Unraveling the contribution of jets and discs to far-infrared line emission

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As part of *Herschel's* key programme "Gas in Protoplanetary Systems" (GASPS), we have analyzed far-IR (60—190µm) spectra of protoplanetary discs around 76 T Tauri stars located in Taurus in different evolutionary states (Class I down to Class III), 27 show jet/outflow activity. We derived fluxes of all detected atomic and molecular lines — [OI], [CII], CO, H_2O and OH — to produce a complete and consistent FIR lines catalogue. Outflow sources are found to have the richest spectra and highest line fluxes, while non-outflow sources are rather poor in lines. We find correlations between several emission lines which suggests a common origin. To verify whether the line emission is associated with the protoplanetary disc or shocks, we compared the observed line fluxes and their ratios with disc and shock models. We find that just from an observational perspective, the outflow rather than the disc dominates the emission at early evolutionary stages (Class I/II).

SAMPLE & OBSERVATIONS

The sample is composed of 76 T Tauri stars with spectral types between G0—M6. According to their SED classification these stars are in different evolutionary states, from Class I to Class III. More than one third are binaries and 27 show jet/outflow activity.
The observations were conducted with the PACS spectrometer in chop—nod mode to remove the background emission.

RESULTS

A large number of sources show atomic ([OI] and [CII]) and molecular (CO, H_2O and OH) emission lines in the range 60 to 190µm. These are brighter (10^{16} vs. 10^{17} W/m²) and more often detected (42% vs. 16%) in outflow sources than in non-outflow ones (**Fig. 1**). From an observational perspective, the outflow rather than the disc dominates the emission at early evolutionary stages (Class I/II). We find correlations between several emission lines and continuum fluxes, suggestive of a common origin.

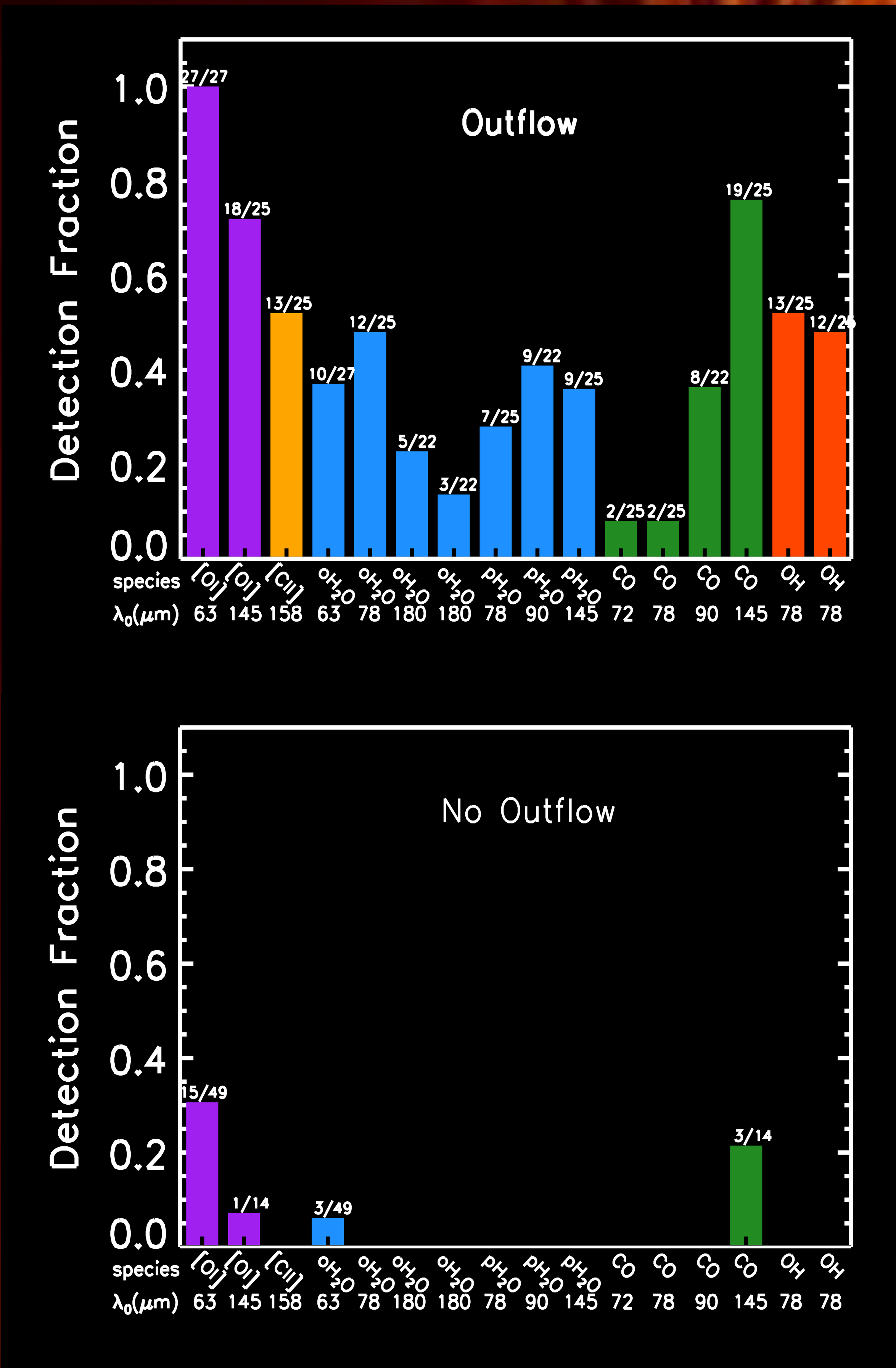

Fig. 1. Line emission detection fractions for the different species observed within PACS range. Objects with (*top*) and without (*bottom*) an outflow. The number on top of the bars refer to the total detections fractions.

What scenarios are compatible with these observations?

JET SCENARIO

The jet/outflow scenario is predominantly favoured by:

1. Detections in outflows (**Fig. 1**)
2. Extended emission in outflow sources (Podio et al. 2012)
3. Compatibility with shock models (**Figs. 2 and 3**)

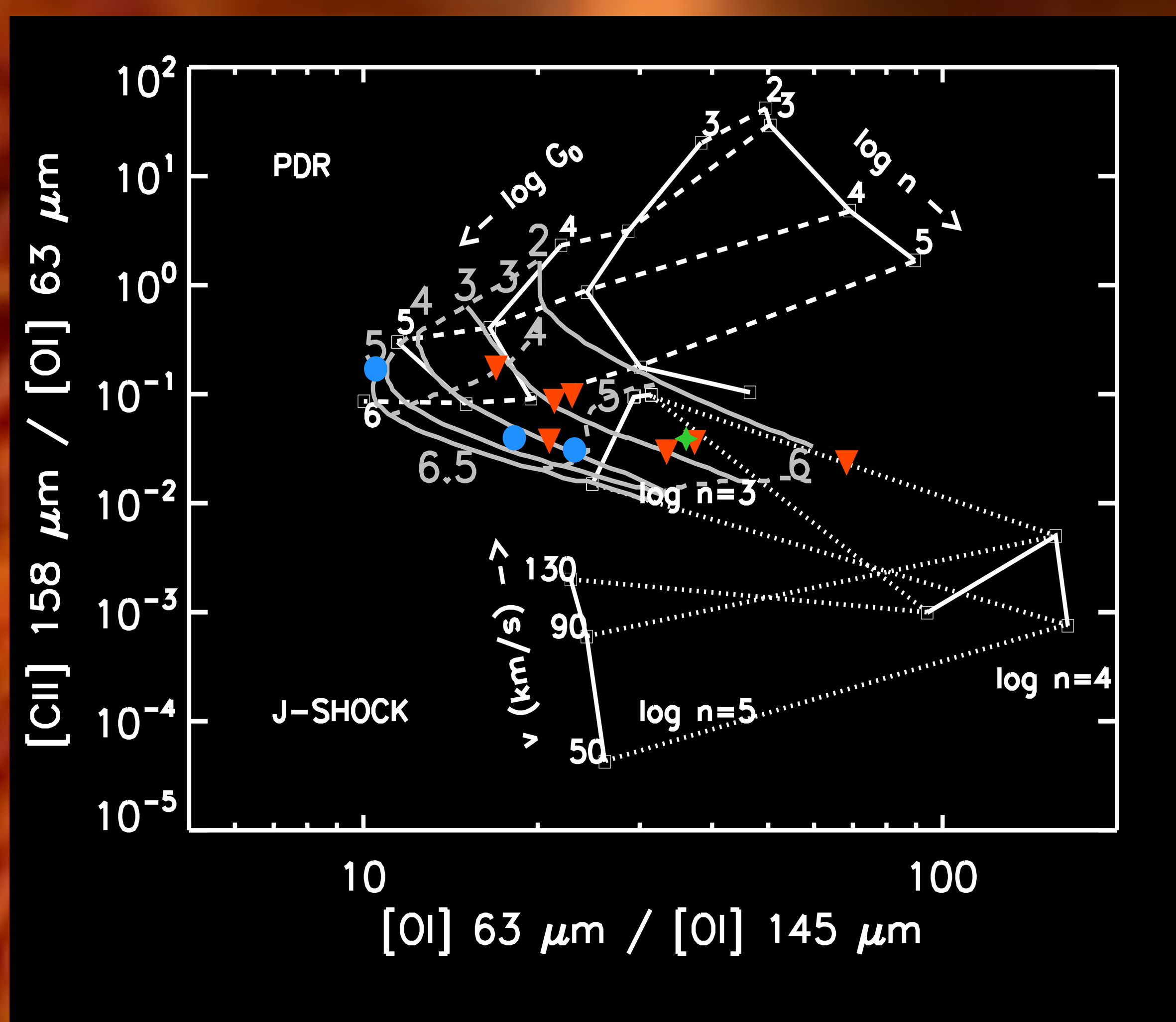

Fig. 2. Observed [OI]63/[OI]145 and [OI]63/[CII]158 line flux compared with the PDR models from Wolfire et al. (1990) (dashed lines) and Kaufman et al. (1999) (grey solid lines); and J-shock models from Hollenbach & McKee (1989) (dotted lines). Circles are Class I, triangles are Class II and stars are TD.

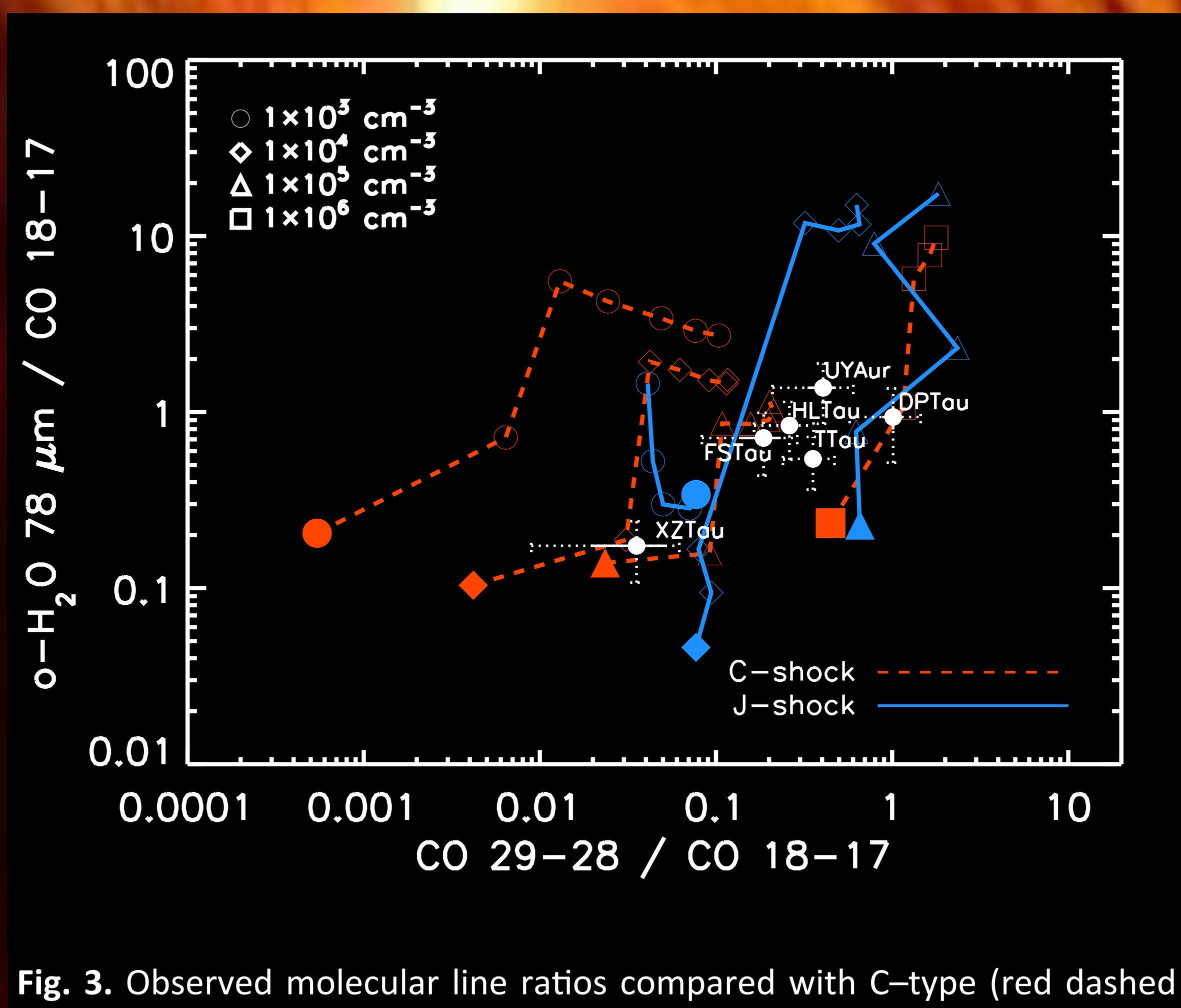

Fig. 3. Observed molecular line ratios compared with C–type (red dashed lines) and J–type (blue lines) model predictions from Flower & Pineau des Forêts (2015). Filled symbols indicate the position of the lowest velocity (V_{shock}=10 km/s).

DISC SCENARIO

The disc scenario is predominantly favoured by:

1. Correlations with dust tracers (**Fig. 4**)
2. Compact molecular emission
3. Compatibility with disc models, but fail for high fluxes

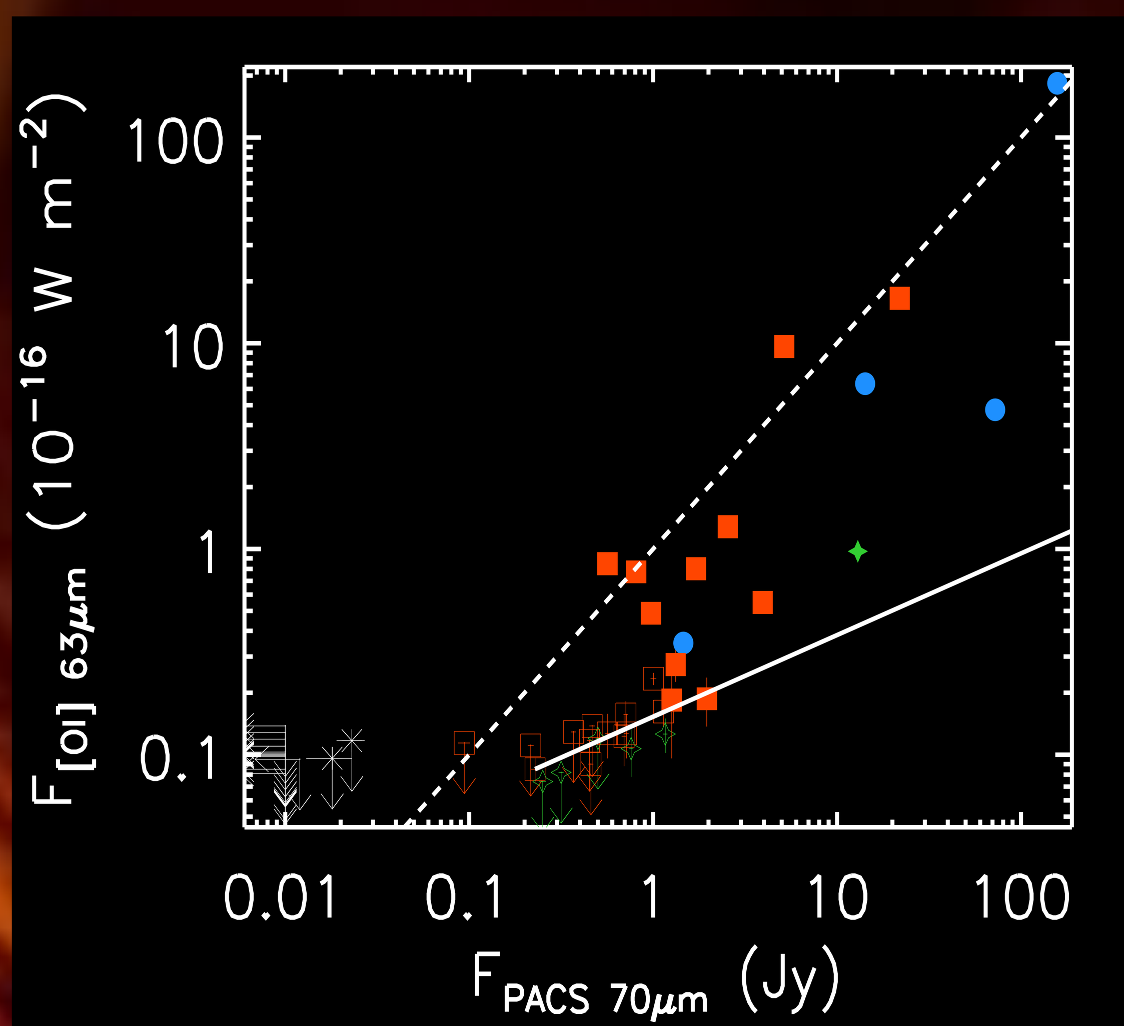

Fig. 4. The [OI] 63 µm line as a function PACS 70 µm (right) continuum fluxes. Class I, Class II, Class III and transition discs (TD) are represented by circles (blue), squares (red), asterisks (black) and stars (green), respectively. Filled symbols correspond to outflow sources. Arrows indicate upper limits.

From the [OI]-70µm fit to non-outflow sources we estimated the disc contribution to the [OI] line emission in different evolutionary states (Table 1).

Table 1. Ranges and mean (median) values of disc contribution in percentage of [OI] 63 µm flux for different SED classes.

SED Class	Range	Mean (Median)	Nº sources
Class I	1%-51%	19% (18%)	4
Class II + Jet	3%-100%	38% (24%)	11
TD + Jet	43%	43% (43%)	1
Class II	65%-100%	92% (99%)	7
TD	100%	100% (100%)	2

CONCLUSIONS

- The observed correlations support the interpretation of jet/outflows as the dominant contributor to FIR line emission.
- The correlations with 70µm indicate that the contribution from the disc to the [OI] 63 µm line may be up to 50% for the jet/outflow sources.
- Fast (V_{shock} = 50—130 km/s) J-shocks at low densities (n = 10^3 cm^{-3}) and PDR models can reproduce the [OI]63/[OI]145 and [CII]158/[OI]63 line ratios observed. Although [CII] is most likely associated with PDR emission from the reflection nebulae.
- Molecular emission (CO, H_2O and OH) can be reproduced with J- and C- type shocks with V_{shock} = 15-30 km /s and n = 10^4-10^6 cm^{-3}.
- Massive discs and/or low dust-to-gas ratios may also account for the high molecular fluxes.
- Spatially and/or velocity resolved observations are needed to pin-point the origin of the emission lines. Moreover, complex models including discs, jets and their interaction are needed to interpret these observations.

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Reference: Alonso-Martínez et al., submitted

Background image: Artist's impression of the baby star TMC-1A (Credits: *National Astronomical Observatory of Japan*).