Herschel/PACS Survey of Protoplanetary Disks in Taurus/Auriga -- Observations of [OI] and [CII], and Far Infrared Continuum

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ABSTRACT

The Herschel Space Observatory was used to observe ~ 120 pre-main-sequence stars in Taurus as part of the GASPS Open Time Key project. PACS was used to measure the continuum as well as several gas tracers such as [OI] 63 µm, [OI] 145 µm, [CII] 158 µm, OH, H_2O, and CO. The strongest line seen is [OI] at 63 µm. We find a clear correlation between the strength of the [OI] 63 µm line and the 63 µm continuum for disk sources. In outflow sources, the line emission can be up to 20 times stronger than in disk sources, suggesting that the line emission is dominated by the outflow. The tight correlation seen for disk sources suggests that the emission arises from the inner disk (< 50 AU) and lower surface layers of the disk where the gas and dust are coupled. The [OI] 63 µm is fainter in transitional stars than in normal Class II disks. Simple SED models indicate that the dust responsible for the continuum emission is colder in these disks, leading to weaker line emission. [CII] 158 µm emission is only detected in strong outflow sources. The observed line ratios of [OI] 63 µm to [OI] 145 µm are in the regime where we are insensitive to the gas-to-dust ratio, and we cannot discriminate between shock or PDR emission. We detect no Class III object in [OI] 63 µm and only three in continuum, at least one of which is a candidate debris disk.

Taurus-Auriga

- One of the closest (~140 pc) young stellar associations
- Rich population of PMS stars (T Tauri stars and brown dwarfs) with at least 250 cluster members
- Age 1 - 3 Myr, although some as young as 0.5 Myr and a few as old as 15 - 20 Myr.
- No Class 0 objects, but quite a few young Class I protostars (in the opaque regions of dark clouds) and many Class III objects scattered throughout the area.

PACS observations

- Photometry observations of 93 stars. We detected 50 stars including three Class III objects.
- Spectroscopy observations targeting [OI] 63 µm, [OI] 145 µm, [CII] 158 µm, as well as several transitions of OH, H_2O, and CO. We observed 75 fields in spectroscopy; at least in [OI] 63 µm. Here we only report on the results of [OI] 63 µm, [OI] 145 µm, and [CII] 158 µm. Results of the o-H_2O line at 63.32 µm were discussed in Riviere-Marichalar et al. (2012, A&A, **538**, L3) while other molecular transitions were discussed by Podio et al. (2012, A&A, 545, 44) in a sub-sample of strong outflow sources.
- The [OI] 63 µm line was detected in 43 sources (not in any Class III object), [OI] 145 µm in 17 sources, and [CII] 158 µm emission in 10 sources.

Results

- The [OI] 63 µm emission line is by far the strongest line we observed. The line is spatially unresolved except in a few strong outflow sources (see Podio et al. 2012)
- The [OI] 145 µm line is much fainter (10 - 25 times) than the 63 µm line, which is what one would expect for both PDR and shock emission.
- The [CII] 158 µm is only detected in strong outflow sources, where the line seems to be excited by PDR emission and not shock excited. The low detection rate (10 out of 37) was somewhat surprising - based on earlier ISO observations we had expected a higher detection rate. Even though we do not have velocity resolved spectra, it appears that the [CII] emission originates in the outflow, not in the disk.

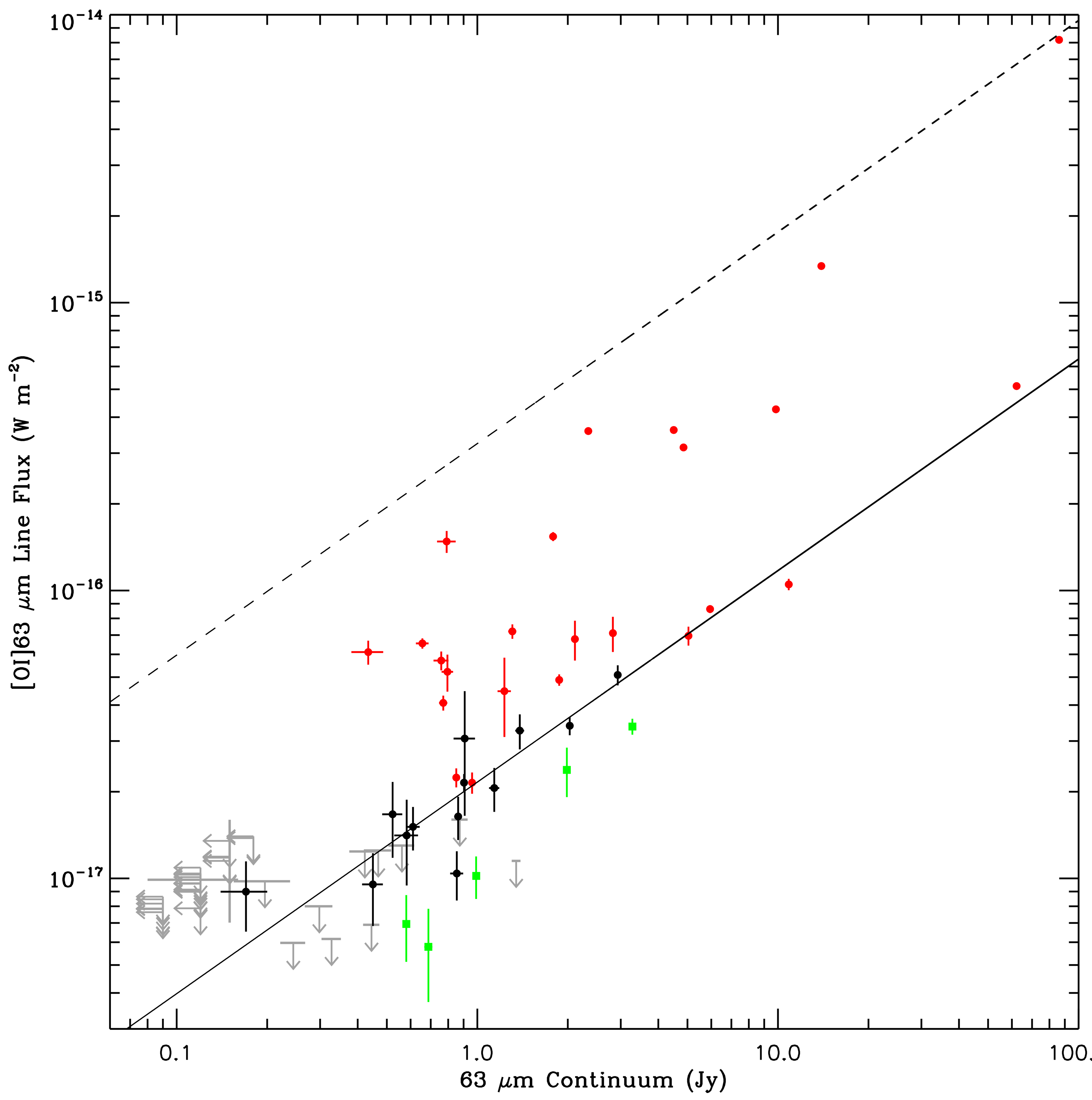

***Figure**: [OI] 63 µm line emission vs. 63 µm continuum emission for the GASPS Taurus sample. Non-outflow sources are plotted in black, outflow sources in red and transitional disks are plotted in green. Sources for which there is less than a 3σ detection in line flux or continuum are plotted in grey as 3σ upper limits.*

We find no correlation between the line intensity of [OI] 63 µm and spectral type, which is not surprising, since most of our targets span a narrow range in spectral type and effective temperature - most stars have a spectral type of K or early M. Neither do we find a correlation between [OI] line intesity and accretion rate, nor between line intensity and disk mass. The latter is not too surprising, since the [OI] 63 µm emission is expected to be optically thick in circumstellar disks.

However, after dividing our sample into two main groups: stars which are known to power outflows and/or jets and non-outflow sources, which are very weak or unmeasurable ouflow activity, we found a strong correlation between the [OI] 63 µm line emission and 63 um continuum emission (measured simultaneously and therefore insensitive to calibration errors), see the above Figure. The same trend continues if we include outflow sources, although the line emission can be twenty times stronger in an outflow source compared to a non-outflow source. This suggest that the [OI] 63 µm emission can be completely dominated by the outflow. However, as we can see from the above Figure, there are outflow sources (six in our sample), which show no excess due to the outflow and these obey the same linear relation as the non-outflow sources (aka disk-only), where all the emission is emitted from the disk. Transitional disks also stand out, having generally fainter [OI] 63 µm emission than classical T Tauri stars (marked with green in the Figure).

The tight correlation between [OI] line and 63 µm continuum emission in the disk-only sample suggests that they originate from the same region of the disk. Simple disk models suggest that the [OI] 63 µm line and continuum emission orignates in the inner part and upper surface layers of the disk, where both gas and dust are approximately thermalized. This can also explain the weaker line emission of transition disks, since the dust responsible for the 63 µm continuum emission appears to be cooler than in classical T Tauri disks.

For more details, see Howard et al. (2013, ApJ, **776**, 21)