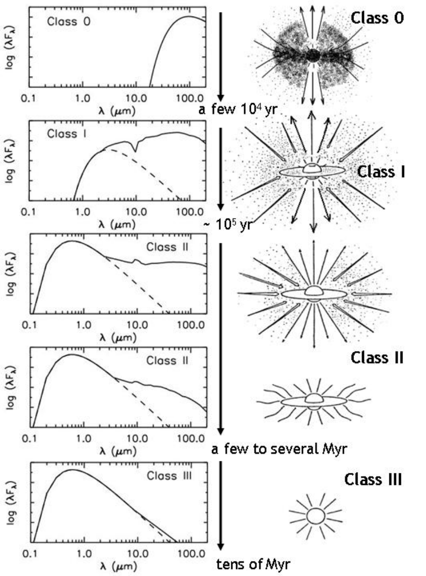
Multi-wavelength Spectroscopic Observations Of Young Stellar Objects

P. Rivière-Marichalar

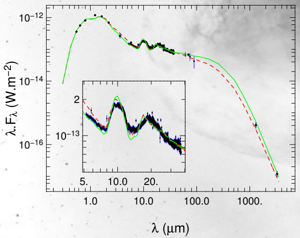
ESAC Science Seminars, February 2017

On behalf of C. Eiroa, I. Kamp, B. Merín, B. Montesinos

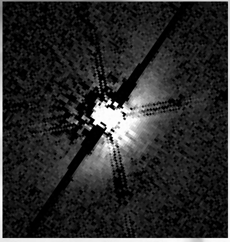

Class 0
log (λF_λ)
0.1
1.0
10.0
100.0
λ (μm)
a few 10⁴ yr
Class I
~ 10⁵ yr
Class II
a few to several Myr
Class III
tens of Myr

Protoplanetary discs

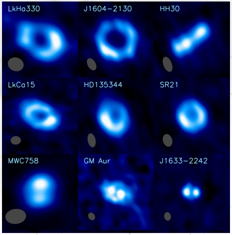
- Discs of gas and dust surrounding young stars. Birthplace for planets
- Dust: IR-excess.
  - SED modelling
  - Scattered light
  - Resolved thermal emission
- Gas: spectroscopy at many wavelengths



SED: dust
Pinte+ (2008)



Scattered light imaging: dust
Pinte+ (2008)



Continuum thermal emission: dust
Williams and Cieza (2009)

Protoplanetary discs

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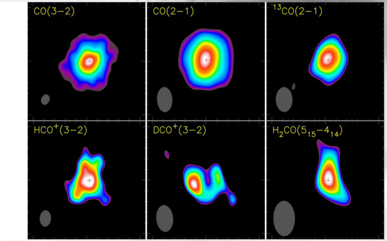
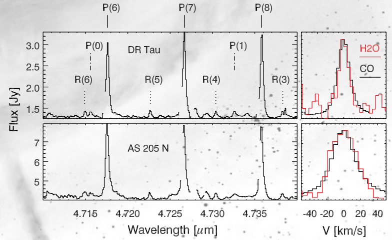
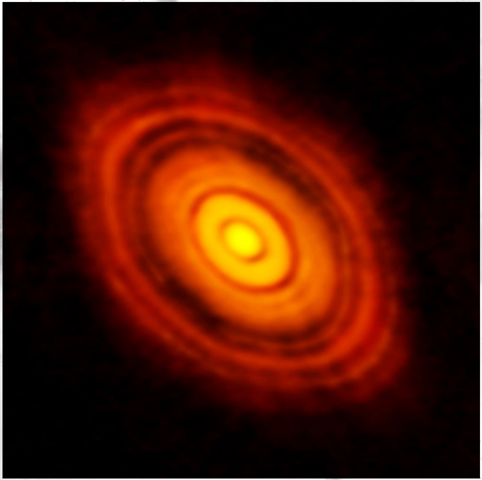


Sub-mm spectroscopy: gas
Williams and Cieza (2009)



Near-IR spectroscopy: gas
Salyk+ (2008)

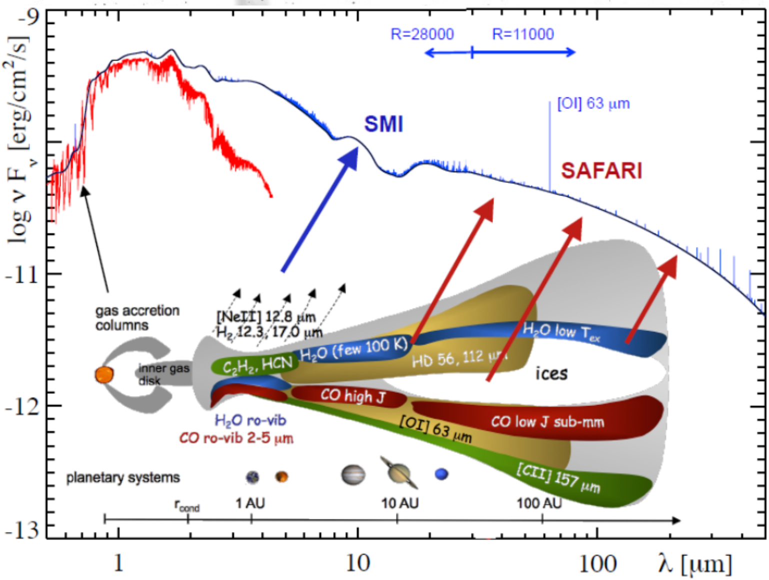
Plane formation?



(ALMA consortium)

Gas VS dust

- A **gas-to-dust ratio of 100** is typically assumed
- However, gas is much harder to observe
- First detections in the 80s: **IR-excess** $\rightarrow$ **dust**
- First observations of gas in the disc were indirect: accretion signatures on the star's surface (H_{α})
- ISO detected gas emission from prominent sources
- **ISO: the most prominent and and frequent far-IR emission line is that of [OI] at 63** $\mu\mathrm{m}$


log ν F_ν [erg/cm²/s]
-9
-11
-12
-13
1
10
100
λ [μm]
R=28000
R=11000
[OI] 63 μm
SMI
SAFARI
gas accretion columns
[NeII] 12.8 μm
H₂ 12.3, 17.0 μm
inner gas disk
C₂H₂, HCN
H₂O (few 100 K)
HD 56, 112 μm
H₂O low T_ex
ices
CO high J
H₂O ro-vib
CO ro-vib 2-5 μm
[OI] 63 μm
CO low J sub-mm
[CII] 157 μm
planetary systems
r_cond
1 AU
10 AU
100 AU

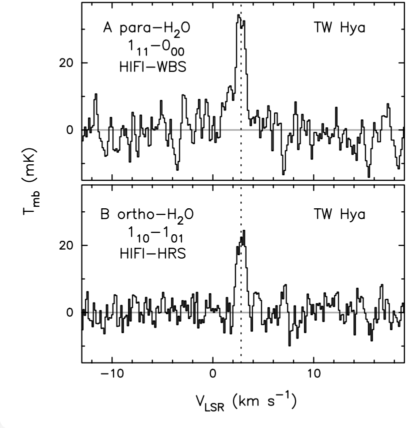
Herschel contribution

- Cold water vapor in TWA Hogerheijde et al. (2011)
- Discovery of warm water vapor in protoplanetary discs in Taurus (Riviere-Marichalar+, 2012)
- TW Hya gas modelling (Thi+, 2010)

Herschel contribution

TW Hya cold water

- C
- D
(F
- T



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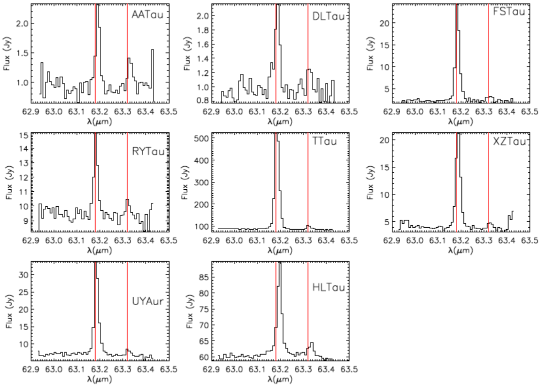
Herschel contribution

Taurus warm water



- C
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Herschel contribution

Taurus warm water

- C
- D
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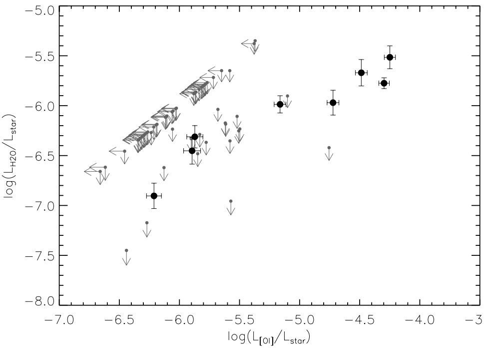
- T



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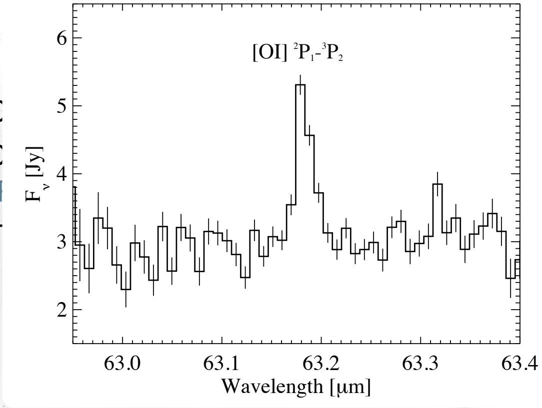
Herschel contribution

[OI] in TW Hya



- C
- D
  (I
- T

The mistery

Where does the emission comes from?

- The envelope?
- The disc?
- Jest and winds?

→**Track evolution of gas emission with class (evolutionary stage)**

YSO evolution as seen by Herschel: Class 0 (embedded sources)

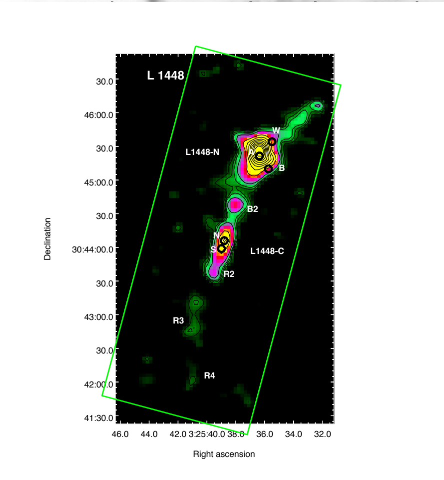
- CO rotational diagrams show two components (Karska+ 2015)
- "In many sources, [OI] is of greater spatial extent than CO" (Green+ 2013)
- No link between Spitzer and Herschel tracers of outflowing gas and (Green+ 2013)
- No link between Spitzer and Herschel fine structure lines (Green+ 2013)

YSO evolution as seen by Herschel: Class 0 (embedded sources)

- "[...] shocks are more important than the passively heated envelope in powering the far-IR lines" van Kempen+ (2010)
- [OI] extended emission along the outflow direction (Podio+ 2012, Nisini+ 2015)
- **[OI] emission towards Class 0 seems to be dominated by the jet, with contributions from the passively heated envelope and shocks along the cavity walls.**

YSO evolution as seen by Herschel: Class 0 (embedded sources)

- "[...] shocks a ... ely heated envelope in p... en+ (2010)
- [OI] extended ... on (Podio+ 2012, Nisini+ 2015)
- **[OI] emissio... ominated by the jet, with cont... ted envelope and shocks a...**



YSO evolution as seen by Herschel: Class I

- Two components, as in Class I, but the hot component is weaker compared to Class 0 (Karska+ 2013): weaker jets?

YSO evolution as seen by Herschel: Class II

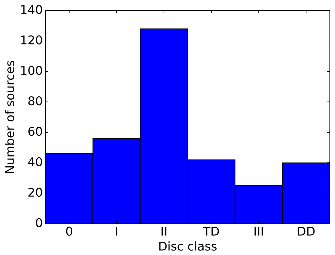
- Emission aligned with jet direction in sources with known jets (Podio+ 2012)
- Most [OI] detections are in sources with a jet, but not all of them (Howard+ 2013)
- Warm water detections only observed in sources with a jet (Riviere-Marichalar+ 2012)

Herschel data can contribute to solve the mistery... $\rightarrow$ my ESA fellowship

The idea

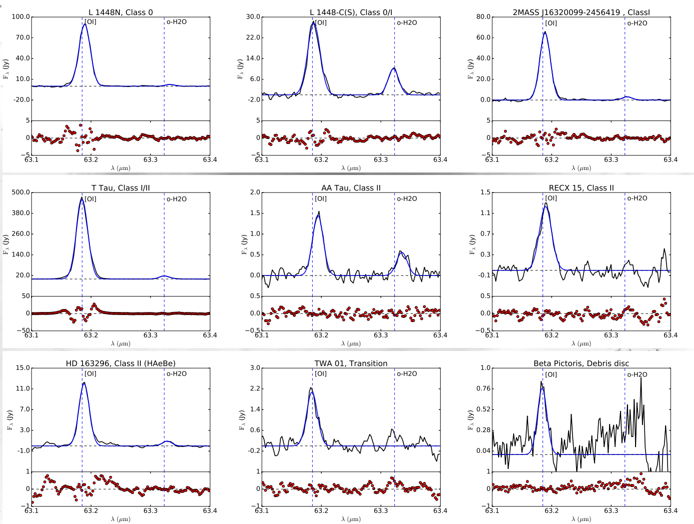
- Use the *Herschel*-PACS catalogue to look for spectroscopic observations of [OI] and H_2O in YSO 63 μm
- Why 63 μm? It is the more visited wavelength, and we can analyze two transitions in a single shot
- Take advantage of PACS spatial resolution to retrieve information about the spatial distribution of the lines
- Carefully analyze the profile of the lines to look for different dynamical contributions

The sample

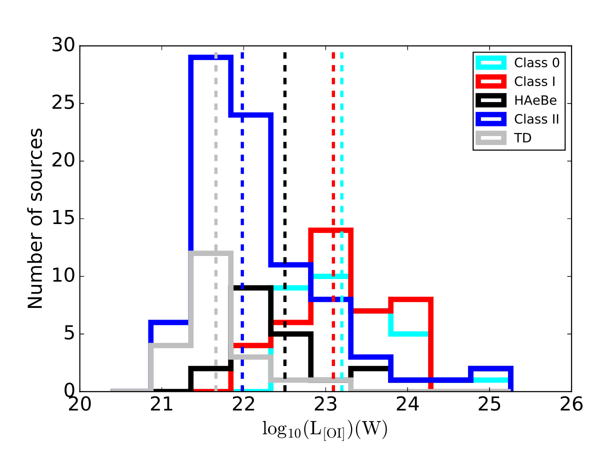


Program ID	observations	Sensitivity
–	–	$(10^{-18}\mathrm{W/m^2})$
GT1_vgeers_1	2	2.5
KPOT_bdent_1	185	3.1
KPOT_nevans_1	65	7.3
KPGT_golofs01_1	6	2.9
KPGT_evandish_1	28	8.6
OT1_ascholz_1	1	1.2
OT1_cespaill_2	38	20.0
OT1_ckiss_1	9	3.5
OT1_gmeeus_1	2	28.0
OT1_ipascucc_1	30	1.6
OT1_maudar01_1	11	23.0
OT1_vgeers_2	4	2.5
OT2_amoor_3	2	3.8
OT2_evandish_4	49	7.7

Some examples

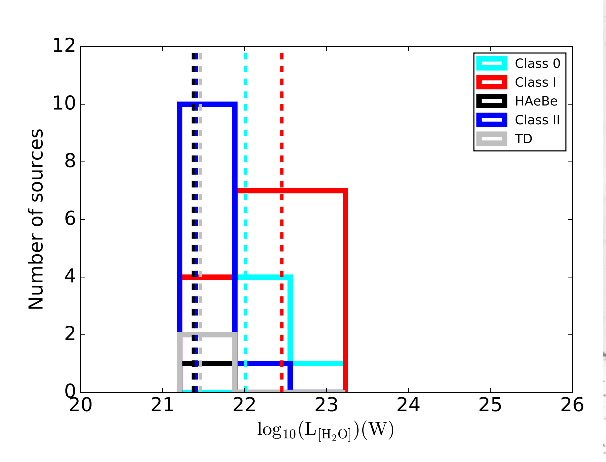


Luminosity distributions: [OI] 63 μm



Evolutionary trend: weaker $L_{[OI]}$ for more evolved sources

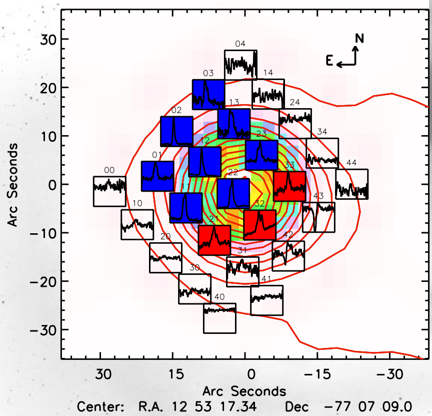
Luminosity distributions: H_2O 63 μm



Evolutionary trend: weaker L_{H_2O} for Class II sources and transitional

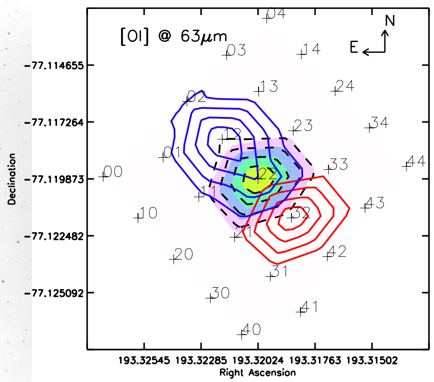
The case of DK Cha

DK Cha shows clear signs of [OI] extended emission



The case of DK Cha

... and many components



[OI] extended emission?

PACS IFU: compare integrated and central spaxel fluxes

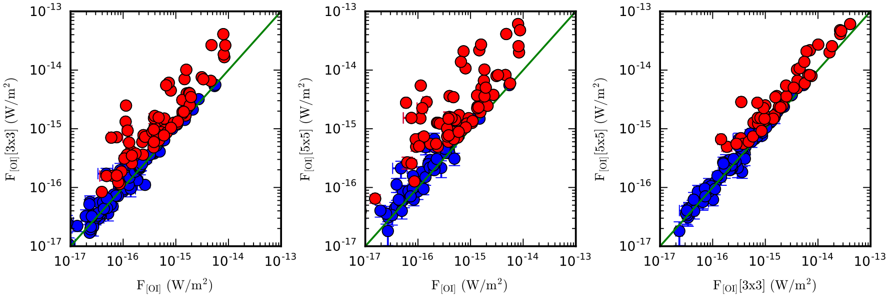
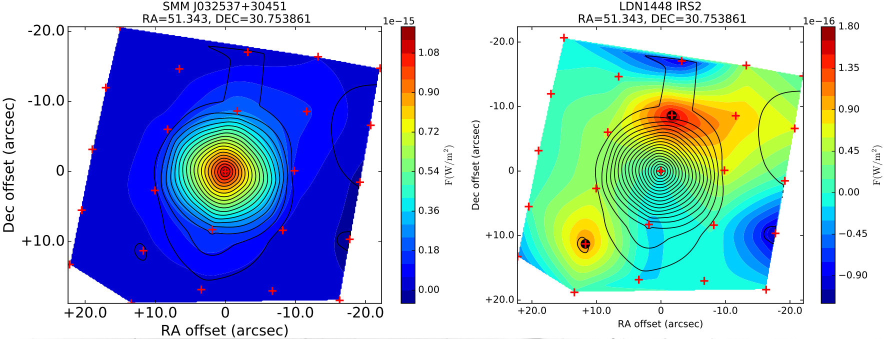


Figure: Extended emission tests for sources in the sample. Red dots identify sources showing extended emission in each of the tests used. The solid diagonal line depicts a one-to-one to help identifying extended emission.

[OI] extended emission? Line emission and residual maps



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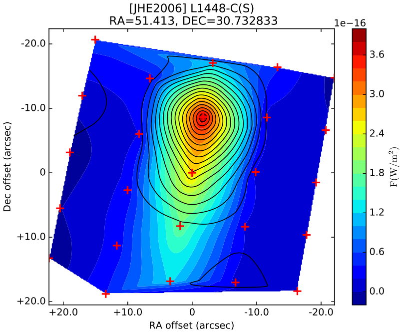

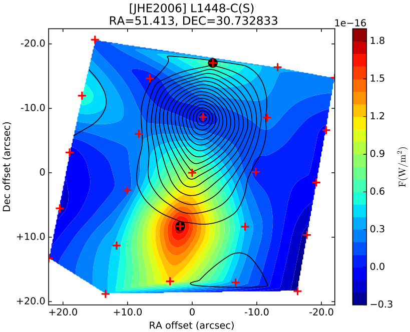

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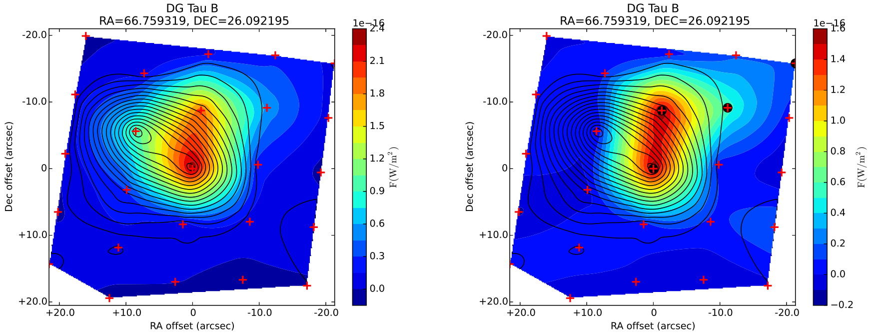

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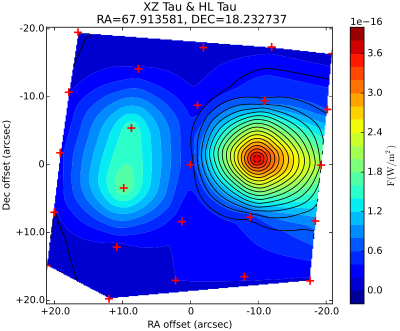

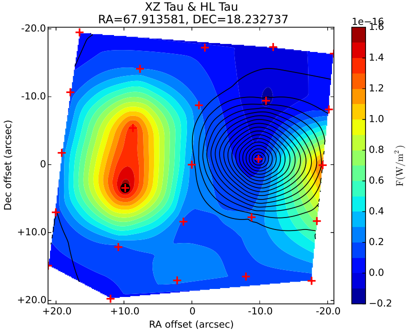

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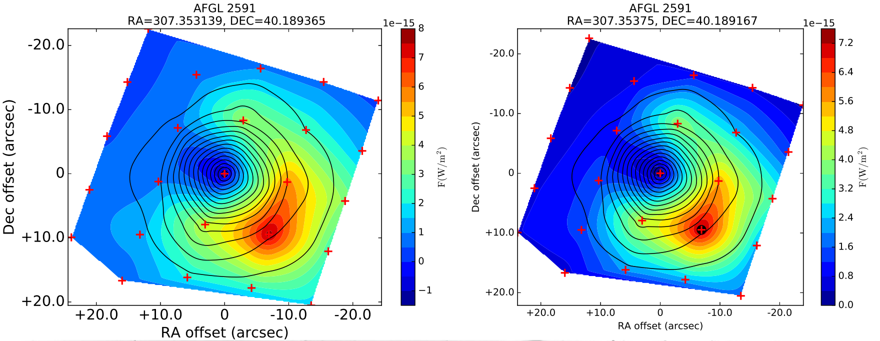
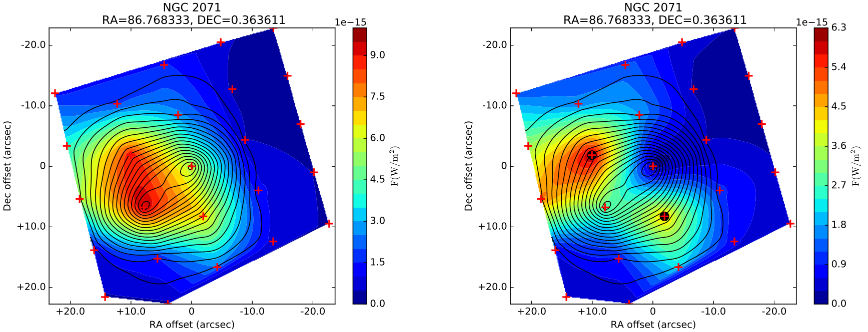
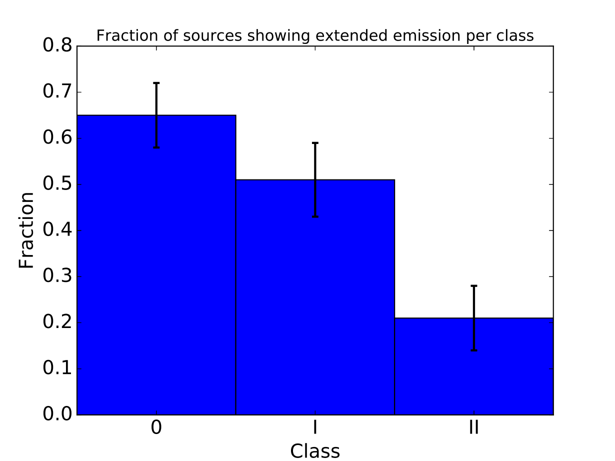


[OI] extended emission? Line emission and residual maps

The only source showing also extended H_2O 63 μm



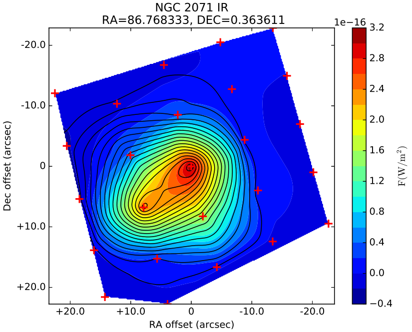
[OI] extended emission? Fraction per class

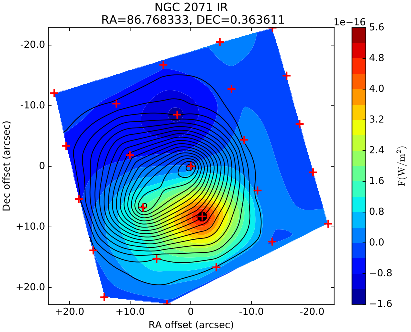


Clear evolution of fraction with age: evolutionary trend

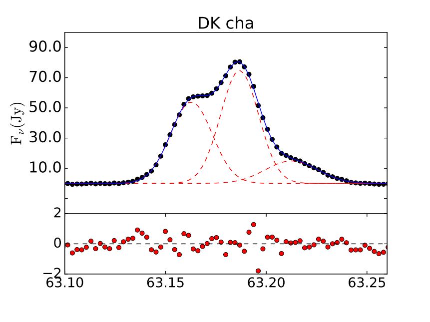
H_2O extended emission? Line emission and residual maps

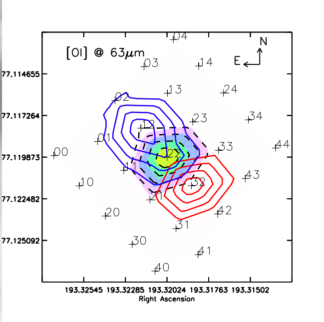
NGC 2071





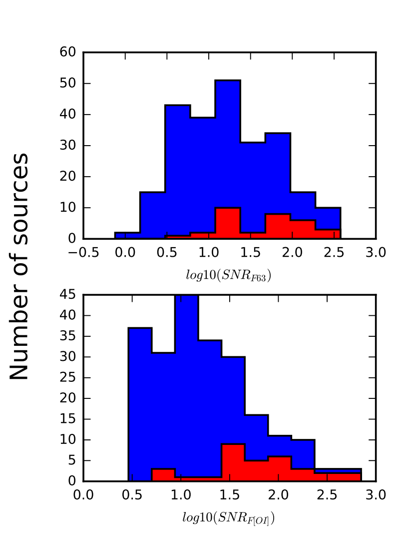
Multiple components with dynamical footprints





BIC analysis: 30 sources needed 2-3 components to fit the shape of the line → different components contribute to emission

...and maybe more



What about H_2O?

No need for multiple components, but:

- H_2O is always fainter, linked to SNR?
- In some cases, similar shape

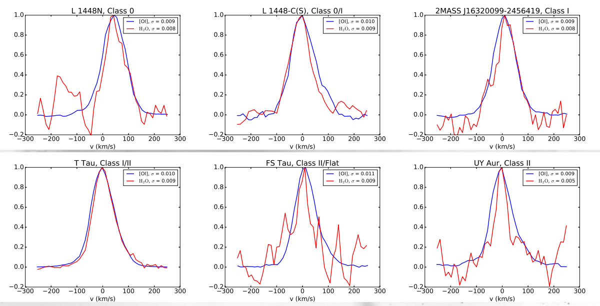


Figure: Comparison of the [OI] and o-H_2O line profiles for sources whose [OI] profiles are better reproduced by multiple Gaussians. In the legends we show the measured σ of the Gaussian fits.

Some correlations might help...

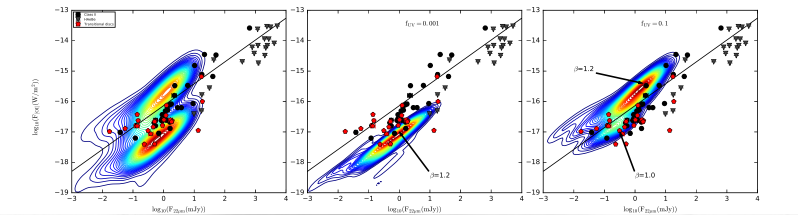
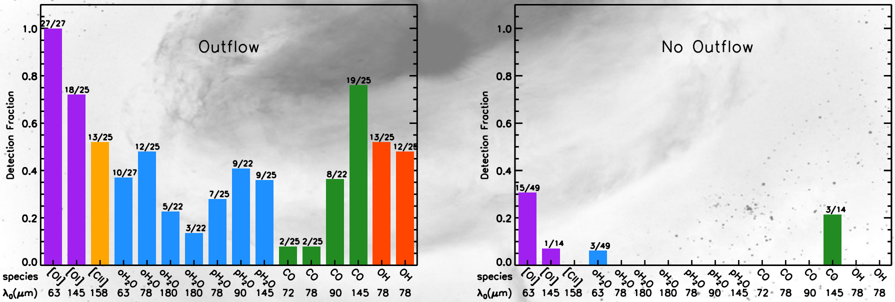


Figure: [OI] fluxes at 63 μm versus WISE flux at 22 μm: observations compared to models. The contours show the density of points for models from the DENT grid. Black dots show the position of observed Class II sources, red pentagons are transitional discs and gray triangles are HAeBe stars. The top panel shows the whole distribution of selected models. The middle panel shows the distribution of models with $f_{UV} = 0.1$, while the bottom panel show models with $f_{UV} = 0.001$. The arrows point to the location of sources with different values of β. The solid line is a linear fit to the observed data.

Sources in Taurus

Most detections of any species are dominated by jet-harboring systems. Still, we find 15 sources with [OI] and no jet contribution **only in Taurus**



Alonso-Martín + (submitted.)

Summary: Riviere-Marichalar+, 2016

- 357 YSOs observed with Herschel PACS in chop-nod, pointed mode @ 63 μm
- [OI] extended in 77 sources
- H_2O extended in one source (NGC 2071 IR, Class 0)
- [OI] shows evidence for contributions from different dynamical components
- H_2O does not show evidence for these many components (may be linked to low SNR), but asymmetries are observed, similar to those in [OI]

The origin of the emission

- Sources with a jet/outflow show brighter [OI] emission, and dominate detections of H_2O at 63 μm.
- Extended [OI] emissions (along jet direction)
- Different dynamical components can be observed
- [OI] is observed in transitional, debris and protoplanetary discs without jets, therefore demonstrating that the disc contributes to the emission.

Towards a better compression of the chemistry in protoplanetary and transitional discs

- Sources with a complete inventory of transition lines studied in detail $\rightarrow$ Need for multi-wavelength studies
- Detailed modeling of a large sample of sources with compatible assumptions can help us $\rightarrow$ MADEX
- The use of other instruments with **better spatial resolution** or **better spectral resolution** can help us get a more detailed explanation for the origin of the different lines

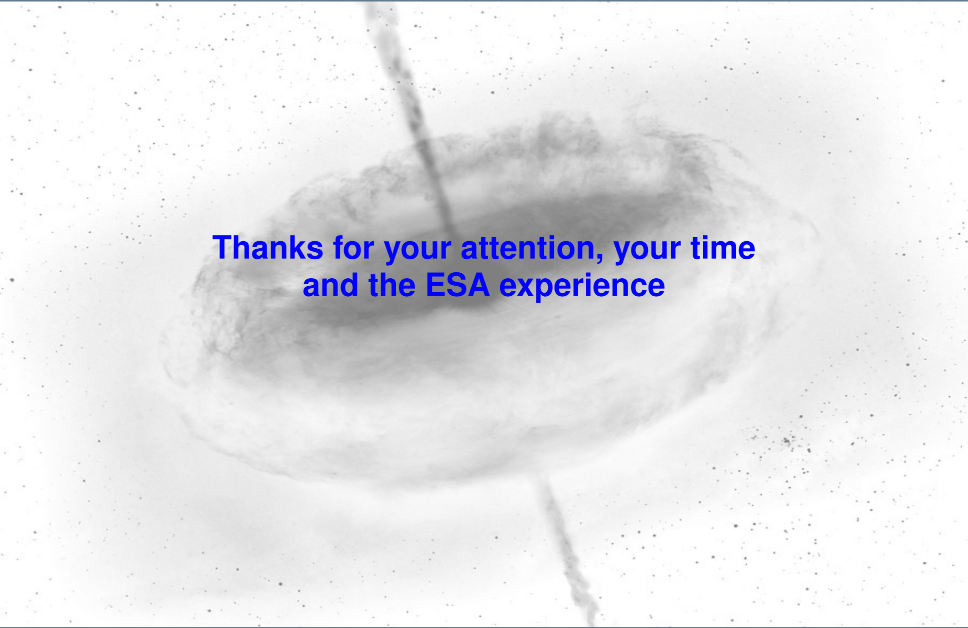
Future project

- Use observations of protoplanetary discs at submm and mm wavelengths to complete the present sample of observations
- Model in detail AB Aur (Class II) and R Mon (Class 0)

...and overall, model in detail the chemistry of S to understand its under-abundance.

With SPICA we could detect lines at all evolutionary trends,as well as ice features $\rightarrow$ SPICA is fundamental for the evolution of the field....

Help us know how planets are formed,
support SPICA



Thanks for your attention, your time and the ESA experience