Revista Mexicana de Astronomía y Astrofísica, **35**, 85–96 (1999)

STELLAR SPECTROSCOPY IN NGC 6611: BINARY FREQUENCY AND NEW SPECTRAL TYPES OF SEVERAL EARLY TYPE STARS

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Received 1998 June 8; accepted 1999 March 8

RESUMEN

Presentamos un estudio de velocidades radiales de las diez estrellas más tempranas del cúmulo estelar joven NGC 6611. Con las mediciones de velocidad radial hemos examinado la existencia de posibles binarias espectroscópicas. Entre las estrellas estudiadas, una es definitivamente una binaria de línea simple, y otras dos estrellas son binarias de líneas dobles de períodos mayores. Otras tres estrellas pueden ser también de características múltiples. La velocidad radial media de las estrellas del cúmulo es similar al valor determinado a partir de las líneas de recombinación del gas interestelar en la región H II asociada. Además, hemos determinado tipos espectrales de estrellas más débiles dentro de la región de NGC 6611, encontrando varias estrellas de tipo B, posiblemente pertenecientes al cúmulo.

ABSTRACT

We present a study of radial velocities of the ten earliest type stars in the young open cluster NGC 6611. With the radial velocity measurements we have examined the possible existence of spectroscopic binaries. Among the studied stars, one is definitely a short period single-lined binary, and two other stars are longer period double-lined binaries. Three other stars may also be multiple. The mean radial velocity of the cluster stars is found to be similar to the value determined from the recombination lines of the interstellar gas in the related H II region. Additionally, we have also determined spectral types for fainter stars in the region of NGC 6611, finding several B type stars to be possible cluster members.

Key words: **BINARIES: SPECTROSCOPIC — STARS: EARLY TYPE — STARS: FUNDAMENTAL PARAMETERS (SPECTRAL CLASSIFICATION) — OPEN CLUSTERS AND ASSOCIATIONS: INDIVIDUAL (NGC 6611) — TECHNIQUES: RADIAL VELOCITIES**

1. INTRODUCTION

Binary properties of stellar populations are extremely important for numerous astrophysical problems. In the particular case of massive spectroscopic binary stars, they are likely to be the progenitors of observed puzzles, like binary neutron stars and neutron star —black hole pairs, as the expected original masses of these objects lie between 10 and 40 $M_\odot$ (Portegies Zwart & Yungelson 1998; Bethe & Brown 1998). Dynamical properties of early-type binary stars put constraints on the molecular cloud core parameters, before and during collapse (Boss 1997; Bodenheimer 1995). Also, the number and distribution

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of undetected binary stars within a stellar cluster can modify global properties determined for it, such as the initial mass function (IMF), or stellar velocity dispersion, both linked to determinations of the cluster's total mass, and not necessarily yielding the same result in practice.

However, the process of detecting binary systems and establishing their properties is a very slow one. Although short period binaries show changes in their velocity overnight, several observing runs are necessary to identify binaries with longer periods. The determination of reliable orbital parametres takes even longer observation campaigns. One of the first studies of binary frequency among O-type stars was published by Garmany, Conti, & Massey (1980). They gathered radial velocity measurements for 67 stars, brighter than 7th magnitude and north of $\delta = -50°$. This selection criteria increases the number of stars for statistics, but includes stars from different environments, and different evolutionary stages. Undetected binary companions increase the apparent brightness of an object, which could be introducing a bias in a sample limited by magnitude. In order to reduce any possible selection effect, it is desirable to analyze the distribution and characteristics of binaries in an environment that provides a set of stars sharing common properties and evolutionary history, such as a young open cluster.

The open cluster NGC 6611 ($\alpha = 18^h16^m, \delta = -13°48', 1950$) embedded in the bright nebula M16, provides a suitable scenario for this kind of study. Walker (1961) first studied photometrically the region of NGC 6611 in his series of papers involving extremely young open clusters. He discriminated stars which were not members of the cluster by their anomalous extinction properties. Thereafter, several authors have presented studies dealing with the membership of stars to the cluster according to the stellar proper motions (van Schewick 1962; Kamp 1974; Tucholke, Geffert, & Thé 1986), showing disagreements with Walker's results. The abnormal extinction law of the M16 nebula, first studied by Chini & Krügel (1983), Neckel & Chini (1981), and Thé et al. (1990), could be the main reason for the discrepancies. Hillenbrand et al. (1993) (hereafter HMSM), performed a spectrophotometric study combining CCD photometry in the $UBV + JHK$ bands for the whole cluster and spectral classification for a number of stars. In this way they could estimate the ratio of total to selective extinction R_v individually for each star with spectral type known, finding a large range of values for it. This variation of the extinction law was also found by de Winter et al. (1997). *Hubble Space Telescope* (*HST*) images in the area of the so called "elephant trunk", show an amazing detail of the interaction of the ionizing flux from the massive stars and the molecular cloud where new stars are being born, as discussed in Hester et al. (1996). The brightest and closest star to that region, W367 could be suggested as having formed in a similar way as the evaporating gaseous globules (EGGs) that are seen in the molecular gas columns in the *HST* images. This object is one of our program stars, and we will discuss its link with Hester et al.'s observations later.

The distance estimates to the NGC 6611 cluster are also subject to the extinction problem. HMSM calculated a distance modulus of 11.5±0.1 from their study. On the other hand, Thé et al. (1990) and de Winter et al. (1997) find it to be 12.1 (2.6 kpc). From a comparison of observations with the evolutionary tracks in a H-R diagram, HMSM find the stellar mass function of the cluster, and a mean age of 2 Myr for the most massive stars. However, there is mounting evidence towards a considerable age spread in NGC 6611. The simultaneous presence of a B2.5 I star and more massive stars still in the main sequence indicates so, plus the detection of pre-main sequence stars, and EGGs where formation of lower mass stars still occurs nowadays (de Winter et al. 1997; Hester et al. 1996).

There is still no thorough study of the radial velocities of the stars in the NGC 6611 cluster. Only scattered results from different observers have been published previously by Hayford (1932), Neubauer (1943), Sanford (1949), Trumpler (in Walker 1961), Feast & Thackeray (1963), Conti, Leep, & Lorre (1977) and Brown et al. (1986).

In this paper we present a radial velocity study of the earliest type stars in NGC 6611, along with additional spectral classification for some fainter stars.

2. OBSERVATIONS

In order to perform a radial velocity analysis, we have obtained multiple spectra of ten of the brightest OB type members of NGC 6611. The program stars are listed in Table 1, where, in the successive columns we list for each the stellar identifications according to Walker (1961) in column 1, BD and HD numbers (columns 2 and 3, respectively), magnitude (column 4), $B - V$ colour (column 5), and spectral classification (column 6).

Most of the observations were obtained in August 1991 and May 1993, at the Complejo Astronómico El Leoncito (CASLEO), San Juan, Argentina, with the Böller & Chivens Cassegrain spectrograph attached to the 2.15-m telescope. A grating of 1200 l mm^{-1} was used, giving a 29 Å mm^{-1} reciprocal dispersion in its second order, corresponding to a 2 pixel resolution of 1.2 Å. In order to gather spectral data from 3900 to 4700 Å we worked with different grating tilts, as our spectral range in the 400×592 pixels Thomson CCD used as detector was of only 350 Å. The S/N ratio of our data ranges from 100 for the brightest, to 80 for the fainter ones.

In order to reduce errors in the wavelength cal-

TABLE 1

STARS OBSERVED FOR RADIAL VELOCITY DETERMINATIONS IN NGC 6611

No.[a]	BD	HD	V^{b}	$B-V^{b}$	Sp.[b]
205	−13°4926	168076	8.18	0.43	O5 V((f*))
175	−13°4923	...	10.09	0.84	O5.5 V((f))
197	−13°4925	168075	8.73	0.45	O7 V((f))
246	−13°4927	...	9.46	0.82	O7 II(f)
401	−13°4932	168137	8.90	0.40	O8.5 V
166	...	...	10.36	0.57	O8.5 V
367	−13°4930	...	9.39	0.24	O9.5 V
280	−13°4928	...	10.12	0.43	O9.5 V
412	−14°4991	168183	8.18	0.34	O9.5 I
314	−13°4929	...	9.85	0.58	B0 V

[a] Numbers according to Walker (1961).
[b] Visual magnitudes, $(B-V)$ colors and spectral types from Hillenbrand et al. (1993).

ibration introduced by long exposures, comparison He-Ar lamps were recorded before and after each set of stellar spectra. Four constant radial velocity early-type stars selected from Fekel (1985) and Garmany et al. (1980), were also observed to check for the stability of the spectrograph and radial velocity zero-point corrections. The objects selected are HR 811, HR 8404, HR 1996, and HR 2806.

In addition, we have also obtained several digital high resolution spectra. Five spectra were obtained during October 1985 at the European Southern Observatory (ESO) La Silla, Chile, with the Cassegrain Échelle spectrograph (CASPEC) + CCD attached to the 3.6-m telescope. The RCA CCD used was 512 × 320 pixels large, with 30 μm pixels. An échelle grating of 31.6 l mm^{-1} and a cross disperser of 300 l mm^{-1} were used. The readout was binned in the dispersion direction, yielding a resolution of 0.5 Å in a range from 4000 to 5000 Å. One spectrum was obtained at Cerro Tololo Inter-American Observatory (CTIO) Chile, in March 1992 with the 1.5-m telescope and the Bench Mounted Échelle (BME) + Reticon CCD of 1200 × 400 pixels (27 μm $pixel^{-1}$). We used the cross disperser KPGL2 and échelle grating of 31.6 l mm^{-1} giving a resolution factor of 14,000. Three spectra were obtained at CASLEO, Argentina, in March 1994 with the REOSC échelle spectrograph + Tek 1K CCD with a 31.6 l mm^{-1} grating and a cross disperser of 400 l mm^{-1}. This instrumental configuration yields a 2 pixel resolution of 0.3 Å over 2500 Å (3500 - 6000 Å).

Lower resolution spectra for spectral classification purposes were obtained with the two dimensional photon counting detector in the Cassegrain spectrograph attached to the 1.0-m telescope at CTIO, Chile, during July 1993. A grating of 600 l mm^{-1}

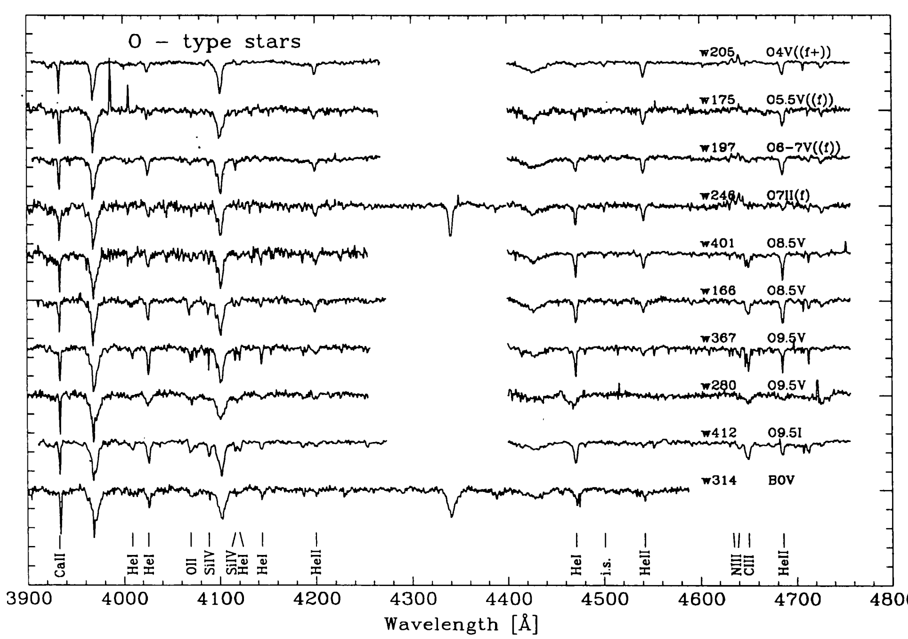

Fig. 1. Higher resolution rectified spectra of the earliest type stars in NGC 6611. Wavelengths are expressed in Å, and the ordinate axis are in arbitrary units. Identified features are Ca II λ3934; He I $\lambda\lambda$4009,4120,4471; He I+II λ4026; O II λ4070; Si IV $\lambda\lambda$4089,4116, and He II $\lambda\lambda$4200,4542,4686 absorptions. N III $\lambda\lambda$4634–40 emissions are present in the O((f)) stars and Si IV $\lambda\lambda$4089,4116 are also in emission in Walker 205.

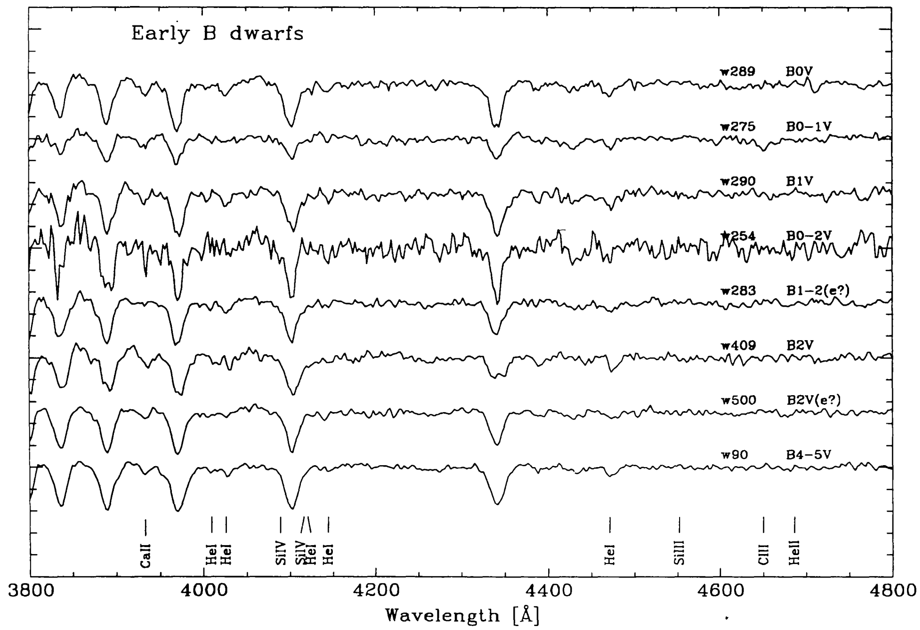

Fig. 2. Lower resolution spectra of early B type stars in NGC 6611. Identified features are Ca II λ3934; He I λλ4009,4026,4120,4143,4471; Si IV λλ4089,4116; Si III λ 4552; C III λ4650, and He II λ4686.

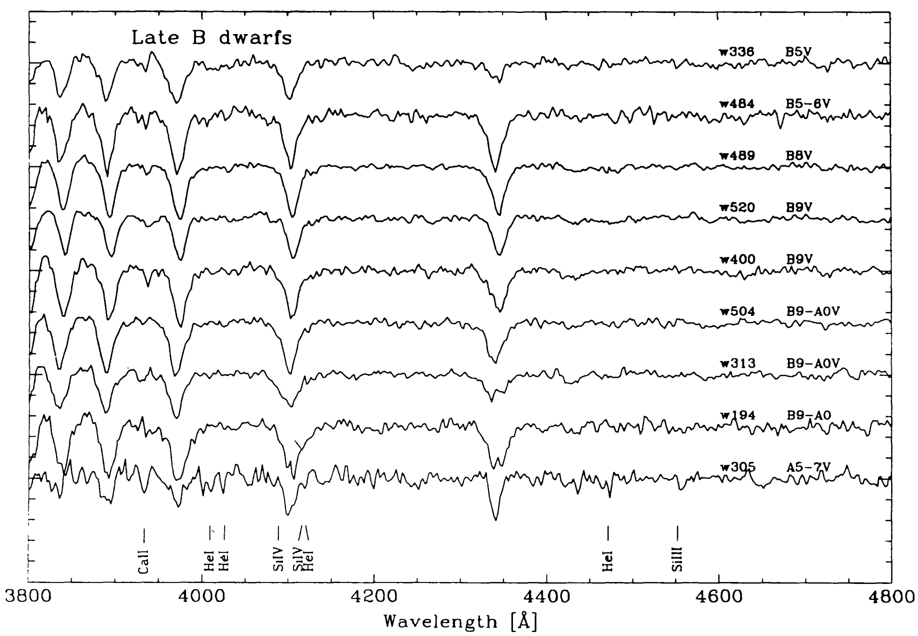

Fig. 3. Lower resolution spectra of late B type stars in NGC 6611. Identified features are Ca II λ3934; He I λλ4009,4026,4120,4471; Si IV λλ4089,4116, and Si III λ 4552.

was used, giving a 3-pixel resolution of 4.3 Å. With this configuration, we obtained spectra for 19 faint stars in the vicinity of NGC 6611. These stars had been considered probable members from proper motion studies and have colours indicative of B-type stars, according to the photometric data from Thé et al. (1990) available at the time of the spectroscopic observations.

The spectral data were debiased, flat-fielded, extracted, wavelength calibrated, normalized and measured using IRAF Software Package version 2.9 & 2.10 installed in workstations HP 9000 at La Plata Observatory, and SUN sparc2 at CASLEO, respectively.

3. RESULTS AND DISCUSSION

3.1. *Spectral Classification*

Our data for spectral classification can be split in two main groups: intermediate and high resolution spectrograms for the stars selected for radial velocity measurements, and lower resolution spectra for the stars which were observed only for classification purposes. We have used the classification criteria detailed by Walborn & Fitzpatrick (1990) in their digital atlas. Stars beyond the scope of the atlas were classified according to the criteria displayed in the atlas by Morgan, Abt, & Tapscott (1978) and by Jascheck & Jascheck (1987). MK classification standard stars were also observed in order to check for differences between our material and the one published in the atlases. We have also observed, in the lower resolution mode, several stars already classified by HMSM and those for which we already had medium and high resolution spectrograms.

The whole set of spectra are shown in Figures 1 to 3. The spectra are shown with different wavelength ranges, as the nature of the observations were diverse. The strong emission lines from the nebula, proved difficult to be removed, and residuals are present in some cases.

The spectral types of stars in NGC 6611 determined from our spectra are listed in Table 2. From this table we see that our classification is in good agreement with previous MK classification, listed in column 4.

We will discuss briefly the case of W205 (HD 168076), as this is the most massive star in the cluster. It was classified by HMSM as O5 V ((f*)), in our spectra we find it to be O4 V ((f+)) as previously classified by Walborn (1973). Our classification of W205 follows from the comparison with the spectra of the MK spectral classification standard stars HD 46223 O4 V ((f)) and HD 46150 O5 V ((f)). Our spectra of W205 clearly resemble more that of HD 46223, particularly due to the presence of NV $\lambda\lambda$4604–20 absorption lines.

The earlier spectral type of W205 turns out to be important for the bolometric correction, as stated by HMSM, and thus influences the mass estimate from the evolutionary tracks for W205. In the theoretical HR diagram of HMSM an O4 V ((f+)) would fit just on the track of an 85 $M_\odot$ star. This would be quite more massive than the most massive star yet found empirically, that is, determined from orbital studies of binary stars. However, it must be kept in mind that this result depends on the particular choice of evolutionary tracks and distance to NGC 6611.

The Q method for selecting early type candidates from photometry, as described by Massey (1998) proved to be useful. A few stars were found to be of later types and are included in Table 2 although they are beyond the aims of our research. The membership of these stars to NGC 6611 is discussed in de Winter et al. (1997).

3.2. *Radial Velocities*

For the determination of the stellar radial velocities, each spectral line had its radial velocity measured individually, by fitting a gaussian profile. This procedure was adopted in view of the early spectral types of the studied stars, in whose spectra the stellar winds may introduce systematic differences between different lines. Also, in a double lined spectroscopic binary, different lines may belong to different components.

The laboratory wavelengths of the spectral lines measured were taken from Moore (1945) and Conti et al. (1977). Radial velocities determined from our observations of standard stars are presented in Table 3. From this table we note that our radial velocities agree with those published by Fekel (1985) and Garmany et al. (1980), thus no appreciable systematic errors appear to be present in our data. A summary of determinations of radial velocities for the program stars is described in Table 4. Columns 4 in Tables 3 and 4, indicate the dispersion of the mean value calculated in column 3, also referred to as the external dispersion. Column 5 in Table 4 shows the average dispersion of the mean value calculated for each stellar spectra. The ratio of external to internal velocity dispersion is used as an indicator of radial velocity variation, described in Abt, Levy, & Gardet (1972). The external dispersion shows the observed changes in the stellar radial velocity, whilst the average internal dispersion measures the uncertainty in the radial velocity itself. The values for the interstellar Ca II 3934 Å line included in Table 4 were measured as another internal check of the measured velocities against the one of the interstellar matter towards NGC 6611.

The individual radial velocity determinations are given in Table 5. In the following, we will discuss the results for each program star:

W412: As is evident from the data in Table 4, the radial velocity of this star, of type O9.5 I, is variable, as also noticed by Neubauer (1943). We find W412 to be a short period single-lined binary. Radial velocity measurements show large variations between consecutive nights, the lines have narrow profiles and the period seems to be about 4 days. Preliminary circular orbital elements for W412 are listed in Table 6, and the radial velocity orbit is shown in Figure 5.

TABLE 2

SPECTRAL CLASSIFICATION OF STARS IN NGC 6611

No. (1)	V (2)	Sp. Type (This work) (3)	Sp. Type (Literat.) (4)	Membership (5)
205	8.18	O4 V ((f+)) †	O5 V ((f))[a], O4 V ((f))[b]	y
175	10.09	O5.5 V ((f)) †	O5.5 V ((f))[a]	y
197	8.73	O6-7 V ((f)) †	O7 V ((f))[a]	y
246	9.46	O7 II (f) †	O7 II (f)[a]	y
401	8.90	O8.5 V †	O8 V[c]	...
166	10.36	O8.5 V †	O8.5 V[a]	y
367	9.39	O9.5 V †	O9.5 V	y
280	10.12	O9.5 V †	O9.5 V[a]	y
412	8.18	O9.5 I †	O9.5 I[a]	y
314	9.85	B0 V †	B0 V[a]	y
289	12.60	B0-2 V	B5[d]	y
275	12.12	B0-1 V	B1.5 V[a]	n
290	12.14	B1 V	B2[h]	y,y
305	13.51:	B1 V	early B [a]	y
254	10.80	B0-2 V	B1 V[a]	y
283	...	B1-2 (e?)	...	...
409	12.82	B2 V	B9[e]	y
500	11.28	B2 V (e?)	B9[e], B6[h]	y,y
90	11.73	B3–5 V	B0[d]	y
336	13.29	B5 V	B3[h]	y,y
484	12.46	B5–6 V	B7[h]	y,y
489	11.57	B8 V	F2[f], B7[h]	y,y
520	11.64	B7: V	B5[h]	y,y
400	12.87	B9 V	A2[g], B8[h]	y,y
504	12.78	B9: V	B5[h]	y,y
313	12.92	B9: V	B4[h]	y,y
194	13.90	B9	B5[j]	y
163	13.09	F7	O9[j]	d
174	13.04	F–G	late [a]	n
534	12.88	G	K2III[h]	n,n
599	10.16	late G	G2[e], G9[h]	y,n
411	12.10	G–K	K5III[h]	d,n

Note. Stars are classified from medium resolution spectra, except for stars marked with a † which have been classified from higher resolution spectrograms (see text).
Key to columns follows: (1) Stellar identification from Walker (1961); (2) visual magnitudes from HMSM; (3) our spectral classification; (4) previous spectral classification —if any.
References: (a) HMSM, (b) Walborn (1973), (c) Hiltner & Morgan (1969), (d) Trumpler (from Walker 1961), (e) Pronik(1958), (f) van Schewick (1962), (g) Walker(1961), (h) de Winter et al. (1997), (j) Thé et al. (1990), (5) Membership probability from Tucholke et al. (1986), de Winter et al. (1997), or from the former only when one is shown, y denotes members, d doubtful members, and n non-members.

TABLE 3

SUMMARY OF RADIAL VELOCITIES FOR STANDARD STARS

Star (1)	n (2)	Average radial velocity (3)	External σ (4)	Published radial velocity (5)	Ref. (6)
HR 811	9	13	2	14.3	a
				15.0	b
HR 8404	9	−2	2	0.4	a
				1.1	c
HR 1996	9	108	2	109.8	d
				106.6	e
HR 2806	9	27	4	28.0	d
				25.9	e

Note. Radial velocities and dispersions are shown in km s^{-1}.
Key to columns follows: (1) Stellar identification from the Bright Star Catalogue. (2) Number of observations. (3) Our average radial velocities. (4) External dispersion of averages shown in column (3). (5) Average radial velocities found in the literature. (6) Key to references for values shown in column (5): a. Fekel (1985); b. Campbell & Moore (1928); c. Wolff (1978); d. Garmany et al. (1980); e. Penny et al. (1993).

TABLE 4

SUMMARY OF RADIAL VELOCITIES FOR PROGRAM STARS

Star (1)	n (2)	Mean radial velocity (3)	External σ (4)	Average internal σ (5)	Mean Ca II (i.s.) radial velocity (6)
W166	7	13	3	12	−10
W175(a)	22	var	...	...	− 9
W197	21	var	...	...	− 3
W205	22	14	9	14	− 2
W246	18	15	8	9	− 6
W280	12	13	12	19	− 2
W314	12	19	7	8	2
W367	17	4	4	8	1
W401	17	18	4	6	− 1
W412	7	var	...	...	− 3

Note. Radial velocities and dispersions are shown in km s^{-1}.
Key to columns follows: (1) Stellar identification from Walker (1961). (2) Number of observations. (3) Our average radial velocities. (4) External dispersion of averages shown in column (3). (5) Average internal dispersion of radial velocities used to calculate the values shown in column (3). (6) Average of radial velocities of interstellar Ca II lines.

W367: The O9.5 V spectrum of this star shows sharp lines, most of them from H, He I, O II, and C III, and their radial velocity remains constant in our data. However, the mean radial velocity (4 km s^{-1}) that we have determined for W367 is about 11 km s^{-1} lower than the value ($\sim$ 15 km s^{-1}) for the rest of the stars in the NGC 6611 cluster. This star also shows lower observed colour excess in $(B-V)$ than other cluster stars (HMSM), although it appears projected near the "elephant trunk" region,

TABLE 5

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JD	$< v_r >$	σ_i	n
Walker 205			
6340.56 *(a)*	12	4	8
8490.75	14	23	6
8491.52	10	15	5
8492.71	10	23	6
8493.53	-1	24	6
8494.57	34	*	3
8495.58	16	*	3
8496.57	5	*	3
8497.59	21	*	3
8498.49	18	*	3
8704.81 *(c)*	14	6	5
9117.62	6	*	3
9118.61	13	*	3
9120.66	20	5	7
9121.64	13	11	6
9122.61	17	10	7
9123.58	5	*	3
9124.65	31	*	3
9125.66	-1	*	3
9126.60	20	16	7
Walker 175 (He I & H)			
8493.58	53	*	2
8494.61	49	*	2
8495.60	21	*	2
8496.65	22	*	2
8497.60	42	*	2
9118.71	-9	*	2
9120.87	-8	*	2
9121.75	-11	*	2
9122.88	-71	*	2
9124.70	5	*	2
9125.80	27	*	2
9443.90 *(b)*	-72	10	4
Walker175 (He II)			
8493.58	-82	*	2
8494.61	-58	*	2
8495.60	-1	*	2
8496.65	20	*	2
8497.60	-25	*	2
9118.71	8	*	2
9120.87	19	*	2
9121.75	49	*	2
9122.88	50	*	2
9124.70	40	*	2
9125.80	43	*	2
9443.90 *(b)*	68	13	6
Walker 1997 (He II)			
6340.53 *(a)*	20	6	10
6340.54 *(a)*	17	4	9
8490.62	50	*	3
8491.54	34	*	2
8492.69	30	*	3
8493.62	30	*	3
8494.57	32	*	2
8495.59	26	*	2
8496.58	15	*	2
8497.58	21	*	2
8498.51	16	*	2
9117.65	20	8	4
9118.66	15	26	4
9120.71	15	13	5
9121.83	-2	10	5
9122.64	-10	5	5
9123.65	13	46	4
9124.62	-7	11	4
9125.89	7	31	4
9126.69	-11	6	4
9441.89 *(b)*	22	12	23
Walker 246			
8490.68	20	*	3
8491.62	17	13	6
8492.66	3	10	7
8493.56	7	10	4
8494.58	20	15	4
8495.62	14	11	4
8496.62	11	11	4
8497.63	13	*	3
8498.54	4	*	3
9117.71	19	10	4
9120.82	9	*	3
9121.89	23	*	3
9122.67	14	*	3
9123.75	29	13	4
9125.92	31	8	4
126.73	11	*	3
Walker 401			
6341.51 *(a)*	18	5	13
8490.70	17	7	5
8491.74	10	*	2
8493.67	19	4	5
8494.67	14	5	5
8495.71	23	6	5
8496.71	26	7	5
8497.70	17	5	5
8498.64	15	3	5
9117.77	20	5	5
9118.84	17	5	5
9120.74	19	5	5
9121.86	18	6	4
9122.78	15	*	3
9123.72	19	7	5
9124.90	21	7	5
9125.64	22	9	5
9126.93	13	7	5

TABLE 5 (CONTINUED)

JD	$< v_r >$	σ_i	n	JD	$< v_r >$	σ_i	n	JD	$< v_r >$	σ_i	n
Walker 367				*Walker 280*				*Walker 314*			
6341.49 (*a*)	1	4	9	8491.69	-5	32	4	8490.66	19	16	4
				8492.58	-1	*	3	8491.65	10	11	4
8490.75	4	7	7	8493.63	12	*	3	8492.60	25	6	4
8491.73	6	12	7	8494.65	-3	25	4	8493.61	14	*	3
8492.56	2	11	7	8495.66	9	*	3	8494.63	20	*	3
8493.66	6	4	7	8496.67	13	*	4	8495.64	15	8	4
8494.69	6	10	7	8497.65	9	*	3	8496.69	28	*	3
8495.72	-1	4	7					8497.68	15	6	4
8496.73	5	6	7	9117.91	27	*	3	8498.59	10	9	4
8497.71	1	5	7	9120.91	32	*	2				
8498.68	9	4	7	9121.79	28	*	2	9117.86	25	*	3
				9124.76	21	21	4	9123.88	29	*	3
9117.82	6	9	7	9126.76	11	*	3				
9118.86	3	5	7								
9120.78	1	6	5					*Walker 166*			
9121.92	2	15	5	*Walker 412*							
9122.93	4	9	4					6341.52 (*a*)	20	6	15
9123.92	1	10	5	9118.83	46	20	8				
9124.93	1	11	6	9120.69	-17	8	4	9118.78	4	22	9
9125.70	5	5	7	9121.67	-52	17	5	9121.70	13	9	6
				9122.75	42	25	5	9122.82	26	28	6
				9123.68	92	21	9	9123.82	15	15	9
				9124.80	-22	13	9	9124.85	16	19	9
				9125.87	-52	9	8	9125.75	13	12	9
				9126.65	20	*	3	9126.83	23	21	6

Note. Column 1 gives the heliocentric Julian Date of observation, col. 2 shows the calculated radial velocity of the star in km s^{-1}, col. 3 shows the internal dispersion of the average radial velocity in km s^{-1}, and col. 4 indicates the number of lines measured in each spectra. An asterisk in col. 3 means that too few lines were measured as to consider their dispersion. Échelle spectra are identified in col. 1 as: (*a*) CASPEC, (*b*) REOSC, (*c*) BME.

TABLE 6

PRELIMINARY CIRCULAR ORBITAL ELEMENTS FOR W412

Element	
Period	4.05 days
V_0	16.0 km s^{-1}
K	72.2 km s^{-1}
T_0	2449123.552
$f(M)$	0.16

where higher reddening is expected. Applying the same criteria used for determining membership from proper motions to our radial velocity data, would lead to a very low probability of W367 being member of the cluster. However, we keep in mind that while the proper motion is averaged over a long period of time, the radial velocity is an "instantaneous" velocity, and the difference could also be explained by a binary nature of W367. Still the peculiar kinematic of this star, and its uncertain membership to the cluster should be kept in mind when linking it to the EGGs and star formation in the area.

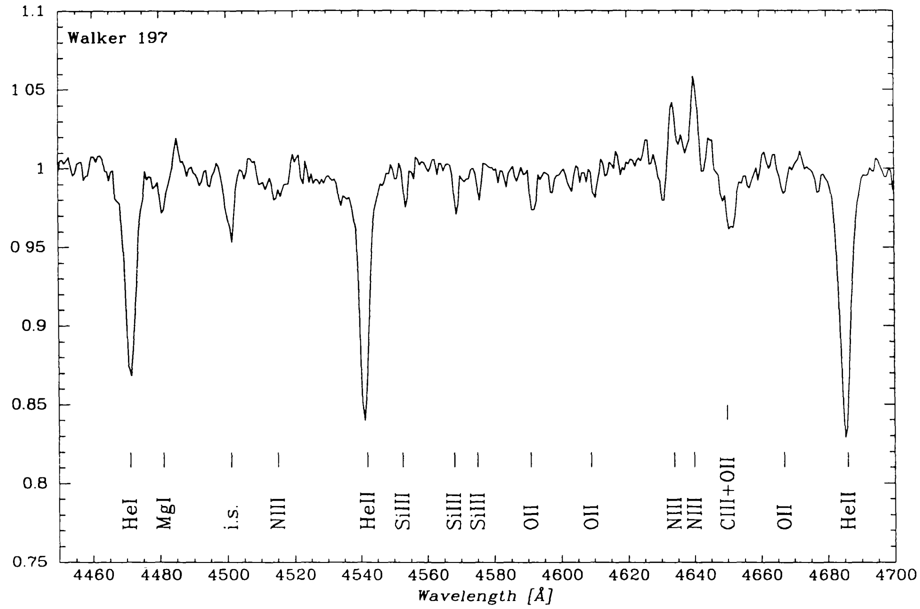

Fig. 4. High resolution spectrum of star W197. Identified features are He I λ4471; Mg I λ4481; interstellar λ4501; N III λλ4511–15; He II λλ4542,4686; Si III λλ4553,4568,4575 and O II λλ4591–96 absorptions. N III λλ4634–40 are present, and indicative of an O((f)) type star.

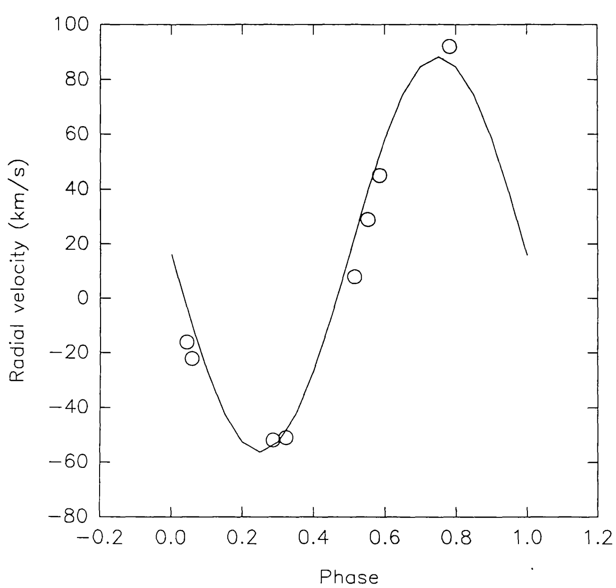

Fig. 5. Plot of radial velocities of star W412 together with a preliminary circular orbital fit from Table 6.

W314: Several lines in the spectrum of this B0 V type star seem to show faint secondary components, as already noticed by Trumpler (cited in Walker 1961). Unfortunately, in our data the lines of the fainter component are too weak as to be measured with confidence for radial velocity. No radial velocity variation is detected in the stronger spectral lines in our data.

W205: This O4 V((f+)) type star is the earliest and the brightest star of the cluster, and the most massive according to its luminosity. From two discordant determinations Conti et al. (1977) proposed this star to be a radial velocity variable. We find an average velocity similar to that of other stars in NGC 6611, but with a large internal dispersion. This could be explained by the presence of turbulence within the strong stellar wind or unresolved lines in a multiple star system. The variability found by Conti et al. (1977) may be due to the fact that different lines were averaged in each determination.

W197: In the spectrum of this O6–7 V((f)) type star the analysis of the radial velocities of the He II 4200, 4542 and 4686 Å lines shows that, although they remain almost constant within each epoch of observations, they differ by 40 km s^{-1} between August 1991 and May 1993. This points to a long period binary nature, and confirms the statement by Conti et al. (1977) that this star has variable radial velocity. In Table 4 we have included only the radial velocities measured from He II absorption lines. In the spectra of W197, as shown in Figure 4 we have detected Si III, O II, and N II absorption lines. These lines are not expected to be observable in the spectra of early O-type stars (cf. Walborn & Fitzpatrick 1990); therefore, we consider that they originate in a B0–1 type companion. Considering the relative luminosities we estimate that these lines could be produced by a B0–1 II–III type companion. As we find in our spectra a slight variation in the relative intensities of He I 4471 and He II 4541 Å, we assign to the O star a spectral type O6 V, considering that the changes in the intensity of the He I line may be due to the B type companion. More data are needed to confirm the binary orbit and the spectral type of each component.

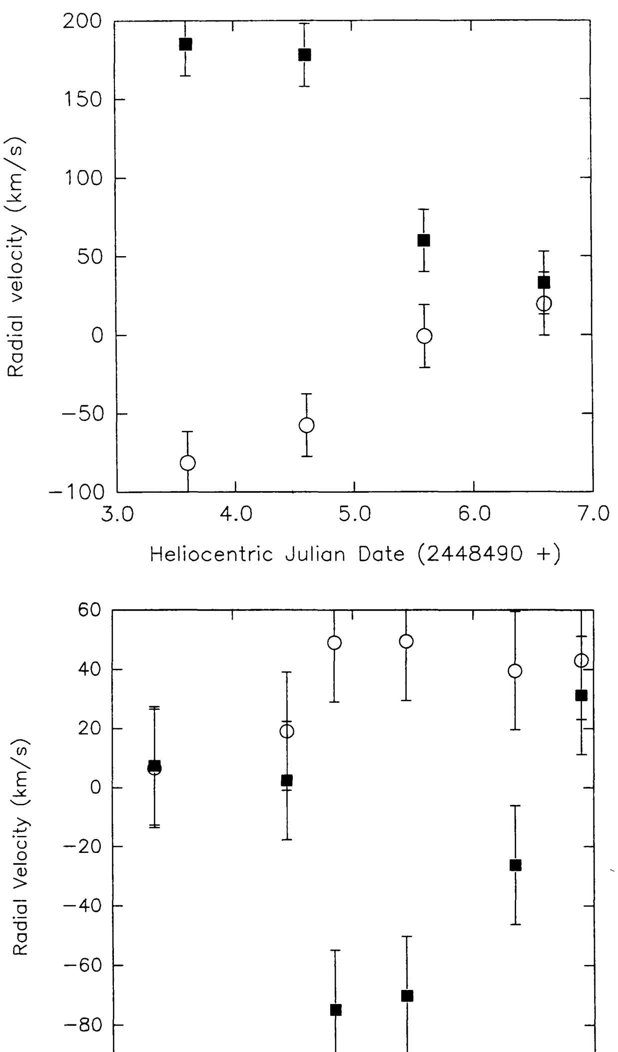

Fig. 6. Plot of the radial velocities of star W175. Filled boxes correspond to the He I lines and hollow circles to the He II lines. Panel (*a*) shows the measurements for the data obtained in August 1991, and panel (*b*) shows the ones for spectra obtained in May 1993.

W175: This star of spectral type O5.5 V((f)) has no previous radial velocity measurements. We find it to be probably a double-lined binary, since lines of He II and He I show different radial velocity behaviour. As shown in Figure 6*a* and Figure 6*b*, they seem to be related to an orbital motion of two stars, one having stronger He I lines and the other one stronger He II lines. We have included in Table 4 the radial velocities of He II and He I + Hδ separately. He I and Hγ seem to have similar radial velocity behavior. A single high resolution spectrum of this star obtained at CASLEO shows double features in the He II and He I lines indicating the presence of two O-type stars. A period longer than 8 days is suggested by our observations, but more data are necessary to determine the binary orbit.

The radial velocity measurements for stars with Walker numbers 166, 246, 280, and 401, listed in Table 5, do not show significant variations in our data, and we consider them to be probably constant.

4. CONCLUSIONS

We have performed a radial velocity study of a sample of the ten earliest type stars in the open cluster NGC 6611. In this group we find three stars: W412, W197, and W175 showing radial velocity variations that indicate them to be binary systems. One of these, W412, is undoubtedly a short period single-lined binary. The other two have longer periods and require further data for the determination of their orbital periods. Star W205 shows a great internal dispersion in the radial velocity values of all lines and, hence, should be observed at higher resolution. Since the number of known early O-type binaries is very low, it is important to study further these stars and to determine their binary orbits. Other two stars, W367, and W314 are also candidate binary or multiple systems.

Although the total number of objects considered is relatively small, we can restrict the observed frequency of spectroscopic binaries to the 30% – 50% range. This encompasses the 36% spectroscopic binary detection rate of Garmany et al. (1980) and the 50% determination by Levato et al. (1991a,b) for Trumpler 14 and 16, in the η Carinae complex. The true fraction of multiple systems may well be over 60%, as shown by Mason et al. (1998) for stars brighter than 8th magnitude.

We have compared the mean velocity of our sample with the velocity of the H II region related to NGC 6611. If we average all the radial velocity values in Table 4, excluding W367 and the binaries, we find $\overline{v_r} = 15 \pm 2.6$ km s^{-1} for the cluster. This is in excellent agreement with the value of 15.5 km s^{-1} obtained for the radial velocity of the ionized gas in the H II region from Fabry-Perot interferometry by Georgelin & Georgelin (1970).

We have also performed spectral classification for several faint stars in the cluster neighborhood. Most of these stars are of B type, confirming that they are early type members of NGC 6611. These stars will be included in future studies to extend the determination of binary frequencies towards B-type stars in the cluster.

We thank the referee for his comments and suggestions that improved the original version of this paper. G.L.B. and N.I.M. wish to thank the staff at CASLEO, for their friendly support during the observations. V.S.N. is grateful for telescope time at ESO. N.I.M. would like to thank the Director and staff at CTIO for the use of their facilities.

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