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13-COLOR PHOTOMETRY OF PRE-MAIN SEQUENCE STARS: PRELIMINARY REPORT AND RESULTS

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RESUMEN

Se presenta un reporte preliminar de la fotometría de banda ancha (*UBVRI*) y banda intermedia (13 colores) de 160 estrellas seleccionadas del catálogo de Herbig y Rao, con el propósito de completar los datos publicados de esas estrellas en la región óptica. Se presentan resultados fotométricos en 13 colores y su aplicación a estrellas pre-secuencia principal.

ABSTRACT

Broad (*UBVRI*) and intermediate (13-color) band photometry of 160 stars selected mainly from the Herbig Rao catalogue are being carried on currently, mainly to complement the published data of these stars in the optical window (for example shortward of the Balmer and longward of the Paschen discontinuities). The 13-color photometric system and its applications to pre-main sequence stars are briefly discussed. First results are presented.

Key words: PHOTOMETRY – STARS-PRE-MAIN SEQUENCE – STARS-EVOLUTION

I. INTRODUCTION

Although much observational photometric and/or ectrophotometric data of the Orion population stars s been published in the last two decades by many thors, a significant number of known or suspected embers of this stellar population remain unobserved. her stars have been scarcely observed and should be ecked by an independent observer. Most of the Orion pulation stars have been observed without even vering the entire optical window (3300-10000 A). The thors believe that the recent survey by Cohen and hi (1979) probably represents the most complete served sample of the Orion population stars. Unfortutely it only covers the spectral ranges from 4300 A to 00 A (as well as longer than 1.25μ), missing the lmer and Paschen discontinuities. All photometrically ll observed T Tauri-like stars are found to be variables the RW Aurigae type, but many still remain to be ecked for variability. When the star is known to be a riable star, it is still not clear how its spectral energy stribution changes with wavelength and time, and how ese changes are connected with variations of the stellar e emission and absorption spectrum. These and other asons were the motivation to undertake the task of serving repeatedly in the optical window a significant mple of these stars. A list of bright objects were lected mainly from the catalogue by Herbig and Rao 972), to be observed principally in the 13-color otometric system (Mitchell and Johnson 1969) with e 84-cm telescope at the Observatorio Astronómico cional, located in San Pedro Mártir, Baja California. ir program was to be completed by doing *UBVRI* photometry of some of the stars. It is also intended in the future to extend the 13-color observations to selected fainter stars using the 2.12-m telescope at San Pedro Mártir and also to extend it to some selected Orion population stars of the southern hemisphere with $\delta < -40°$. First observations and an example of the utility of the 13-color photometric system in studying Orion population stars are also given.

II. INSTRUMENTATION

The first observational runs were done using the original "blue" and "red" photometers (which use a 1P21 and a RCA 7107 as light detectors, respectively) with the original set of filters that defined the 13-color photometric system (Johnson, Mitchell and Latham 1967; Mitchell and Johnson 1969) on the 84-cm telescope. Filters are named by their approximate effective wavelength, and these are given in Table 1, together with their corresponding effective rectangular bandpasses. In order to observe the project stars in all filters during the same night and with the same telescope, the photometers must be changed. Future research will include a pulse counting system with a RCA 31034 A photomultiplier and a new filter set with no significant red leaks and with an interference *63* filter. It will be impossible with this system to do the *110* bandpass.

When carrying out the red observations of project stars with the original photometer, too long an integration time per filter was needed to reduce the error bars below a 10% figure. This was due to the faintness of the

TABLE 1

EFFECTIVE WAVELENGTHS AND BANDPASSES OF THE 13C SYSTEM*

Filter	λ (A)	Effective rectangular bandpass (%)
33	3371	3.3
35	3536	3.6
37	3751	3.4
40	4030	5.6
45	4571	6.1
52	5183	5.0
58	5827	3.8
63	6356	5.1
72	7241	8.1
80	8000	5.4
86	8584	5.6
99	9831	5.9
110	11084	7.4

* taken from Johnson and Mitchell (1975).

objects observed, the size of the telescope used, and the poor spectral detectivity of the photomultiplier employed. It was decided to drop the red observations (filters *72, 80, 86, 99* and *110*) until the photon counting system is in operation.

III. PRELIMINARY PHOTOMETRY OF SELECTED STARS

In Table 2 preliminary 8C photometry of selected stars are presented. The colors and magnitudes a referred to zero air mass. Normally, a 20 second of a diaphragm was used and the sky was measured at mo than 30″ of the star. Extinction corrections were dor following a standard procedure. Since the bandwidths the 13-color filters are small, second order extinctic coefficients were ignored. The standard stars were take from the catalogue by Johnson and Mitchell (1975). N systematic errors are to be expected since the observ tions were made with the original instrument th defined the photometric systems.

Stars 4 and 6 of Table 2 are main sequence stars ar were used by Chavarría-K. (1981) as distance ar reddening indicators of the local dust cloud of V13 Cygni. A finding chart of these stars can also be found there. The line emission star AS 501 probably is not member of the Orion population. Merrill and Burw (1950) give $m_{pg} = 10^{m}.5$. In contrast to this, we fir $m_{pg} \gtrsim 14$, in agreement with earlier 1979 visual es mates by one of us (C.C.-K.). The star is now bei checked for long term variability. Excluding LkHα32 the remaining stars of Table 2 are T Tauri-like stars. T nature of LkHα324 is unclear: Herbig and Rao (197 give a spectral type "Geβ" for this star, while Cohen ar Kuhi (1979) give a spectral type ":B5" (B5, uncertair The strength of the Hα absorption on a Lick red cou spectrogram is appropriate for a B star (Herbig 198(The *UBV* photometry of the star is best explain assuming a B9 V star (Chavarría-K. 1981). As can seen further on, the spectral energy distribution of t star fits best that of an F7 star. Definitely, mo observations are required to clarify its nature.

TABLE 2

PRELIMINARY 8C PHOTOMETRY OF SELECTED STARS[a]

Star	*52*	*33-52*	*35-52*	*37-52*	*40-52*	*45-52*	*52-58*	*52-63*	JD-244400(
V1331 Cyg	12.13	1.90	1.53	1.12	1.16	0.66	0.43	1.05	528.7285
V1331 Cyg	12.07	2.48	1.13	1.12	1.15	0.65	0.37	0.93	529.6826
LkHα 321	12.61	1.47	1.38	1.25	1.42	0.75	0.58	1.10	528.7819
LkHα 321	12.63	1.28	1.19	1.20	1.38	0.74	0.58	1.09	529.7035
LkHα 324	12.94	1.62	1.14	1.15	1.20	0.60	0.62	1.18	528.7563
LkHα 324	12.81	1.57	1.31	1.02	1.23	0.69	0.49	0.99	529.7382
4[b]	11.67	0.82	0.64	0.55	0.58	0.33	0.34	0.52	529.7736
6[b]	10.54	0.25	0.20	0.35	0.65	0.42	0.29	0.50	529.7569
As 501[c]	13.97	3.04[d]	1.75[e]	...	2.59[e]	1.54	1.19	2.58	529.8354
DI Cep	11.71	0.48	0.32	0.71	0.98	0.44	0.48	0.85	529.8639

a. Every star was observed at least 40 effective seconds through each filter. The magnitude corresponding to a 10 second integrati time through any of the filters deviated less than $0^{m}.20$ from the mean (unless otherwise specified).

b. Stars 4 and 6, illuminate the same dark cloud as V1331 Cyg does. The sky 1950.0 position of star 4 is $\alpha = 21^{h}01^{m}24^{s}$ a $\delta = +50°00'50''$, and that of star 6 is $\alpha = 21^{h}02^{m}25^{s}$ and $\delta = 49°55'15''$.

c. From the TiO bands shown on a 180 A mm^{-1} Landessternwarte spectrogram of the blue-red stellar spectral type K7 or later derived. From its optical, infrared and radio properties this star probably is not a member of the Orion population.

d. $\sigma_m > 0^{m}.3$.

e. $0^{m}.1 \leq \sigma_m \leq 0^{m}.3$.

TABLE 3

COMPARISON TABLE BETWEEN THE OBSERVED EXTINCTION LAW AND THAT OF CYGNUS

	E(λ-52)/E(40-52)						
	33-52	*35-52*	*37-52*	*40-52*	*45-52*	*52-58*	*52-63*
Mean from stars 4 and 6	1.5	1.3	1.1	1.0	0.5	0.5	0.8
Cygnus[a]	1.46	1.28	1.11	1.50	0.51	0.43	0.75

a. given by Johnson (1977).

V. SPECTRAL ENERGY DISTRIBUTIONS OF V 1331 CYGNI, LkHα321 AND LkHα324

From an inspection of the Palomar sky survey prints t appears that all stars have reflection nebulosities surrounding them and are in the immediate vicinity of he same dark cloud. The observed radial velocities, at adio wavelengths, of the surrounding clouds of each of he three stars is essentially the same. Therefore it can be nferred that V 1331 Cygni, LkHα321 and LkHα324 are it the same distance. With 13C photometry of stars 4 nd 6 of Table 2 we are able to check earlier results btained from *UBV* observations on interstellar reddening and distance to V1331 Cygni by Chavarría-K. (1981). For the reddening of star 4 (A0 Vp) we assumed hat the intrinsic colors are those of an unreddened A0 V object (defined as 0.00 in the 13C system). For the eddening of star 6 (B3 V) we assumed its intrinsic color o be the mean of six unreddened B3 V stars from the atalogue of Johnson and Mitchell (1975). This color xcess was normalized to E(*40-52*) = 1 to give the nterstellar extinction law shown in Table 3. From a omparison of this law with that for the Cygnus region (Johnson 1977) it has been concluded that they are the ame within our observational errors, in agreement with he result of Chavarría-K. (1981). Thus there is no mpelling reason for us not to use the normal Cygnus xtinction law to stars 4 and 6. In Table 4 we give the

TABLE 4

ESTIMATION OF VISUAL EXTINCTION AND DISTANCE TO THE DARK CLOUD SURROUNDING V1331 CYGNI

tar	m_V[a]	M_V[b]	E(*40-52*)	A_V	Distance (pc)
4	11.41	0.4	0.58	1.60	759
6	10.32	−1.7	0.90	2.49	806
lean	...	...	0.74	2.05	782

. Obtained by linearly interpolating the flux between filters *52* and *58*, using the absolute calibration of Vega by Hayes and Latham (1975), and assuming $R = A_V/E(B-V) = 3.4$.
. Absolute visual magnitudes taken from Schmidt-Kaler (1965).

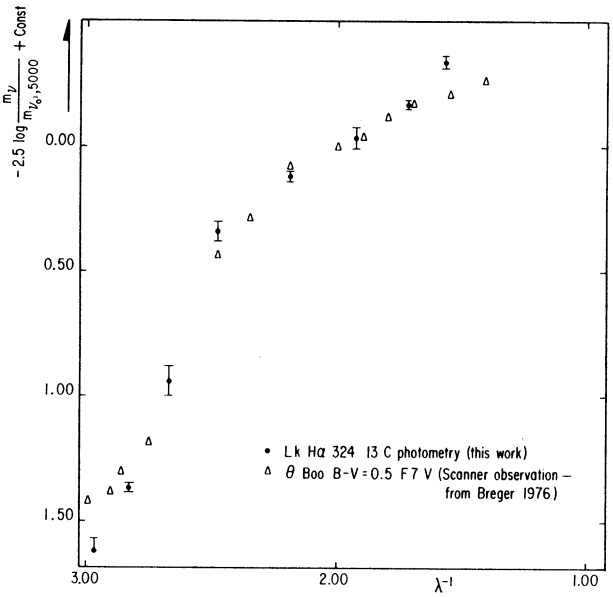

Fig. 1. Spectral energy distribution of LkHα324.

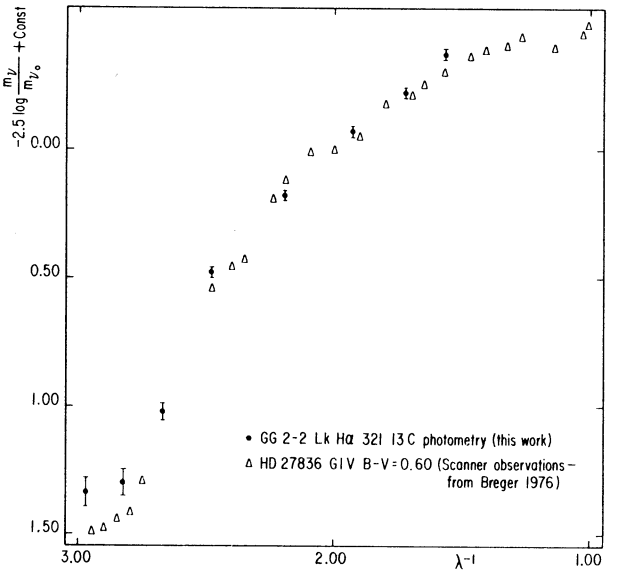

Fig. 2. Spectral energy distribution of LkHα321.

resulting estimates of interstellar visual extinction and distance to the local dark cloud surrounding V1331 Cygni, LkHα321 and LkHα324. The mean values for A_V and the distance in Table 4 do not deviate in a significant amount from the earlier results of Chavarría-K. (1981), $A_V \cong 2^m.38$ and $d \cong 700$ pc, respectively.

The photometry in Table 2 for V1331 Cygni, LkHα321, and LkHα324 was corrected for interstellar extinction with the Cygnus law (Johnson 1977) using the mean color excess $E(40\text{-}50) = 0^m.74$. Using the absolute calibration of Vega by Hayes and Latham (1975) and the 13-color photometry of this star by Johnson and Mitchell (1975), the absolute stellar fluxes of the program stars at the effective wavelengths of the 13C filters were estimated, interpolating linearly when necessary. The spectral energy distributions of V1331 Cygni, LkHα321 and LkHα324 obtained in this way are displayed in Figures 1 to 3.

LkHα324: The spectral type derived from its spectral energy distribution is F7. The principal controversies regarding this star have already been discussed earlier in this work.

LkHα321: The spectral energy distribution of this star is best explained by assuming a spectral type G1. This is in excellent agreement with the spectral type obtained from he stellar absorption spectrum (Herbig and Rao 1972). The star shows a moderate UV excess ($\sim$ 25%) for its spectral type.

V1331 Cygni: The spectral energy distribution, as derived from our photometry, agrees with that of a star with spectral type between F0 and F4. Chavarría-K. (1981) had found that they are best explained by assuming a spectral type F0 using the (better) scanner observations of the stars by Kuhi (1974).

Based on the example of the three stars given here, we hope to extend the 13C photometry to the study of Orion population stars.

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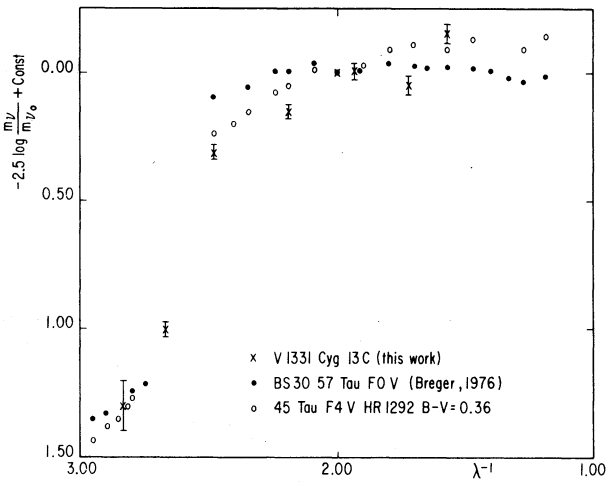

Fig. 3. Spectral energy distribution of V1331 Cygni.

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DISCUSSION

Calvet: ¿Corriges por contaminación de líneas de emisión los filtros de longitudes de onda entre 3647 y 4000 A?

Chavarría: No la he corregido, y es claro que las líneas en emisión contaminan el filtro *37*.

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