FAR INFRARED SPECTROSCOPY OF PRE-MAIN SEQUENCE STARS: THE LESSON LEARNED FROM ISO AND PERSPECTIVES

D. Lorenzetti, T. Giannini, and B. Nisini

Osservatorio Astronomico di Roma - Via Frascati, 33 00040 Monte Porzio (Roma), Italy

Abstract

We have recently analyzed the ISO-LWS spectra (43-197 μm) of two classes of Pre-Main Sequence objects, the Herbig Ae/Be (HAEBE) and the FU Orionis stars. ISO-LWS has provided an unbiased view of the neighbourhood of the central object by sampling the physical scale (≈ 80 arcsec) where the interaction with the closeby environment is taking place. The obtained spectroscopical results along with the comparison with model predictions are reviewed here. However, these far IR surveys have pointed out how remarkable aspects remain still unaddressed and have originated new questions which can be answered by using the capabilities offered by FIRST.

Key words: Stars: circumstellar matter – Stars: formation – Infrared: ISM: lines – Infrared: stars

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The [OI]63 μm, 145μm and [CII] 158μm are by far the strongest features observed and have been used (see Fig.1) as a diagnostic of the excitation mechanism (Lorenzetti et al. 1999). Radiation field values indicate that the illuminating field is enhanced by a factor $> 10^3$ with respect to the interstellar field value (G_o). This circumstance along with the correlation between the [CII] luminosity and the bolometric luminosity of the central star supports the hypothesis of a stellar rather than an interstellar origin for the FUV photons. The photodissociation (PDR) models agree with the observed lines only if an additional heating (photoelectrons from PAH and small grains) is considered (Kaufman et al. 1999). Shock models do not seem so much promising in interpreting the data: J-shock models (e.g. Hollenbach & McKee 1989) predict intensity ratios which fall in the hatched area in Fig.1, thus do not account for the observed ratios; whereas C-shocks models (e.g. Draine et al. 1983) do not predict any substantial [CII] emission.

1. Herbig Stars (HAEBE)

The investigated sample of HAEBE by means of the Long Wavelength Spectrometer (43–197μm) on board ISO is reported in Table 1.

Table 1. Parameters of the observed HAEBE.

Source	Spect. Type	L_{bol} ($L_\odot$)	A_V (mag)	Outflow Activity	dist. (pc)
LkHα198	B-Ae	340	4.5	CO/HH	600
V376 Cas	B5	517	5.2	HH	600
HD 97048	B9.5	30	1.3		150
IRAS 12496	A	50	11	CO	250
CoD-42°	B0	1120	7.1		400
MWC 297	B1.5	923	8		250
R CrA	A5	132	1.9	CO/HH	150
PV Cep	A5	100	0.4-9.5	CO/HH	500
V645 Cyg	O7	$1.3\ 10^5$	4.9	CO/HH	6000
LkHα234	B5/7	283	3.4	CO/HH	1000
MWC 1080	B0	$1\ 10^4$	5.3	CO/HH	1000

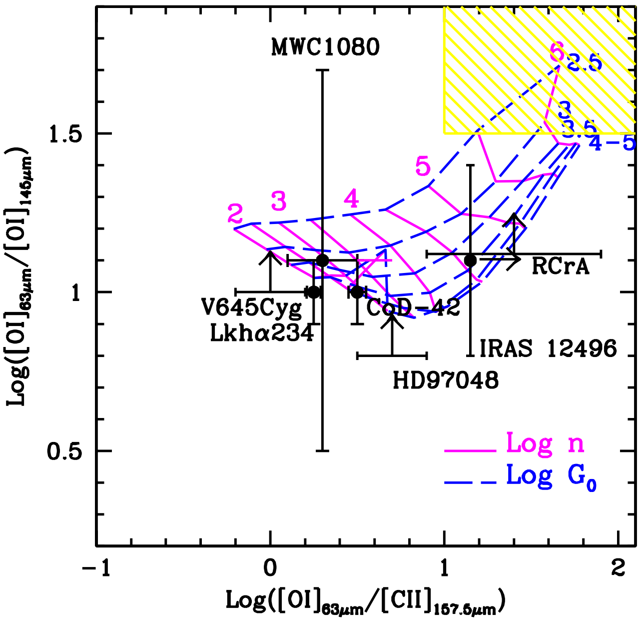

Figure 1. Observed line ratios superimposed to the PDR model of Kaufman et al. (1999).

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Molecular emission in form of CO and OH transitions with no evidence of water vapour emission has been detected in 3 sources (IRAS 12496, RCrA, LKHα234), namely those expected to have higher density circumstellar material (Giannini et al. 1999). These data have been fitted with an LVG model and the emission appears to originate in warm, dense gas, which is located in very compact regions. Clumpy PDR models (Burton et al. 1990) provide an explanation to the observed molecular data and values of n and G_o comparable to those from Fig.1 are derived. Again, shock models fail in interpreting the molecular transitions. In particular, in J-shocks the cooling is predicted to be dominated by [OI] 63μm and by H_2O rotational lines [$L(H_2O)/L(CO) \sim 10$] contrasting with the observed luminosity values $L(CO) \geq L(OI)$ and the absence of H_2O. While in C-shocks the expected values for the cooling ratios are $L(H_2O)/L(OH) \sim 10^2$ and $L(H_2O)/L(CO) \sim 10$, at strong variance with the observations.

2. FU ORIONIS OBJECTS

We have spectroscopically surveyed the FU Ori systems listed in Table 2.

Table 2. Parameters of the observed FU Ori.

Source	Spect. Type	L_{bol} ($L_\odot$)	A_V (mag)	Outflow Activity	dist. (pc)
RNO1B	F8II	1000	...	CO	850
Z CMa	B5-8neq	3500	2.8	CO/HH	1150
V346 Nor	F8III	290	...	CO/HH	700
(Re13)	...	50	...	HH	700
V1057 Cyg	F0-F3II	370	3.0	CO	600
V1331 Cyg	B05-F0	36	2.4	CO/jet	600
V1735 Cyg	...	250	10	CO	900

[OI] and [CII] are commonly observed, but the observational novelty is the presence, in most of the sources, of the [NII] transition at 122μm at a level of S/N $\sim$ 3 (Lorenzetti et al. 2000). To emphasize this detection, we have constructed a "mean spectrum" (Fig.2) by averaging all the spectra: it demonstrates that [NII] line is indeed real. [NII] 122μm line is important since it probes low ionisation and low density material not easily studied with other lines, owing to its low ionisation potential (IP = 14.5 eV) and its critical density ($n_{cr} = 3\ 10^2$ cm^{-3}). The central star (F-G type) cannot provide the required ionising photons to produce [NII] and [CII], but the UV photons produced at the disc-star boundary layer are able to generate an Extended, Low Density Warm Ionised Medium (ELDWIM by Petuchowsky & Bennett 1993) where only [NII] and [CII] occur. Such a scenario apparently contradicts the lack of optical NII, or other ionised lines, but at the very low temperatures typical of these HII regions (T $\sim$ 4000 K - Heiles 1994) only far-IR fine structure lines are expected to be excited. In conclusion, the interpretation of the observed spectra requires the presence of two components: (*i*) well localised J-shocks responsible for the [OI] emission ([OI] is well correlated with $\dot{M}$ as J-shock models predict - Hollenbach 1985); (*ii*) an ELDWIM produced by UV photons from the disk boundary layer, responsible for [NII] and [CII] emission.

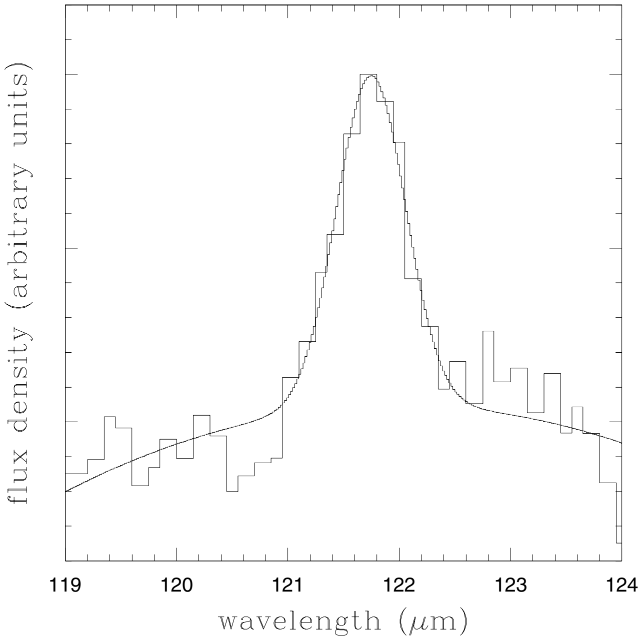

Figure 2. Mean spectrum in the range 119-124μm obtained by averaging all the individual spectra.

3. FUTURE PERSPECTIVES

These FIR spectroscopical surveys (HAEBE and FU Ori) have both clarified many aspects of the interaction between these young objects and their close environment, and have originated new questions which can be hopefully answered by using the instrumentation on board FIRST. In the following, we report specific items addressable by means of the forthcoming facility.

- The ISO-LWS mapping capability is enough to derive (from [OI] and [CII] line ratios) the gross distribution of G_o and density: an example for the region NGC 7129 is given by Lorenzetti et al. (1999). The morphology of the line emission allowed us to trace a low density PDR illuminated by the star BD+65°1637, whereas another more dense and clumpy PDR is associated with LkHα234. A better spatial resolution of $\sim$

10 arcsec, provided by PACS aboard FIRST, is in order to investigate the internal structure of the detected PDR's by tracing the transition zones $C^+/C/CO$, thus clarifying whether or not clumpiness is an important ingredient in HAEBE.

- The observed ratio [OI]63μm/[OI]145μm is always lesser than predicted (≤ 10) from both standard PDR and J- C-shocks models. As discussed above, to find a satisfactory agreement with the observed data (Fig.1), we pushed the PDR models toward the lowest [OI] 63/145 values by considering an additional heating source, although well compatible with the HAEBE properties. Studying whether this large scale behaviour stems from properties intrinsic to the emitting gas or results from averaging different emission *vs.* absorption components, deserves a spatial resolution much better (by $\sim$ an order of magnitude) than that of ISO-LWS.
- Molecular emission in HAEBE has been detected on a few sources (3 out of 11), coming from very compact (≤ 10 arcsec) regions. A systematic study carried out with a better sensitivity and spatial resolution could both give a definitive answer to the size of the emitting regions and significantly affect the detection rate of molecular emission.

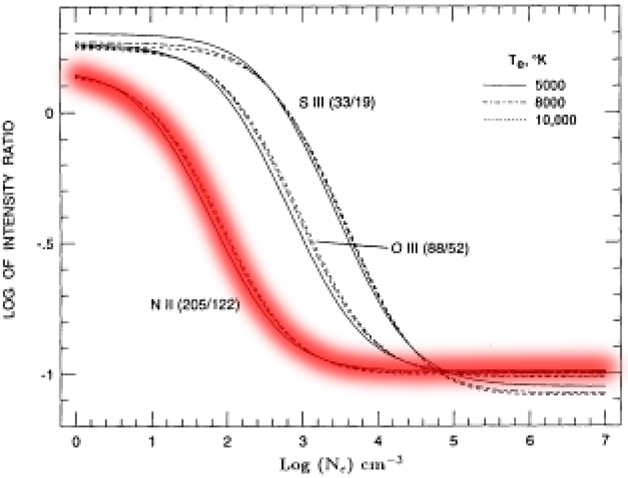

Figure 3. [NII] 205/122 intensity vs. electron density for different electron temperatures. Other indicators of N_e are reported, but the [NII] ratio is most sensitive to the lowest N_e (Rubin et al. 1994).

- ISO-LWS missed the fine structure transition of [NII] at 205μm, instead observable with PACS. The diagnostic diagram in Fig.3 predicts, by using the [NII] line pair, the electron density in the N^+ volume and the fractional ionisation in the environment around FU Ori objects. This will allow to verify our hypothesis about the [NII] excitation mechanism in that class. Moreover the higher resolution of FIRST-HIFI can resolve the [NII] 205μm line (expected to be brighter than the 122μm one), allowing to better constrain the origin of this line.

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