FAR INFRARED WATER LINE EMISSION IN THE ENVIRONMENT OF CLASS 0 OBJECTS

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Abstract

We have conducted with ISO-LWS a study of the far infrared line emission of a sample of 17 Class 0 objects and their associated outflows. At variance with more evolved young stars, such as Class I and pre-main sequence stars, the investigated spectra show a copious molecular emission in form of CO, H_2O and, to a minor extent, OH transitions. Our analysis demonstrates that the bulk of the emission arises from very small, dense and warm regions, where the ambient gas is heated by non-dissociative shocks, associated with the high energetic outflows characterizing this early phase of the star formation. Wherever gas phase water has been observed, large abundances are commonly estimated, with values which appear to be correlated with the gas temperature. OI, CO and H_2O contribute rough equally the whole line luminosity, indicating that a strongly prevailing cooling channel does not exist. These results are however still not conclusive, given the poor statistics and the large uncertainties associated with the water abundance determinations. In this contribution we will show how the FIRST instrumental capabilities are well suited to put firm conclusions on these questions.

Key words: Stars: formation – ISM:jets and outflows

1. Introduction

Class 0 sources are the early manifestation of an accreting protostar. They are identified for having a large ratio of submillimeter to bolometric luminosity, implying that their central mass is still smaller than the envelope mass (Andrè, Ward-Thompson & Barsony, 1993); hence they are very young sources, deeply embedded in the parent nebula and thus difficult to be directly observed. Class 0 sources drive strong outflows, usually more energetic than more evolved Class I sources of the same luminosity (e.g. Bontemps et al. 1996). Studying of the outflow properties is thus a powerful tool to indirectly derive information on the exciting source. However the derivation of the outflows parameters by means of CO millimeter mapping suffers from large uncertainties, due to poorly defined assumptions such as the outflow inclination and the lines optical depth. A new approach to indirectly study the interaction between the protostar and its outflow is to observe the radiation emitted by shock excited material along the flow. This method gives the energy istantaneously released without any morphological or physical assumption. From the ground, the shock cooling is commonly traced by means of the H_2 near infrared emission. The results obtained with the ISO spectrometers have however shown that the contribution of the H_2 is only a fraction of the global gas cooling and a quantitative analysis cannot be done without considering other coolants, as OI, CO and H_2O, which emit most of their energy in the far infrared (e.g. Nisini et al. 1999a). Water abundance, in particular, is expected to be enhanced up to 10^4 times with respect with the values observed in the cold interstellar medium (Snell et al. 2000). Here we report the first results on the ISO-LWS spectra of 17 Class 0 sources, with a particular attention to the water emission and to its connection with this phase of the protostellar evolution.

2. Observations and Analysis

Our sample (Table 1) is composed by 17 out of the 42 Class 0 sources (or candidate members) listed by Andrè, Ward-Thompson & Barsony (2000), which have been observed with ISO-LWS (43 - 197 μm). Both the sources and their associated outflows have been mapped by means of different pointings with the 80$''$ LWS field of view. We note that the selected objects have $L_{bol} \leq 75$ $L_\odot$ and D $\leq$ 730 pc, thus avoiding any distance dependent effects.

The investigated spectra (Figure 1) show as a prominent feature the copious presence, both on source and along the ouflow lobes, of pure rotational lines of abudant molecules (CO, H_2O, OH), which are instead more rarely observed in more evolved objects, such as Class I sources and pre-main sequence stars (see e.g. Giannini et al. 1999). [OI] 63 μm and [CII] 158 μm have been detected in all sources as well, while no trace of ionized lines has been found. Both atomic and molecular emission is frequently observed also in the outflow lobes, circumstance which strongly favours continuos, non dissociative shocks associated with the low velocity components of the gas in the outflow as the main origin of the excitation (C-shocks, see e.g. Kaufman & Neufeld 1996). The molecular emission has been fitted in a Large Velocity Gradient approximation in order to derive the physical conditions of the gas. In principle, independent determinations of all the parameters (gas temperature and density, ratio be-

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Table 1. Our sample of Class 0 objects

SOURCE	α(2000.0)	δ(2000.0)	L_{bol}	D
	h:m:s	o:':''	($L_\odot$)	(pc)
L1448-IRS3	03:25:36.3	+30:45:15	11	300
L1448-MM	03:25:38.8	+30:44:05	9	300
NGC1333-IRAS2	03:28:55.4	+31:14:35	40	350
NGC1333-IRAS4	03:29:10.3	+31:13:31	14	350
IRAS 03282+3035	03:31:20.8	+30:45:31	1.5	300
HH211-MM	03:43:56.8	+32:00:50	5	300
L1527	04:39:53.9	+26:03:10	2	140
L1641-VLA1	05:36:22.8	-06:46:07	50	450
HH24-MMS	05:46:08.3	-00:10:42	5	450
HH25-MMS	05:46:07.5	-00:13:36	6	450
IRAS 16293-2422	16:32:22.7	-24:28:32	23	160
L483-MM	18:17:29.8	-04:39:38	9	200
IRAS 18273+0113	18:29:49.9	+01:15:20	46	310
L723-MM	19:17:53.7	+19:12:20	3	300
B335	19:37:00.8	+07:34:11	3	250
L1157-MM	20:39:06.2	+68:02:22	11	440
CepE-MM	23:03:13.1	+61:42:26	75	730

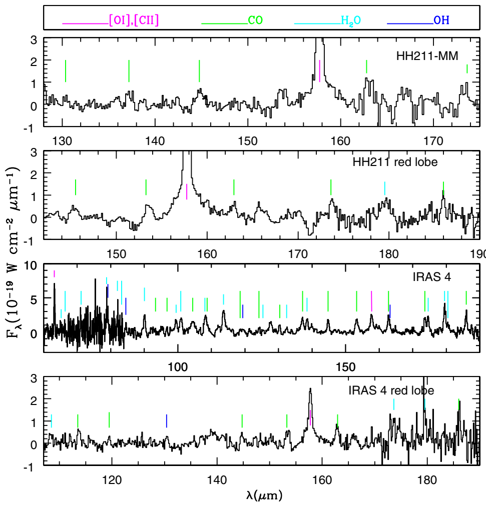

Figure 1. Typical spectra of Class 0 objects (Giannini et al. 2000). Together with [OI] 63 and 145 μm and [CII] 158 μm, many pure rotational lines of abundant molecules (H_2O, CO, OH) are commonly observed both on source and along the outflow lobes.

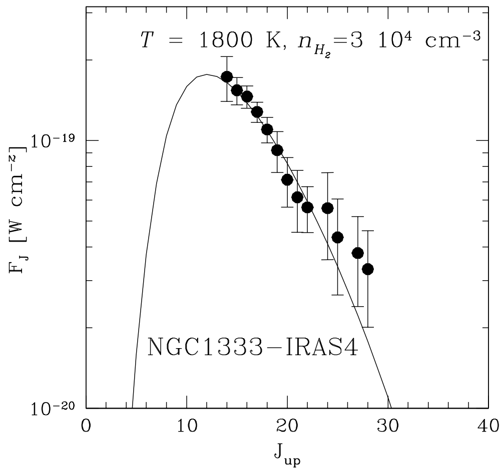

Figure 2. CO Large Velocity Gradient fit of the CO emission observed in NGC1333-IRAS4. Gas temperatures and densities span for all the sources in the range $150 \leq T \leq 1800$ K and $10^4 \leq n \leq 10^7$ cm^{-3}, respectively, indicating that the molecular emission comes from warm and dense gas.

tween column density and intrinsic linewidth) could be derived by modelling the emission of each species. In fact, CO lines result optically thin, and, as such, can constrain only temperature and density, while H_2O and OH lines, having in general opacities of the order of unities or more, depend also on the ratio $N/\Delta V$ (Nisini et al. 1999b), but they are usually too few to constrain all the parameters. This difficulty can be circumvented by assuming all the molecular species emitted from the same gas component. This allows firstly to derive temperature and density from the CO fit, and, as a second step, to use the H_2O and OH lines to estimate both the respective $N/\Delta V$ ratios (or absolute column densities, if the velocity dispersion is independently known), and the extendness of the emitting area. As an example, we show in Figure 2 the fit of the CO emission detected in NGC1333-IRAS4, from which we have derived temperature and density, while in Figure 3 two water line ratios measured in this source (i.e. F(75μm) / F(179μm) and F(82μm) / F(179μm)), are superimposed over the model predictions for a large range of the water column density. We derive in such way a water column density of $\sim 4\ 10^{16}$cm^{-2}. By applying the same procedure for all the sources we found as a general result temperatures between 150 and 1800 K and densities between 10^4 and 10^7 cm^{-3}. A reliable estimate of the water abundance has been provided in 9 LWS observed positions (Table 2).

3. Discussion

C-shocks models predict that gas phase water should be copiously producted as a consequence of very efficient high temperature (T$\gtrsim$300 K) reactions (H_2 + O $\rightarrow$ OH + H; OH + H_2 $\rightarrow$ H_2O + H) which convert into water all the oxygen not still incorporated in CO . The final H_2O abundance should be in this case larger than $\sim 10^{-4}$. Table 2 shows that, wherever we obtained reliable abundance determinations, we found values ranging from 10^{-5} to few times 10^{-4}. In Figure 4 we plot the estimated abundances as a function of the gas temperature derived from our fits to the molecular lines.

There is a trend for the water abundance to increase almost linearly with the temperature up to values of about $5\,10^{-4}$, which is the maximum water abundance expected

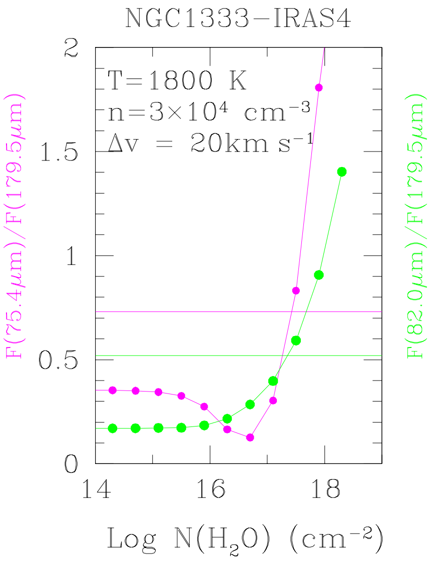

Figure 3. *H_2O line ratios as a function of the column density. The horizontal lines refer to the values measured in NGC1333-IRAS4. Typical values of the H_2O column densities span from 10^{16} to 5 10^{17} cm^{-2}. The size of the emitting regions is typically 10^{-9}-10^{-10} sr.*

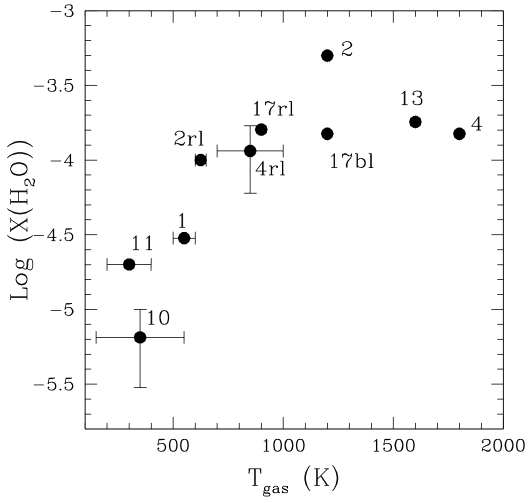

Figure 4. *$X(H_2O)$ as a function of the gas temperature. There is an apparent trend for the water abundance to linearly increase with the temperature up to a value of ∼5 10^{-4}, which is reached for T_{gas} > 1000 K. This behaviour, which needs to be confirmed on a larger statistical basis, is in contrast with chemical models predicting a sharp increase of $X(H_2O)$ as soon as T_{gas} > 400K.*

Table 2. Water abundance in low mass Class 0 sources

SOURCE	T_{gas} (K)	$n(H_2)$ (10^5 cm^{-3})	$X(H_2O)$ (10^{-4})
L1448-IRS3[1]	500-600	1-2	0.3
L1448-M[1]	1200	6	5
L1448-flow[1]	600-650	0.1-0.3	1
NGC1333-IRAS4	1800	0.3	1.5
IRAS4-flow	700-1000	0.3-1.2	0.6-1.7
HH25-MMS[2]	150-550	5-80	∼ 0.01
IRAS 16293-2422[3]	200-400	40-50	0.2
IRAS 18273+0113	1600	1.2	1.8
CepE-MM	900-1200	1.2	1.5

Note to the Table: 1) Nisini et al. 2000; 2) Benedettini et al. 2000; 3) Ceccarelli et al. 1998

by chemistry models, corresponding to the whole oxygen converted into H_2O. Such a value is however reached for gas temperatures exceeding 600 K, i.e. larger than the 300 K expected for the quick water formation. Such dependence of the abundance on the gas temperature can be explained by considering the timescales needed to form water. If the post-shock gas temperature is between 300 and 400 K, the time needed to convert all the oxygen into water is ∼10^4 yr (Bergin et al. 1998), i.e. comparable with the typical ages of the Class 0 sources. On the other hand, a decrease in the newly formed post-shock water is expected because of the quick depletion of water onto grains, with timescales which strongly depend on the density of the medium. According with the model by Bergin et al. (1998), water is depleted with timescales of about 10^4 yr for densities larger than 10^6 cm^{-3}. Actually, we derive the lowest values of $X(H_2O)$ in those sources whose derived densities are of the order of 10^6 cm^{-3} or more.

Summarizing, the different values of the water abundance derived, spanning about an order of magnitude around the value of 10^{-4}, may result from a time dependent chemistry during either the water formation or depletion after the shock passage.

A high water abundance should also result in its prevaling contribution to the overall gas cooling, due to the many cooling channels available in the rich H_2O energy levels diagram. To investigate this point in the framework of C-shocks models, we have estimated for each source the shock velocity corresponding to the derived temperatures, adopting the relationship given in Kaufman & Neufeld (1996). In Figure 5 we plot the observed cooling ratio $L(H_2O)/L(CO)$ against the so estimated shock velocities. The observational ratios are superimposed onto C-shocks predictions in the 10^4-10^6 cm^{-3} range of the pre-shock density. We note that all the points are located in a tight range around $L(H_2O)/L(CO) \approx 0.6$-5: this ratio agrees with the expected values up to shock velocities of ∼ 20 km s^{-1}, but it is under the predictions for the higher velocities exhibited by IRAS4 and IRAS 18273.

4. Conclusions and Future Perspectives

Our ISO-LWS observations have clearly demonstrated that a strong far infrared molecular emission, and in particular H_2O emission, is a peculiarity of the environments of

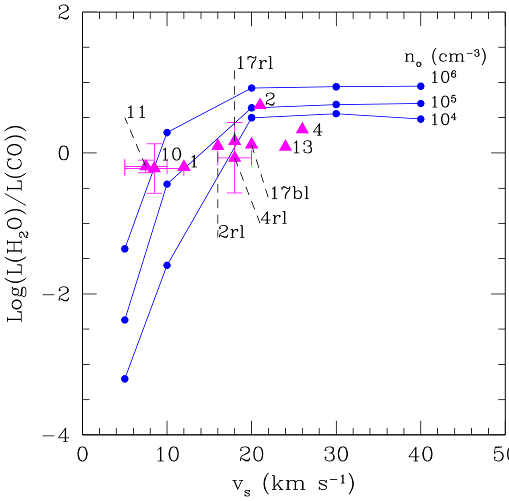

Figure 5. The observed cooling ratio L(H_2O)/L(CO) is plotted against the estimated shock velocity. Superimposed there are the cooling ratios expected from the C-shock model of Kaufman & Neufeld (1996). We note that all the points are located in a tight range around L(H_2O)/L(CO) ~ 0.3: this is in agreement with the expected values up to velocities of ~15 km s^{-1}, but it is systematically under the predictions for higher velocities.

Class 0 sources. However, firm conclusions both on the role of the water cooling and on the physical processes at the origin of its formation and desruption are prevented by the poor statistics and the large uncertainties associated to the determination of the physical parameters. These problems are clearly associated with the low sensitivity limit of LWS and its poor spatial and spectral resolution. In particular, we remark that, for estimating the X(H_2O)/X(CO) value on the basis of LWS measurements, the following assumptions are needed:

- CO and H_2O are emitted from the same region inside the LWS beam;
- gas temperature and density are constant over all the emitting region;
- the CO abundance is assumed;
- the intrinsic linewidth Δv is fixed.

All these assumptions will be overcome by the high spatial and spectral resolution of FIRST instrumentation: in particular the angular resolution of PACS (9.4 arcsec) is comparable with the typical sizes of knots of shocked material, which thus will be easily spatially separated; moreover, with HIFI high resolution observations, both CO and H_2O line profiles could be resolved.

We can also estimate the lowest water abundance detectable with FIRST instrumentation. We plot in Figure 6 the predicted intensities of the water line ratio I(179μm) / I(113μm) against the H_2O column density for two different temperatures and fixed n and Δv. Superimposed on the curves are the sensitivity limits of ISO-LWS, HIFI and PACS, by assuming an emitting area of 10 arcsec. We note that instrumentation aboard FIRST will allow to measure H_2O column densities down to $\sim 10^{14}$ cm^{-2}, i.e. X(H_2O) about two orders of magnitude lower than those measured by ISO-LWS. From the inspection of Table 2, this leads to a gross estimate for the limit water abundance of $\sim 10^{-7}$. Finally, we remark that FIRST will be able to detect all the species involved in the O-chemistry (O, O_2, CO, H_2O, OH), thus allowing the relative abundances to be studied, and the time dependent chemistry models to be improved.

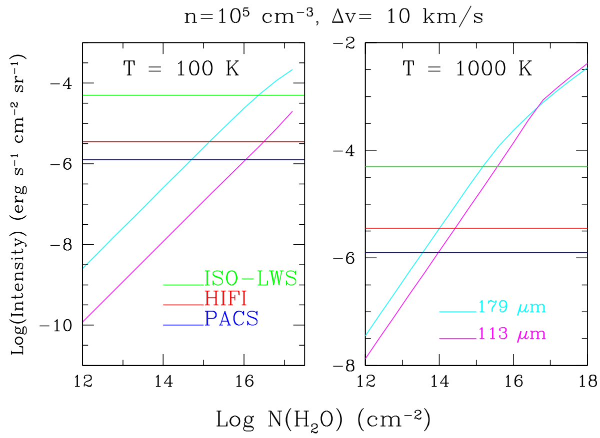

Figure 6. H_2O 179 and 113 μm predicted intensities plotted vs. the H_2O column density for two different temperatures and n=10^5 cm^{-3}, Δv = 10 km s^{-1}. The sensitivity limits of ISO-LWS, HIFI and PACS are shown by assuming an emitting area of 10 arcsec.

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