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Accretion properties of low mass embedded young stellar objects

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Abstract. The low and medium resolution spectra, obtained with ISAAC at VLT, of five embedded Young Stellar Objects (YSOs) in the R CrA star forming core have been analyzed in order to constrain the nature of the central objects and their accretion properties. Photospheric absorption features typical of late type stars have been detected in all the sources, including the Class I sources HH100 IR and R CrA IRS2, whose low resolution spectra only present several lines in emission. We derived spectral types, veiling and stellar luminosity for the five observed sources, which in turn have been used to infer their mass and age. Only HH100 IR and IRS2 have a bolometric luminosity mainly due to accretion ($L_{\rm acc}/L_{\rm bol}$ ~0.8 and 0.6 respectively), while the other three investigated sources, including the Class I object IRS5a, present low accretion activity ($L_{\rm acc}/L_{\rm bol}$ < 0.2) We observe a general correlation between the accretion luminosity, the IR veiling and the emission line activity of the sources while a correlation between the accretion activity and the spectral energy distribution slope is less recognizable. Our analysis therefore shows how the definition of the evolutionary stage of deeply embedded YSOs by means of IR colors needs to be refined.

Key words. Star formation–protostars–IR spectroscopy

1. Introduction

During the first evolutionary stages of a young star, the energetic of the protostellar system is dominated by a variety of phenomena occurring in different regions of the circumstellar environment. These latter include the accretion disk, the magnetospheric accretion region, collimated jets and, in more embedded sources, the still not dispersed dusty envelopes. In T Tauri systems, where the contribution from the dusty envelope has become negligible, there is the possibility to disentangle, through observations at different wavelengths, the properties of the star itself from those of the different active circumstellar regions, and to define in detail the properties of these latters. For the more embedded sources (the so-called Class I objects), however, the large extinction coupled with strong emission excesses due to the circumstellar activity, make the study of their stellar properties extremely difficult, even at infrared wavelengths. Hence the evolutionary state of Class I objects appears in-

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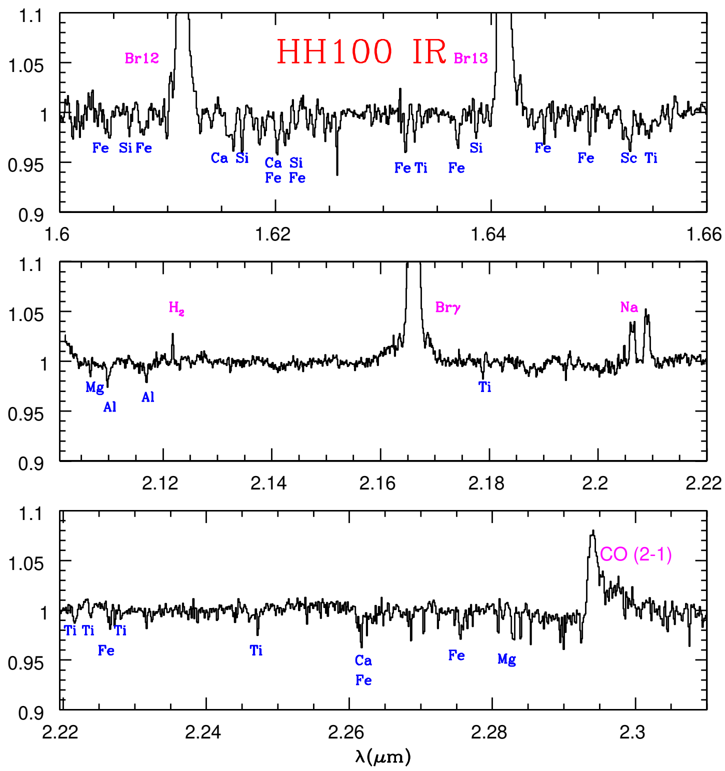

Fig. 1. Continuum normalized medium resolution spectra of HH100 IR. The most important emission and absorption features are labelled.

deed rather bad-defined. They are believed to derive most of their luminosity from accretion through a circumstellar disk. However, the rate of mass accretion is observationally poor constrained, since it is not known the real fraction of the source luminosity due only to accretion and the current mass of the protostellar object. Recent studies aimed to derive the accretion luminosity in samples of Class I objects give in fact contrasting results. Greene & Lada (2002) measured, through the direct observation of IR photospheric absorption lines, an L_{acc}/L_{bol} ~0.7 in the ρ Oph Class I source YLW15. On the other hand, White et al. (2004), derived that most of the Class I sources in Taurus have low mass accretion rates similar to those measured in the more evolved Class II sources of the same cloud. In this contribution we present the results of similar analysis performed on a sample of young embedded sources in the R CrA star forming core, at a distance of 130 pc, with the aim of comparatively derive the evolutionary properties of sources belonging to the same cloud.

2. Observations and analysis

The investigated sources have been selected from the list of IR young stellar objecs in the R CrA cloud core by Wilking et al. (1997), for having K magnitudes smaller than 10.5 mag and IR colors compatible with the locus of young embedded protostars with intrinsic IR excesses (Lada & Adams 1992). The sam-

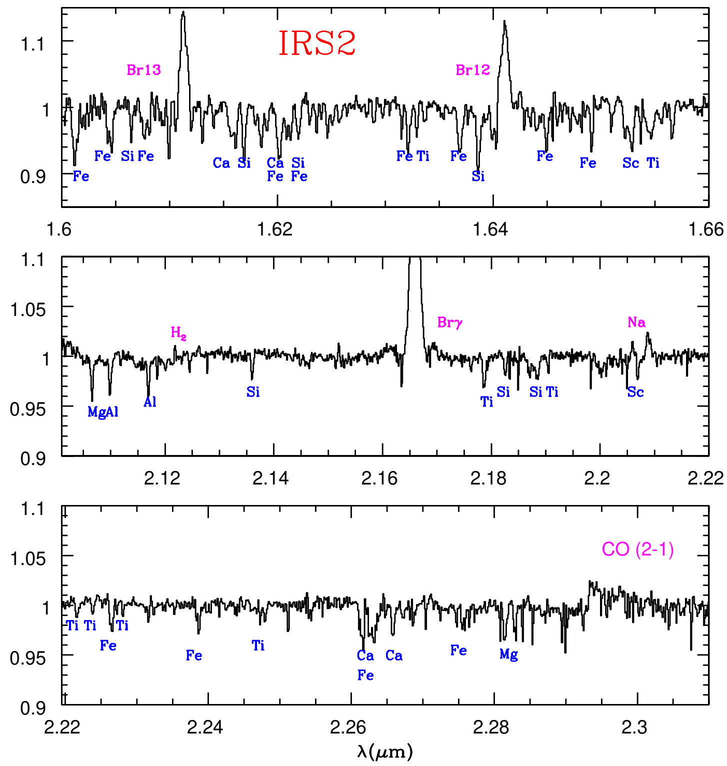

Fig. 2. The same of Fig. 1 but for R CRA IRS2.

ple consists of five sources (namely HH100 IR, IRS2, IRS5a, IRS6a and IRS3) having luminosities which range between ~1 and 15 $L_{\odot}$. Full spectra in the *J*, *H* and *K* bands have been obtained with ISAAC in low resolution mode (R~800). In addition, medium resolution (R~9000) spectra have been acquired in three spectral segments centered at 1.629μm, 2.161μm and 2.261μm, each covering intervals of ~0.122μm (in the *K* band) and ~0.080μm (in the *H* band) around the central wavelength. The sources having the steepest SEDs (namely HH100 IR and IRS2) are also those showing a prominent emission line spectrum, where the brightest line is Brγ at 2.16μm. In the other sources only few absorption features, and in particular the CO band heads longward 2.3μm, are observed. In Figures 1 and 2, the medium resolution spectra of HH100 IR and IRS2 are shown. We see that the higher resolution allows to detect the weak absorption lines which remained undetected in the low resolution spectra.

The observed absorption lines are the typical features expected from the photosphere of late type (K-M) stars (e.g. Luhman & Rieke 1998), therefore they can be effectively used to infer the source spectral type. The equivalenth width (EW) of these lines can be however significantly reduced by the presence of strong continuum excesses due to the emission from the circumstellar environment (accretion disk, dusty infalling envelope). Hence, to determine the effective temperature and luminosity class, we have to use ratios between diagnostic features as close as possible in wave-

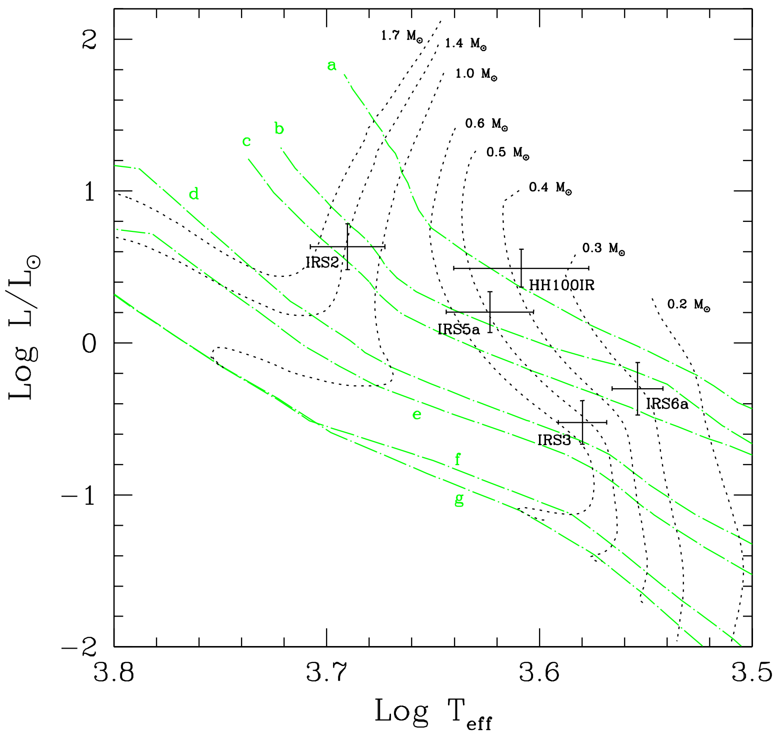

Fig. 3. HR digram of the R CrA sources with T_{eff} and stellar luminosity derived from the analysis of the medium resolution IR spectra. Evolutionary tracks (short dashed lines) and isochrones (dot-dashed lines) from D'Antona & Mazzitelli (1997) are shown for stellar masses between 0.2 and 1.7 $M_\odot$. Isochrones are reported for a - 10^5 yr, b - 5 10^5 yr, c - 10^6 yr, d - 5 10^6 yr, e - 10^7 yr, f - 5 10^7 yr and g - 10^8 yr.

length. In the case of HH100 IR and IRS2, a further problem is that some of the lines which are usually adopted for spectral classification (i.e. the Na lines 2.21 μm and the CO 2-0 bandhead, Doppman et al. 2004) are here observed in emission from the circumstellar environment. Therefore we have to rely on other independent diagnostic ratios for defining the spectral type of these objects. Sensitive ratios have been found in the spectral range around 2.12 and 2.23μm, where few strong features (in particular MgI(2.1066μm), AlI(2.1099μm), TiI(2.2217, 2.2240 μm) and FeI(2.2266 μm)) are present. In order to define the spectral types of the sources we have compared the observed ratios with those of the spectral standard stars taken from Wallace & Hinkle (1996) (for K band), and Meyer et al. (1998) (for the H band). Most of the sources are consistent with being dwarfs with ST between K2 and M2, as also found for other low mass YSOs (e.g.. Greene & Lada 1997). As expected, HH100 IR and IRS2 have the largest veiling values, r_K ~6 and 3 respectively, which are in the range measured in other very embedded young stellar sources (Greene & Lada 1997, 2002). The other sources show lower veiling values, more typical of T Tauri stars, where r_K is usually between 0 and 2 (Johns-Krull & Valenti 2001, Folha & Emerson 1999). Finally, the de-

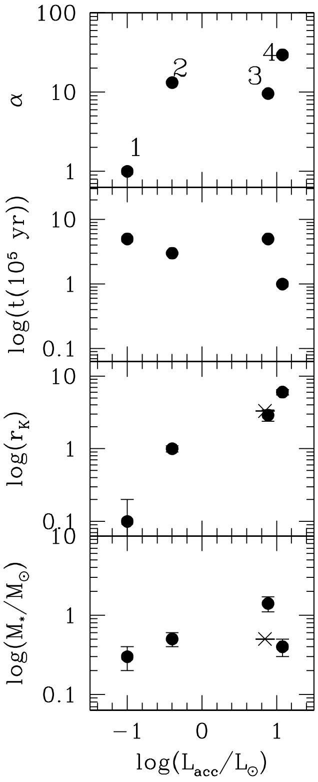

Fig. 4. Correlation between the derived accretion luminosity $L_{\rm acc}$ and, from the bottom to the upper panel, source mass, K band veiling, age and spectral index between 2 and 12μm. The sources plotted as filled dots are IRS6a (1), IRS5a (2), IRS2 (3) and HH100 IR (4). The Class I source ρ Oph YLW15, analyzed by Geene & Lada (2002), is also indicated (asterisk) whenever one of the stellar parameters were known.

rived veiling in the H band is about a factor of two smaller than the r_K value. From the knowledge of the spectral types and veiling, and from the (H-K) observed and intrinsic colors for the given spectral type, it is possible to estimate the effective temperature, the $A_{\rm V}$ and the stellar luminosity and radius of the different objects. We can then place them in the HR diagram and define their mass through a comparison with pre-main sequence evolutive tracks (Figure 3). Masses in the range 0.3-1.5 $M_\odot$ are found. Moreover, the difference between the derived L_* and the source L_{bol} can give an estimate of the excess luminosity due to accretion L_{acc}.

3. Discussion and conclusions

The stellar parameters, accretion luminosity and mass accretion rates derived from the analysis of the star photospheric features can be used to assess the relative evolutive phase between the observed sources and their degree of accretion.

Only in HH100 IR and IRS2 the accretion luminosity dominate over the total bolometric luminosity ($L_{\rm acc}/L_{\rm bol}$ ~0.8 and 0.6 respectively) and the derived mass accretion rates are of the order of $3\,10^{-6}$ and $5\,10^{-7}$ $M_\odot\,{\rm yr}^{-1}$ respectively, i.e. higher by an order of magnitude than the average values derived in T Tauri stars. In contrast, in IRS5a only ~2% of the luminosity is due to accretion. When compared with standard evolutionary tracks for pre-main sequence evolution, the derived stellar luminosities and effective temperatures indicate that HH100 IR is the youngest of the sources, with an age ~10^5 yr. On the other hand, IRS2, IRS5a and IRS6a have about the same age (~$5\,10^5$-10^6 yr) despite the large differences in their accretion properties.

To better understand how the accretion luminosity depends on other source properties we have plotted in Figure 4 the derived $L_{\rm acc}$ as a function of the source mass, veiling, age and spectral index. In this figure we have also plotted the values relative to the Class I source YLW 15 analyzed by Greene & Lada (2002). In general, the better correlation is found between the accretion luminosity and the IR veiling, indicating that the main source of veiling in these sources is probably the emission from the dusty envelope heated by the shock accretion photons (Calvet et al. 1997). A correlation between the accretion activity and the spectral energy distribution slope is recognizable with the notable exception of IRS5, which has an $L_{\rm acc}$ too low for its class. Finally, there is a hint that the accretion luminosity, for sources of the same age, may depend on the accumulated stellar mass, a result not totally unexpected and already suggested for more evolved Class II sources (e.g. Natta et al. 2004). We also point out that the accretion luminosity also strongly correlate with the line emission activity of the sources. In particular we find that the correlation between $L_{\rm acc}$ and $L_{\rm Br\gamma}$, previously reported for optical T Tauri stars (Muzerolle et al. 1996), can be extended to our sample of embedded sources, up to at least one order of magnitude larger line luminosity. In conclusion, our analysis shows that sources broadly defined as Class I protostars may be very different in terms of accretion activity. This indicates how the definition of the evolutionary stage of deeply embedded YSOs by means of IR colors needs to be refined. Low resolution IR spectroscopy can give a better diagnostic of the accretion activity of young embedded sources, evidenced by the presence of emission lines, HI recombination lines and CO overtone emission in particular. However, we have shown that the combination of low and high resolution spectroscopy may be effective in constraining both the stellar and circumstellar properties of even highly veiled objects, making it possible to directly derive the accretion luminosity and mass accretion rates back to the first 10^{-5} yr of protostellar evolution.

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