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ISO-LWS study of Pre-Main Sequence Sources

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We present the results obtained with the ISO Long Wavelength Spectrometer on a sample of Pre-MS sources, where several molecular lines of CO, H_2O and OH have been detected. The analysis of the CO lines indicates that gas temperatures as low as 200 K are consistent with the data. This would be in agreement with the relatively low abundance of water in the gas phase measured in most of the objects.

1. Introduction

We used the Long Wavelength Spectrometer (LWS, Clegg et al. 1996) aboard the Infrared Space Observatory (ISO, Kessler et al. 1996) to observe a sample of Pre-Main Sequence (Pre-MS) sources selected for having high submillimeter continuum and strong molecular outflows (Saraceno et al. 1996, 1997). The choice of the sources was carefully done to sample all the evolutionary stages of the Pre-MS phase (Class 0, I and II objects).

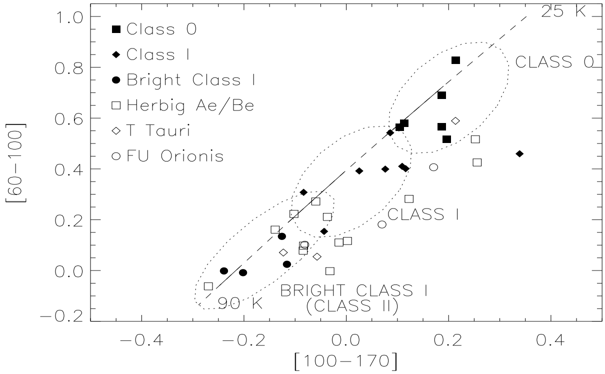

Fig. 1: ISO-LWS two colours diagram for some of the objects of the sample. The line shows the blackbody colours from 25 K to 90 K, changing style at temperatures: 30, 35, 40, 50, 65 and 75 K.

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Figure 1 shows the ISO-LWS two colours diagram of 41 sources of the sample (Pezzuto et al. 1999). The different classes of objects lie in different zones of the plot.

Class 0 have colour temperatures (Tc) ranging from 28 to 35 K, low luminosity Class I ($L<10^3 L_\odot$) have $Tc \sim 35-45\,K$ and Bright Class I ($L>10^4 L_\odot$) span the range $Tc \sim 50-85\,K$. The last temperatures are also the ones expected for Class II sources. However, a few Class II sources (Herbig Ae/Be stars (HAeBe) and FU Orionis) show a lower Tc, probably due to the presence in the ISO beam of a cool companion. The continuous trend in temperature of the objects in Figure 1 ensures that the sample is representative of the Pre-MS evolutionary scenario.

The different classes of objects show also different emission line spectra as reported in Saraceno et al. (1999): in general, the low luminosity sources have spectra very rich in molecular transitions, which are the major coolants of the gas; an example is given by the spectrum of T Tauri (Spinoglio et al. 1999), shown in Figure 2. On the contrary, the high luminosity Class I sources and the HAeBe stars have weak or no molecular lines and generally the atomic and ionic lines are the main coolants of the gas.

2. Molecular line fitting

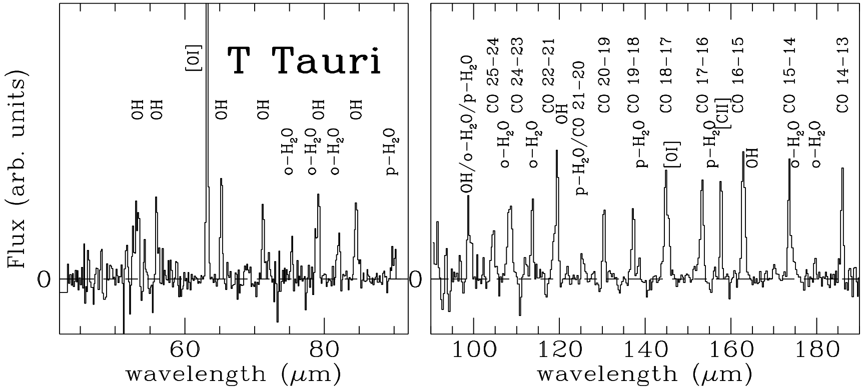

Fig. 2: The ISO-LWS continuum subtracted spectrum of T Tauri.

One of the most exciting results of the ISO-LWS spectrometer is the detection of several molecular lines around young stellar objects (see Figure 2). Table 1 reports the cooling luminosities of the sources of the sample for which a satisfactory analysis has been done. In these sources we detected for the first time thermally excited water, plus several hydroxil lines and carbon monoxide high-J transitions (J_{up} >14). All these lines are tracing a warm and dense ($T=100-2000$ K; $n(H_2)= 10^4$ - 10^6 cm^{-3}) gas.

CO emission is one of the best diagnostic tool for the determination of the physical conditions of the gas, both for its high abundance and large dissociation energy and for having transitions ranging from the millimeter wavelengths (cold molecular clouds) to the near-IR (roto-vibrational lines excited in stellar atmospheres). The LWS CO data have been fitted using a Large Velocity Gradient (LVG) model (Nisini et al. 1999a, Giannini et al. 1998), assuming that the line-widths are equal to the maximum velocity observed in the associated molecular outflow. The emission of the CO lines, as a function of the upper rotational level (J_{up}), can be fitted to derive the gas temperature (T) and volume density (n). The derived optical depths are generally small (<1), so

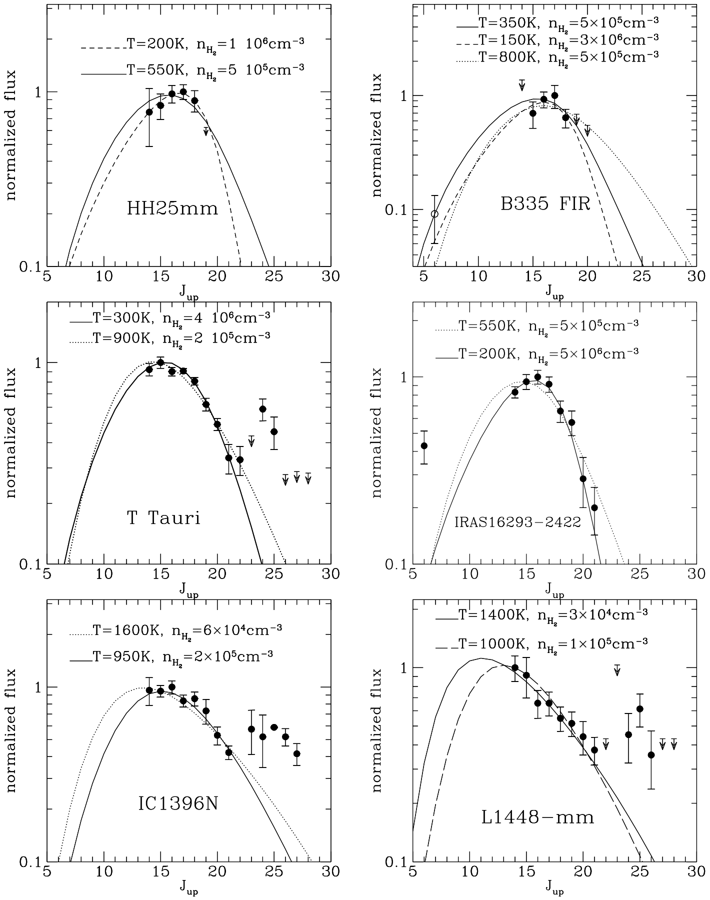

Fig. 3: Observed CO line fluxes and model fits. The derived range of temperature and density are indicated. From the top to down: HH25mm (Class 0, Benedettini et al. 1999), B335 FIR (Class 0, Nisini et. al 1999), T Tauri (Class II, Spinoglio et al. 1999), IRAS16293-2422 (Class 0, Ceccarelli et al. 1998), IC 1396 N (Class I, Saraceno et al. in preparation) and L1448-mm (Class 0, Nisini et al. 1999b).

that the CO line intensities are proportional to the product of the column density and the beam filling factor, which therefore cannot be determined independently. For the sources in Table 1, however, the detection of other molecular transitions emitted in conditions similar to the CO lines and having larger opacities, like H_2O and OH, can allow to independently derive (Nisini et al. 1999b) both the column densities and the size of the emitting regions, whose values are reported in the last column of Table 1.

Figure 3 presents the model fits of the CO lines for some of our sources. They have in general a relatively high indetermination of T, due to the lack of lines at J_{up} <14. These lines at higher wavelengths will be observed by SOFIA and FIRST in the future.

In spite of this indetermination, we found that most of our sources are consistent with tem-

Table 1: Line cooling (Luminosities expressed in $L_\odot$)

Source	Class	L_{bol}	$L_{[OI]}$	L_{CO}	L_{H_2O}	L_{OH}	L_{lines}	$\frac{L(mol)}{L([OI])}$	$\frac{L(lines)}{L(bol)}$	$\frac{Size}{[arcsec]}$
B335 FIR	0	3	0.002	0.004	<0.001	...	0.006	2	2 E-3	1-2
IRAS16293	0	27	0.005	0.04	0.003	0.003	0.05	9.2	1.8 E-3	...
L1448mm	0	10	0 008	0.03	0.045	...	0.083	9.3	8 E-3	7-12
HH25mm	0	5	0.024	0.03	0.015	...	0.07	1.9	1.3 E-2	2.7
IC1396 N	I	235	0.1	0.63	0.17	...	0.9	8	3.8 E-3	3-8
TTau	II	28	0.013	0.01	0.01	0.02	0.05	6.6	2.0 E-3	2.5
R CrA	II	132	0.038	0.03	<0.002	0.01	0.078	1.05	5.9 E-4	3.4-10
IRAS12496	II	50	0.005	0.008	<0.001	...	0.013	1.6	2.6 E-4	2.5
LkH$_\alpha$234	II	270	1.68	0.5	...	...	2.18	0.3	8 E-3	2.5-3.7
HH54B	HH	-	0.026	0.01	0.002	0.001	0.039	0.5	...	...
HH26C	HH	-	0.022	0.025	0.02	...	0.067	2.04	...	1-10

peratures T$\sim$200 K, with the exception of IC 1396N and L1448-mm, for which temperatures of the order of 1000-1500 K are estimated. In the hypothesis that the observed gas is heated by shocks, such low temperatures would imply shock velocities not exceeding $\sim$10-15 km s^{-1} (Kaufman & Neufeld 1996). Alternatively, temperatures of about 200 K can be obtained directly in the circumstellar envelopes, where the gas is heated by the central source. A detailed discussion is given in Saraceno et al. (1999).

We also note from Table 1 that the sources for which a low CO temperature has been derived show a lower contribution of the water lines to the total gas cooling. Indeed, for temperatures below 300 K, the gas phase reactions for water production are very inefficient (Graff & Dalgarno 1987) and the detected water is likely to be produced by evaporation from the grain mantles (e.g. van Dishoeck & Blake 1998).

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