Gas in transition discs: using CO as a tracer

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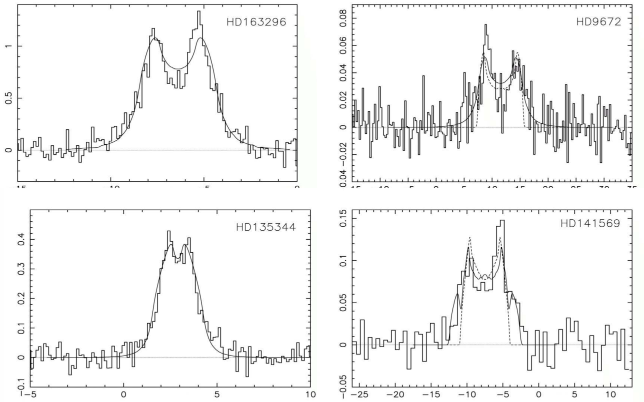
Summary

Young protostars (Class 0-I) are surrounded by clouds with a gas:dust ratio of ~100:1 (ie close to that of the parent molecular cloud). By contrast debris discs around older main sequence stars have little or no detectable gas. How does this transition occur? We describe results from a survey of the J=3-2 CO line in F-B stars of ages>3Myr with a measured infrared excess, in order to investigate this process.

The results show a significant molecular gas mass can surround stars of age up to ~20Myr. As long as the dust disc is sufficient thick to shield the gas from photodissociation, CO will inevitably be found in the circumstellar discs. Although ^{12}CO is generally optically thick, some basic parameters such as the size and inclination of the disc can be derived from the line shape.

The derived gas disc size appears to be independent of the stellar spectral type. However, the apparent disc radius decreases with time, with a mean size of ~210au for disc ages of 3-7Myr, and ~70au for 7-20Myr. These extended discs can provide a gas reservoir of > 10^{-3} $M_{Jupiter}$ of H_2 in the outer "pre-Kuiper Belt" regions for a period of ~20Myr.



Spectra

Most spectra are double-peaked or significantly wider than ambient (FWHM>1km/s).
In some of the brighter targets, the CO is spatially resolved in published interferometry images, and shows the gas is in a rotating disc. But most are too faint or compact to resolve, and we rely on a model and the single-dish spectra to deduce the underlying structure. Spectra above are typical of the double-peaked profiles, and are superimposed on models (described right).

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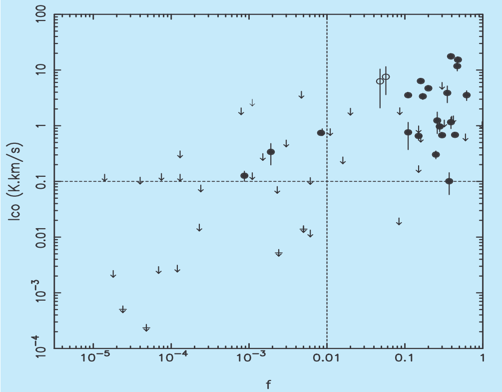
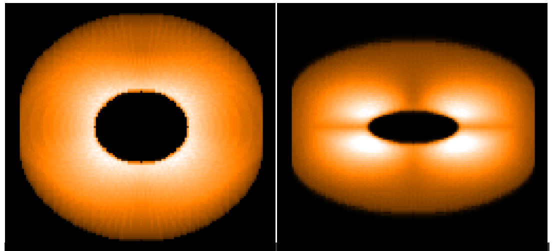


Detectability of CO

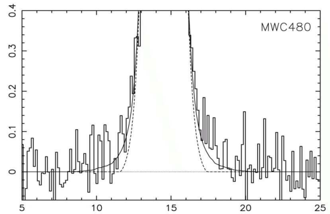
The measured CO intensity (normalised to 100pc) is plotted as a function of infrared fractional excess. Objects where CO was detected are indicated by filled circles.

The data is consistent with >95% of stars with *f*>0.01 having a significant CO mass (>$10^{-3}M_{Jupiter}$). Only 3 low-excess stars have CO: HD141569, HD9672 and HD4881.



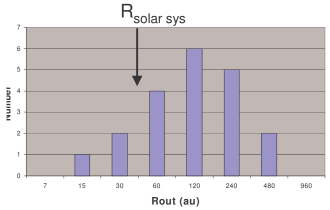
Disc models

A simple inclined disc model is used to derive basic physical parameters from the spectra: disc inclination *i*, inner radius *Rin*, outer radius *Rout*, and thickness/opening angle θ.
The images above show example CO images of models viewed at *i*=30 and 60 degrees (without spatial smoothing).



Inner radii

The spectra of MWC480 shows the effect of truncating the model disc at *Rin*=60au (dashed line) compared with 10au (solid line). It implies molecular gas exists at radii ≤30au. There is no evidence of an inner hole on this scale.
Higher-velocity gas can be detected from radii <30au when the peak s:n>10. This can be seen in 6 of our objects.

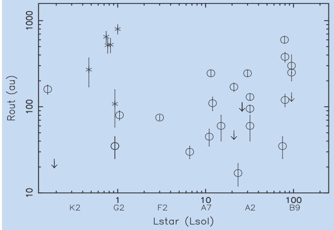


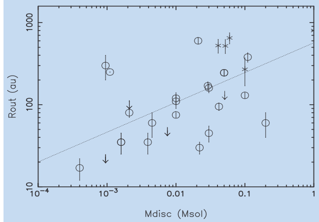
Disc radius

The derived disc radii peak around 150au (see above), or ~3x larger than the Solar System.

Radius vs spectral type

The plot below shows that stellar luminosity has little effect on the disc radius.

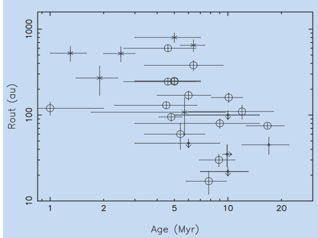




Radius vs disc mass

The variation of outer radius as a function of disc mass (where mass is derived from the *dust* continuum flux).

The correlation has a slope of 0.35, close to that expected if the disc were constant mean density (although there is clearly significant scatter).



Rout vs age

Variation of radius as a function of age. All stars of known age where CO is predicted to be present (ie *f*>0.01) are shown.
Star symbols are published observations of young (mostly T Tauri) stars with resolved discs. Splitting the sample into two (3-7Myr, and 7-20Myr), the mean size drops from 210au to 70au. Gas at R>100au lasts for ~7Myr; gas at <100au lasts for ~17Myr.

Points arising

- *Gas removal timescale*

A fit to the results indicates that R_{out}~$T^{-0.8}$. Assuming that Mass~R_{out}^3, then M_{gas}~$T^{-2.4}$. This compares with M_{Dust}~$T^{-1.8}$ suggesting that the decay rates of gas and dust are similar. The time for the mass to drop below $1M_{Earth}$ is then ~30Myr

- *Molecular gas in the outer regions of planetary systems*

CO masses of >10^{21}kg *can* remain for up to ~20Myr in the ~70au region. This is enough for >10^9 comets in this outer Kuiper Belt region, assuming typical cometary CO fractions.

- *Gas tracers*

CO is ubiquitous in high-*f* discs. It is well-known that photodissociation will reduce CO abundance in optically thin discs, so gas in discs with *f*<10^{-3} should be traced using atomic species.

- *Primordial vs. debris*

All discs with CO are likely to be primordial, not debris. Therefore even low-*f* discs such as those around HD141569 and HD9672 are not dominated by collisional cascades.