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ON THE PMS STAR HBC 498 AND ITS ASSOCIATED NEBULOUS STARS[1] (RESEARCH NOTE)

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RESUMEN

Presentamos observaciones espectroscópicas (resolución $\geq$ 1750 en λ = 6708 Å) y fotométricas ($ubvy$-β) recientes de la singular estrella T Tauri con líneas en emisión débiles HBC 498 (= DL Ori/G1), aún asociada a su nube de polvo progenitora, y de otras cuatro estrellas vecinas y brillantes, todas ellas con nebulosidades de reflexión asociadas, las cuales conforman un trapecio estrecho en L1641 en la constelación de Orión. Dos estrellas resultan ser del tipo T Tauri "clásicas" y dos del tipo T Tauri "con líneas en emisión débiles". La mayoría presentan la huella de juventud del Li I en su espectro. De los datos y su comparación con modelos evolutivos de estrellas pre-secuencia principal, encontramos que son coetáneas, con masas alrededor de 1 $M_\odot$ y edades del orden del tiempo de contracción gravitacional o menor ($\approx 1-5\times10^5$ años). Finalmente, discutimos brevemente el estado evolutivo de estos objetos y sus repercusiones.

ABSTRACT

We present recent spectroscopic (resolution $\geq$ 1750 at λ = 6708 Å) and photometric ($ubvy$-β) observations of the singular weak-line T Tauri star HBC 498 (= DL Ori/G1) still associated with its parental dust cloud and of at least four other bright neighboring stars associated with reflection nebulosities that together form a tight trapezium in L1641 in Orion. Most of them have the youth signature of Li I in their spectra. We find that two of the objects are "classic" T Tauri and another two are "weak-line" T Tauri stars. From the data and their comparison with models of pre-main sequence stellar evolution we find that they are coeval, and that they have masses of the order of 1 $M_\odot$ and ages of the order of their gravitational contraction times or less ($\approx 1-5\times10^5$ yr). Finally, we briefly discuss their evolutionary state and its repercussions.

Key Words: **STARS: ABUNDANCES — STARS: EMISSION LINE — STARS: INDIVIDUAL (HBC 498) — STARS: PRE-MAIN SEQUENCE**

1. INTRODUCTION

The emission line star HBC 498 (= DL Ori/G1 in Cohen & Kuhi's 1979 designation) and another four nebulous stars in its immediate vicinity stand

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out because of their associated reflection nebulosities (Dorchner & Gürtler 1963; van den Bergh 1966; Bernes 1977); Gyulbudaghian, Glushov, & Denisyuk 1978) and because they apparently constitute a tight trapezium of young stellar objects (Cohen 1980; Cohen & Kuhi 1979) associated with a small dark cloud in the direction of L1641(see Figure 1). The separation between any two stars in the trapezium is of about 0.20 pc (at a distance of 460 pc). The 25 year old spectrophotometric (resolution $\Delta\lambda = 7$ Å) and near infrared (JHK) photometric study of this region by Cohen & Kuhi (1979) is the most complete yet published, since it includes all five stars with associated reflection nebulosities. They designated them DL Ori/G1 to DL Ori/G5 inclusive. The stars are apparently connected by a dust lane to the nearby classic T Tauri star (CTTS) DL Ori, nine arc minutes to the east of the trapezium. Except for DL Ori/G2, for which Cohen and Kuhi report no Hα emission, the objects were included in the "Herbig-Bell catalogue of emission-line stars of the young Orion population", namely HBC 498, 497, 495, and 496, respectively (Herbig & Bell 1988), since they fulfil the pre-main sequence (pms) criteria for solar-like stars (Herbig 1962). Unfortunately, Cohen and Kuhi made no reference of the Li Iλ6708 Å line possibly present in their spectroscopic data, a key indicator of low-mass PMS stars. However, these authors gave means to estimate the physical parameters of HBC 498 and its neighboring stars. From their data one infers that they are very young solar type stars. Carballo, Eiroa, & Mampaso (1988) subsequently secured near infrared ($JHKL$) observations of DL Ori/G2, HBC 495, HBC 498, and HBC 497, i.e., their sources IRS 1, 2, 3, and 4 of GGD 7 (Gyulbudaghian et al. 1978), respectively, confirming the youth of the trapezium. Additionally, they observed a faint star south-west of HBC 497, their IRS 5, which could belong to the system. From their data and the mid-infrared IRAS fluxes, they found that HBC 497 is, easily, the most luminous object of the region.

More recently, Alcalá et al. (1996) associated HBC 498 with the X-ray *RASS* source RXJ0540.8–0806, observing it spectroscopically (resolution $\Delta\lambda \approx 4$ Å) and photometrically ($UBVRI$ and *ubvy*-β), and finding that it is a weak-line T Tauri star (WTTS). This is reinforced by further observations made with higher spectroscopic resolution (Alcalá et al. 2000). Despite the fact that it is the singular case of a WTTS still associated with its parental cloud and despite the presence of other four nebulous objects associated to the HBC 498's dust cloud,

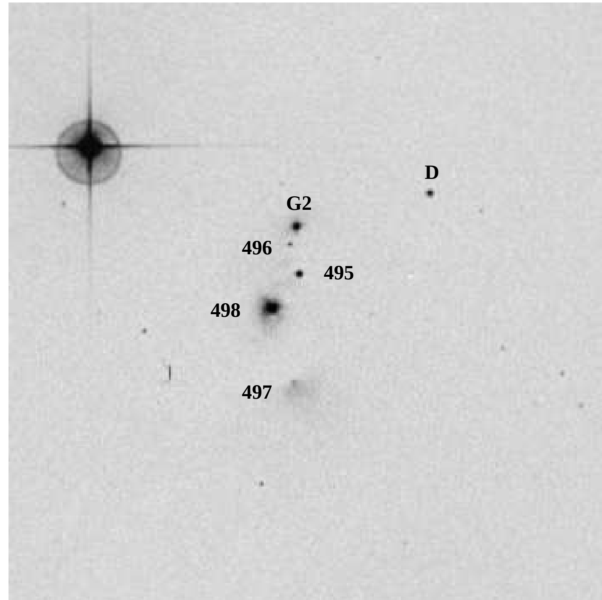

Fig. 1. POSS-red $10' \times 10'$ image of the HBC 498 region. North to the top and east to the left. The bright object at the left corner is the A0/A1 V star HD 37846.

all recent works make no allusion to the additional young stars. Here we intend to remedy the situation, motivated by the fact that the WTTS HBC 498 associated reflection nebulosity and its nebulous companions apparently lie in the same small dark cloud and have had no time to drift from their formation site. This provides an opportunity to examine star formation in the region.

2. THE OBSERVATIONS.

2.1. *Spectroscopy*

On the nights of 2000 January 30 and 31 we performed medium-low resolution spectroscopy ($\lambda/\Delta\lambda \simeq 1750$ by λ6708) of the brightest stars located in the region surrounding HBC 498 with the Italian Boller & Chivens spectrograph attached to the f/7.5 focus of the 2.1 m Cassegrain telescope of the Sierra San Pedro Mártir National Astronomical Observatory in Baja California, México (SPMO hereafter). A diffraction grating of 600 lines per mm, blazed at 13° and a slit with an effective aperture of 150 μm ($\simeq 2''$, sky-projected) were used for the observations. The instrument was provided with a Tektronics TK1024AB 1024 × 1024 square pixel light detector, the CCD-TEK#2 of SPMO. We reobserved the region on 2002 December 16 with the same instrumentation, dispersion (2.07 Å/pixel) and spectral resolution ($\Delta\lambda = 3.8$ Å) but with another CCD detector: the SITE #1 of SPMO. For details

TABLE 1

CCD'S CHARACTERISTICS[a]

Detector[b]	I_d $\frac{e^-}{(hr\ px)}$	Gain $\frac{e^-}{ADU}$	Well e^-	Noise[c] e$^-$	Lin. %
SITE#1	0.02	1.20	$3.00 \cdot 10^5$	7.8	≤ 0.45
TEK#2	0.35	1.12	$2.96 \cdot 10^5$	3.6	≤ 0.19
TEK#1	0.76	1.22	$3.19 \cdot 10^5$	3.0	≤ 0.02

[a]More details in www.astrosen.unam.mx.
[b]The three CCD's have pixel-sizes of 24 μm × 24 μm.
[c]Read-out noise RMS value.

of the detectors, consult Table 1. The spectrum of a He/Ar comparison lamp was used for wavelength calibrations. Two exposures of the comparison lamp, one with a 1-second integration time and the other with a 3-second integration time were taken after observing a program star. An exposure time of 1200 seconds was used for HBC 498, DL Ori/G2 and HBC 495, and of 2400 seconds for HBC 496. A total of 12 spectra with useful signal to noise (S/N) ratio were secured: four of HBC 498, three of HBC 495, two of DL Ori/G2, two of HBC 496 and one of the westernmost of the stars, DL Ori/D, observed here for the first time (cf. Fig. 1). The spectrograms were reduced using standard *MIDAS*[3] and *IRAF*[4] procedures for the first and second runs, respectively. The exposures were cosmic ray-corrected, bias-substracted, and flat-field-corrected in the usual way. The wavelength calibration was done by fitting with a third or fourth degree polynomial the comparison spectrum, and care was taken to minimize diffuse sky light contamination on the spectra of the program stars. Each spectrum was normalized by dividing it with a spline-fit of its continuum. Selected resulting spectra are displayed in Figure 2.

In addition to the above set of spectra, two spectra of HBC 498 and two of HBC 495 were also at our disposal for this work, taken by J. M. Alcalá and C. Chavarría-K on the night of 1996 November 12, with the same instrumental setup, but with a thinned (film-coated) Metachrome II Tektronics TK1024AB CCD, TEK#1 of SPMO (cf. Table 1). Finally, a medium-high dispersion spectrogram of HBC 498 ($\Delta\lambda/\lambda = 18,000$ by $\lambda = 6708$ Å) was available for this work. It was secured on 2002 December with the *REOSC* Echelle spectrograph attached to the f/7.5 focus of the 2.1 m telescope.

2.2. Hα *and (R,I)$_C$ Imagery*

In order to check for any emission from the nebulosities in which the program stars are immersed,

[3]Munich Image Data Analysis System of the European Southern Observatory Organization.
[4]Image Reduction and Analysis Facility by NOAO.

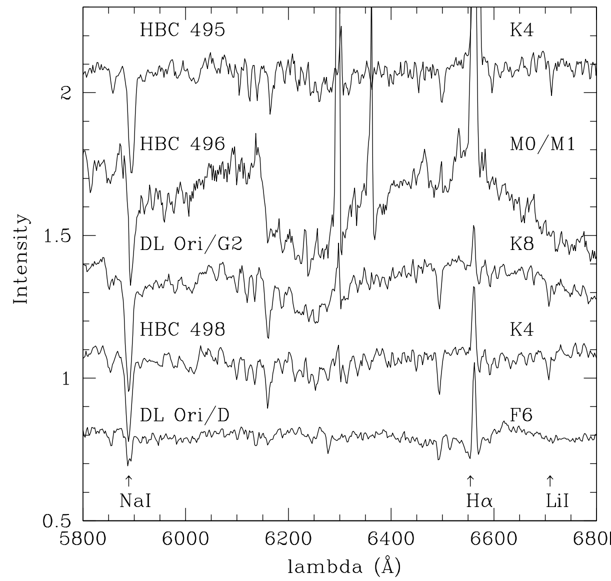

Fig. 2. Normalized spectra of the program stars, shifted arbitrarily along the intensity axis for convenience.

on the night of 2000 January 24 we took three direct Hα images of the region around HBC 498 with the 84 cm f/15 Cassegrain telescope of SPMO, using the SITE#1 CCD. The Hα filter had a central wavelength of $\lambda = 6563$ Å and a passband of $\Delta\lambda = 10$ Å. The exposure time of each image was 1200 seconds and they were taken with fair to good seeing ($\approx 1\overset{''}{.}5$). All three exposures were bias, flat-field, and cosmic ray-corrected with IRAF. The three exposures were then coadded to improve the overall S/N ratio of the resulting image, which is shown in Fig. 3. Two additional 900 sec Hα exposures centered on the Balmer line but with a passband of 80 Å, as well as two R and two I 180 s images in the Cousins photometric system were taken on 2003 February 10 under good seeing conditions ($\leq 1''$) with the same instrumental setup, but the night was not photometric.

2.3. *ubvy-β Photometry*

Stars HBC 498, DL Ori/G2, HBC 495, and DL Ori/D were observed photometrically in the *ubvy-β* system in four different seasons with the Danish six channel photometer attached to the 1.5 m *Harold L. Johnson* telescope of SPMO. Stars HBC 495 and DL Ori/G2 were observed on six, HBC 498 on five, and DL Ori/D on three different nights, respectively. For details regarding the instrument see Nissen (1984) and Terranegra et al. (1994). The sky was usually measured in the RA direction with an average off-set of 30$''$ and using a diaphragm of 14$''$ for

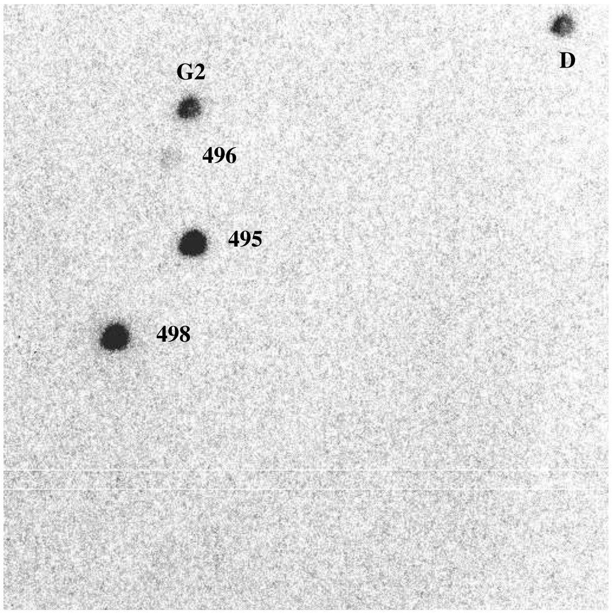

Fig. 3. Composite Hα image of the region of HBC 498 with an effective exposure time of 3600 s. Same orientation as Fig. 1. See text for details.

the observations. The reductions to Olsen's (1984) reference system were made following usual procedures (Mitchell 1960) with the *RainBow.v01* photoelectric photometry reduction package (Chavarría, de Lara, & Chavarría-K 2000). The night of 1996 November 23 was photometric, but only HBC 495 and DL Ori/G2 were measured with sufficient precision to obtain reasonable estimates of the V magnitude (≤ 2 %) and the $(b-y)$ color ($\leq 2\%$). On 2000 February 27, $ubvy$-β photometry was obtained of the three brightest stars in the region, namely HBC 498, HBC 495, and DL Ori/G2. The weather was fair to good, with a few thin clouds present. On 2000 December 15, 16, and 17, and on 2002 December 14 the photometry was done under good observing conditions. The observations were atmospheric extinction-corrected and linearly transformed to Olsen's (1984) system with a set of eighteen, twelve, thirteen and fourteen standard stars in common among the two photometric systems, observed during the first, second, third and fourth runs, respectively, making a total of 32 different reference stars to tie the observations. The resulting photometry and its 1σ uncertainties for a single observation are given in Table 2. The uncertainties were estimated from the observed count-rates of the different filters and from the linear transformations of the standard stars to the reference system.

3. RESULTS

3.1. *Spectroscopy*

The spectral types of the visually brightest program stars are given in Table 3. They were determined by intercomparison of our spectra with those of stars with known MK spectral types taken during different observing runs with the same instrumental setup (the SPMO grid, e.g., A96), and/or by interpolation with the grid of spectra by Jacoby, Hunter, & Christian (1984) which have a spectral resolution similar to ours. The comparison spectra were normalized prior to the confrontation with the problem spectra. We expect the accuracy in the resulting MK classification to be of ± 1 sub-class.

The three brightest objects, namely HBC 498, HBC 495 and DL Ori/G2 have Li Iλ6708 Å strong in absorption (see Fig. 2 and Table 3), with equivalent widths stronger than the richest Li I stars with similar spectral types in the Pleiades cluster (i.e., "Li I rich stars"). The Li I line is apparently present in the spectrum of HBC 496, but the spectra are too noisy to be conclusive. We also observed DL Ori/D, a reddened F6V*e* star with Li Iλ6708 Å present in its spectrum (see Table 3). The 9$^{\rm th}$ magnitude star HD 37846 was also observed by us on January 2000. We found it to be an A0/A1 V star. Within the expected uncertainties of Cohen & Kuhi (1979) and our work, both results compare reasonably well, but with the difference that ours are hotter, on average, by two subclasses. Moreover, our result for HBC 498 also compares well with the spectral type given by other authors (Alcalá et al. 1996, 2000).

On the other hand, contrary to Cohen and Kuhi's (1979) spectrogram of DL Ori/G2, we see Hα clearly in emission in one of the two spectrograms of the star taken by us (see Fig. 2). We conclude that stars HBC 498 and DL Ori/G2 have Hα mildly in emission or filled-in with emission (W(Hα) ≤ 10 Å), while the equivalent widths of the Hα emission line of HBC 495 and HBC 496 are comparable with those of CTTS's. The equivalent widths of the photospheric Li I and Ca I lines and of the Hα and/or Hβ lines in the spectra of the program stars are given in Table 3, where we only report the equivalent widths of the lines on those spectrograms with the best S/N ratio. The equivalent widths were obtained by integrating the lines on the normalized spectra with a Gaussian fit with the *Splot* subroutine of IRAF that plots and analyzes spectra. The continuum fitting across the pertinent line is the major source of error of the equivalent widths, and it is also dependent on the signal to noise S/N ratio of the spectrum. An exception is the Hα line of HBC 498 and of HBC 496,

TABLE 2

ubvy-β PHOTOMETRY OF HBC 498 AND NEIGHBORING STARS

Name	V	$b-y$	β	m$_1$	c$_1$	J.D. 2451000+
			UT 1996 November 23			
HBC 495	13.52	1.05	2.48	0.29	0.10	410.9451
DL Ori/G2	14.10	1.06	2.61	0.74	–[a]	410.9337
$1\sigma =$	0.03	0.01	0.02	0.02	0.02	
			UT 2000 February 27			
HBC 495	13.84	1.08	2.44	0.50	0.01	601.6538
DL Ori/G2	14.00	1.10	2.43	0.68	0.36	601.6691
HBC 498	12.84	0.88	2.48	0.40	0.18	601.6812
$1\sigma =$	0.03	0.01	0.02	0.02	0.02	
			UT 2000 December 15			
HBC 495	13.61	1.05	2.39	0.73	−1.18:	893.8410
DL Ori/G2	14.11	1.12	2.33	0.56	0.10	893.8524
HBC 498	12.81	0.83	2.36	0.45	0.47	893.8319
$1\sigma =$	0.02	0.02	0.04	0.04	0.05	
			UT 2000 December 16			
HBC 495	13.77	1.05	2.58	0.29	−0.17	894.7774
DL Ori/G2	14.29	1.12	2.53	0.87	−2.39:	894.7833
HBC 498	12.89	0.92	2.44	0.41	0.44	894.7712
DL Ori/D	14.94	1.61	2.52	−0.46	1.57	894.7927
$1\sigma =$	0.03	0.03	0.04	0.04	0.04	
			UT 2000 December 17			
HBC 495	13.72	1.11	2.28	0.46	0.29	895.7410
DL Ori/G2	14.15	1.13	2.63	0.68	1.27:	895.7479
HBC 498	12.82	0.93	2.52	0.37	0.27	895.7347
DL Ori/D	14.71	1.67	2.42	−0.16	0.58:	895.7559
		UT 2002 December 14				J.D. 2452000+
HBC 495	13.52	1.05	2.54	0.54	0.05	622.8229
DL Ori/G2	14.05	1.17	2.52	0.66	0.15	622.8420
HBC 498	12.68	0.88	2.52	0.39	0.28	622.8049
DL Ori/D	14.58	1.59	2.97	0.07	0.99	622.8583
$1\sigma =$	0.04	0.02	0.01	0.01	0.03	

[a] $c_1 = -1.08$ but uncertain due to low count rates in u and v. Entries with a colon suffix ":" are uncertain.

which we found to be variable and for which we give average values of the equivalent widths. Stars HBC 498 and DL Ori/G2 fulfil the principal conditions to belong to the WTTS class (Chavarría-K, Moreno-Corral, & de Lara 1995) while HBC 495 and HBC 496 those of the CTTS class (Herbig 1962).

3.2. Hα *and* $(R, I)_C$ *Imagery*

In our search for extended Hα emission in the environs of HBC 498, we found no significant line-emission anywhere near or around the region of interest, giving support to the reflection nature of the

TABLE 3

SPECTROSCOPIC RESULTS

Star	SpT[a]	W(H$_\beta$)	W(H$_\alpha$)	W(Li I)	W(Ca I)
			Angstrom Å		
HBC 498	K4	2.06[b]	−0.12	0.61	0.27
DL Ori/G2	K8	0.46	0.15[c]	0.60	0.41
HBC 495	K4	−0.29	−18.20[c]	0.63	0.28
HBC 496	M0/M1	...[d]	−70[c]	1.3[d]	...[d]
DL Ori/D	F6 V$_e$	2.84	−1.53	0.13	0.16
HD 37846	A0/A1V	...	...	...	...

[a]Assigned assuming luminosity class V. [b] Has an emission reversal in its core. [c] Variable, see Fig. 2 and text for details. [d] Spectrogram with low S/N ratio ≤ 9 at 6400 Å.

associated nebulosities, and also in agreement with radio observations of the region (Rodríguez et al. 1980).

Star HBC 497 does not appear on the 2000 January 24 combined image of Figure 3, to a threshold (1σ) magnitude $m_{H\alpha} = 18\overset{m}{.}5$. On the red POSS-print, the star HBC 497 appears very faintly at the apex of its associated fan-shaped cometary nebula (Gyulbudaghian et al. 1978; Cohen 1980). In the I images taken by us it appears on the tip of the nebula and has about the same magnitude as HBC 496. Cohen & Kuhi (1979) estimated $V = 18.7$:. Finally, our I-band exposures also revealed a star-like object in the location of IRS 5 (Carballo et al. 1988).

3.3. *uvby-β Photometry*

From our photoelectric *uvby*-β photometry and published photometric and spectroscopic data of the program stars, assuming a distance to the complex of 460 pc (= Orion's SFR distance) we are able to estimate their principal stellar parameters as follows:

3.3.1. *Stars with uvby-β Photometry*

i) We dereddened the photometry with an interstellar extinction law adequate for star-forming regions (Terranegra et al. 1994), i.e., a total-to-selective extinction ratio $A_V/E(b-y) = 5.3$ or $A_V/E(B-V) = 4.0$. This is a typical outer cloud reddening law (Mathis 1990). We used the color excesses obtained from the observed colors of the program stars and those of their zero-age main sequence counterparts (Olsen 1984).

ii) The luminosity estimates were derived by applying bolometric corrections (Hartigan, Strom, & Strom 1994) to the dereddened visual magnitudes in the usual way with $(M_{bol})_\odot = 4\overset{m}{.}64$.

iii) Comparing the bolometric luminosities with a grid of models of stellar evolution (D'Antona & Mazzitelli 1994; Palla & Stahler 1993) we estimate masses and ages of the program stars.

3.3.2. *Stars with Published near-IR Photometry*

i) Star HBC 496: The star has near-IR photometry (Cohen & Kuhi 1979; Carballo et al. 1988). From its position in the two-color ($H-K, K-L$) diagram, we expect it to be extinguished visually by about 5^m, with moderate IR excess due to a warm dust circumstellar envelope. More precisely, with an outer cloud interstellar extinction law (Mathis 1990), with the spectral type M0/M1 of Table 3 and its near-IR photometry, together with near-IR intrinsic colors for main sequence stars (Koornneef 1983), we obtain the reddening in the V, H, and K magnitudes: we find that $A_V = 2.9 \times E(H-K) = 6\overset{m}{.}6$, $A_H = 0.19 \times A_V = 1\overset{m}{.}32$ and $A_K = 0.12 \times A_V = 0\overset{m}{.}81$. It is well known that extrapolation of the uncertainties made in the near-IR has a small effect in the final estimate of the visual brightness of the objects based on intrinsic color calibrations or unreddened spectral energy distributions of stars with the same spectral type. We expect that the largest uncertainty is due to the adopted intrinsic color. Hence, from its dereddened near-IR magnitudes and its intrinsic colors we estimate its dereddened visual magnitude ($V_\circ = 13\overset{m}{.}07$) and its bolometric luminosity ($\log L_{bol}/L_\odot = 0.55 \pm 0.07$). With its luminosity and spectral type, we can then fix the star in the luminosity-temperature diagram and, by comparison with evolutionary tracks (D'Antona & Mazzitelli 1994), we then determine its age and mass, as given in Table 4.

ii) Cohen & Kuhi (1979) and Carballo et al. (1988) have published spectrophotometry and near-IR photometry for HBC 497. The near-IR photometric data of Cohen & Kuhi (1979) and of Carballo et al. (1988) compare reasonably well. We adopt the mean $(H - K)$ index given by both and the $(K - L)$ index only observed by Cohen and Kuhi. From its location in the two-color $(H - K, K - L)$ diagram, the star seems reddened by $A_V \approx 10^m$ and has little or no IR excess. Now, similarly to HBC 496 above, using Koornneef's intrinsic colors and the spectral type by Cohen and Kuhi, we find $E(H-K) = 0.67 \pm 0.09$, $A_V = 8\overset{m}{.}6 \pm 0.9$, $A_H = 1\overset{m}{.}63 \pm 0.12$, $A_K = 1\overset{m}{.}03 \pm 0.11$, a mean $V_\circ = 11\overset{m}{.}63 \pm 0.07$ given by the H and K passbands, an $M_V = 3\overset{m}{.}24 \pm 0.11$, and with $BC = -1.09 \pm 0.10$, we find $\log L_*/L_\odot = 1.00 \pm 0.06$ dex. From a comparison of the adopted spectral type and luminosity with a grid of evolutionary tracks (D'Antona & Mazzitelli 1994), we find $M_*/M_\odot = 0.5 \pm 0.1$ and age $= (0.8 \pm 0.1) \times 10^5$ yr. Note that our $V_\circ$ and A_V estimates compare reasonably well with the visual estimate given by Cohen & Kuhi of $18\overset{m}{.}7$. A word of caution to the reader: because of the proximity of HBC 497 to an IRAS infrared source, Carballo et al. (1988) give a significantly higher luminosity for the object than that given here.

iii) IRS5: this case is more complicated, since we do not have its spectral type. From its $(H - K)$ color we estimate that the star is reddened by $0\overset{m}{.}4 \leq E(H - K) \leq 0\overset{m}{.}6$, or $5\overset{m}{.}1 \leq A_V \leq 7\overset{m}{.}8$. Assuming $A_V = 6\overset{m}{.}5$, we obtain E(H-K) =0.5, $A_H = 1\overset{m}{.}2$ and $A_K = 0\overset{m}{.}8$, or $H_\circ = 10\overset{m}{.}3$ and $K_\circ = 10\overset{m}{.}0$. If the star belongs to Orion's cloud, then its spectral type is G5(V) or later (but it is a PMS star). By further assuming that the star has a spectral type typical of PMS stars, somewhere between K5 and M5, then we find $\log L_*/L_\odot = 0.3 \pm 0.4$ dex, age $\approx (4.5 \pm 4) \times 10^5$ yr and $0.3 \leq M_*/M_\odot \leq 1$, with $M_\odot = 0.7$ as its mean value. In any case, it is expected to be a low mass young PMS star. The large uncertainties are due to our ignorance of its spectral type.

Intercomparison between PMS models of different groups (Baraffe et al. 1998; Siess, Dufour, & Forestini 2000; D'Antona & Mazzitelli 1997) show strong discrepancies in the regime of very low mass stars ($M_* < 0.5\,M_\odot$), with good agreement for higher stellar masses. The tracks of D'Antona & Mazzitelli (1997) have strong deviations from the other models for stellar masses $< 0.3\,M_\odot$. For higher masses, the morphology of the tracks is similar and differences in temperature $\simeq 200\,^\circ K$ are noted (Siess et al. 2000). The error in the mass estimate from the evolutionary tracks is expected to be small, a few tenths of a solar mass (Tout, Livio, & Bonnell 1999), but the age determination by comparison with isochrones remains very uncertain for young ages ($< 1 \times 10^6$ yr), with errors of a factor of 2–5, particularly when the isochrone corresponds to an age of the order of one gravitational contraction time or less, since the models have not had time to relax, and hence strongly depend on their initial conditions (Chavarría-K 1981; Tout et al. 1999).

TABLE 4

PARAMETERS OF THE PROGRAM STARS[a]

Name	$\log T_*$	A_V	$V_\circ$	$\log L_*$	M_*	10^5 yr
HBC 498	3.662	1.46	11.35	0.81	1.3	3.5
	0.016	0.12	0.13	0.08	0.1	0.5
DL Ori/G2	3.591	1.84	12.28	0.71	0.5	0.9
	0.010	0.13	0.14	0.09	0.1	0.2
HBC 495	3.662	2.43	11.23	0.86	1.3	3.5
	0.016	0.05	0.09	0.05	0.1	0.1
DL Ori/D	3.801	7.18	7.56	2.16	3.5	1.5
	0.080	0.16	0.21	0.10	0.3	0.2
HBC 496	3.57	7.0	13.1	0.55	0.4	0.9
	0.03	1.0	0.10	0.07	0.1	0.1
HBC 497	3.59	8.6	11.63	1.00	0.5	0.8
	0.02	0.9	0.10	0.06	0.1	0.1
IRS 5	3.58	6.5	13.6	0.3	0.6	4.5
	< 0.7	1.0	0.7	0.4	0.4	4

[a] A distance of 460 pc was assumed. Uncertainties are given in the row after that containing the star's name.

Since the program stars belong to the mass-rich regime, and to simplify comparisons of our results with those of previous authors, we use the models by D'Antona & Mazzitelli (1994) to obtain the stellar masses and ages. Our estimates of the stellar parameters of the program stars and the corresponding errors are summarized in Table 4, and for simplicity, depicted in Figure 4.

4. DISCUSSION

Although we only marginally detect Li Iλ6708 Å in the HBC 496's spectrum, because of the Hα emission in its spectrum, its associated circumstellar disk inferred from the near-IR-flux excesses and because of its associated reflection nebulosity (Carballo et al. 1988), we conclude that

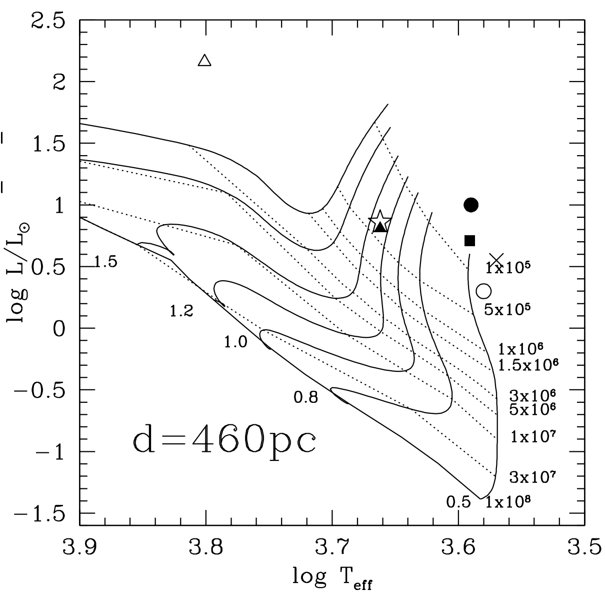

Fig. 4. Loci of the program stars in the HR diagram (HBC 498 filled triangle, DL Ori/G2 filled square, HBC 495 empty star, HBC 496 "X", HBC 497 filled circle, IRS 5 empty circle and DL Ori/D empty triangle. Excluding IRS 5 (see text for details about this star), typical errors in temperature and luminosity are $\varepsilon_{\log T} = 0.029$ and $\varepsilon_{\log L} = 0.075$, respectively.

this object is a young PMS star. From its location in the ($\log L_*/L_\odot, \log T_{\rm eff}$) diagram it appears to have an age of 0.9×10^5 yr, similar to the ages of the brighter PMS stars in the trapezium. On the other side, considering the observational and calibration uncertainties involved, we see that the luminosity estimates of HBC 498, HBC 495, and of DL Ori/G2 by Carballo et al. and Cohen & Kuhi are in reasonable agreement with those of Table 4. The previously published higher luminosity estimate of HBC 497 of $20\,L_\odot$ (Carballo et al. 1988) includes the mid-IR fluxes of the nearby IRAS source. However, this inclusion is uncertain due to the complexity of the region and the PMS stars involved. If we exclude the IRAS med-infrared fluxes from their data, then their luminosity would be in accordance with Cohen & Kuhi's or our estimates.

To end the discussion, some remarks about IRS 5 of Carballo et al., located southwest of HBC 497, are in order: they identified the source with a very faint optical counterpart on the POSS red plate. Our I-band exposures of the region confirm the optical counterpart of IRS 5 given by Carballo et al. It has an $(J - H)$ index typical of an intermediate F or later spectral type star, depending on the amount of interstellar extinction between the object and the observer. If the star is physically associated with the region, then its location in the luminosity-temperature diagram would imply a disagreement with the rest of the cluster members, being much older ($\approx 3 \times 10^7$ yr) than the other stars of the region. We believe that it is, more likely, a field star beyond the group.

5. CONCLUSIONS

An important issue resulting from this work is that we verify spectroscopically the young PMS nature of at least three and possibly five, stars. From our data and previously published ones we find that the objects are coeval, that they belong to a spatially tight system of five very young ($\simeq 2.4 \times 10^5$ yr) PMS-stars, that they are still surrounded by their placental cloud and that two objects have been stripped of their circumstellar envelope (the WTTS HBC 498 and DL Ori/G2) and another two are still accreting matter (the CTTS HBC 495 and HBC 496). It is remarkable that we see physically associated with the dust cloud two CTTS, two WTTS and probably a post-T Tauri star (DL Ori/D) of about the same short age. This result is independent of the distance to the trapezium. This is also a very rare case, where WTTS's are located in the immediacy of their formation site.

It is also important to note that if the program stars belong to Orion, and with exception of the mass-rich star DL Ori/D, the objects are undergoing their quasistatic convection phase towards the ZAMS (see Fig. 4), as is expected from the theory of stellar evolution and supported by observations of CTTS's with known stellar parallaxes (cf. Bertout, Robichon, & Arenou 1999). However, our result summarized in Fig. 4 is in contrast to the X-ray selected WTTS and Lithium-rich stars with known (Hipparcos and photometric) stellar parallaxes (Neuhäuser & Brandner 1998; Chavarría-K et al. 2005), which are in their quasistatic radiative phase towards the ZAMS. Our results have repercussions on the current scenario of stellar evolution of low mass, pre-main sequence stars, where WTTS are considered descendants of the CTTS (Shu, Adams, & Lizano 1987; Zinnecker, McCaughrean, & Wilking 1993), and also on the dissipation times of the associated circumstellar disks. Undoubtedly, this remarkable region deserves further observations with better instrumentation.

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