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FIR CO LINE EMISSION OF PROTOSTARS IN NGC1333

E. Caux[1] C. Ceccarelli[2] A. Castets[2] L. Loinard[3],
S. Molinari[4], P. Saraceno[5], H.A. Smith[6], & G.J. White[7]
[1]CESR, BP 4346, F-31028 Toulouse Cedex 04, France
[2]Laboratoire d'Astrophysique de l'Observatoire de Grenoble, B.P.53X, F-38041 Grenoble Cedex, France
[3]Institut de Radio Astronomie Millimetrique, F-38406 St. Martin d'Hères, France
[4]IPAC, California Institute of Technology, MS 100-22, Pasadena CA 91125, USA
[5]IFSI - CNR, Via G. Galilei, CP27, 00044 Frascati, Italy
[6]Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge MA 02138, USA
[7]Queen Mary & Westfield College, Mile End Road, London E1 4NS, UK

ABSTRACT

Using the Long Wavelength Spectrometer aboard ISO, we have observed three very young sources (Class 0 or I) in the molecular cloud NGC1333. We discuss in this contribution the FIR CO line emission observed towards the sources themselves and conclude that both a rather warm ($\sim$ 1500 K) and dense ($\sim 10^5$ cm^{-3}) gas or a colder ($\sim$ 300 K) and much denser ($\geq 10^8$ cm^{-3}) gas are consistent with the data. Based on this analysis only we cannot distinguish between the two cases and therefore assess whether the observed emission originates in a shock associated with the outflow or in the innermost, dense and warm regions of the envelopes that surround these sources.

Key words: molecular lines; star formation.

1. INTRODUCTION

The Long Wavelength Spectrometer (LWS) on board the Infrared Space Observatory (ISO) allowed for the first time to investigate the line emission from relatively low-luminosity sources in the FIR wavelength range. A handful observations have already been published (Liseau et al. 1996; Nisini et al. 1996; Saraceno et al. 1996; Ceccarelli et al. 1998a, 1998b, 1999a), showing intense CO emission from the high J rotational transitions in young low-luminosity sources (see also Saraceno et al. in these proceedings). The origin of the observed emission is still controversial, mainly because the relatively large beamwidth ($\sim 80''$) and small spectral resolution ($\sim$ 250) of these observations does not allow to locate exactly where the emission originates. Ceccarelli et al. (1998a) suggested that the FIR CO lines originate in the same region traced by the J=6 transition (which is observed with ground based telescopes having much higher spectral and spatial resolution than ISO), and that probably originate in the shock caused by the interaction of the outflows with the surrounding medium. However, Saraceno et al. (these proceedings) considered a sample of five embedded very young sources in which molecular line emission was measured and concluded that current shock models fail to account for the observed emission. Finally, Ceccarelli et al. (these proceedings) suggested that the FIR water emission observed in the same sources originates in the innermost, dense and warm, regions of envelope.

In this contribution we present the ISO-LWS observations obtained towards three young embedded sources in NGC1333 and discuss some implications.

2. OBSERVATIONS AND RESULTS

The three sources IRAS2, IRAS4 and IRAS6 in NGC1333 were observed as part of the Guaranteed Time Program of the LWS. The observations were performed during revolutions 831 and 847, thanks to the extended lifetime of ISO. IRAS2 was observed on 5 positions, one on-source, and four on each side of the two perpendicular outflows. IRAS4 was observed on 3 positions, one on-source, and two on each side of the outflow. IRAS6 was only observed on-source. Fig. 1 shows the 1.3mm continuum map of the region and the observed positions.

In this contribution, we only discuss the origin of CO line emission observed on-source.

The ISO-LWS observations were performed using the AOT L01 (grating scans, spectral resolution $\sim$ 250 - Clegg et al. 1996, Swinyard et al. 1996) with an oversampling of 4. The integration time used on-source was $\sim$32 sec per spectral element. Fig. 2 presents six of the CO lines observed on the source IRAS6. The lines are fitted with gaussian profiles.

Table 1 lists the line fluxes measured towards each source.

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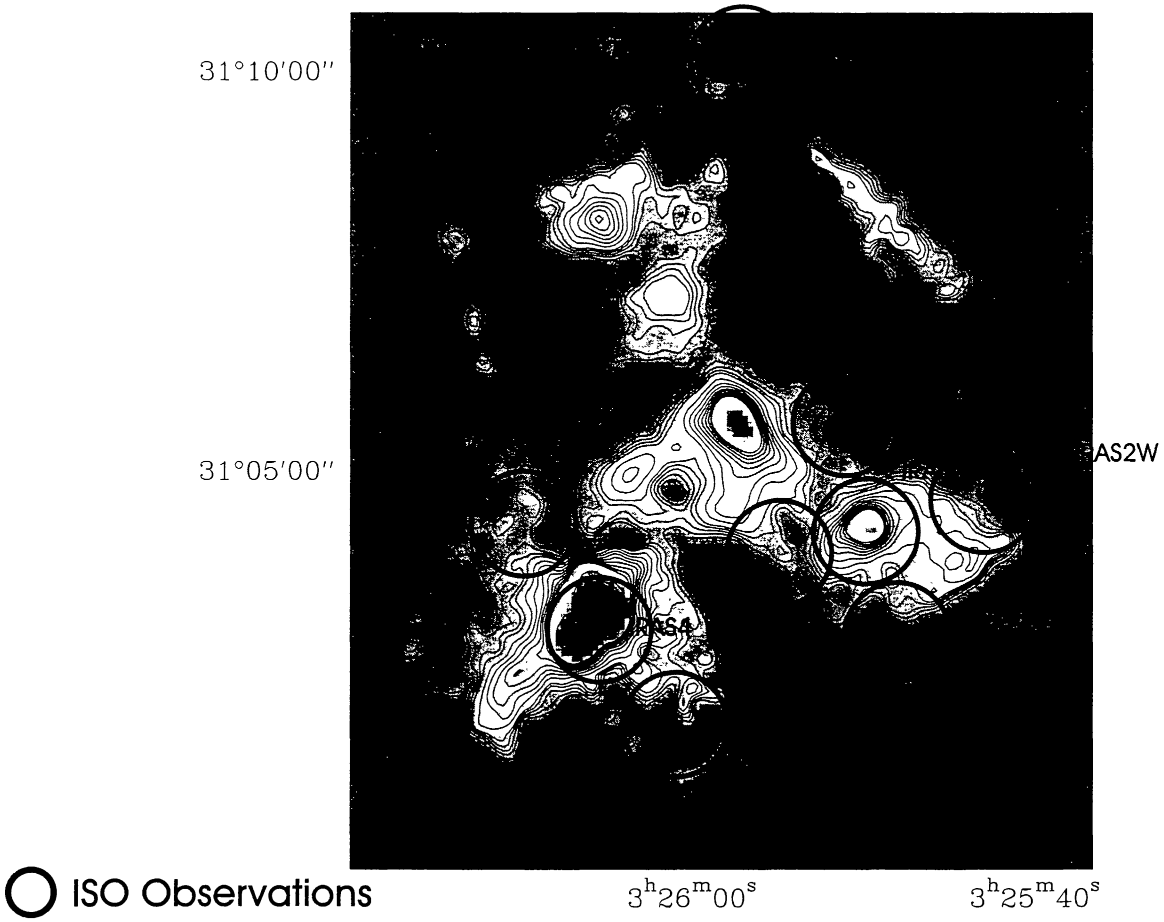

Figure 1. Observations of ISO-LWS of the molecular cloud NGC1333. The observed positions (circles) are overimposed to the 1.3mm continuum map (gray colours) obtained by Lefloch et al. (1998).

Table 1. Observed high J CO rotational lines on the sources IRAS2, IRAS4 and IRAS6 in NGC1333. Line flux unit: 10^{-12} *erg* s^{-1} cm^{-2}

CO line	IRAS2	IRAS4	IRAS6
(14-13)	0.43	1.72	0.58
(15-14)	0.32	1.54	0.58
(16-15)	0.32	1.44	0.55
(17-16)	0.22	1.28	0.46
(18-17)	0.24	1.20	0.43
(19-18)	nd	1.12	0.41
(20-19)	0.23	0.81	0.37
(21-20)	nd	0.62	nd

One can note that the CO line spectra of the three sources are remarkably similar, *the main difference being a mere multiplicative factor.* This is also what we found for the H_2O line spectra of these three sources, which show line ratios between the sources rather independent on the upper level of the transition (Ceccarelli et al. 1999a, see also Ceccarelli et al. in these proceedings). This characteristics implies that the excitation conditions, i.e. gas density and temperature, in the three sources are very similar.

3. DISCUSSION

To interpret the CO emission, we used a LVG model, applied to a slab geometry (see Ceccarelli et al. 1998a). This model considers the first 50 rotational levels (collisional excitation rates from McKee et al. 1982) and a ratio [CO]/[H2] = 10^{-4}. The free parameters of the model are the gas density, temperature and CO column density. Given the relatively large ISO-LWS beam also the source extent enters as a free parameter in modelling the absolute flux of the observed lines. Note that the two last parameters, the CO column density and source extent, are independent only if the lines are optically thick.

We used the ratio of the observed lines with the highest (J=20) and lowest (J=15) energy level to constraint the range of allowed temperatures and densities. As previously mentioned, the J=15 over J=20 line ratio is remarkably similar in the three sources, being 1.3, 1.5 and 1.9 in IRAS2, IRAS6 and IRAS4 respectively (the slight difference is within the calibration error of the fluxes, so it is not considered real). In Fig. 3, we report the J=15 over J=20 line ratio as function of density and temperature: as already known (Ceccarelli et al. 1998a) the FIR lines observed with ISO-LWS alone cannot efficiently constraint the two parameters. In this specific case either

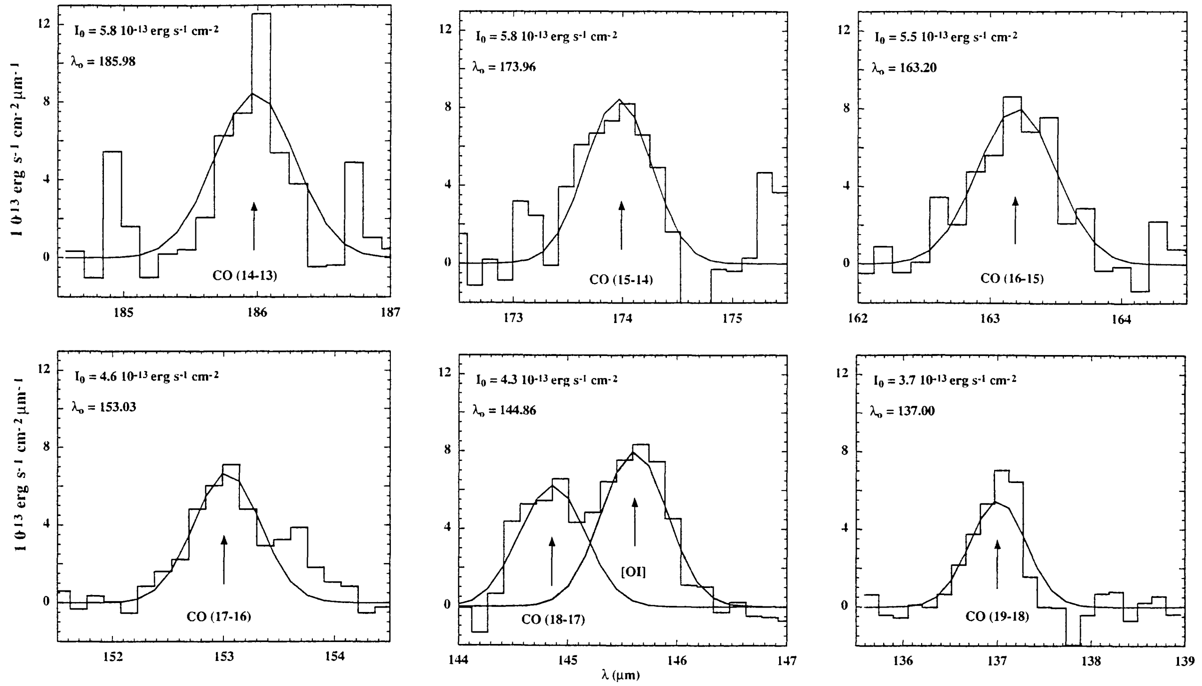

Figure 2. Observed CO lines on the source IRAS6

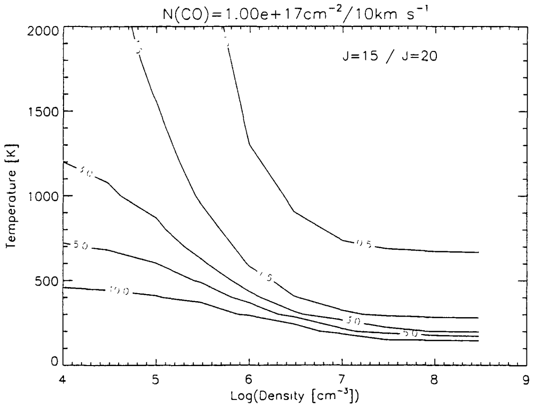

Figure 3. CO line J=15 / J=20 ratio as function of temperature and density. The range of observed values is marked by the grey lines. The CO column density is 10^{17} cm^{-2} *with* $\delta v = 10$ *km* s^{-1}.

a rather warm (~ 1500 K) and dense (~ 10^5 cm^{-3}) gas or a colder (~ 300 K) and much denser ($\geq 10^8$ cm^{-3}) gas are consistent with the data.

This is also shown in Fig. 4, where the CO observed and computed spectra are reported for each source. The less dense case would probably correspond to a shock originated at the interface of the outflow with the surrounding medium (Ceccarelli et al. 1998a), while the extreme denser case may be explained either by a denser shock or in term of thermal emission from the surrounding envelope (Ceccarelli et al. 1999a and 1999b, these proceedings). At this stage of the analysis we cannot distinguish between these different hypothesis. Assuming a CO column density of N[CO] = 10^{18} cm^{-2}, the typical sizes of the emitting regions for the three sources are:
IRAS2: 6"x 6", IRAS4: 3"x 3", IRAS6: 5"x 5"
where we emphasize that, since the lines are predicted to be optically thin, *we can only constraint the product of the CO column density and the source extent.* Therefore the difference in the CO emission of the three sources has to be attributed either to a different CO column density or to a different angular extent of the emitting region.

Finally, we notice the striking difference between the CO line spectra of our sources when compared to that observed towards HH54B (Liseau et al. 1996). In HH54B the J=15 / J=20 ratio is larger than 10, implying a gas either colder or less dense (see Fig. 3) of that responsible of the CO emission in the three sources of our sample. In the HH54B case CO line emission was attributed to a low velocity, C-type shock. Clearly, if the origin of the observed CO emission in the sources of our sample is also a shock, it has to be a different shock than that seen in HH54B.

4. CONCLUSIONS

We obtained ISO-LWS spectra at low spectral resolution (~ 250) of three young protostars in the NGC1333 molecular cloud.

The on-source spectra are dominated by high-J CO rotational line emission detected from J = 14 up to J = 21. The three sources have a similar J=15/J=20 ratio (~ 1.5), implying similar excitation conditions. This ratio is definitely different from that observed

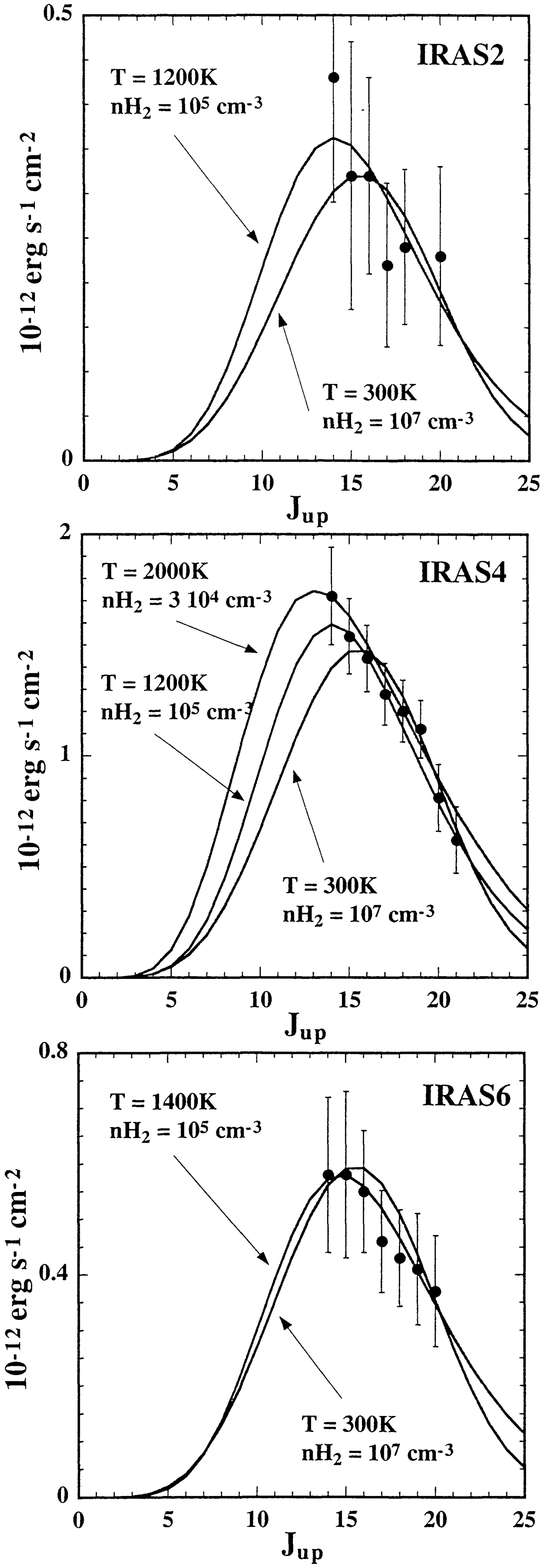

Figure 4. CO line spectrum of IRAS2 (top), IRAS4 (middle) and IRAS6 (bottom) as function of the upper level J.

toward HH54B (Liseau et al. 1996). In that case, the CO emission originates in a low velocity shock.

The observed line fluxes are consistent with either a high density ($\geq 10^8$ cm^{-3}) and a warm gas ($\sim$ 300 K), or a less dense gas ($\sim 10^5$ cm^{-3}) and warmer gas ($\sim$ 1500 K).

Since the lines are predicted to be optically thin, we can only estimate the product CO column density multiplied by angular extent of the sources. Then the difference in the absolute fluxes between the three sources has to be attributed either to a different column density or a different extent of the emitting region.

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