Astron. Astrophys. 214, 123–130 (1989)

ASTRONOMY AND ASTROPHYSICS

A photometric study of F-type stars of high galactic latitude

A. Arellano Ferro[1,*], Sunetra Giridhar[2], M. Chavez[3], and L. Parrao[3]

[1] Instituto Nacional de Astrofísica Optica y Electrónica, Tonantzintla, Apdo. Postal. 51, y 216 Puebla 72000, México
[2] Indian Institute of Astrophysics, Bangalore 560034, India
[3] Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 70-264, México D.F. 04510, Méxíco

Received March 29, accepted August 17, 1988

Summary. Photometry in the O I 7774A line and the *uvbyβ* system has been performed for a group of high galactic latitude F-type stars classified as luminosity type I. The O I 7774A line photometric index $\Lambda(16)$ has been calibrated in terms of luminosity using F-G supergiants belonging to open clusters. This $\Lambda(16)$ index indicates high luminosity for these high latitude stars, which is consistent with the luminosity type I ascribed to them and places these objects far away from the galactic plane. However, *uvby* photometric indices indicate almost solar abundances and gravities larger than 3.0. The absolute magnitude M_v estimated using the reddening free indices [m1] and [c1] does not suggest very high luminosity for these stars, hence they would not be very distant from the galactic plane. Their location on the HR diagram suggests that they occupy a region near the AGB. It is possible that the O I 7774A photometric index $\Lambda(16)$ is being contaminated by neighbouring lines or the O I 7774A feature has become abnormally strong due to contribution from the extended atmospheric layers. That being the case, these stars seem to be neither very luminous objects nor are situated much above the galactic plane and therefore are not tracers of recent star formations in the halo. Instead, most of these stars appear to be low mass stars of the old disk population and therefore do not conform to the UU Herculis class.

The only exception to the above conclusions is the star BD 45° 1872 ($V = 10.2$ mag) for which the distance and gravity derived from different methods point to $Z \sim 9.5$ kpc., $\log g \sim 2$ and $[Fe/H] \sim -2$. It is probably of low mass ($\sim 0.6 \mathscr{M}_\odot$) and very similar to some members of the UU Her Group.

Key words: clusters: open – distances – planetary nebulae: general – spectrophotometry – stars: supergiant

1. Introduction

The presence of young massive stars out of the galactic disk as an indication of recent star formation in the halo is a controversial topic often discussed in the literature and yet not well understood.

During the last three decades some of the F supergiants found at high galactic latitude have been investigated by several workers. The most extensively studied among them are 89 Her (F2 Ib), and HD 161796 (F3 Ib). A differential curve-of-growth analysis for these two stars was done by Abt (1960) who derived low metallicity consistent with their high galactic latitude and suggested that they were possible tracers for star formation in the halo. However later studies by Searle et al. (1963), and more recently by Giridhar et al., (1987), report almost solar abundances. The distance of these objects from the galactic plane would of course depend upon the luminosity ascribed to them. Their evolutionary status is also not clear. If these are indeed normal young supergiants of intermediate mass as suggested by the resemblance of their spectra with yellow supergiants, then they were probably formed out of the galactic plane and evolved from high latitude B stars.

It has also been suggested that these objects can be low mass stars in the post-AGB evolutionary phase (Luck et al., 1983; Luck and Bond, 1984; Parthasarathy and Pottasch, 1986). Recent evolutionary calculations indicate that low mass stars can attain for some time high luminosity and appear like F supergiants, a likely example of this is HD 46703 (Bond et al., 1984; Luck and Bond, 1984).

The evidence does exist for the binary nature of 89 Her from spectroscopic studies and the solution of the orbit predicts a mass of at least $13 \mathscr{M}_\odot$ (Arellano Ferro, 1984).

A small group of high latitude variable F supergiants has been identified according to their photometric and spectroscopic behaviour by Sasselov (1983a). This group is characterized by light variations of long period (40–100 days), small amplitude, pulsation mode switching, supergiant-like spectra and radial velocities typical of population II objects. 89 Her, HD 161796, UU Her and HR 4912 are among the well known members of this group (Burki et al., 1980; Fernie, 1981; Arellano Ferro, 1981, 1985; Luck et al., 1983; Fernie and Garrison, 1984; etc.). Sasselov (1983b) suggested the generic name of UU Her type for these stars after the prototype. Incidentally UU Her itself was classified as a RV Tauri star by Preston et al. (1963) and SRd type by Dawson (1979) with a note on its alternating period. In a recent paper Worrell (1986) prefers to consider it a RV Tau type again. However, its photometric behaviour, when compared with well established RV Tau stars, makes that classification inappropriate (Fernie, 1986b).

Send offprint requests to: A. Arellano Ferro
* On leave from Instituto de Astronomía, UNAM. México.

Recently, Sasselov (1984) identified 33 high galactic latitude stars classified in Bartaya (1979) as F0–F5 supergiants (mostly of luminosity class I). He suggests that these stars might belong to the UU Her class and be tracers of recent star formation out of the galactic disk. In what follows we shall refer to these star as the candidates. Since the discovery of so many young, massive stars out of the galactic plane would be a valuable finding, we decided to undertake a photometric study of the candidates, with the aim of determining distances, gravities and metal abundances. Here we report the results of our O I 7774A line and *uvbyβ* photometry, which throws some light on the nature of the candidates.

We describe our $\Lambda(16)$ photometric system and the observations in Sect. 2. The calibration of $\Lambda(16) - M_v$ relationship is presented in Sect. 3. Section 4 deals with *uvbyβ* photometry of the candidates and the atmospheric parameters derived using Strömgren photometric indices. Discussion and conclusions arrived at are presented in Sect. 5.

2. Observations

2.1. O I 7774A line photometry

The observations were performed in 1986 November 23–26, with a pulse-counting photometer on the 0.84 m telescope at San Pedro Mártir Observatory, Mexico. A system of two filters kindly made available to us by Dr. E. Mendoza was used. It consists of a narrow (FWHM = 16 A) and a wide (FWHM = 120 A) filter, both centered at 7774A. The transmittance of these two filters is shown in Fig. 1. The counts with each filter, once the sky background was subtracted, denoted by L_N and L_W respectively, were combined by the formula

$$\Lambda(16) = -2.5 \log (L_W/L_N)$$

to define the index $\Lambda(16)$. From measurements of stars observed on different night throughout our run, we estimate the uncertainty of the $\Lambda(16)$ index as ± 0.007.

A similar system based on three filters, called $\Lambda(9)$, has been described by Mendoza (1971) and widely used as a luminosity and metallicity discriminator (see Mendoza, 1976 and references therein).

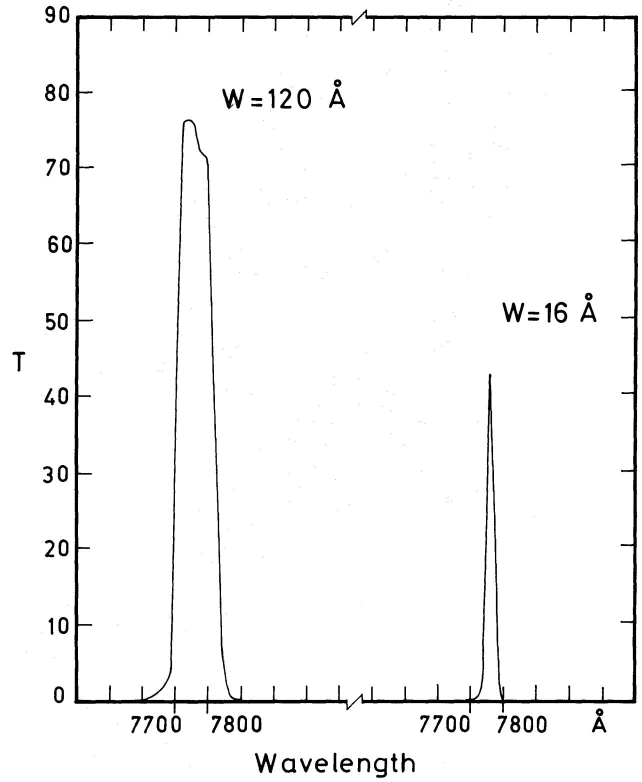

Fig. 1. Transmittance of the two filters defining the $\Lambda(16)$ photometric system

To show that the $\Lambda(16)$ index is a good measure of the equivalent width of O I 7774A, W(7774), we searched the literature for the equivalent widths of the feature in some of the supergiants in Table 1. In Table 3 those equivalent widths are listed and their relationship with the index $\Lambda(16)$ is displayed in Fig. 2. A

Table 1. F-G stars in open clusters and their $\Lambda(16)$ photometry

Cluster	Star	HD/BD	V	Sp. type	$\Lambda(16)$	n
NGC 129	A	59° 0067	8.86	F5 Ib	2.1913	3
h and χ Per		HD 11544	6.82	G2 Ib	2.1444	3
		HD 14662	6.27	F7 Ib	2.1693	3
		HD 17971	7.75	F5 Ia	2.2135	3
		HD 18391	6.89	G0 Ia	2.2003	3
NGC 2168	101	24° 1124	8.55	G2 II	2.1540	2
NGC 2287	F	−20° 1568	7.77	G8 II–III	2.1554	2
NGC 3114	1	HD 87283	5.94	F0 II		
Stock 14		HD 101947	5.01	G0 Ia		
NGC 6067	7400p	−53° 7400	8.25	G0 Ib		
	7400f	−53° 7400	9.01	F0 Ib		
IC 4725	150	−19° 5053	7.39	G6 II		
NGC 6664	C	−8° 4647	10.33	G8 II		
NGC 7654	2	60° 2532	8.22	F7 Ib	2.1853	3
α Per		HD 20902	2.32	F5 Ib	2.1766	2
NGC 457		HD 7927	5.00	F0 Ia	2.2257	3
NGC 654		HD 10494	7.32	F5 Ia	2.2213	3
Cr 121		HD 54605	1.80	F8 Ia	2.2135	2

Table 2. $\Lambda(16)$ index for candidate stars

BD/BSD	Sp. type[a]	$\Lambda(16)$	n
46° 186	F0 I	2.142	1
61° 928	F2 I	2.190	2
60°1025	F0 I	2.181	2
61° 954	F0 I	2.193	2
61° 959	F0 I	2.192	2
61° 972	F3 I	2.176	2
44° 1647	F2 I	2.204	2
60° 1059	F5 I	2.186	2
60° 1060	F5 I	2.182	2
45° 1459	F3 I	2.210	2
45° 1462	F5 I	2.189	2
46° 1307	F0 I	2.182	2
45° 1507	F5 Ib	2.193	2
74° 351	F0 I	2.191	2
74° 424	F2 I	2.198	2
45° 1620	F3 I	2.188	2
BSD 482	F0 I	2.195	2
45° 1624	F5 I	2.180	2
BSD 940	F0 I	2.196	2
44° 1783	F3 I	2.188	2
43° 1852	F0 I	2.173	2
45° 1650	F5 I	2.185	2
45° 1769	F5 I	2.191	2
45° 1872	F5 I	2.187	2
45° 1930	F5 I	2.193	2
44° 2121	F0 I	2.204	2
46° 1747	F2 I	2.199	1

[a] Spectral types from Bartaya (1979).

mean relationship of the form

$$W(7774) = 20.8\Lambda(16) - 44.3 \quad (1)$$
$$\pm 2.9 \qquad \pm 6.4$$

is found.

We present in Table 1 the measurements of $\Lambda(16)$ index for a group of F-G supergiants, which are believed to be members of open clusters. These indices would be used for $\Lambda(16) - M_v$ calibration. Table 2 contains the $\Lambda(16)$ index measured for the candidates.

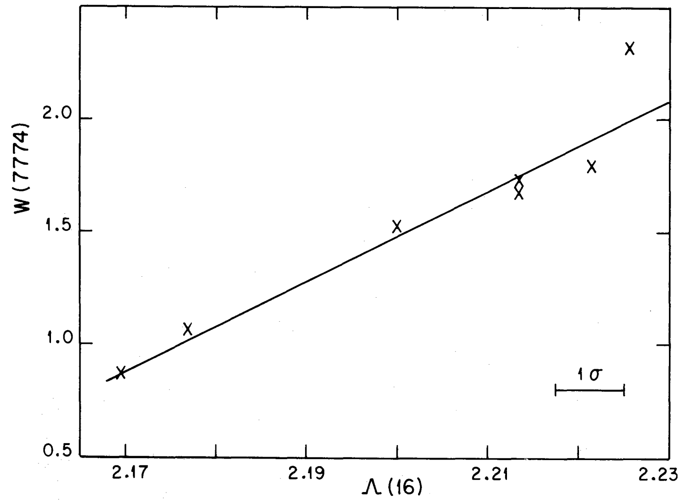

Fig. 2. Calibration of the index $\Lambda(16)$ in terms of the equivalent width W(7774) for the F-G supergiants in Table 3. The equation of the straight line is

$$W(7774) = 20.8\Lambda(16) - 44.3.$$
$$\pm 2.9 \qquad \pm 6.4$$

2.2. *uvbyβ photometry*

The observations were made in 1986 October 19–25, and also in 1987 November 5 and 8, with a four-channel grating spectrophotometer on the 1.5 m. telescope at San Pedro Mártir observatory, Mexico. The passbands in the spectrophotometer are defined by slots properly located on the stellar spectrum and reproduce very closely the original *uvbyβ* filter system of Crawford and Barnes (1970). The candidates were observed along with about 15 standard stars observed every night, which in turn were used to transform the observations into the Crawford and Barnes (1970) standard system. The following transformation equations were found to transform the instrumental values into the standard system;

$$v_s = y_i + 19.334 + 0.039(b-y)_i$$
$$(b-y)_s = 0.946 + 0.973(b-y)_i$$
$$m1_s = -0.380 + 1.026(m1)_i + 0.017(b-y)_i$$
$$c1_s = 0.036 + 0.991(c1)_i + 0.129(b-y)_i$$
$$\beta_s = 2.807 + 1.295\beta_i$$

Table 3. Equivalent widths of O I 7773A in selected stars

Name	HD	Sp. type	1	2	3	4	Average
ϕ Cas	7927	F0 Ia		2.26	2.38		2.32
	10494	F5 Ia		1.77	1.80		1.78
440 Per	14662	F7 Ib			0.87		0.87
	17971	F5 Ia		1.79	1.68		1.73
	18391	G0 Ia		1.52			1.52
α Per	20902	F5 Ib	1.15	0.95	1.05	1.15	1.07
δ CMa	54605	F8 Ia	1.88	1.43	1.70		1.67

References: 1. Keenan and Hynek (1950), 2. Osmer (1972), 3. Baker (1974), 4. Mendoza and Johnson (1979).

Table 4. *ubvyβ* photometry of candidate stars

Star (BD/BSD)	V	σ_v	$(b-y)$	σ_{by}	$m1$	σ_{m1}	$c1$	σ_{c1}	β	σ_β	n
46° 186	9.991	0.026	0.327	0.010	0.277	0.009	0.516	0.043	2.752	0.018	7
61° 928	7.902	0.009	0.292	0.007	0.169	0.001	0.809	0.015	2.725	0.012	6
60° 1025	8.366	0.013	0.099	0.007	0.181	0.012	0.914	0.018	2.858	0.011	8
61° 959	8.419	0.009	0.164	0.004	0.194	0.005	0.904	0.004	2.831	0.005	5
61° 972	9.035	0.027	0.247	0.009	0.151	0.009	0.542	0.018	2.712	0.007	5
44° 1647	10.105	0.061	0.272	0.010	0.162	0.013	0.760	0.035	2.714	0.006	8
60° 1059	9.113	0.028	0.291	0.011	0.136	0.010	0.485	0.016	2.674	0.005	5
60° 1060	8.739	0.007	0.284	0.004	0.133	0.006	0.495	0.003	2.676	0.010	4
45° 1459	8.371	0.008	0.230	0.007	0.186	0.007	0.807	0.016	2.724	0.054	7
45° 1462	8.363	0.007	0.274	0.010	0.147	0.007	0.558	0.018	2.678	0.045	6
46° 1307	9.327	0.058	0.218	0.011	0.226	0.012	0.785	0.027	2.775	0.010	7
45° 1507	8.983	0.020	0.282	0.007	0.139	0.006	0.531	0.015	2.673	0.015	7
45° 1620	7.884	0.015	0.269	0.005	0.164	0.008	0.740	0.017	2.680	0.069	5
BSD 482	10.485	0.026	0.248	0.008	0.133	0.012	0.614	0.016	2.692	0.063	4
45° 1624	8.243	0.019	0.245	0.005	0.144	0.010	0.578	0.015	2.715	0.008	7
BSD 940	10.716	0.025	0.262	0.014	0.139	0.010	0.629	0.013	2.704	0.018	5
44° 1783	8.814	0.010	0.256	0.006	0.145	0.005	0.653	0.017	2.717	0.011	7
43° 1852	9.586	0.008	0.253	0.007	0.142	0.005	0.673	0.009	2.725	0.011	6
45° 1650	8.102	0.010	0.306	0.005	0.149	0.005	0.623	0.012	2.678	0.004	5
45° 1769	7.426	0.000	0.254	0.000	0.171	0.000	0.659	0.000	2.724	0.000	1
45° 1872	10.233	0.000	0.331	0.000	0.080	0.000	0.628	0.000	2.758	0.000	1
44° 2763	9.175	0.016	0.230	0.005	0.263	0.005	0.623	0.006	2.758	0.008	3
45° 2595	7.962	0.012	0.232	0.001	0.216	0.004	0.681	0.008	2.726	0.006	3
60° 1981	8.531	0.024	0.247	0.002	0.188	0.009	0.868	0.013	2.722	0.008	5

We observed 24 of the 33 stars listed by Sasselov (1984) as candidates to the UU Her class. The remaining nine not being accessible to us at the time of the observations. The number of observations for each star ranges between 1 and 8. The average values, the standard deviation of the mean and the number of observations are given in Table 4. Individual observations are available on request.

Intrinsic variability cannot be assessed from the present observations, but judging from the small values of the standard deviation they are probably not variable in the time scale of the survey. Those stars having more than six observations, were measured in two seasons separated by one year and yet they have small deviations.

3. $\Lambda(16) - M_v$ relationship calibration

The sensitivity of the O I 7774A feature to the stellar luminosity is a fact well established in the past (Keenan and Hynek, 1950; Osmer, 1972; Baker, 1974; Sorvari, 1974; and Rao and Mallik, 1978). To use this feature as distance indicator we must calibrate our photometric index from stars of well known distances. We have selected from the literature a group of F-G supergiant stars believed to be members of open clusters, the major sources are Schmidt (1984) and Stothers (1969). We list them in Table 1 along with the measured $\Lambda(16)$ index for those stars observable from our site in our observing season. The cluster distance moduli, taken from different sources, are listed in Table 5 as well as their

Table 5. The distance moduli of open clusters containing F-G supergiants

Cluster	Hagen (1974)	Nicolet (1981)	Others	Adopted $(m-M_v)_0$	$E(B-V)$
NGC 129	11.1		11.0 ± 0.15[1]	11.1	0.61
h and χ Per	11.8		11.8[2]	11.8	0.56
NGC 2168	9.7	9.67 ± 0.28	9.7 ± 0.3[3]	9.7	0.23
NGC 2287	9.1	8.86 ± 0.18	9.0[4]	9.1	0.00
α Perseo	6.1	6.26 ± 0.12		6.1	0.10
NGC 654	12.3	11.85 ± 0.10		12.3	0.89
NGC 457	12.3	11.71 ± 0.55	12.3[1]	12.3	0.47
Cr 121	9.0		9.0[5]	9.0	0.03
NGC 7654	11.4		11.1[6]	11.1	0.62

References: 1. Pesch (1959), 2. Abt (1960), 3. Cudworth (1971), 4. Levato and Maladora (1979), 5. Feinstein (1967), 6. Pesch (1960a).

colour excesses $E(B-V)$. The discrepancies among the moduli are very small and in general we have adopted the values given by Hagen (1974).

The absolute magnitudes Mv for the cluster stars were determined from the parent cluster distance moduli and compared in Table 6 with the stellar absolute magnitude as determined by other authors. The comparisons are satisfactory except for HD 14662, for which the differences are remarkable. This star will be discussed separately.

A plot of the $\Lambda(16)$ index from Table 1 against the adopted absolute magnitude from Table 6 for the cluster stars, is displayed in Fig. 3. A close correlation between the two parameters is depicted, except for the stars HD 11544 and HD 14662. These two stars together with HD 17971 and HD 18391 are located in the so called "outer group" of the double cluster h and χ Persei and for them a mean of the two clusters distance moduli is being used (Schild, 1967). Schild (1967) also found some indication that B-A and red supergiant stars located in the outer group are background stars in the Perseus arm. This might also be the case for HD 11544 and HD 14662. On the basis of the above considerations these two stars were dropped from the least squares fit. The two stars shown as squares in Fig. 3 are 24° 1124 (G2 II) and −20° 1568 (G8 II–III). It has been shown that the O I 7774A feature may be different in class I stars than the class II stars (Keenean and Hynek, 1950; Sorvary, 1974), and then we did not include these two stars in the calibration. Their inclusion would slightly change the calibration so that M_v would be, on an average 0.07 mag. dimmer. The rest of the stars define the relationship

$$M_v = -88.02\Lambda(16) + 187.83 \quad (2)$$

which we consider as our calibration of the $\Lambda(16) - M_v$ relationship for F-G supergiant stars. The above equation allows the estimation of M_v with an uncertainty of 0.6 mag.

A straightforward application of Eq. (2) to the $\Lambda(16)$ index data for the candidates of Table 2, allows the estimation of their M_v's, which, combined with the visual magnitudes and reddenings found in the following section, lead to the stellar distances.

Table 6. Absolute magnitudes for F-G supergiants in open clusters

HD/BD	M_v			M_v from $(m-M_v)_0$
	Baker (1974)	Pesch	Others	
59° 0067				−4.07
HD 11544	−7.03		−6.8[4]	−6.66
HD 17971			−6.4[5]	−5.73
HD 14662	−4.83		−7.7[6]	−7.21
HD 18391			−6.7[5]	−6.59
24° 1124				−1.84
−20° 1568				−1.33
HD 20902	−5.32		−4.5[7]	−4.09
HD 10494	−7.35	−7.5[1]		−7.65
HD 54605	−7.09		−7.4[8]	−7.29
HD 7927	−8.93	−8.7[2]	−8.5[9]	−8.72
60° 2532	−4.27	−4.89[3]		−4.74

References. 1. Pesch (1960b), 2. Pesch (1959), 3. Pesch (1960a), 4. Fernie and Hube (1971), 5. Widley (1964), 6. Stothers (1969), 7. Abt (1957), 8. Feinstein (1967), 9. Humphreys (1978).

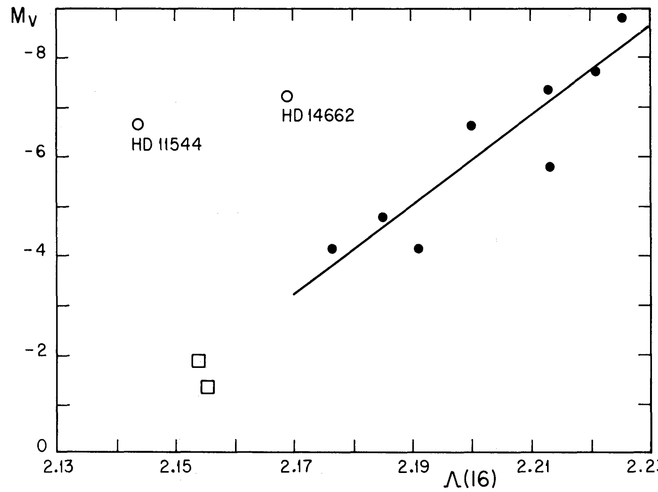

Fig. 3. Calibration of the $\Lambda(16) - M_v$ relationship using supergiants in open clusters. The stars HD 11544 and HD 14662 do not follow the relationship and they are discussed in the text. The squares represent the stars 24° 1124 (G2 II) and −20° 1568 (G8 II–III) which, in spite of their having an incipient O I 7774A line, seem to follow the mean relationship for the hotter and brighter supergiants (filled circles). The straight line, $M_v = -88.02\Lambda(16) + 187.83$ is the least squares fit of the filled circles

The colour excess $E(B-V)$, the absolute magnitude M_v and the projected distance perpendicular to the galactic plane Z, are given in Table 7 for each of the candidate stars. The distance Z is compared with that found by Sasselov (1984). The distances compare very well and indicate that the candidates are considerably far from the galactic plane. However, before drawing any conclusion from this result, we shall proceed to present the results of our analysis of the $uvby\beta$ data.

4. Narrow band photometry analysis

In order to deredden the observations of the candidate stars, we used the extrinsic method for reddening estimation of Burstein and Heiles (1982), which provides us with maps of reddening as a function of galactic position. The redening estimated for each of the candidates is given in column 2 of Table 7. Being the candidate stars of high galactic latitude, all their reddening are small.

The four colour observations in Table 4 were then dereddened according to the following equations: $E(b-y) = 0.73E(B-V)$; $c1_0 = c1 - 0.25E(b-y)$; $m1_0 = m1 + 0.32E(b-y)$ (Crawford, 1975).

The observations of the candidates so dereddened were plotted on the $m1_0 - (b-y)_0$ plane (filled circles) of Fig. 4. The continuous lines are the atmospheric models of Kurucz (1979) for [Fe/H] = 0, −1, and −2 and for $\log g = 2$. For $\log g = 1$, the models would have to be shifted upwards by about 0.02 in $m1_0$. A group of bright F-G supergiant stars in the galactic plane selected from the Bright Star Catalogue, were simultaneously observed with the candidates and were similarly reduced. The observations for those stars will be reported elsewhere. Such population I stars are also plotted in Fig. 4 (open circles).

The $m1_0 - (b-y)_0$ plot in Fig. 4 is mainly sensitive to the metal abundance. It can be seen that the metal abundances for

Table 7. Reddening and distance estimates for the candidates

		Λ(16)		Sasselov (1984)	*uvby*	
BD/BSD	$E(B-V)$	M_v	Z (kpc)	Z (kpc)	M_v	Z (kpc)
46° 186	0.10	−0.71	−0.4 ± 0.3	3.2	−1.46	−0.5
61° 928	0.07	−4.93	1.4 ± 0.5	1.7	−3.38	0.7
60° 1025	0.06	−4.14	1.2 ± 0.4	3.4	−5.43	2.2
61° 954	0.06	−5.19	2.8 ± 0.9	2.5		
61° 959	0.06	−5.11	2.1 ± 0.7	2.0	−4.28	1.4
61° 972	0.05	−3.70	1.5 ± 0.5	2.0	−2.89	1.0
44° 1647	0.06	−6.16	7.2 ± 2.5	4.9	−3.56	2.2
60° 1059	0.05	−4.58	2.3 ± 0.8	3.0	−2.61	0.9
60° 1060	0.05	−4.23	1.7 ± 0.5	2.6	−2.85	0.9
45° 1459	0.06	−6.69	4.3 ± 1.5	2.1	−3.56	1.0
45° 1462	0.06	−4.84	1.8 ± 0.6	2.2	−3.03	0.8
46° 1307	0.06	−4.23	2.3 ± 0.8	2.6	−2.44	1.1
45° 1507	0.06	−5.19	3.0 ± 1.0	2.2	−3.19	1.2
74° 351	0.02	−5.02	2.3 ± 0.7	2.4		
73° 424	0.02	−5.64	2.1 ± 1.0	2.2		
45° 1620	0.02	−4.75	2.0 ± 0.6	2.3	−3.37	1.1
BSD 482	0.02	−5.37	8.9 ± 2.8	6.8	−3.67	4.1
45° 1624	0.02	−4.05	1.7 ± 0.5	2.7	−3.57	1.4
BSD 940	0.02	−5.46	10.3 ± 3.4	9.1	−3.52	4.2
44° 1783	0.02	−4.76	3.1 ± 0.9	3.4	−3.59	1.8
43° 1852	0.02	−3.44	2.4 ± 0.7	5.1	−3.75	2.8
45° 1650	0.02	−4.49	2.0 ± 0.6	2.7	−2.74	0.9
45° 1769	0.01	−5.02	2.0 ± 0.6	2.1	−2.98	0.8
45° 1872	0.00	−4.67	8.4 ± 2.8	8.0	−4.95	9.5
45° 1930	0.00	−5.20	7.3 ± 2.2	6.7		
44° 2121	0.00	−6.16	6.6 ± 2.0	3.8		
46° 1747	0.00	−5.72	6.5 ± 2.0	4.6		

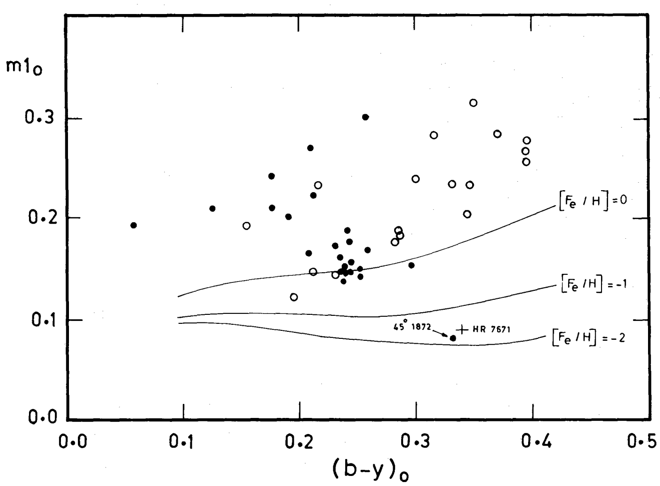

Fig. 4. The $(b-y)_0 - m1_0$ diagram is used to derive [Fe/H] abundance. Solid lines are models from Kurucz (1979) for $\log g = 2$. The candidate stars (filled circles) seem to have nearly solar abundances, similar to a group of selected Pop I F-type supergiants (open circles). The star BD 45° 1872 lies very near to the peculiar star HR 7671; see text for discussion

the candidates of high galactic latitude are similar to their counterparts of low latitude, i.e. nearly [Fe/H] = 0. As reddening variations would move the stars horizontally in Fig. 4, the results are not sensitive to reddening uncertainties.

For the peculiar star HR 7671, using *uvby* photometry Fernie (1986a) derived a value of [Fe/H] ~ −2.0. Our results for this star (Fig. 4) are in agreement with that of Fernie (1986a). We should point out that the star BD 45° 1872 is, among the candidates, the only star that shows as low [Fe/H] as the star HR 7671. We shall return to the case of BD 45° 1872 later.

The plane $c1_0 - (b-y)_0$ of Fig. 5 is mostly sensitive to the gravity. Solid lines represent the atmospheric models of Kurucz (1979) for constant temperature and gravity and [Fe/H] = 0. Similar to Fig. 4, the candidates are shown by filled circles and population I bright F-G supergiants are shown by open circles. It is of interest to note in Fig. 5 the position of some classical members of the UU Her class also observed in our program; UU Her, 89 Her and HD 161796. Their position in the $c1_0 - (b-y)_0$ plane agrees very closely with those found by Fernie (1986a,b). Very clearly one can see that the candidates are separated from the population I F-G supergiants and also from the

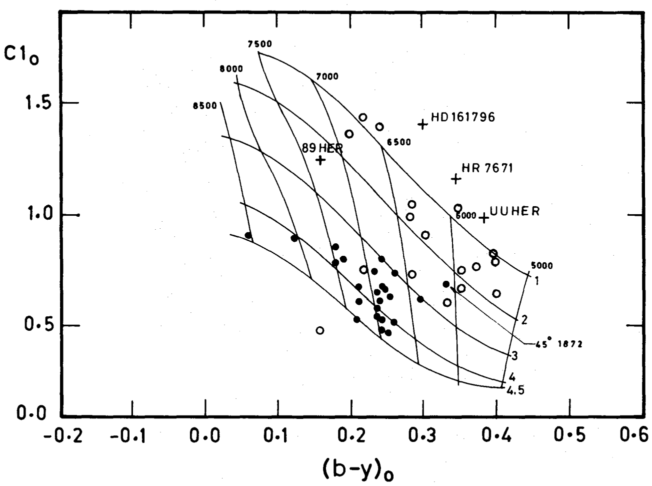

Fig. 5. The $(b-y)_0 - c1_0$ diagram is used to derive surface gravities and temperatures. Solid lines are atmospheric models from Kurucz (1979) for constant gravity and constant temperature and [Fe/H] = 0. The symbols are the same as in Fig. 3. Some classical members of the UU Her group are also plotted for comparison. The candidates are clearly of gravities higher than $\log g = 3$, except for BD 45° 1872 for which $\log g \sim 2$

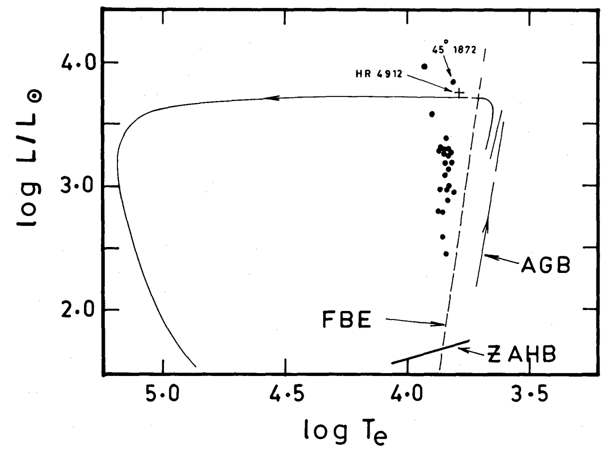

Fig. 6. Evolutionary track of a $0.6\,\mathscr{M}_\odot$ star calculated by Iben (1982). The temperature and luminosities for the candidates were obtained exclusively for uvby data as explained in the text. They all fall to the left of the blue edge of the instability strip and may indeed be low mass stars evolving near the AGB or post-AGB evolutionary phases. The position of BD 45° 1872 near the UU Her type star HR 4912 is worth noticing

classical UU Her type stars and appear to have higher gravities, $\log g \geq 3$. Once again the star BD 45° 1872 stands out from the rest of the candidates for having the lowest gravity ($\log g \sim 2$). The two Pop I supergiants below $\log g = 3$ shall be discussed elsewhere.

The above result is surprising considering the fact that the candidates have been classified as of luminosity class I (Bartaya, 1979), and therefore were expected to be of low gravity.

5. Discussion and conclusions

For F-G type stars the O I 7774A line becomes stronger with decreasing gravity, being very strong for supergiants and not so prominent for dwarfs (Sorvari, 1974; Mendoza, 1971; Keenan and Hynek, 1950). The O I 7774A photometry in Sect. 3 has indicated the feature in the candidates to be as strong as it is in well known luminous supergiants in open clusters. This result is consistent with Bartaya's (1979) classification of the candidates as supergiants. Which in turn implies that they are very distant objects far away from the galactic disk. The luminosities from Bartaya (1979) were used by Sasselov (1984) to estimate their distances, hence leading to the same conclusion. Despite strong O I 7774A feature, *uvby* photometry depicts the candidates as being of solar iron content and being giant or dwarf stars of higher gravities. An independent distance estimate of the candidates from *uvby* data can be done by using the calibration of M_v as a function of the reddening free quantities [c1] and [m1], computed by Antonello (1985) for supergiant stars. We find that M_v for the candidates turns out to be one to three magnitudes fainter than those obtained from O I 7774A line data. It seems therefore that narrow band photometry points the candidates as being more confined to the galactic plane, of lower luminosity and of higher gravity compared to the supergiant stars.

One star among the candidates that does not follow the above conclusions is BD 45° 1872, which seems to be of low [Fe/H] (Fig. 3) and low gravity (Fig. 4). It is also the only star for which our $A(16)$ and $uvby\beta$ data indicate a large distance from the galactic plane (9 kpc), and it agrees with Sasselov's (1984) estimate (8 kpc). The position of the BD 45° 1872 in Fig. 6 is very close to that of HR 4912 found by Luck et al. (1983), and to the $0.6\,\mathscr{M}_\odot$ evolutionary track from Iben (1982).

We may wonder of course if the O I 7774A line photometry has not been affected by other atmospheric lines. The most prominent line nearby is at 7780 of Fe I. This line begins to grow strong for stars cooler than F5 (Rao and Mallik, 1978) and would be stronger for higher gravities. We noted that all the candidates are earlier than F5 from Bartaya's (1979) classification. Bartaya classified the stars from objective prism spectra at a dispersion of 166 A/mm (Sasselov, 1984). At such a dispersion the important luminosity classification criteria for F stars, such as the ratios Ti II 4172/Fe I 4179 and Ti II 4172/Ca I 4227 (Morgan et al., 1978) are hardly discernible. We feel there is a possibility for an improvement in the spectral classifications of the candidates and an MK classification at about 60 A/mm is desired.

Then, if the O I 7774A line is peculiar or if it is indeed getting contaminated by, most likely, Fe I 7780 feature, this would explain the high intensity and hence large luminosities found in Sect. 3. High dispersion spectroscopy of the O I 7774A feature is of course also desired.

Luminosities one to three magnitudes fainter and their temperatures from $(b-y)_0 - T_e$ calibration (Philip and Relyea, 1979), would place the stars in the AGB region of the H-R diagram. Very recently several authors have concluded that some high galactic latitude supergiants are indeed stars in the AGB or post-AGB phases of evolution, e.g. HR 4912 (Luck et al., 1983), HD 161796, HD 101584 (Parthasarathy and Pottasch, 1986) and the object IRAS 18095 + 2704 identified with an F3 Ib star (Hrivnak et al., 1988). We have plotted in Fig. 6 the candidates on the $T_e - \log(L/L_\odot)$ diagram along with the evolutionary track of a $0.6\,\mathscr{M}_\odot$ star calculated by Iben (1982). All stars lie to the left of the blue edge of the instability strip. As it appears in the figure, it is possible that the candidates are low mass stars evolving near the AGB evolutionary phases. At these phases, however, the stars loose mass through stellar wind and may present radial pulsations (Iben and Renzini, 1983). It has been shown that there exists a continuous infrared sequence connecting the evolutionary stages of AGB and PN (Kwok, 1987). Variability among the candidates has not been surveyed properly but infrared excesses would be expected. We have searched the IRAS point source catalogue but none of the candidates was detected as an infrared source.

In conclusion, from our *uvby* photometry analysis we consider the candidates as high gravity, near solar [Fe/H] abundance stars in or near the galactic plane. They could be low mass stars of the old disk population evolving near the AGB phases. Therefore we do not think they are tracers of recent star formation away from the galactic disk. If some material has been already ejected from the star by stellar wind, it could probably be detected from Hα profile observations. The photometric detection of strong O I 7774A feature is surprising if the stars are not really very luminous, but of course, if the whole line spectrum can resemble that of a yellow supergiant, probably the O I 7774A line also can, unless the line photometry is being contaminated by neighbouring lines or the line is abnormally strong due to the presence of extended atmospheric structure of an AGB star in the process of becoming a planetary nebula. It is obvious that a high dispersion analysis of both Hα and O I 7774A for the candidate stars should be carried out in future work.

We consider the star BD 45° 1872 ($V = 10.2$ mag.) as being the only one among the observed candidates to be a halo object, very similar in gravity and [Fe/H] content to the UU Her type stars HR 4912. We very strongly recommend BD 45° 1872 to be considered in future observational programs.

Acknowledgements. The authors are very pleased to acknowledge the financial support of Consejo Nacional de Ciencia y Tecnología (Mexico), the Indian Ministry of Science and Technology, the IAU Commission 38 and the Third World Academy of Sciences, throughout the different stages of this investigation. We are indebted to Dr. M. Gerbaldi for her comments and suggestions and to Maligai Ruíz, Teresa Gómez, Guadalupe Salazar and Cristobal Jiménez for their technical assistance.

References

Abt, H.A.: 1957, *Astrophys. J.* **126**, 138
Abt, H.A.: 1960, *Astrophys. J.* **131**, 99
Antonello, E.: 1985, in IAU Symp. 111: Calibration of Fundamental Stellar Quantities. Eds. V.S. Hayes, L.E. Pasinetti and A.G. Davis Philip., Reidel, Dordrecht, p. 491
Arellano Ferro, A.: 1981, *Publ. Astron. Soc. Pacific* **93**, 351
Arellano Ferro, A.: 1984, *Publ. Astron. Soc. Pacific* **96**, 641
Arellano Ferro, A.: 1985, *Monthly Notices Roy. Astron. Soc.* **216**, 571
Bartaya, R.A.: 1979, *Bull. Avastumani Astr. Obs.* **51**, 1
Baker, P.W.: 1974, *Publ. Astron. Soc. Pacific* **86**, 33
Bond, H.E.: Carney, B.W., Grauer, A.D. 1984, *Publ. Astron. Soc. Pacific* **96**, 176
Burki, G., Mayor, M., Rufener, R.: 1980, *Astron. Astrophys. Suppl.* **42**, 382
Burstein, D., Heiles, C.: 1982, *Astron. J.* **87**, 1165
Crawford, D.L., Barnes, J.V.: 1970, *Astron. J.* **75**, 978
Crawford, D.L.: 1975, *Astron. J.* **80**, 955
Curdworth, K.M.: 1971, *Astron. J.* **76**, 475
Dawson, D.W.: 1979, *Astrophys. J. Suppl.* **41**, 97
Feinstein, A.: 1967, *Astrophys. J.* **149**, 107
Fernie, J.D., Hube, J.O.: 1971, *Astrophys. J.* **168**, 437
Fernie, J.D.: 1981, *Astrophys. J.* **243**, 576
Fernie, J.D.: 1986a, *Astrophys. J.* **301**, 302
Fernie, J.D.: 1986b, *Astrophys. J.* **306**, 642
Fernie, J.D., Garrison, R.F.: 1984, *Astrophys. J.* **285**, 698
Giridhar, S., Arellano Ferro, A., Parrao, L.: 1987, in IAU Symp. 132: The Impact of Very High S/N Spectroscopy on Stellar Physics, eds. G. Cayrel de Strobel and M. Spite, Reidel, Dordrecht, p. 407
Hagen, G.L.: 1974, Atlas of Open Clusters, Publ. D.D.O., **4**, 1
Hrivnak, B.J., Kwok, S., Volk, K.M.: 1988, *Astrophys. J.* **331**, 832
Humpreys, R.M.: 1978, *Astrophys. J. Suppl.* **33**, 384
Iben, I. Jr.: 1982, *Astrophys. J.* **260**, 821
Iben, I. Jr., Renzini, A.: 1983, *Ann. Rev. Astron. Astrophys.* **21**, 271
Keenan, P., Hynek, J.A.: 1950, *Astrophys. J.* **111**, 1
Kurucz, R.: 1979, *Astrophys. J. Suppl.* **40**, 1
Kwok, S.: 1987, in IAU Symp. 131: Planetary Nebulae, Ed. S. Torres-Peimbert, Kluwer, Dordrecht, p. 401
Levato, H., Malaroda, S.: 1979, *Publ. Astron. Soc. Pacific* **91**, 636
Luck, R.E., Lambert, D.L., Bond, H.E.: 1983, *Publ. Astron. Soc. Pacific* **95**, 413
Luck, R.E., Bond, H.E.: 1984, *Astrophys. J.* **279**, 729
Mendoza, E.E.: 1971, *Bull. Obs. Tonantzintla Tacubaya*, **6**, 137
Mendoza, E.E.: 1976, *Rev. Mex. Astron. Astrof.*, **2**, 33
Mendoza, E.E., Johnson, H.L.: 1979, *Publ. Astron. Soc. Pacific* **91**, 465
Morgan, W.W., Abt, H.A., Tapscot, J.H.: 1978, Revised MK Spectral Atlas for Stars Earlier than the Sun, Yerkes Obs., KPNO
Nicolet, B.: 1981, *Astron. Astrophys.* **104**, 192
Osmer, P.S.: 1972, *Astrophys. J. Suppl.* **24**, 247
Parthasarathy, M., Pottasch, S.R.: 1986, *Astron. Astrophys.* **154**, L16
Pesch, P.: 1959, *Astrophys. J.* **130**, 764
Pesch, P.: 1960a, *Astrophys. J.* **132**, 689
Pesch, P.: 1960b, *Astrophys. J.* **132**, 696
Philip, A.G.D., Relyea, L.J.: 1979, *Astron. J.* **84**, 1743
Preston, G.W., Krzeminski, W., Smak, J., Williams, J.A.: 1963, *Astrophys. J.* **137**, 401
Rao, M.K., Mallik, S.G.V.: 1978, *Monthly Notices Roy. Astron. Soc.* **183**, 211
Sasselov, D.D.: 1983a, Inf. Bull. Var. Stars, No. 2314
Sasselov, D.D.: 1983b, Inf. Bull. Var. Stars, No. 2387
Sasselov, D.D.: 1984, *Astrophys. Space Sci.* **102**, 161
Schild, R.: 1967, *Astrophys. J.* **148**, 449
Schmidt, E.G.: 1984, *Astrophys. J. Suppl.* **55**, 455
Searle, L., Sargent, W.L.W., Jugaku, J.: 1963, *Astrophys. J.* **137**, 268
Sorvari, J.M.: 1974, *Astron. J.* **29**, 1416
Stothers, R.: 1969, *Astrophys. J.* **155**, 935
Wildey, R.L.: 1964, *Astrophys. J. Suppl.* **8**, 439
Worrell, J.K.: 1986, *Monthly Notices Roy. Astron. Soc.* **223**, 787