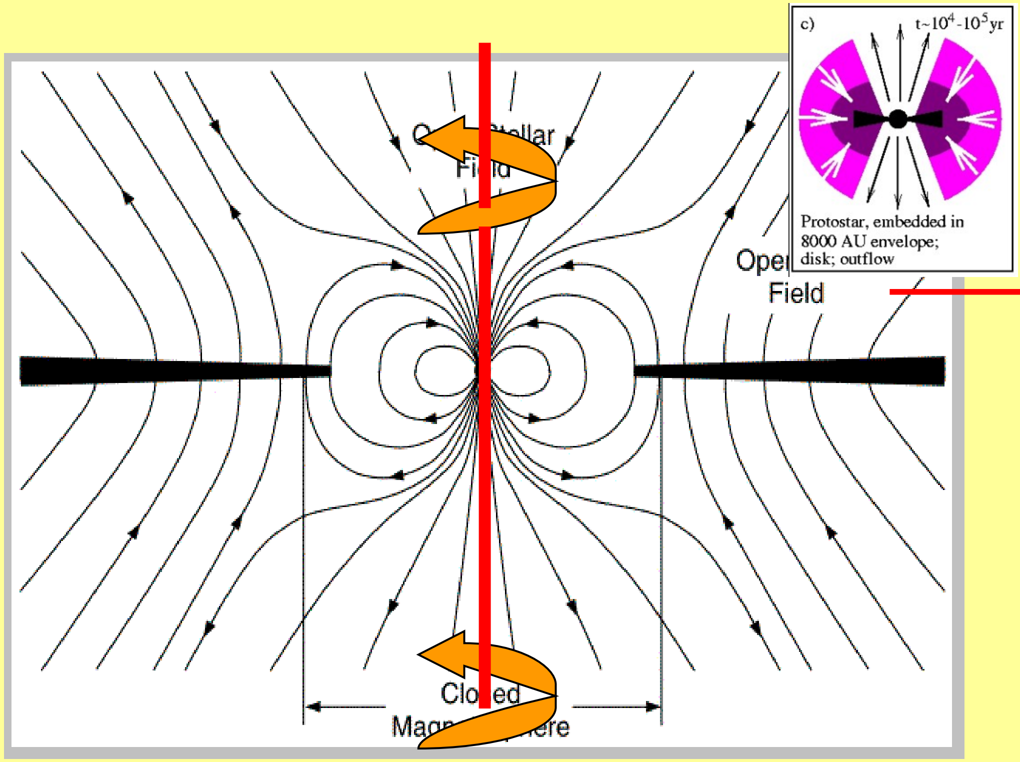
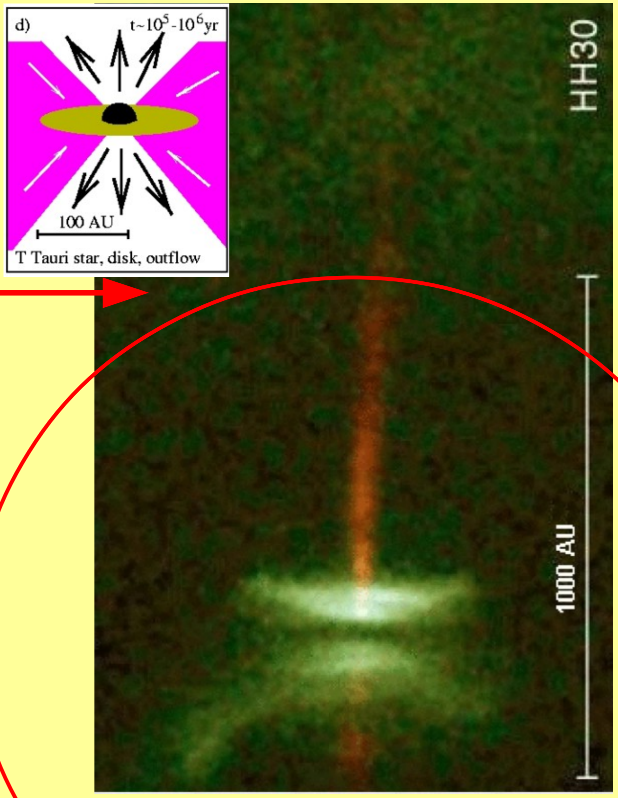
B. Dent (ALMA), G. Aresu (Kapteyn), F. Menard (IPAG), C. Pinte (IPAG)
& the GASPS team

Accretion disks & stellar jets in the star formation process



Class 0/I

Class II



HST - Stapelfeldt et al. 1997

Herschel FOV

To observe line emission from Class II objects we need:
HIGH SENSITIVITY & (possibly) ANGULAR and/or SPECTRAL RESOLUTION !

Molecular emission from CTTSs with Herschel

GASPS: GAS in Protoplanetary System (PI: B. Dent)

Herschel/PACS survey of atomic/molecular gas and dust in ~ 200 disks
wide range of ages: 1-30 Myr
disk masses: 10^{-1} – 10^{-5} Msol
Class II/III sources
spectral types (A to M)
Nearby star-forming regions (Taurus, ηCha, βPic, Herbig Ae/Be, ...): d ~100-200 pc

Dent et al. 2013

MOLECULAR LINES: H_2O, OH, high-J CO (J ≥ 18)

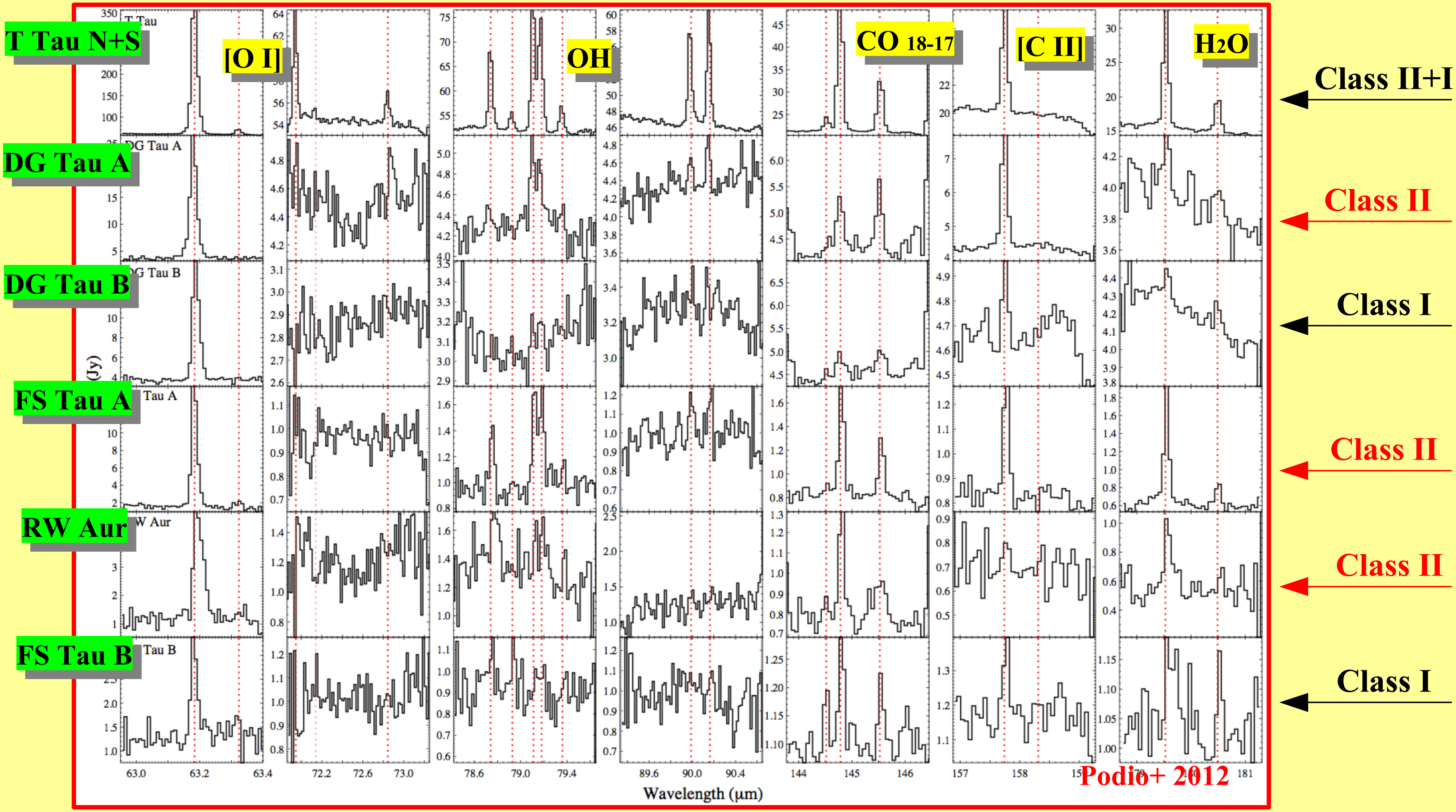
ATOMIC LINES: [OI] 63, 145 um, [CII] 158 um

- ***DISKS***
- ***SHOCKS in the jet***
- ***OUTFLOW cavities***

optical-JET SOURCES ---> FIR ATOMIC, MOLECULAR emission

ATOMIC LINES, i.e. [O I] 63 μm, [C II] 158 μm □ **Extended**, velocity shifted

MOLECULAR LINES, i.e. high-J CO, OH, H_2O □ **Unresolved** with PACS



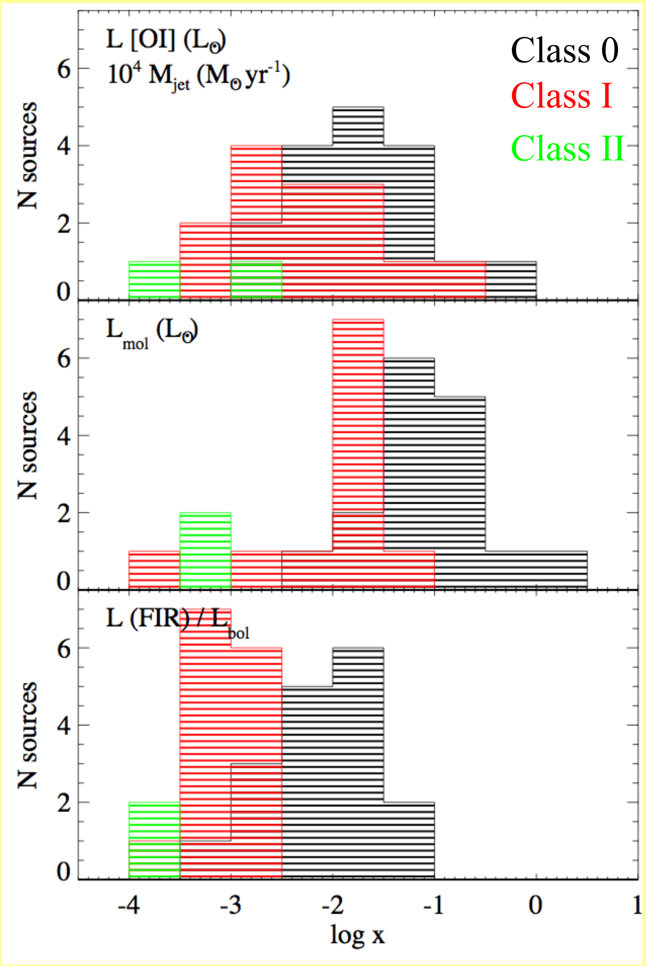
Thanks to Herschel sensitivity we can observe FIR emission associated to CTTSs down to a few 10-18 W/m2 !

FIR cooling & mass loss rate: an evolutionary picture

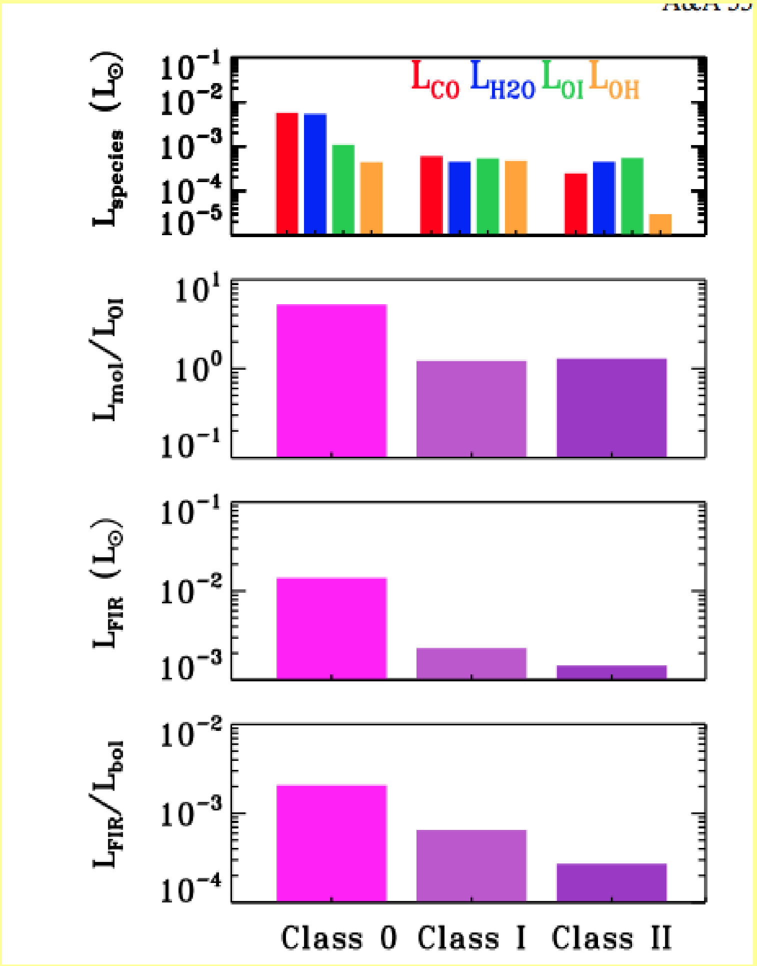
[O I] cooling

Molecular cooling (H_2O, CO)

Outflow efficiency L_{FIR}/L_{bol}



Podio+ 2012



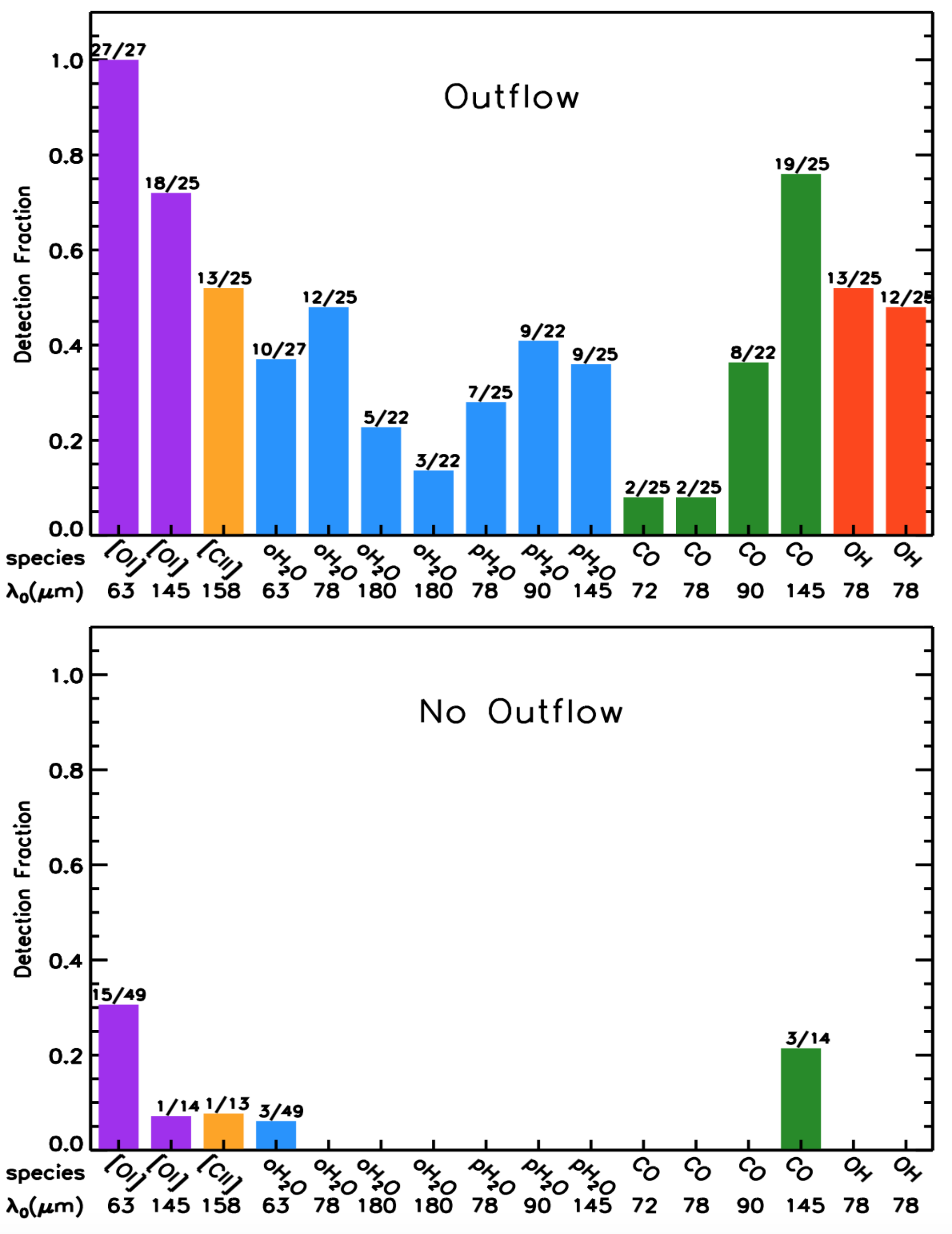
Karska+ 2013

Class 0	Giannini+ 2001 (ISO)
Class I	Nisini+ 2002 (ISO)
	Podio+ 2012 (PACS)
Class II	Podio+ 2012 (PACS)

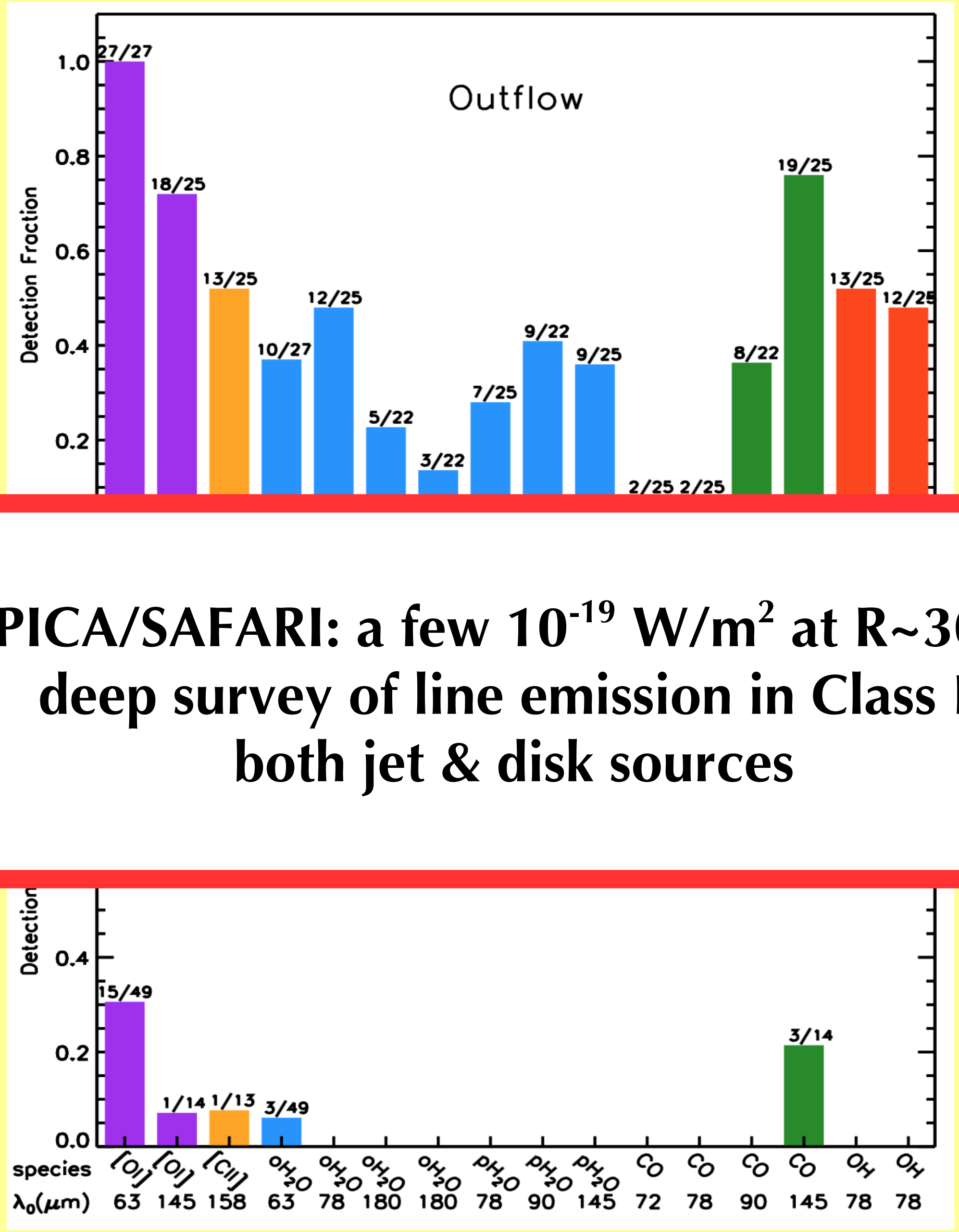
Class 0/I	Karska+ 2013 (PACS)
Class II	Podio+ 2012 (PACS)

Survey of atomic/molecular line emission from CTTSs in Taurus

Alonso-Martinez & GASPS team, 2016



<u>Herschel sensitivity limit</u> □ very few detection in non-outflow sources

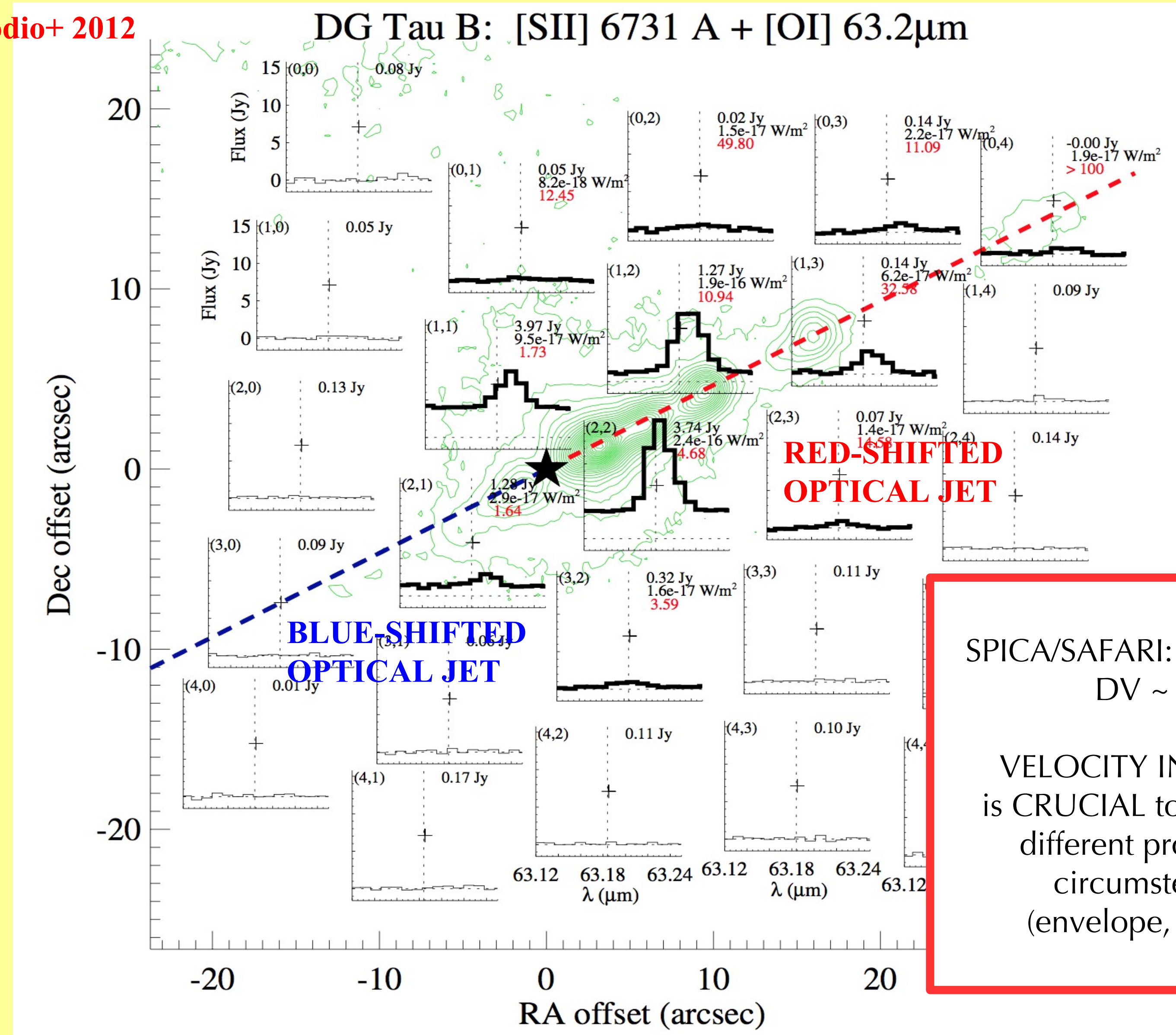


Alonso-Martinez & GASPS team, 2016

SPICA/SAFARI: a few 10^{-19} W/m^2 at R~3000
deep survey of line emission in Class II
both jet & disk sources

Herschel limit in spectral/spatial resolution □ jet vs disk emission ?

Podio+ 2012



Herschel/PACS obs:

<u>LOW SPATIAL RESOLUTION</u>
1 spaxel = 9.4″ x 9.4″

<u>LOW SPECTRAL RESOLUTION</u>
DV > 80 km/s

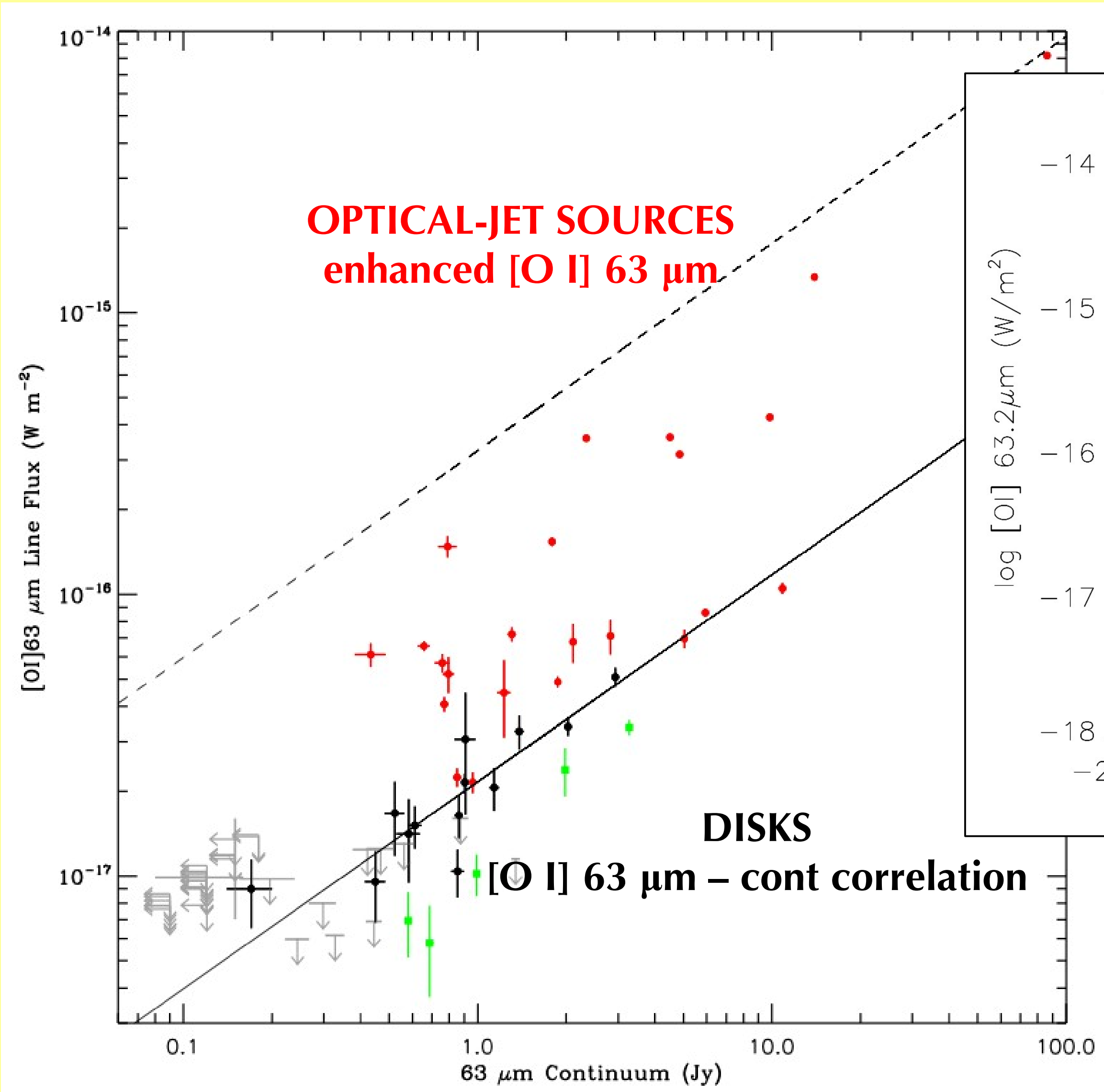
\+ line broadened/shifted when emission is extended

Herschel/PACS:
gas kinematics "resolved" only for fast & bright jets !

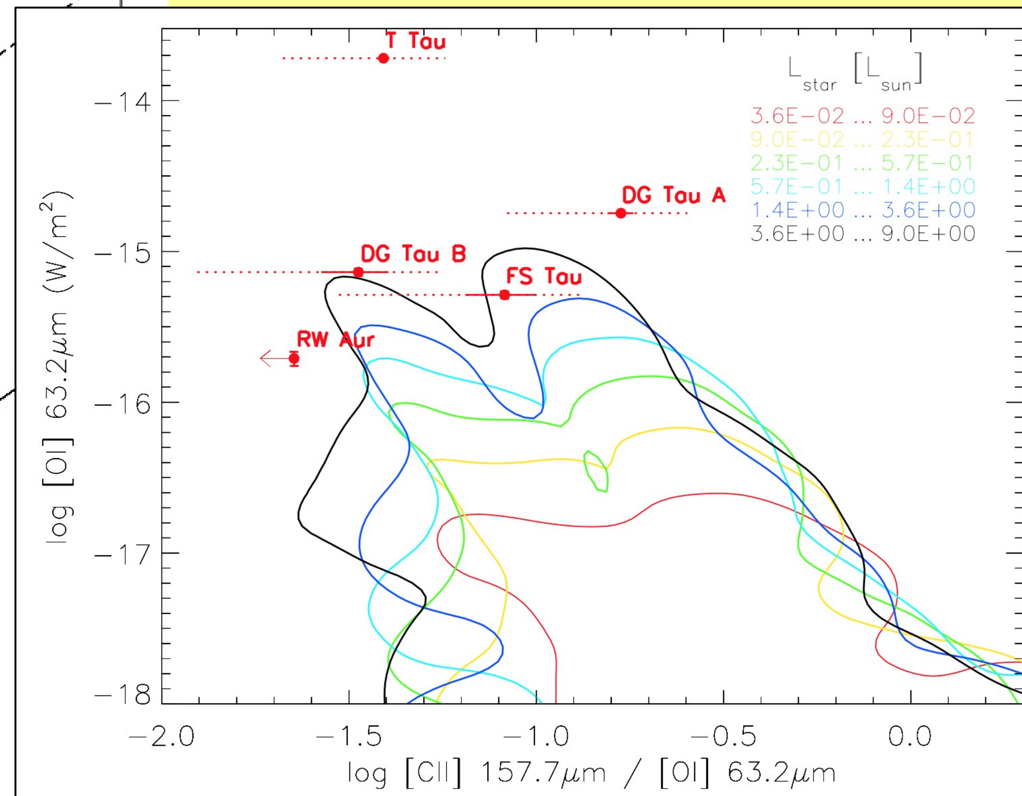
SPICA/SAFARI: R~6000 at 63um
DV ~ 50 km/s

VELOCITY INFORMATION is CRUCIAL to disentangle the different processes in the circumstellar region (envelope, disk, jet , …)

[O I] 63 um in Taurus/Auriga – disk or outflow emission ?



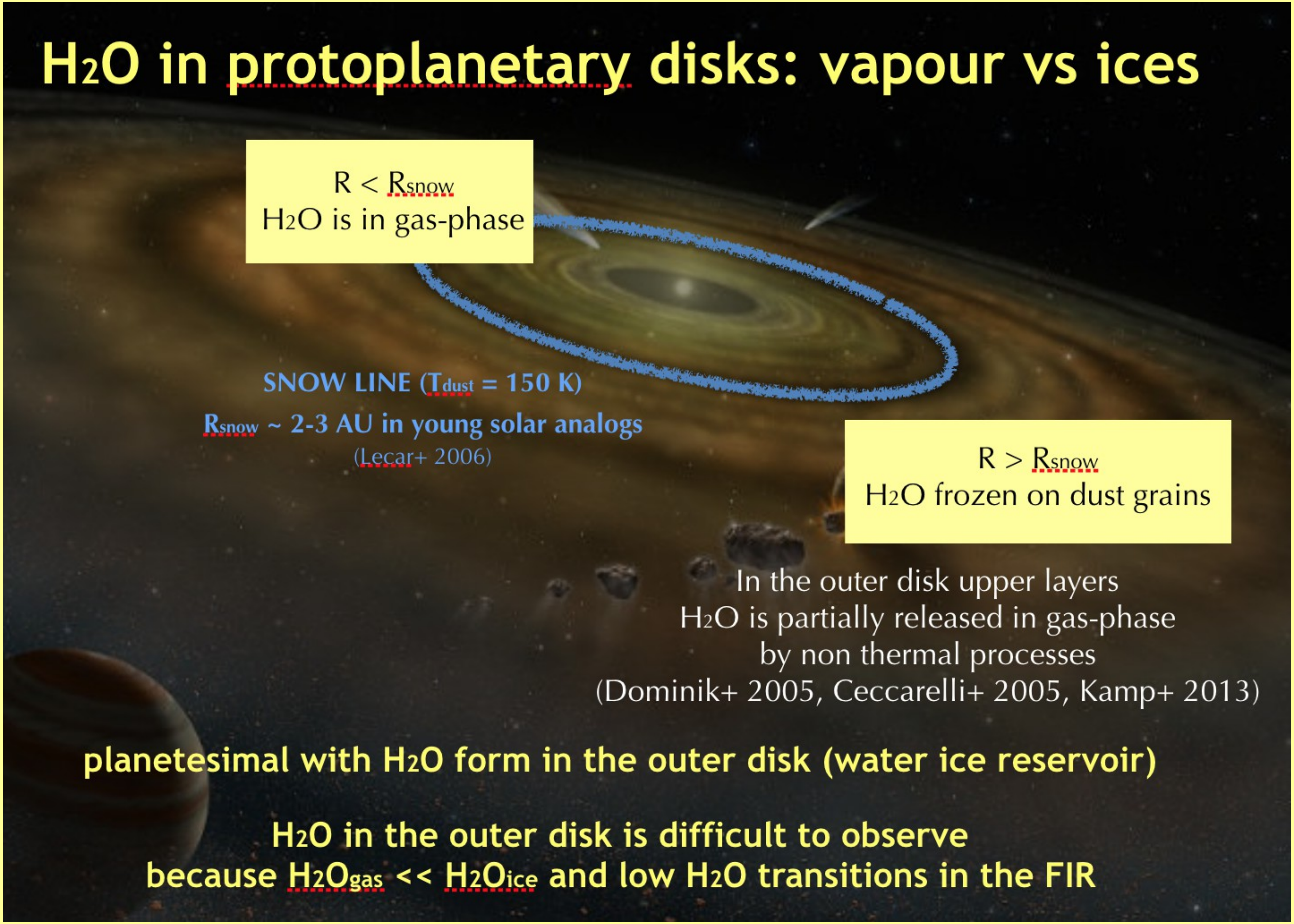
Howard+ 2013



Podio+ 2012

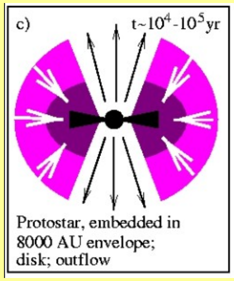
Line origin using diagnostic plots,
e.g. DENT grid of shock models
(Woitke et al. 2009, Kamp et al. 2010)

Searching for water in young solar analogs

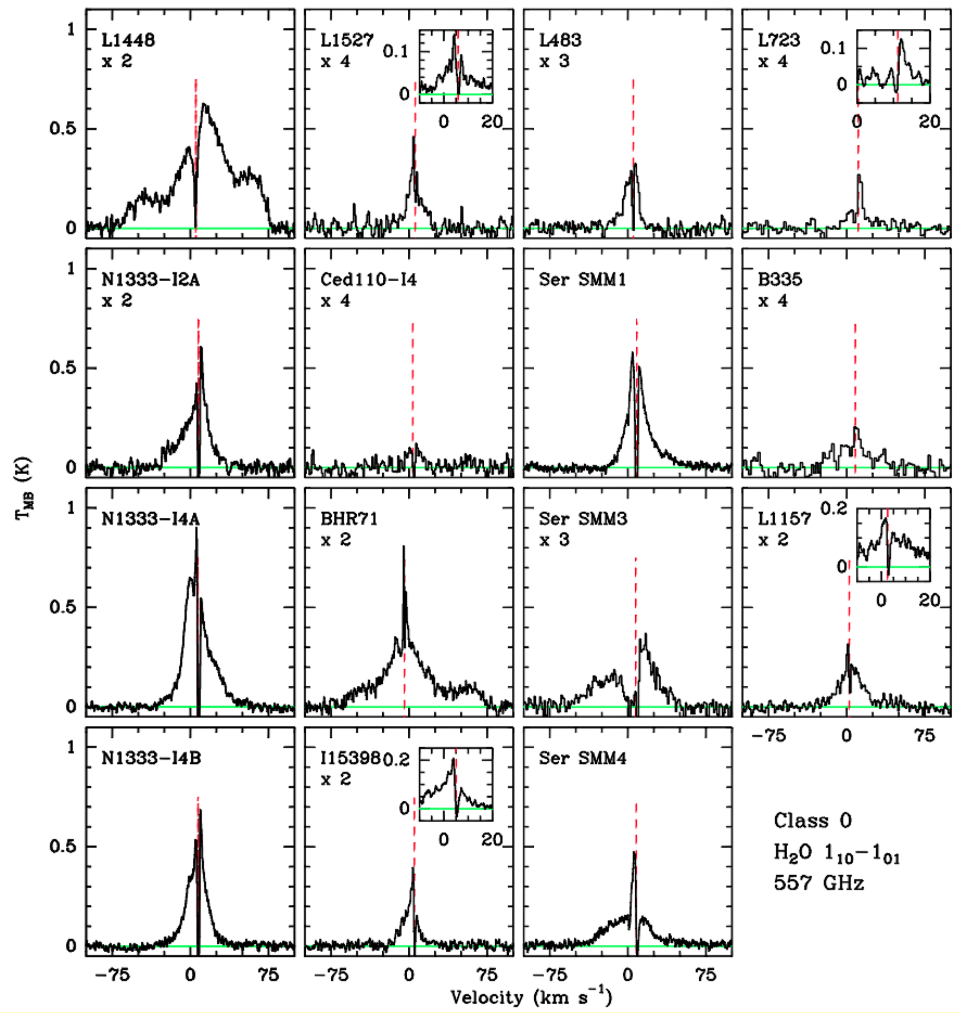


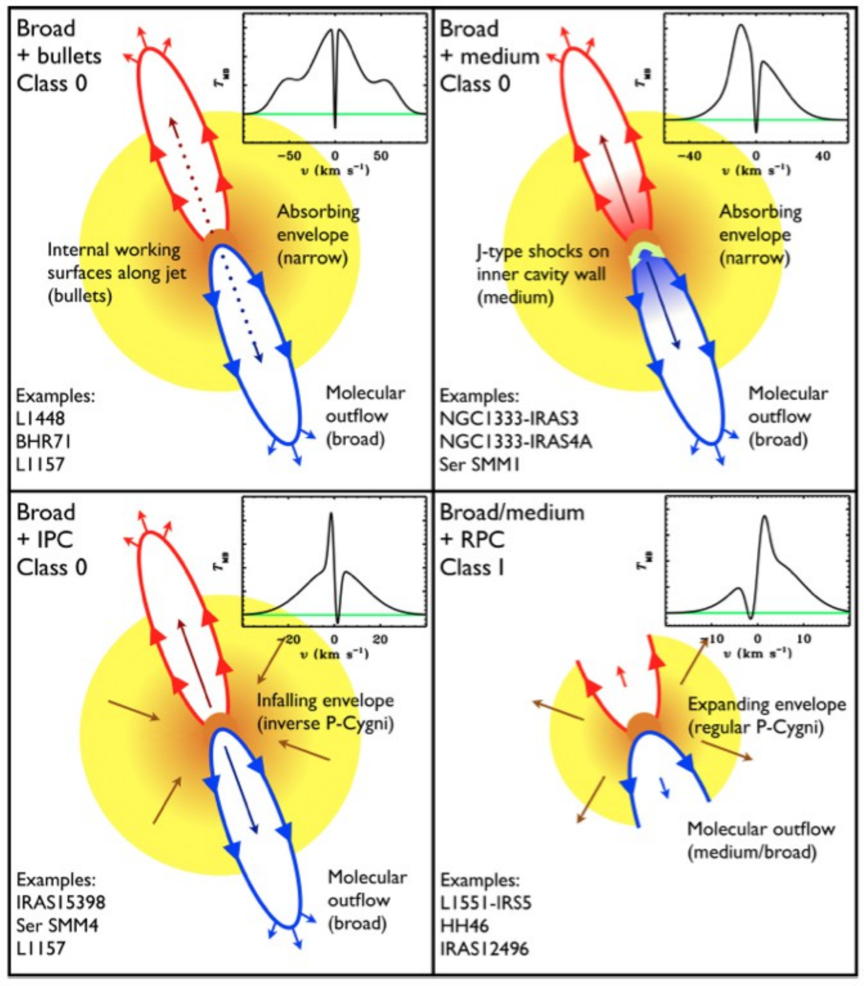
Low-exc H_2O 1_{10}-1_{01} (557 GHz, E_{up} ~ 61 K) from Class 0/I sources dominated by ENVELOPE + OUTFLOW emission

Class 0/I



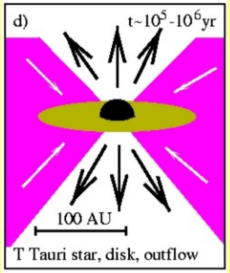
Kristensen+ 2012



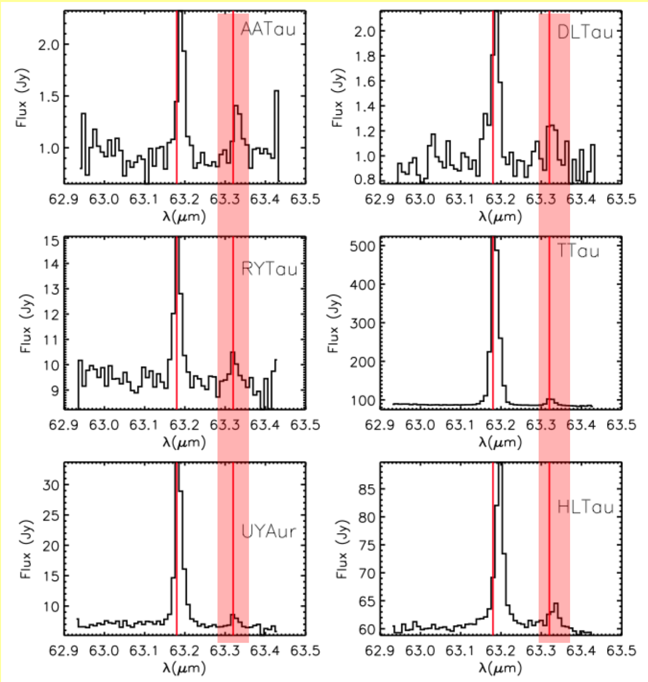


in Class II ?
High excitation H_2O lines from INNER DISK

Class II



detected in 8 TTSs in Taurus ...

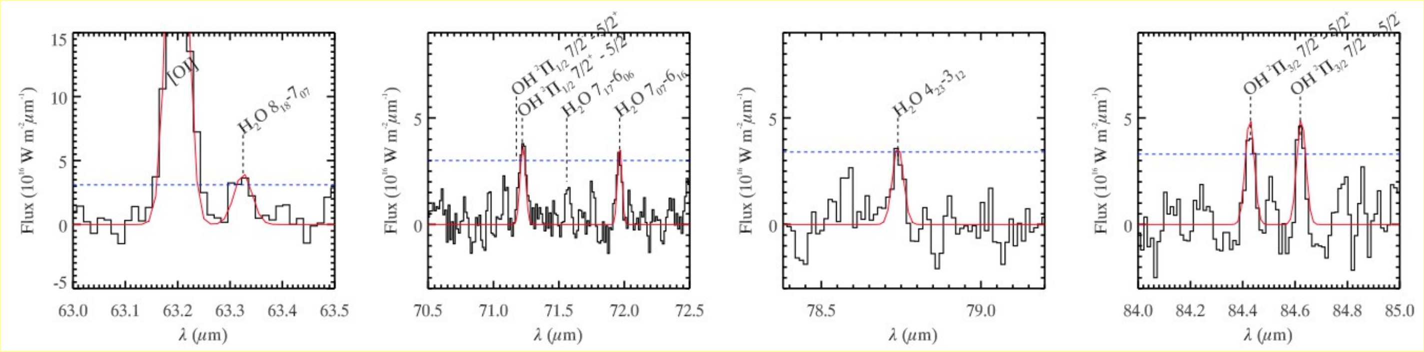


H_2O 63.32um
(E_{up} ~ 1007 K)

Riviere-Marichalar+ 2012

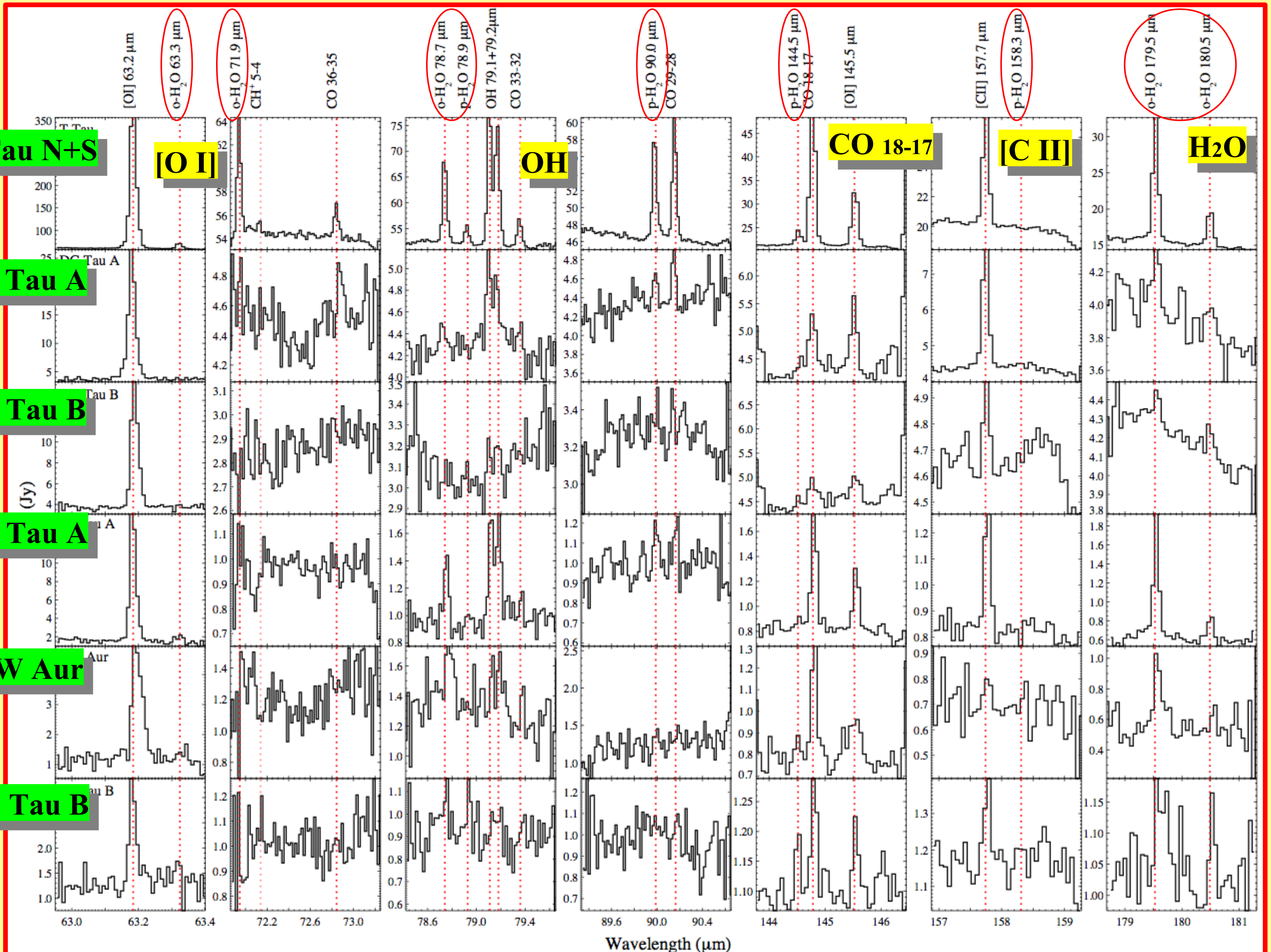
... and in 1 Herbig Ae/Be

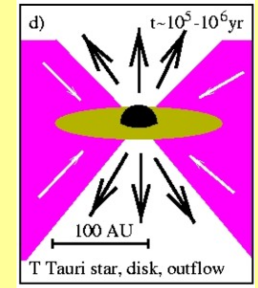
HD 163296



Meeus+ 2012, Fedele+ 2012

Low- and high- exc H_2O (E_{up}~100-1000 K) in jet-driving sources





Herschel/PACS obs

Podio+ 2012

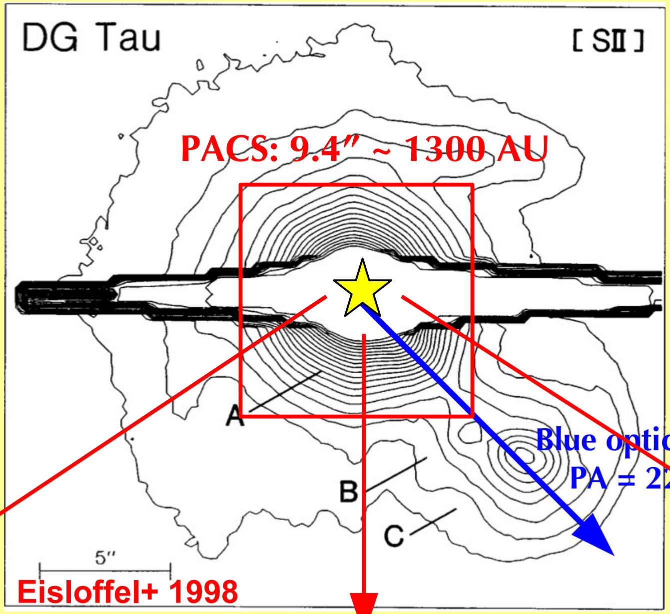
Origin of H_2O emission ??

Herschel/PACS obs:

LOW SPATIAL RESOLUTION
1 spaxel = 9.4″ x 9.4″

LOW SPECTRAL RESOLUTION
DV > 80 km/s

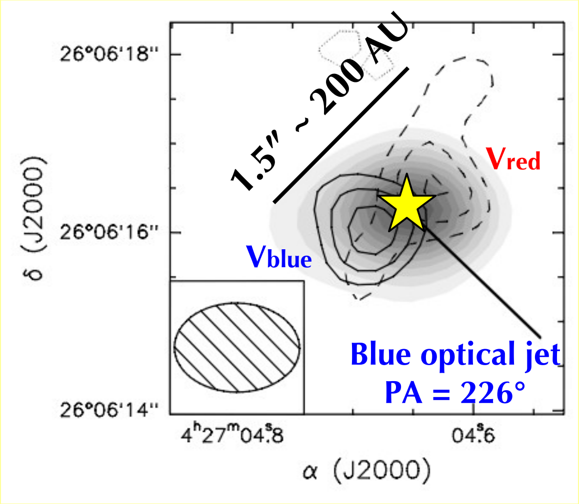
H_2O emission spectrally and spatially unresolved !!



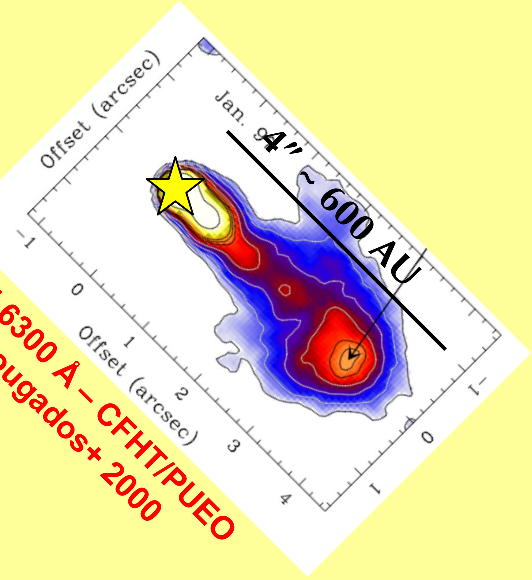
Young solar-analog DG Tau

D = 140 pc
$M_* = 0.7\ M_\odot$
$L_* = 1\ L_\odot$
age = 2.5 Myr

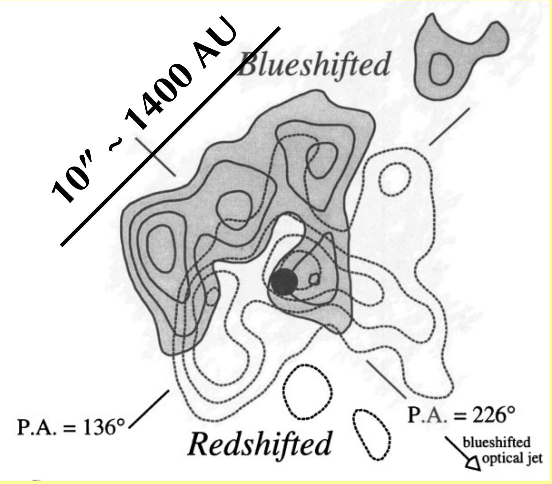
DISK ? **or JET ?** **or ENVELOPE ?**



^{13}CO 2-1 – OVRO – Testi+ 2002



[O I] 6300 Å – CFHT/PUEO
Dougados+ 2000



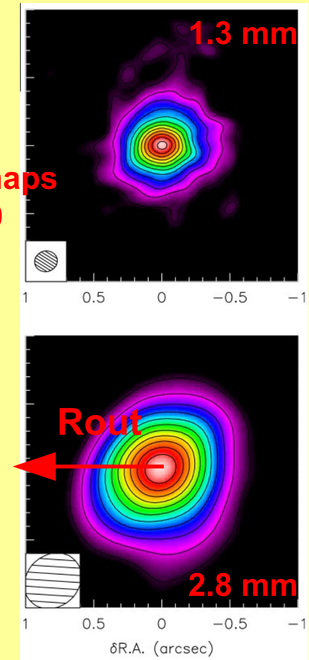
^{13}CO 1-0 – Kitamura+ 1996

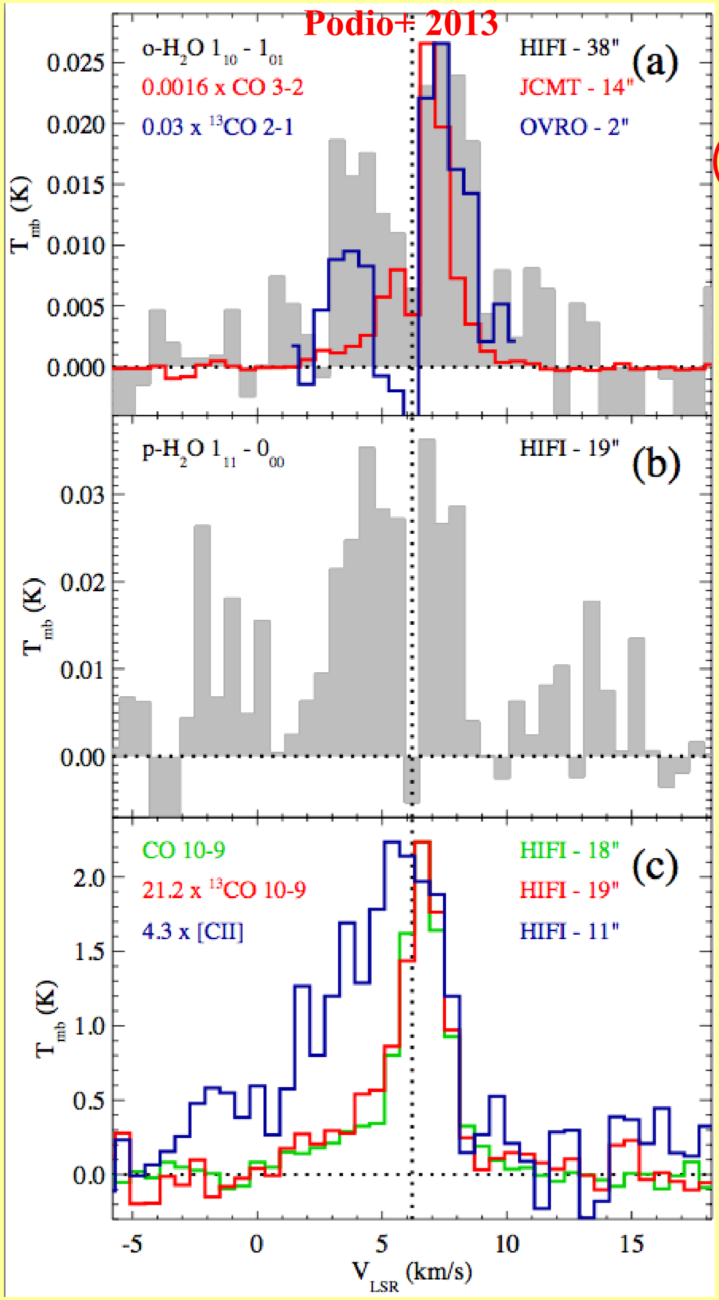
Herschel/HIFI observations of DG Tau
evidence of low-exc WATER emission from OUTER DISK !

1. double-peaked profile:
strong kinematic evidence
of keplerian rotating disk !

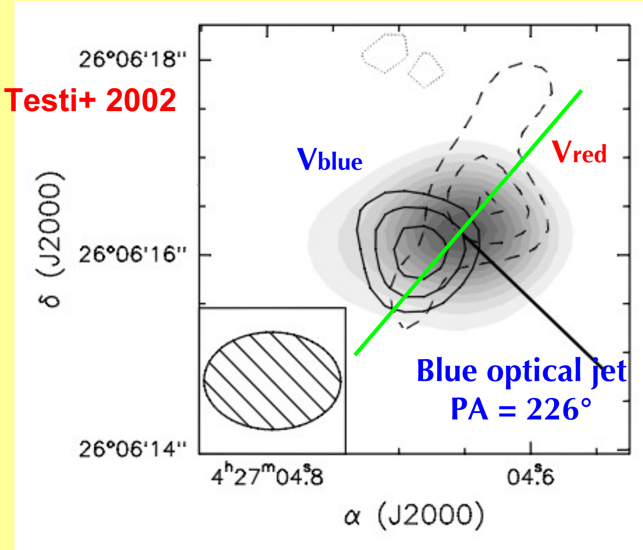
2. $R_{out}(H_2O) \sim 77\text{-}105$ AU $\sim R_{out}$(dust)

CARMA cont maps
Isella+ 2010





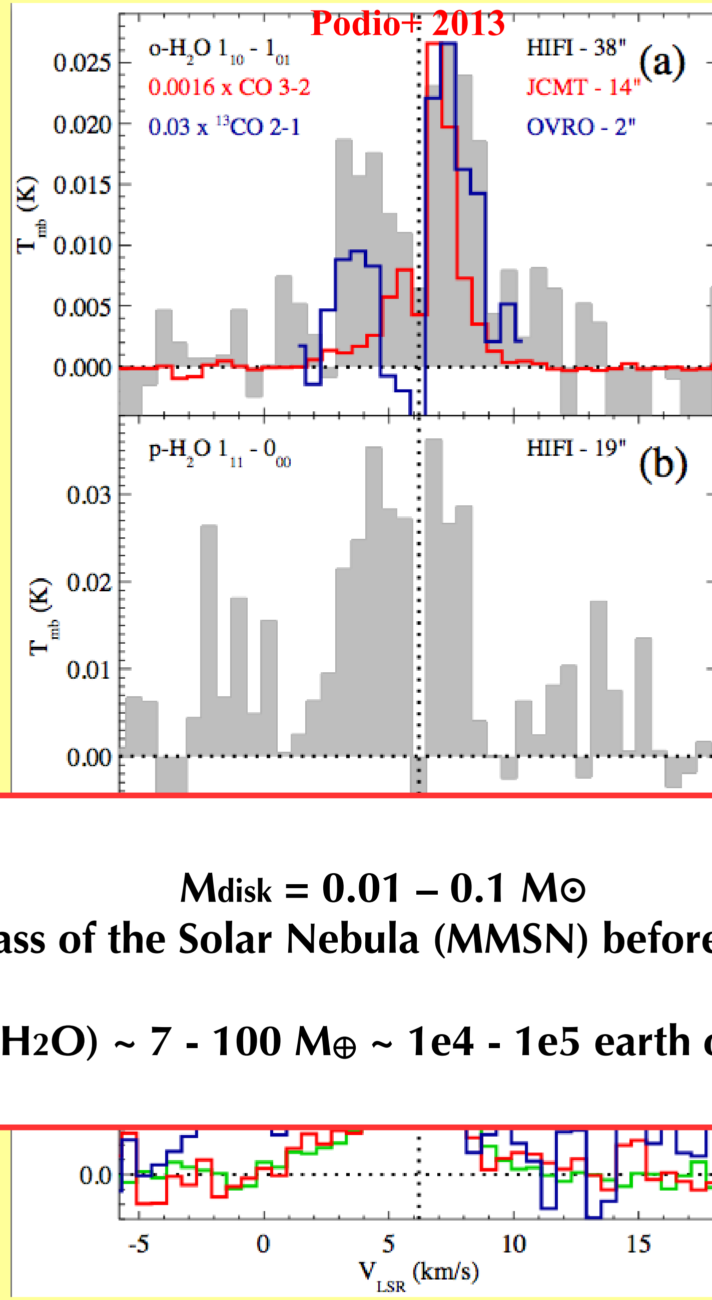
3. H_2O line peaks in the velocity ranges
where ^{13}CO 2-1 interf maps
trace the disk rotation
(V gradient perp to jet direction)



Herschel/HIFI observations of DG Tau
evidence of cold WATER emission from OUTER DISK !

1. double-peaked profile:
strong kinematic evidence
of keplerian rotating disk !

2. $R_{out}(H_2O)$ ~ 77-105 AU ~ R_{out}(dust)



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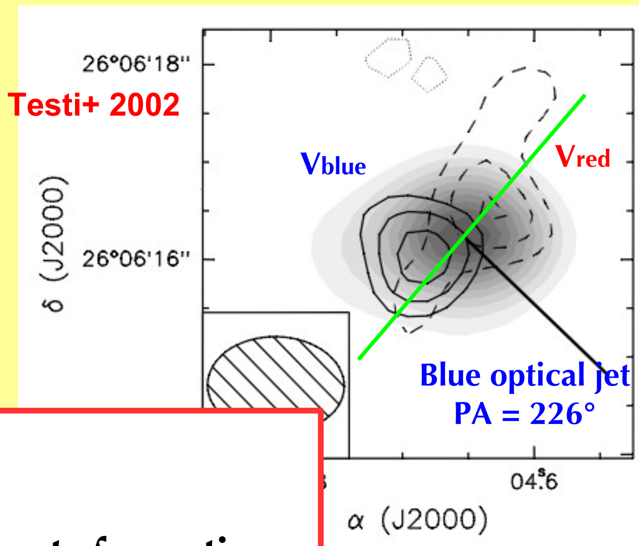
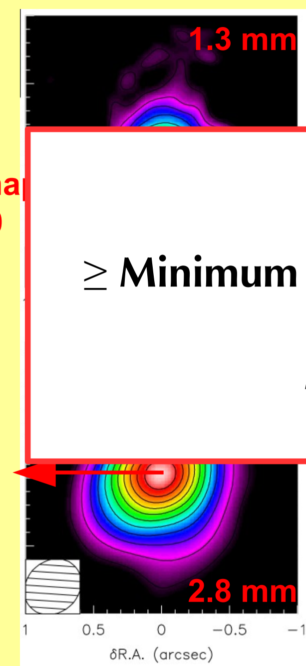


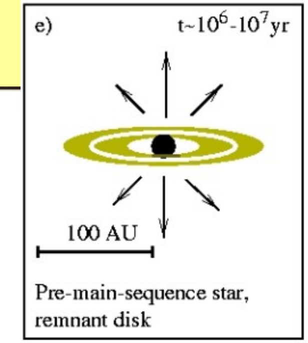


CARMA cont map
Isella+ 2010

Mdisk = 0.01 – 0.1 M⊙
≥ Minimum Mass of the Solar Nebula (MMSN) before planets formation

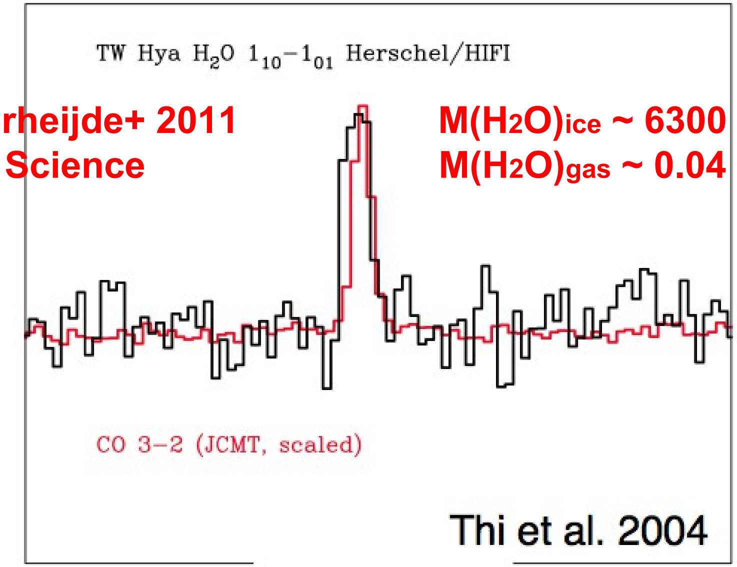
M(H_2O) ~ 7 - 100 M⊕ ~ 1e4 - 1e5 earth oceans

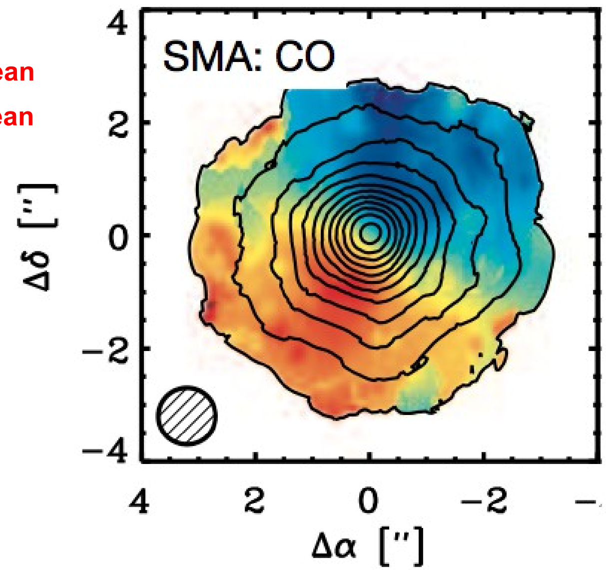
Clear detection of col H_2O from more evolved sources



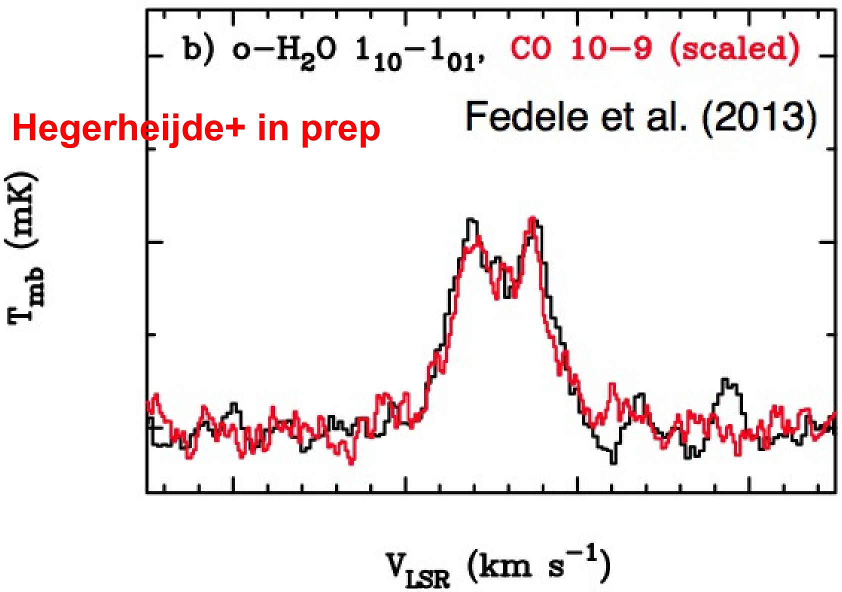
Hegerheijde+ 2011 Science

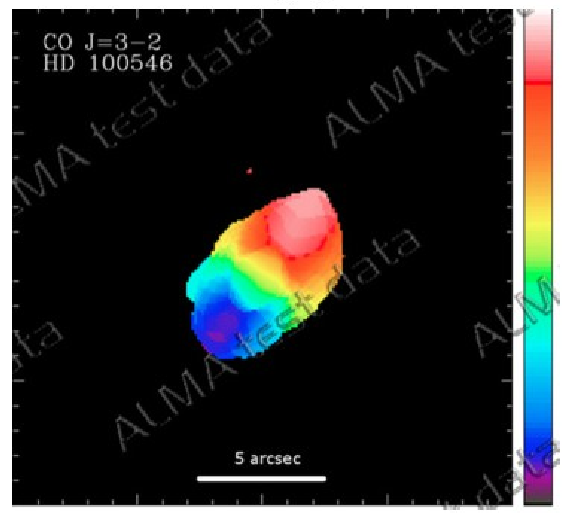
M(H_2O)ice ~ 6300 Mocean
M(H_2O)gas ~ 0.04 Mocean





Hegerheijde+ in prep

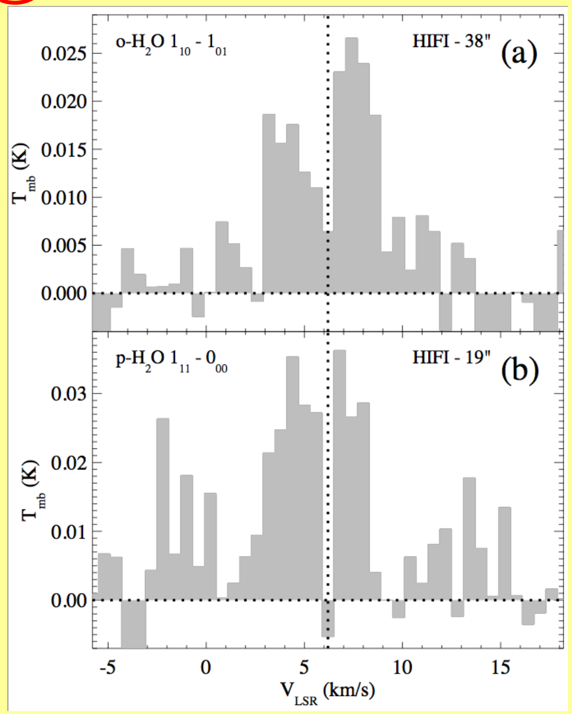




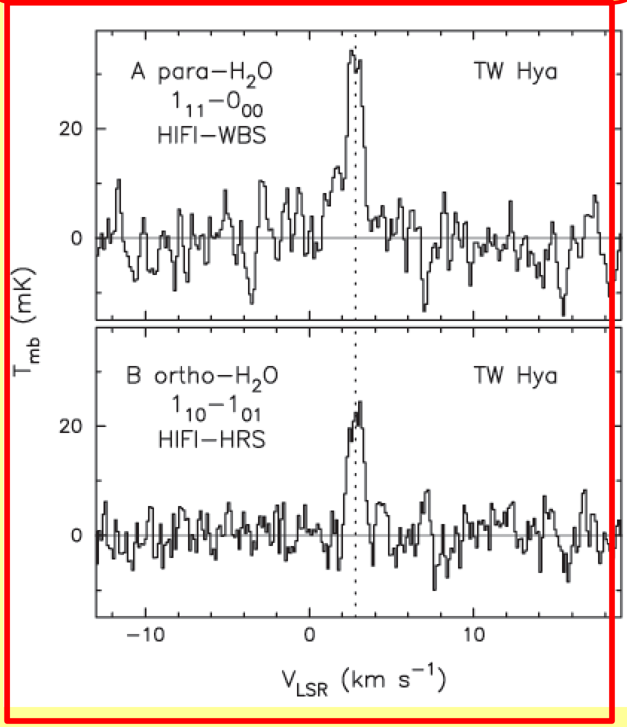
From M. Hogerheijde presentation
Herschel conference

Detections of water in disks with Herschel

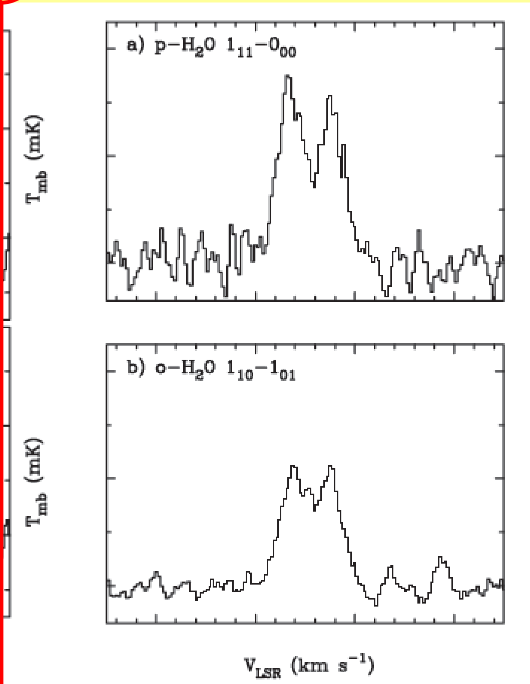
2. DG Tau (Podio+ 13)



1. TW Hya (Hogerheijde+ 11)



3. HD 100546 (Hogerheijde+, in prep)



From M. Hogerheijde presentation
Herschel conference

OT1-OT2 programs on disk sources (PI: Hogerheijde): 200 hours of observing time

<u>---> detection only in 2 sources (TW Hya, HD 100546)</u>

---> upper limits for 5 sources (DM Tau, AA Tau, HD 163296, LkCa15, MWC 480)

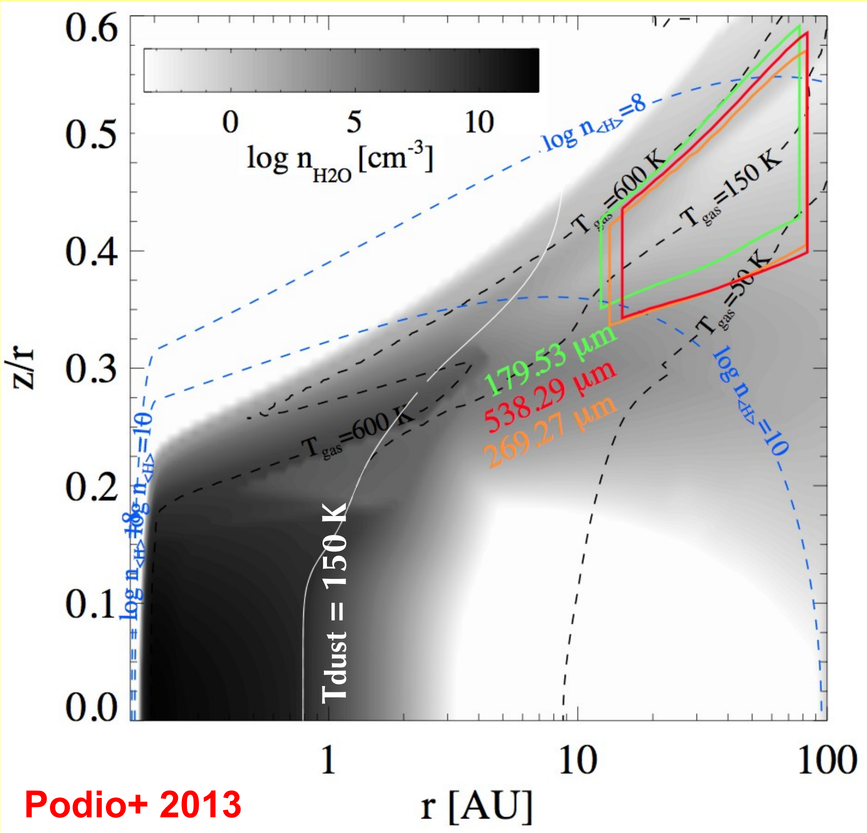
OT1 program on jet sources (L. Podio): 26 hours of observing time

<u>---> disk origin only in 1 source (DG Tau)</u>

---> H_2O by envelope/outflow in T Tau, FS Tau + upper limits for 4 sources (DG Tau B, RW Aur, HD 163296, AB Aur)

WATER in protoplanetary disks with SPICA

DG Tau DISK model
region emitting low-exc H2O lines



***Pro**toplanetary **Di**sk **Mo**dels (ProDiMo)*

Woitke+ 2009, Kamp+ 2010, 2013, Thi+ 2011
Aresu+ 2011, 2012, Meijerink+ 2012

H2O 179.5um line
- probe for cold water vapour in the outer disk
suitable for a survey with SPICA
down to 10^{-19} W/m^2

PB: NO SPECTRAL (& spatial) RESOLUTION !!!

interpretation on line origin is based on models

Line emission from CTTSs with SPICA

SPICA - SAFARI

PLUS up to 2 orders of magnitude more sensitive than Herschel !

~10^{-19} W/m^2, 5 sigma, 1 hr at R~3000

1. Survey of atomic/molecular content of CTTSs (jets & disks)

2. systematic search of cold water from outer regions of protoplanetary disks with H_2O 179.5um

MINUS Low spatial/spectral resolution

difficult to disentangle different processes in the circumstellar region

no resolved profile for line emission from outer disk

SPICA/SMI: high-R (~20 000 – 30 000) spectra at 12-18um

Spectrally resolved high-exc ***H_2O lines from inner disk SNOWLINE***

High-exc H_2O lines (E_{up} ~ 1000-5000 K) were spectrally unresolved with Herschel/PACS and Spitzer

Only partially resolved from ground with VLT-VISIR (Pontoppidan+ 2010b)

Will not be resolved with JWST (R~2000)