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Accretion/Ejection of matter in Young Protostars

New insights from near-IR spectroscopy

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Abstract. Accretion and ejection of matter represent the phenomena energetically more important during the first stages of the formation of a new star. The study of these phenomena in young protostars, however, is largely hampered by the fact that such objects are still deeply embedded in their parental cloud. A diagnostic based on infrared observations is often the only tool to get quantitative information on such active regions around young embedded objects. In this contribution I will discuss the main IR spectroscopic diagnostic features important for the study of jets and accretion regions in embedded young stars. These represent fundamental tools for the best exploiting of present and future high spectral and spatial resolution IR instrumentation.

Key words. Star formation–protostars–stellar jets–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 the active regions close to the source extremely difficult. The development in the last years of sofisticated high spatial and spectral resolution infrared instrumentation has allowed us to make large progresses in the study of these regions through the use of spectroscopic diagnostic lines. Here I will in particular discuss which are the main IR spectroscpic tracers of jets and accretion regions in young stars and how important physical parameters can be derived from these features.

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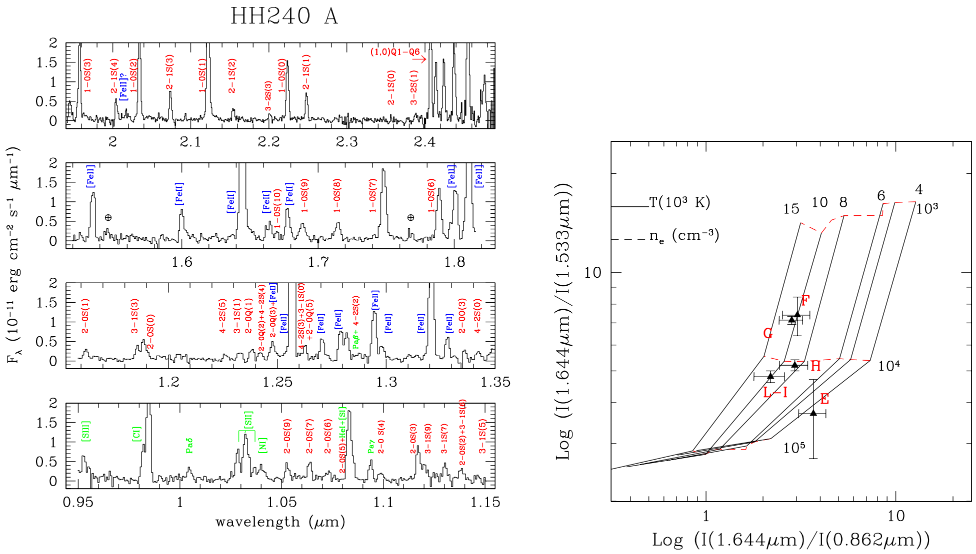

Fig. 1. Left panel: ESO-NTT spectrum of the Herbig Haro object HH240A belonging to a chain of emission knots driven by the protostar IRAS05173-0555. The spectrum is very rich of both atomic (mainly [FeII]) and molecular (H_2) emission lines excited in the interaction of the jet with the ambient medium. Right panel: Diagnostic diagram based [FeII] line ratios. The grid is constructed for electron densities of 10^3, 10^4, and 10^5 cm^{-3} (dashed lines), and for electron temperatures of 4,5,6,8,10,15$\times10^3$ K (solid lines). The symbols indicate the line ratios observed in the HH1 jet knots (Nisini et al. 2005b).

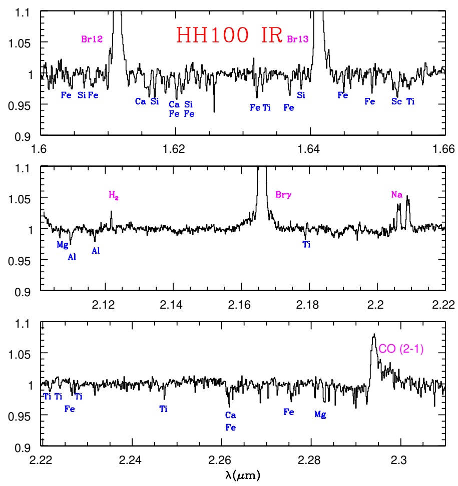

Fig. 2. Continuum normalized medium resolution spectra taken at ISAAC-VLT of the Class I source HH100 IR. The most important emission and absorption features are labelled.

2. Jets diagnostic through near IR lines

Collimated ejection of matter are amongst the most spectacular manifestations of the formation of a new star. Such matter flows are intmately related with the accretion process, since they are the main tool to extract the eccess of angular momentum from the system. Thus, the determination of jets main physical parameters is fundamental for understanding how the accretion takes place and put constraints on the flow origin and acceleration mechanisms. Protostellar jets are highly radiative and emit atomic and molecular lines at different wavelengths. Their near-infrared (NIR) spectrum is particulary rich in emission lines from both [FeII] and H_2 (see Fig.1). The ionic and molecular lines both originate from regions of the jet compressed and excited by the action of shock waves. Fe^+ comes from weakly ionized gas at T=5000–15 000 K located close to the shock front, while the molecular hydrogen is excited in post-shocked regions where the temperature has sufficently declined to allow H_2 to be formed again. H_2 can also originate in wings of bow shocks created in the interaction of the jet with the medium. Ratios of [FeII] transitions from 8000 Åto 2μm can be used to derive the reddening toward the jet (e.g. with the 1.64/1.25μm), and its electron density and temperature as shown in Figure 1 (Nisini et al. 2005b) . These parameters can be in turn used to derive the mass flux rate in the jet ($\dot{M}_{jet}$), providing that the jet velocity has been measured through high dispersion spectroscopy and proper motion study. This is a fundamental quantity to be determined because it governes all the jet dynamics and thus it enters all the comparison between observations and theoretical models. $\dot{M}_{jet}$ values in the range $\sim 10^{-8}$–$5\,10^{-7}$ $M_\odot\,yr^{-1}$ have been derived from the analysis of [FeII] lines in a small sample of Class I sources (Podio et al. 2005), values which are on average higher than those found in T Tauri stars indicating an evolution in the ejection efficiency with age. Similarily, the analysis of the H_2 lines falling in the NIR spectral range can be used to derive the amount of molecular material contributing to the total mass flux. In addition, the ratios of lines from different vibrational levels are strongly dependent from the exitation conditions and thus give constraints on the modality of the shock interaction (e.g. Giannini et al. (2004)) .

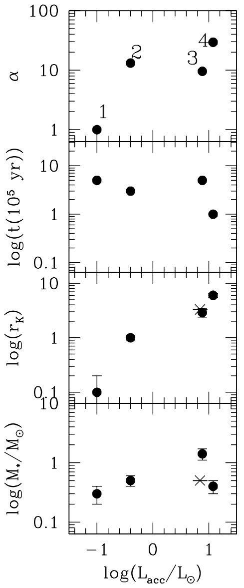

Fig. 3. Correlation between the accretion luminosity derived in a sample of Class I sources of the R CrA star forming region (Nisini et al. 2005a) and, from the bottom to the upper panel, source mass, K band veiling, age and spectral index between 2 and 12μm. The Class I source ρ Oph YLW15, analyzed by Greene et al. (2002), is also indicated (asterisk) whenever one of the stellar parameters were known.

3. Accretion properties of embedded YSOs

Class I objects are believed to be young protostars deriving 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. Indeed, it is very difficult to infer the stellar properties of these objects, since photospheric lines are very difficult to be observed even in the IR, where these sources become detectable. This is because the IR continuum emission of the circumstellar environment produces a stron veiling on the absorption features preventing their detection. Recently, however, the availability of sensitive IR spectrometers at medium/high resolution has allowed the detection of the the weak photospheric features of the stellar spectra of Class I sources, as shown in Fig. 3. This fact, in turn, has opened the possibility of deriving the stellar parameters (mass, radius and luminosity) of Class I sources and inderectly also the accretion luminosity and mass accretion rates (Greene et al. 2002; Nisini et al. 2005a). All this information can be used to assess the relative evolutive phase between the observed sources and their degree of accretion. Figure 4 shows how the accretion luminosity of a small sample of Class I sources in the R CrA star forming region depends on other source properties such as the mass, veiling, age and spectral index. 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. There is also 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 (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. 1998), can be extended to the embedded sources, up to at least one order of magnitude larger line luminosity. This is an indirect probe that the strong permitted emission lines observed in Class I sources at least partially originate from the accretion region.

4. Conclusions

The above discussion demonstrate the potential of IR spectroscopic observations in the diagnostics of both collimated jets and accretion regions of young embedded protostars. Such diagnostic tools will be best applied in the near future with the use of new generation instrumentation at high spectral and spatial resolution. An higher spectral resolution will allow us to analyse the details of the kinematical structure of the jets as well as to maximize the line/contuum ratio of the stellar photospheric lines. On the other hand, with high spatial resolution observations obtainable with AO or interferometric instruments we could derive the jet physical parameters at their bases, where the excitation conditions settled when the jet has been firstly accelerated are still not changed by the interaction with the ambient medium. In addition, interferometric observations will be the only way to resolve the accretion regions at distances < 1 AU from the central source, thus giving the possibility to directly test accretion models.

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