ADONIS 1 to 5 μm observations of Pre-Main Sequence binaries

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Abstract – We report here ADONIS + SHARP&COMIC $1-5\,\mu$m observations of a sample of Pre-Main Sequence (PMS) binary systems in various southern molecular clouds. Our measurements are used to study the precise photometry of both components in the near infrared range (NIR). From these measurements we derive the stellar spectral energy distribution (SED) of the primary and its companion, adjust standard photospheres to estimate their luminosities and temperatures, hence masses and ages through the use of a HR diagram. At the same time, we study the distribution of the circumstellar environment of our PMS targets through their infrared excess longward of $2.5\,\mu$m, to determine how the eventual leftover material is distributed after contraction. Our results were obtained during the first observing run with COMIC, which took place in May 1996, and will be fully developed in a forthcoming paper (Geoffray & Monin, 1998).

1 Introduction

Among other properties, young low mass T Tauri stars (TTS), are thought to possess circumstellar (CS) disks (see eg. Shu *et al.* 1987) and are most of the time members of binary systems (see eg. Ghez *et al.* 1997). Thus, it is likely that interaction(s) between the binary components and their associated disk(s) is an important process in early stellar evolution.

Observations in the sub-millimeter range have shown that the sub-mm flux is lower on binaries whose separation is of the order of 100 AU, suggesting that the outer part of the CS disks around the binary components are truncated by the presence of a companion (see Jensen *et al.* 1996; Osterloh & Beckwith 1995). The same mechanism occurs for binaries with closer separation, and in this case it can be traced by the lack of NIR emission (see eg. the work of Jensen & Mathieu (1997) on spectroscopic binaries). Prato & Simon (1997) showed indirect evidence that in PMS binaries the disks of the two components coevoluate, and used argument based on the survival time of CS disks in a binary environnement to conclude that a common cause (a surrounding circumbinary environnement) might be responsible for the feeding of the individual CS disk. Once the external reservoir is empty, a quick dissipation of both circumstellar disks occurs.

The PMS binary separation distribution peaks around 30-50 AU, corresponding to subarcsecond resolution in the nearest star forming regions, and most of the previous results were obtained on unresolved binaries. In this paper, we present diffraction limited photometry obtained with ADONIS+COMIC (Lacombe *et al.*, 1998) on a sample of close PMS binary stars (typical separations of 50-400AU) in the thermal IR. Most of the observed sources have been chosen in Reipurth & Zinnecker (1993) (see table 1).

The observations are described in section 2, and in section 3, we argue that the good image quality obtained during the observing run allowed us to derive precise photometry for both components. The results of this photometric study are given in section 4, and a conclusion is given in section 5.

Objet	Sep(AU)
BK Cha	140
CoD-29^{o}8887	40
HEN 3600	60
HO Lup	225
SR 9	80
Sz 68	390
V536 Aql	100
V853 Oph	60
WSB 20	140
HBC 634	33

Table 1: Observed sample from Reipurth & Zinnecker (1993)

2 Observations

A sample of a dozen TTS binaries has been observed during three nights in 1996, May 1,2 and 5. The SHARP camera was used during the first two nights and allowed observations in the J, H, & K bands, while the COMIC camera was used during the last night and allowed observations in the L and M bands. Binaries with separations larger than 0.2" (diffraction limit in L band) and smaller than 400 AU, were selected in various southern molecular clouds (Ophiucus, Lupus, Chameleon, and TW Hya) with a median separation value of 100 AU.

The conditions of observation were excellent during the whole run, from the photometric and from the turbulence conditions point of view. The weather was stable with typical parameters like: seeing $\simeq 0.8"$, $\tau_0 \simeq 300\,\mathrm{ms}$, $r_0 \simeq 15-25\,\mathrm{cm}$, see section 3. The targets were bright enough to allow good Adaptive Optics (AO) performances using the primary star as a wavefront reference. As far as the magnitude difference Δm was not too small and the separation not too large (typically $< 1.5''$), the correction has proven to be fully efficient. However, some corrections errors have been observed when both components of the binary system were of similar brightness. In such case, the use of a numerical filter (removing one of the components for the subsequent image analysis) restored the correction capabilities of the instrument. Our run was the first scientific one with the COMIC camera and the overall instrument ran smoothly thanks to the assistance of the ESO & ADONIS staff.

PSF reference stars have been observed before and after each scientific observation, in order to allow further deconvolution and PSF fitting. The observation of two PSFs associated with each object in each band allowed us to study the PSF stability with time (see section 3). All objects were observed at least twice in each band to increase the photometric accuracy. Photometric calibrators have also been observed regularly (typically every other hour) over the night. We have chosen to present our photometric results using the now widely spread Bessell & Brett (1988) standard system.

All the targets have been observed with a good photometric signal/noise ratio, typically 1000 in the J, H, & K bands, and > 100 in the L and M bands. The large integration capacity of the COMIC detector allowed integration times as high as 10 s in the L band and 1 s in the M band. In any case, the integration times have been chosen in order to obtain images limited by the background photon noise in these two latter bands.

Objects as faint as 10.5 mag in L band and 7.8 mag in M band have been observed, with total integration times of 180 s and 230 s respectively. Some faint objects observed in the J, H, & K bands were not observed in the L and M bands. The detailed photometric results will be published in Geoffray & Monin (1998).

3 Image quality

As an example of our results, the images obtained on the binary star V536 Aql are displayed on Fig. 1. This figure offers a striking illustration of the image quality currently achieved in the NIR range with the ADONIS (+ SHARP & COMIC) instrument, for a large range of D/r_0 ratios (typically between 5 and 20). Figure 1 shows the raw image of the object, together with its associated PSF from 1 to 5 μm. The deconvolved image, subsequently convolved by a gaussian of Full Width Half Maximum (FWHM) corresponding to the achieved resolution, is also displayed for each photometric band.

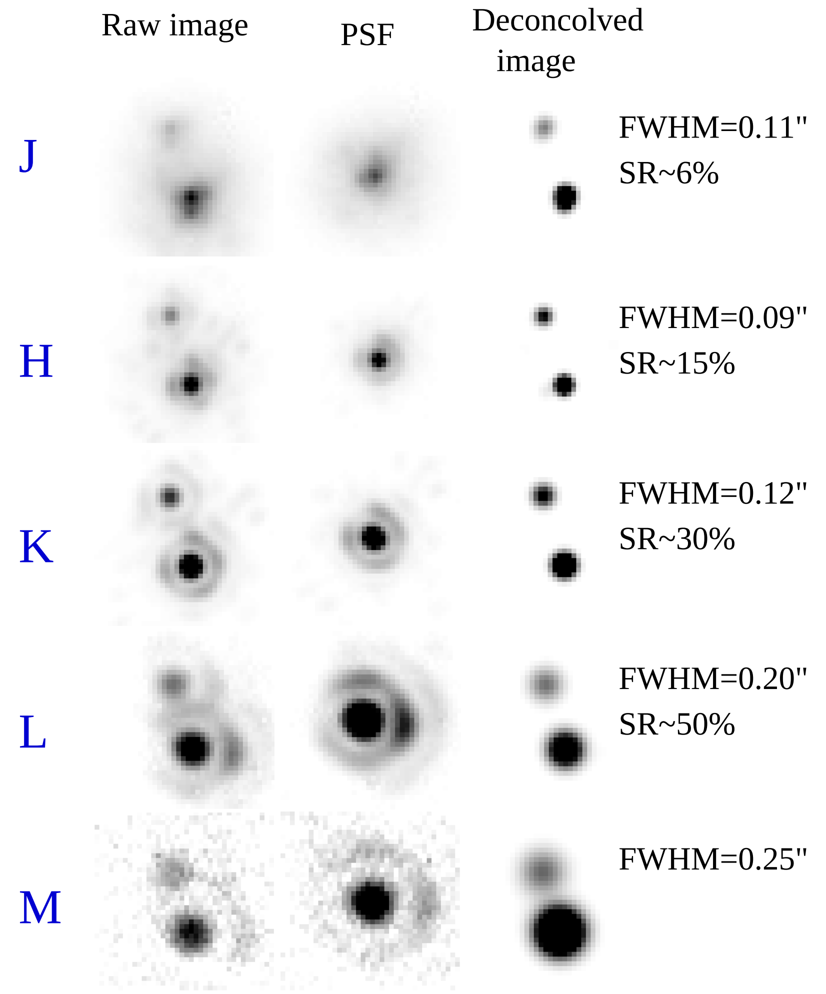

Figure 1: V536 Aql observed between 1 to 5 μm; $sep = 0.54''$, $PA = 17^o$, North is up and East is to the left. The pixel scale is 35 mas in the J, H, and K bands and 40 mas in the L and M bands, so that the binary separation *in pixels* is smaller in the L & M bands than in the J, H, & K bands. There is no actual separation variation from 1 to 5 μm.

The best resolution is actually achieved in the H band (1.65 μm). Figure 2 gives a more quantitative result with respect to the image quality currently achieved with the ADONIS instrument. This figure plots the Strelh Ratio (SR) as a function of FWHM measured on the long exposure PSFs (integration times ≥ 1 min) between 1 to 5 μm. The average SR and FWHM values obtained in each band are given in table 2.

Another important issue is the stability of the correction. Figure 3 displays two couples of long exposure PSF in the K band (total integration time of a few minutes), corresponding to two different positions of the telescope. The time interval between the PSFs measurements of each couple is of the order of 15-20 mn. All the PSFs exhibit some regular patterns (sometimes called “super-speckles”) on the halo, as well as a “triangular coma” on the first Airy ring. The striking point here is the relative stability of the PSF for a given position of the telescope, apart from a few differences in the “super-spekle” patterns. We interpret these “super-speckle” patterns as due to instrumental effects, as local turbulence can hardly explain why such patterns would be so stable with time.

The photometric accuracy obtained on each component our binary systems strongly depends on the PSF stability. Either PSF fitting or deconvolution have been tested in order to obtain the best photometry. We found

NIR Band	J	H	K	L	L'	M
SR	0.040	0.12	0.26	0.60	0.60	0.70
FWHM [$''$]	0.15	0.13	0.14	0.20	0.235	0.255

Table 2: Average SR and FWHM for each photometric passband. The best resolution is obtained in H band.

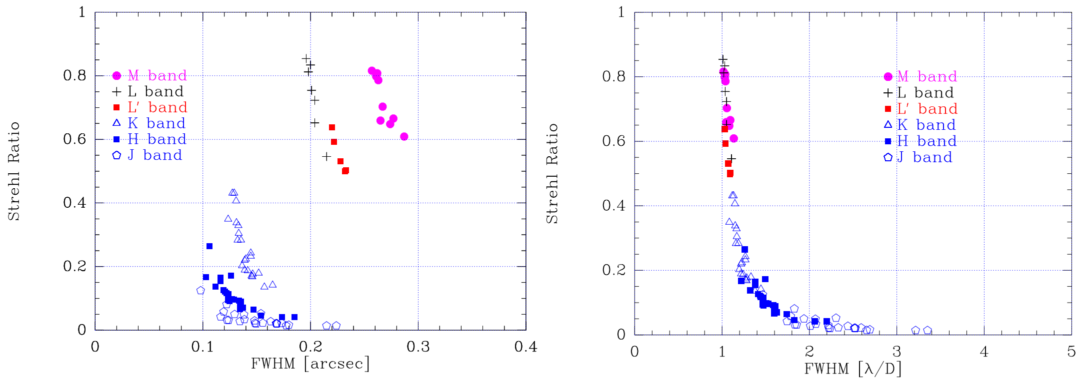

Figure 2: Strelh ratio vs FWHM measured on long exposure PSFs observed during the run. Right: "raw" SR; left: when scaled to λ/D, the points are regularly spread over a smooth curve that represents the instrument response function (similar results have been found on Pueo, CFHT by Rigaut *et al.* (1998)).

that the Lucy-Richardson algorithm gave the best estimates and allowed us to reach a few percents accuracy for separations less than 1" thanks to the good PSF stability (see also Harder & Chelli, this proceeding).
In summary, the photometric error is typically 0.03-0.05 mag in J, H and K band. In L and M bands, this error is of the order of 0.05 mag and 0.1 mag respectively.

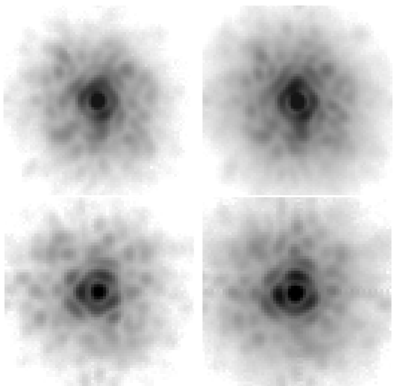

Figure 3: Stability of the K-band PSF during the observing run. Upper row: long exposure PSFs measured for the same telescope position. Lower row: idem, for another telescope position.

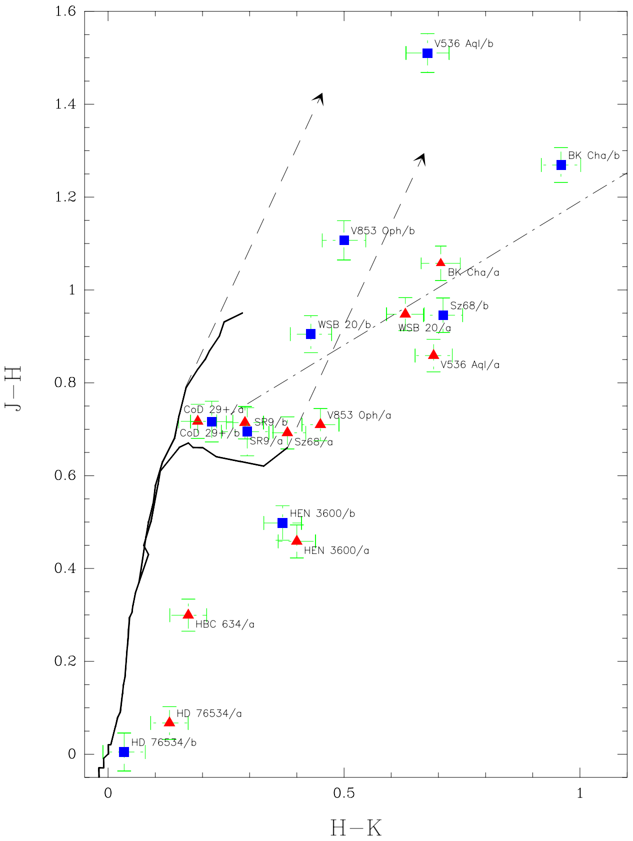

Figure 4: Color-color diagram for the sources of table 1. Solid line : locus of the main sequence dwarfs and giants. Dashed-dotted line: locus of the TTauri Stars from Meyer *et al.* 1997. The reddening vectors are given for $A_V = 5$ (dashed line).

4 Results

4.1 Color-color diagrams

We have used our NIR photometry measurements to place the objects in color-color diagrams. From the J-H/H-K diagram, we can estimate the interstellar extinction and the spectral type for stars later than K7-M0, ie. later than the turnover of the main sequence dwarf locus, along the reddening vectors. For instance, V536 Aql-b and V853 Oph-b appear to be heavily extincted objects. Some stars show an intrinsic reddening, which cannot be explained by interstellar extinction, but rather by the presence of an optically thick CS disk. The distinction between stars with and without optically thick circumstellar disk (respectively CTTS and WTTS) is more obvious in a H-K/K-L diagram because the (K-L) color index is less sensitive to interstellar reddening ($E(K-L) = 0.05A_V$). Thanks to the availability of the COMIC instrument, the thermal infrared excess of close binaries can now be measured. This diagram will be presented in Geoffray & Monin (1998). The dereddenned K-L index can be used to discriminate between objects with and without an optically thick CS disk: $(K-L) > 0.3$ for CTTS, $(K-L) < 0.3$ for WTTS (Hartigan *et al.*, 1995).

4.2 Circumstellar disks

Among other results, we can illustrate the benefit of AO in the full NIR range on two objects of our list (Sz68 and CoD-29°8887). Sz68 presents a dereddened K-L index larger than 0.6 for both components. We can therefore confidently conclude that both components of this binary possess a disk, and Sz68 is a C/C binary. On the contrary, CoD-29^{o}8887 has a dereddened K-L index lower than 0.1 for both components and is most likely a W/W binary.

Amongst the (previously unresolved) WTTS binary stars in our list, none of the two components possess an optically thick disk, ie. both components are WTTS. This could have been anticipated, since the presence of a CTTS in a couple should provide a sufficiently large $H\alpha$ equivalent width for the binary as a whole when the source does not have a large flux ratio. For the (previously unresolved) CTTS binary stars of the sample, we find that half of them are CTTS-CTTS pairs.

Prato & Simon (1997) have studied 12 binary systems with separation ranging from 40 to 350 AU in the Taurus cloud. Amongst these close binaries, none appear to be mixed pairs (i.e. CTTS-WTTS). This result has been confirmed more recently by Duchêne *et al.* (1998).

This disagreement between previous studies and our results with mixed pairs for close binaries maybe be explained by the different physical conditions prevailing in the Taurus cloud, as compared to other star forming regions.

4.3 SED fits

In some systems, a fit of the spectral energy distribution of each component has been performed. This has been possible thanks to previous measurement from the literature completed by our new results :

- the spectral type of the primary, used when the flux ratio of the binary is large enough in the visible.
- the $UBV(RI)_c$ photometry for the unresolved system.
- the known extinction coefficient A_V; we assumed that this coefficient was identical for both components (as found for instance by Brandner & Zinnecker (1997)). The extinctions have been derived from the $E(R-I)$ excess and the spectral type of the system. In most cases, the value from the literature was in good agreement with the value deduced from our J-H/H-K color diagram.

The spectral energy distributions corrected for interstellar extinction have been fitted with standard intrinsic colors of main sequence dwarfs. The free parameters of the fit are the visual magnitude of the primary, the visual magnitude and the spectral type of the secondary. The errors on both the spectral type and the V magnitudes mainly come from the uncertainty on the interstellar extinction coefficient A_V, from the photometric variability of the objects (visible and infrared photometric measurements are not simultaneous) and, to a minor extent, to photometric uncertainties.

Two examples of SED fits are displayed on Figure 5, for Sz68 and CoD-29^{o}8887. When the object possesses an infrared excess, the fit has been performed mainly on the RI wavelength range (Sz 68 for example). The fit is strongly constrained when the object does not possess infrared excess (CoD-29^{o}8887). The resulting spectral type for each component is constrained to within one subclass.

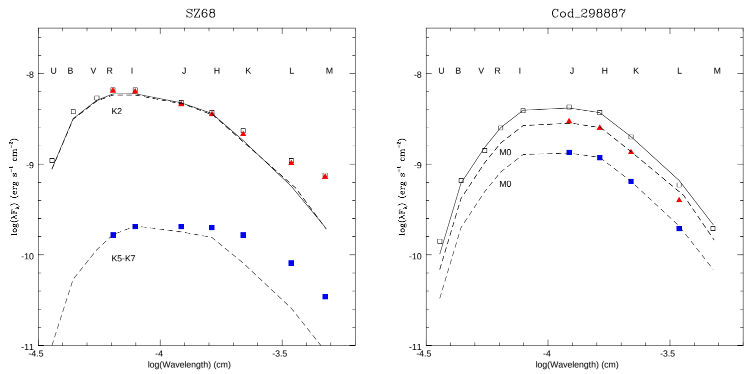

Figure 5: SED fits (solid and dashed lines). The measurements are plotted with filled triangles for the primaries, filled squares for the secondaries and open squares for the corresponding sum.

4.4 HR diagram for the two sources Sz 68 and CoD-29°8887 (CoD-29)

Using the fitted temperature and the luminosity of the objects, it is then possible to place them in an HR diagram to estimate masses and ages for both components. The result is displayed in Figure 6.

The evolutionary tracks computed by D'Antona & Mazzitelli (1994) are also plotted in this diagram, and we find that within the error bars, the two components of CoD-29°8887 (separation 40 AU) are coeval, while the components of Sz68 (separation 390 AU) are not.

Hartigan *et al.* (1994) studied binaries in Taurus with separation ranging from 400 to 6000 AU. They found that 2/3 of the binaries of their sample are coeval. More recently Brandner & Zinnecker (1997) studied 14 binaries systems (in Chameleon, Lupus, and ρ Ophiucus clouds) with separation ranging from 90 to 250 AU and found that for all pairs the individual components appear to be coeval.
Although based on small numbers, our results are in agreement with these previous studies.

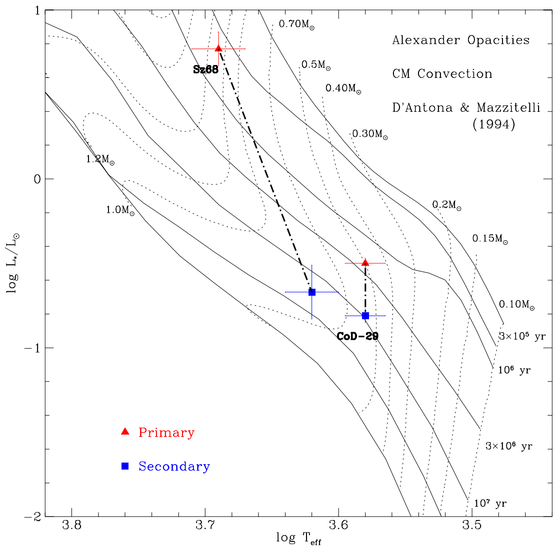

Figure 6: HR diagram.

5 Conclusion

We have presented ADONIS + (COMIC & SHARP) observations of a sample of close pre-main sequence T Tauri binaries with typical separation between 50 and 400 AU. The large spectral coverage (from 1 to 5 μm) and high angular resolution ($\simeq 0.2''$ on a 4m class telescope) of these observations allowed us to estimate the physical parameters of both components in most of these close systems.
In the observed PMS binaries, COMIC gives access to the $(K - L)$ index of both components and it can be used to detect the presence of an optically thick accretion disk. These results will be presented in full details in a forthcoming paper (Geoffray & Monin, 1998), together with a discussion on the relative coevolution of TTS components in binary systems. We have also performed a careful study of the ADONIS PSF caracteristics over the whole NIR wavelength range. In the future, further observations with larger telescopes equiped with Adaptive Optics (eg. the VLT+NAOS), will allow to enlarge the sample by giving access to closer systems, where the separation distribution peaks, leading to a better unterstanding of PMS binary formation and evolution.

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