1997PASP..109.1077G

Publications of the Astronomical Society of the Pacific
109: 1077–1084, 1997 October

Elemental Abundances and Atmospheric Parameters of Seven F–G Supergiants[1]

SUNETRA GIRIDHAR
Indian Institute of Astrophysics, Bangalore 500034, India
Electronic mail: giridhar@iiap.ernet.in

A. ARELLANO FERRO[2]
Departamento de Astronomía, IFUG, Universidad de Guanajuato, Apdo. Postal 144, Guanajuato 36000, México
Electronic mail: armando@astro.ugto.mx

L. PARRAO
Instituto de Astronomía, UNAM, Apdo. Postal 70-264, México D.F. 04510, Mexico
Electronic mail: laura@astroscu.unam.mx

Received 1996 November 25; accepted 1997 June 18

ABSTRACT. Spectroscopic abundance determinations for a sample of seven F–G stars have been carried out. The majority of them have large galactic latitudes. One objective in deriving spectroscopic abundances is to differentiate evolved objects seen at high galactic latitudes from the young Population I supergiant stars that happen to have large galactic latitudes but actually belong to the galactic disk. Second, it is important to get good calibrators for photometric metallicity indices. It has been suggested in the past that many high galactic-latitude F–G stars that are classified as supergiants are in reality subgiants or dwarfs. Our spectroscopically derived gravities show that two of the stars studied in this paper, HR 5165 and HD 114520, are not supergiants as classified in the *Bright Star Catalogue* but are subgiants belonging to the solar neighborhood. In our sample, HR 3229 and HR 8470 display solar abundances and the derived gravities support the bright giant luminosity class ascribed to them. HR 4114, HR 4912, and HR 7671 have abundances significantly different from those of young supergiants of galactic disk. The evolutionary status of these objects is discussed.

1. INTRODUCTION

Yellow supergiants in general and particularly those at high galactic latitudes are very interesting objects to study. Semiregular and regular light variations have been found in many of them. For several objects, the presence of circumstellar material has been detected. There has been much interest in the study of high galactic latitude supergiants since many of them have, very conclusively, turned out to be evolved objects, like post-AGB stars, despite their supergiantlike spectra. A search among high galactic latitude objects is more efficient in locating evolved stars since formation of massive stars is less likely to take place at large distances from the galactic plane. There would be the added advantage of less or no interstellar extinction. But in the absence of reliable distances it is often difficult to say if the star is indeed away from the galactic plane. A sample of F–G supergiants in the galactic plane might contain a much smaller fraction of evolved objects but that does not imply that such searches should not be made.

On the other hand one cannot be unduly certain of the post-AGB status of all high galactic latitude objects as there are faint blue objects that are considered to be formed at a large distance from the galactic disk (Conlon 1993) and from which massive young A–F–G supergiants are evolved. Bidelman (1993) published yet another list of A–F supergiants with a large Strömgren c_1 index, characteristic of low-gravity stars, and indicated that some of them may be evolved post-AGB stars. As one sees, there is considerable confusion about the evolutionary status of some field F–G supergiants.

A high galactic latitude may not always imply a large distance above the galactic plane and the actual distance is hard to determine for field objects. Detection of infrared excess to ascertain if the star is an evolved object has been a very important but not a final clue towards their evolutionary status. One may recall that the well-known post-AGB star BD +39°4926 studied by Kodaira et al. (1970) does not have infrared excess.

A large radial velocity is a common characteristic of Population II objects but evolved objects are also found in the thick disk with not very high radial velocities (e.g., RV Tau stars) and hence the velocity criteria cannot be used decisively. A further complication arises due to variations in the radial velocity, reported for many post-AGB stars, that might conceal the real systemic velocity. In fact there is growing evidence towards binarity of many well-known post-AGB stars.

Then it would appear that the most reliable way of ascertaining the evolutionary status is by determining accurate abundances. Though this approach is laborious, as one requires high-resolution spectra and detailed model atmosphere calculations, the unambiguous determination of abundances is enough reward. These abundance determina-

---

[1] Based on observations at the European Southern Observatory, La Silla; VBO Kavalur and McDonald Observatory.

[2] On leave from Instituto de Astronomía, UNAM.

TABLE 1
Basic Data of Program Stars

Star	l	b	$(B-V)$	Sp. Type	V_r (km s^{-1})	Infrared fluxes (Jy) 12 μm	25 μm	60 μm	100 μm
HR 3229	236.°63	+10.°11	1.07	G5 Ib/II	+16	3.94	0.96	0.40L	1.00L
HR 4114	285.22	−00.89	0.31	F2 II	+10	3.15	0.72	12.35L	130.80L
HR 4912	304.30	+36.40	0.68	F3 Ia	−22	1.24	1.59	0.55	1.00L
HR 5165	321.03	+44.82	0.80	G0 Ib-IIa	+1	1.69	0.35L	0.40L	1.00L
HR 7671	30.60	−21.53	0.52	F1 III	−12	0.65	0.32	0.40	1.08
HR 8470	26.98	−54.70	0.49	F2 II	−28	0.78	0.30	0.40	1.00
HD 114520	340.90	+82.63	0.42	F2 II	−6				

tions not only help in ascertaining the evolutionary status of these objects, but can also be used for calibrating photometric metallicity indices in various photometric systems.

The detailed spectroscopic studies of these objects have yet another important aspect. In addition to metallicity, accurate temperatures and gravities are also derived. A good fraction of F−G stars of high galactic latitude supergiants are in reality subgiants or dwarf stars (misclassified as supergiants in the *Bright Star Catalogue*) as reported by Mendoza and Arellano Ferro (1993). That makes the detailed spectroscopic study of field F−G supergiants (high galactic latitude or not) a very important task. The spectroscopically derived gravities can serve in identifying the various luminosity classes. It is important to recall that the galactic IMF (initial-mass function) uses star counts in different mass groups. Misclassification of a host of low-luminosity stars for the massive supergiants might adversely affect the accuracy of IMF and subsequent galactic evolutionary calculations.

In the present work we have derived abundances for seven supergiants; HR 3229 (HD 68752, G5 Ib/II), HR 4114 (HD 90853, F2 II), HR 4912 (HD 112374, F3 Ia), HR 5165 (HD 119605, G0 Ib-IIa), HR 7671 (HD 190390, F1 III), HR 8470 (HD 210848, F7 II), and HD 114520 (F2 II). For HR 4114, HR 5165, HR 8470, and HD 114520, spectroscopic abundances have not been determined before. The abundances for HR 7671 are derived by Luck et al. (1990). HR 3229 was included in the study of Gratton et al. (1989), McWilliam (1990), and Luck and Wepfer (1995). We also included HR 4912 in our list despite the fact that Luck et al. (1983) have also done chemical analysis for a large number of elements and have shown the star to be metal poor. Our reason for doing so was that an important element Zn was not included in the study of Luck et al. and the abundance of S is based on a single line. It has been pointed out by Bond (1992) and Van Winckel et al. (1992) that the detection of Zn is a very important finding in metal-poor post-AGB stars. With the grain condensation affecting the abundances of many refractory elements, abundances of S and Zn are the best indicators of metallicity in evolved objects. We used all three good lines of Zn available in the visual region.

Additionally, the spectral regions employed by us for HR 3229, HR 4912, and HR 7671 are different from those employed by earlier workers and hence our estimate can be treated as independent determinations though they are not the first ones for these three stars. As will be shown later, we obtain very good agreement with the earlier estimates. We will also show, that HR 4114, HR 4912, and HR 7671 show abundances significantly different from solar values.

2. OBSERVATIONS

The basic data on our program stars is presented in Table 1. Details of our observations are presented in Table 2. The bulk of spectra for HR 3229, HR 4114, HR 7671, and HR 8470 were obtained with the coudè echelle spectrograph on the 1.52-m ESO telescope at the La Silla Observatory on the nights 1991 May 31, June 1, and June 2. This spectrograph is equipped with a RCA 1024×624 pixel CCD (No. 13); the pixel size is 15×15 μm. This spectrograph gives a resolution of about 30,000. Exposure times were between 20 and 60 min to obtain a S/N of 100 or more.

One spectrum of HR 4114 was obtained with a coudè echelle spectrograph on the 1-m telescope of Vainu Bappu Observatory, Kavalur, India. This spectrograph uses a Photometrics CCD of 384×576 pixels. The pixel size is 22×22 μm. The resolution is lower, $\sim$ 15,000. But this spectrum was used only to examine a Hα profile and no lines were measured for the abundance work.

HR 5165, HD 114520, and HR 4912 were observed using a cassegrain echelle spectrograph at the 2.1-m telescope of the McDonald observatory between 1995 June 20 and June 22. The spectra were recorded on a Reticon 1200×400 pixel CCD. This spectrograph gives resolution 50,000. The stars being quite bright, exposures of

TABLE 2
Log of Observational Material

HR	Date	Spectral region (Å)	Exposure time (min)
Hr 3229	1991 June 1	4920–5240	35
	1991 June 2	4580–4880	22
HR 4114	1991 May 31	5260–5600	20
	1991 June 1	4920–5240	35
	1997 Jan. 18	5920–7000	15
HR 4912	1995 June 20	5700–7200	10
	1995 Jan. 18	4430–4980	20
HR 5165	1995 June 21	4430–4980	5,5
HR 7671	1991 May 31	5260–5600	60
HR 8470	1991 May 31	5260–5600	55
HD 114520	1995 June 21	4430–4980	10

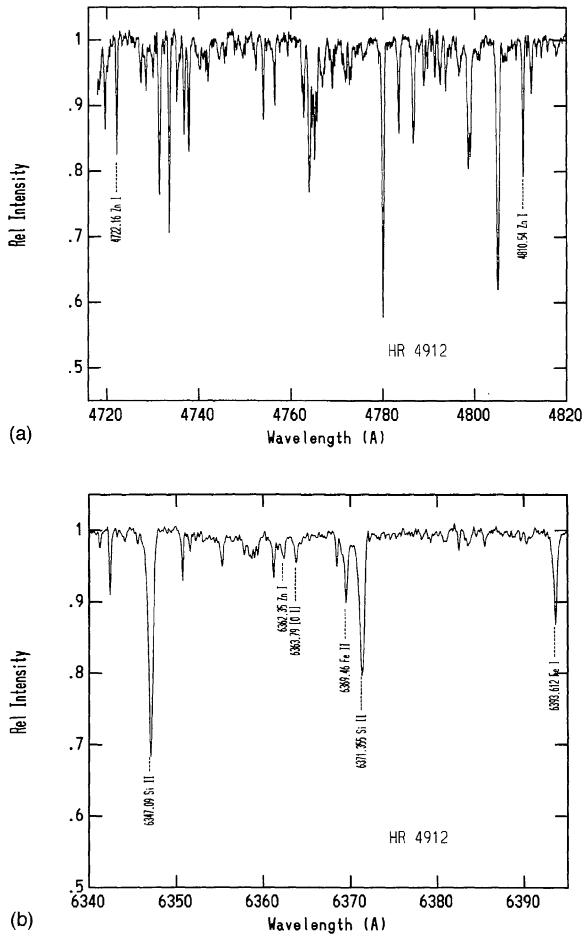

FIG. 1—(a) Spectrum of HR 4912 showing Zn I lines at 4722 and 4810 Å. (b) Spectrum of HR 4912 showing Zn I line at 6362 Å.

10–20 min. were generally adequate to give a S/N ratio of 100 or more.

A Th–Ar hollow-cathode lamp was observed immediately following the exposures for wavelength calibration.

2.1 Spectral Reduction

The spectra were bias subtracted, flat fielded, and wavelength calibrated using an echelle spectra reduction package contained in IRAF. These reductions were made using the Sparc 20 workstation at the Department of Astronomy of the University of Guanajuato, Mexico. With the spectral resolution of about 30,000 available to us, the accuracy of the equivalent width measured is 6%–10% for ESO spectra.

HR 5165, HD 114520, and HR 4912 were observed at a resolution of 50,000 and hence we could get a large number of weak unblended features, even in the blue spectral region. HR 4912 was observed in the blue as well as in the red spectral regions. We could measure three Zn I lines at wavelengths 6362.35 Å, 4810.54 Å, and 4722.16 Å. Figures 1(a) and 1(b) show the spectra of HR 4912 with Zn I features marked on them. Fortunately for us, the Zn I line at 6362.35 Å was not affected by telluric lines. We could also measure and use three lines of S I to derive the S abundance. Our O I abundance uses only the forbidden lines at 6300.3 Å and 6363.8 Å, as the lines in the 6156 Å region were not usable.

TABLE 3
Atmospheric Parameters Derived for Program Stars

Star	$T_{\rm eff}$ (K)	log g	Microturbulence Velocity (km s^{-1})
HR 3229	5000	1.75	2.4
HR 4114	7000	1.50	4.5
HR 4912	6000	1.00	4.7
HR 5165	6000	3.25	3.2
HR 7671	6500	1.25	3.2
HR 8470	6300	2.00	2.8
HD 114520	6300	3.25	2.8

3. DETERMINATION OF ATMOSPHERIC PARAMETERS AND ABUNDANCES

We used a grid of model atmospheres computed using the MARCS code of Gustafsson et al. (1975). This grid was kindly lent to us by Dr. R. E. Luck. We have calculated equivalent widths using a computer program originally written by Sneden (1973) and revised by one of us (S.G.). The assumptions are local thermodynamic equilibrium (LTE), plane-parallel atmosphere, and hydrostatic equilibrium. Since our calculations use photospheric metal lines of moderate strengths, these assumptions do not affect the accuracy of derived abundances. Various steps involved in deriving abundances using this approach are explained in detail in Giridhar (1983). We have first determined atmospheric parameters $T_{\rm eff}$, log g and microturbulence velocity using a set of Fe I and Fe II lines. The atmospheric parameters could be estimated with an accuracy of 200 K in $T_{\rm eff}$, 0.25 in log g and 0.5 km s^{-1} in microturbulence velocity. The atmospheric parameters derived for our sample stars are presented in Table 3. This chosen model atmosphere for each star was used to derive elements for the remaining elements.

The sensitivity of the derived abundances to the accuracies of the atmospheric parameters is demonstrated in Table 4 of Giridhar et al. (1994).

Oscillator strengths for Fe I lines were taken from Lambert et al. (1996), and from the NBS compilation by Martin et al. (1988). Fe II gf values are taken from Giridhar and Arellano Ferro (1995). For the remaining elements experimental determinations of gf values compiled by Luck (1994) were used. Our derived atmospheric parameters and abundances for each star are presented in Tables 4–8 and that for each star gives derived abundances with standard errors. One can see that though our atmospheric parameters are derived using Fe I and Fe II lines, the good agreement between Ti I, Ti II lines, and between Cr I and Cr II lines lends further support to our estimated atmospheric parameters.

TABLE 4
Derived Elemental Abundances for High-Gravity Stars

Element	No. Lines	HR 5165 [M/H]	σ	No. Lines	HD 114520 [M/H]	σ
C I	2	−0.10	0.07	2	0.21	0.01
Na I	1	0.16		1	0.14	
Mg I	3	0.11	0.17	2	0.23	0.22
Ca I	6	−0.13	0.17	3	0.28	0.13
Ti I	11	0.07	0.18	10	0.01	0.14
Ti II	4	0.00	0.14	8	0.00	0.16
V I	3	−0.03	0.15			
Cr I	12	0.08	0.17	16	0.03	0.25
Cr II	5	0.03	0.08	5	0.04	0.07
Mn I	2	0.25	0.20	3	0.45	0.21
Fe I	52	0.11	0.11	29	−0.02	0.16
Fe II	7	0.09	0.09	6	0.00	0.14
Ni I	15	−0.13	0.19	10	0.02	0.16
Zn I	2	−0.11	0.06	2	−0.07	0.03
Y II	2	0.27	0.02	2	0.27	0.20

4. RESULTS AND DISCUSSION

We found four stars in our sample displaying solar-system abundances. The remaining three are metal deficient in varying degree. Within the solar-abundance group, two subgroups emerged: stars with high gravities and more luminous stars with lower gravities.

4.1 Stars with High Gravities: HR 5165 and HD 114520

High-resolution spectra of high S/N were available for these two stars and therefore we could measure a large number of weak lines covering most of the Fe group elements. Hence the atmospheric parameters as well as abundances could be derived with better accuracy. As one can see in Table 4 the line-to-line scatter is quite small. There is a good agreement between the Fe I and Fe II, Ti I and Ti II, and between Cr I and Cr II lines that supports our ionization equilibrium. Spectroscopic abundances have not been determined earlier for these two objects. The derived effective temperatures are in good agreement with the color temperatures. The high value of gravity (derived spectroscopically) indicates that the two stars are most likely subgiants of luminosity type approximately IV (see Table 3). For an adopted M_v of 1.0, the distance for HD 114520 is estimated to be 150 pc while that of HR 5165 is 100 pc. Notwithstanding their high galactic latitudes, they appear to be members of the solar neighborhood as indicated by their abundances.

TABLE 5
Derived Elemental Abundances for Low-Gravity Stars

Element	No. Lines	HR 3229 [M/H]	σ	No. Lines	HR 8470 [M/H]	σ
C I	1	−0.44		1	−0.08	
Mg I	1	−0.06		1	+0.37	
Si I	1	−0.18		1	+0.01	
Ca I	4	−0.26	0.07	4	−0.12	0.06
Ca II				1	−0.35	
Sc II	4	−0.16	0.11	2	−0.26	0.04
Ti I	29	−0.25	0.22	1	+0.06	
Ti II	4	−0.10	0.26	1	−0.13	
Cr I	12	−0.19	0.21	6	−0.06	0.11
Cr II	5	−0.16	0.19	5	−0.14	0.32
Mn I	2	+0.05	0.01			
Fe I	99	−0.16	0.16	45	+0.06	0.11
Fe II	7	−0.21	0.13	5	+0.06	0.09
Co I	3	−0.22	0.33	1	+0.09	
Ni I	35	−0.24	0.24	5	0.00	0.29
Y II	5	−0.30	0.15	1	−0.38	
Zr II	1	−0.07				
Ce II	2	+0.17	0.01	2	−0.02	
Pr II	1	−0.10				
Nd II	5	−0.22	0.11			

But then it would appear that stars classified as supergiants in the *Bright Star Catalogue* (Hoffleit and Jaschek 1982) and the supplement (Hoffleit et al. 1983) are not necessarily high-luminosity objects. Mendoza and Arellano Ferro (1993) had already predicted this from medium-resolution spectroscopy and narrow-band photometry measuring the strength of the O I triplet at 7774 Å. In fact, very few stars from their sample of 73 high-galactic-latitude stars turned out to be metal-poor evolved objects. Our spectroscopically derived abundances give strong confirmation to the above-mentioned finding of Mendoza and Arellano Ferro (1993).

However, if the number of such misclassified objects is significantly large then it might affect the shape of the initial mass function in the solar neighborhood. The IMF may contain a larger number of massive stars than exist. This in turn would affect the accuracy of galactic evolutionary calculations.

4.2 More Luminous Objects: HR 3229 and HD 8470

Table 5 presents abundances for HR 3229 and HR 8470 that essentially have solar abundances. HR 3229 was investigated by Gratton et al. (1989) who estimated $T_{\rm eff} = 5100$ K, $\log g = 1.56$, $V_t = 2.3$ and [Fe/H] = +0.21. McWilliam (1990) estimated $T_{\rm eff} = 4890$ K, $\log g = 1.98$, $V_t = 3.3$, and [Fe/H] = −0.27. Recently Luck and Wepfer (1995) estimated $T_{\rm eff} = 4725$ K, $\log g = 1.6$, $V_t = 2.3$, and [Fe/H] = +0.03. Our estimates given in Table 3 agree very well within the errors of estimate with all of them. Most elements in HR 3229 show a small deficiency with respect to the solar value but it is not very significant. On the other hand, derived [C/Fe] is quite typical to those found in giant stars (Lambert and Ries 1981). The star HR 3229 generally appears to be a normal supergiant with a moderate radial velocity of 16 km $\rm s^{-1}$ as given in the radial-velocity catalog of Wilson (1953).

HR 8470 also displays near-solar abundances for most elements indicating that this star is also a normal supergiant. No earlier spectroscopic estimate of metallicity has been made for this star.

The derived gravities for these two stars indicate that M_v could be in the −2 to +1 range. Then it would imply that the distances of these stars must be 200–300 pc. However, a radial velocity −28 km $\rm s^{-1}$ for HR 8470 is high for a normal Population I star and a bit surprising. It will be of interest to see if radial-velocity variations exist. As such very little work has been done for this star.

TABLE 6
Derived Elemental Abundances for Metal-Poor Stars

Element	No. Lines	HR 4114 [M/H]	σ	No. Lines	HR 4912 [M/H]	σ	No. Lines	HR 7671 [M/H]	σ
C I	1	−0.28	0.04	4	−1.27	0.04			
O I				2	−0.28	0.01			
Na I				3	−0.46	0.07			
Mg I	1	−0.36		2	−0.40	0.14			
Si I				4	−0.46	0.11			
Si II				1	−0.28				
S I	1	−0.11		3	−0.71	0.10			
Ca I	4	−0.23	0.14	10	−1.03	0.28	3	−1.06	0.05
Ca II	1	−0.28							
Sc II	4	−0.45	0.15				1	−0.92	
Ti I	4	−0.26	0.12	4	−1.02	0.38	1	−0.80	
Ti II	6	−0.30	0.19	8	−0.95	0.10			
Cr I	6	−0.36	0.14	8	−1.40	0.14	3	−1.20	0.04
Cr II	5	−0.32	0.17	5	−1.35	0.19	5	−1.28	0.14
Fe I	49	−0.37	0.15	40	−1.08	0.20	21	−1.14	0.17
Fe II	6	−0.40	0.13	6	−1.11	0.13	5	−1.15	0.06
Ni I	5	−0.30	0.28	13	−0.97	0.10	1	−1.02	
Zn I				3	−0.86	0.06			
Y II	1	−0.40	0.14	2	−1.45	0.04			
Ce II				3	−1.30	0.04			

4.3 Metal-Poor Stars: HR 4114, HR 4912, and HR 7671

HR 4114 shows moderate metal deficiency by a factor of 2 or so. The Fe peak elements Sc, Ti, and Cr show deficiency of similar magnitude. The light elements C and Mg also show deficiency of similar magnitude. Sulphur is less deficient, almost solar. Significantly, this star has the largest infrared flux in our sample. As one can see in Table 7 the relative abundances of C, α elements Mg, S, and Ca and those of heavy *s*-process elements like Y relative to Fe found for HR 4114 bear good resemblance to those found in 89 Her, HD 161796, and HD 70379. The [Fe/H] for these objects is in the −0.3 to −0.4 range. Abundances for 89 Her and HD 161796 are given in Luck et al. (1990) and those for HD 70379 are taken from Reddy (1996). All the three objects mentioned above have significant infrared fluxes and their [C/Fe], [N/Fe], [O/Fe] cannot be accounted by CN processing that occurs at RGB evolution. These abundance ratios for a large sample of red giant stars are presented in Lambert and Ries (1981) who found that the average value of [C/Fe], [N/Fe], [O/Fe] for red giants are −0.2, +0.35, and +0.10, respectively. The observed [C/Fe], [N/Fe], [O/Fe] for the stars of Table 7 obviously indicate a more advanced evolutionary stage, most likely post-AGB state. However, 89 Her and HD 161796 do not show the *s*-process enrichment that should follow the third dredge up but HD 70379 shows mild *s*-process enrichment.

Unfortunately, our spectral region does not cover lines of elements like Al and Zn, and even our estimate of S abundance is based on a single line. It would be very interesting to determine abundance ratios S/Fe, Zn/Fe, and Al/Fe for this object as well as C, N, O abundances since HR 4114 is likely to be an evolved object that might have gone through some mass loss as indicated by the infrared flux. However, the spectrum in the Hα region (Fig. 2) does not show any emission although asymmetry is evident. It appears that Hα has a wide shallow component and a deep narrow component (both in absorption). It is a variable star and radial-velocity variations are reported, but no periodicity is reported so far. Arellano Ferro and Madore (1986) had examined ultraviolet spectra in search of a blue companion but no detection was accomplished. However, one cannot rule out the possibility of an evolved cool companion that might be responsible for the infrared flux.

We had measured the strength of the O I triplet using high-resolution spectra (Arellano Ferro et al. 1991) and derived $M_v = -4.4$. The derived temperature and gravity also points to M_v in the −4 to −5 range. For an assumed M_v of −4.4 the distance turned out to be ~ 400 pc. If one

TABLE 7
Important [X/Fe] Ratios for HR 4114 and other High-Latitude Objects of Similar Metallicity

Star	[Fe/H]	[C/Fe]	[N/Fe]	[O/Fe]	[Mg/Fe]	[Ca/Fe]	[S/Fe]	[Y/Fe]	References
HR 4114	−0.31	+0.10			−0.02	+0.12	+0.27	+0.02	This work
89 Her	−0.41	+0.15	+0.66	+0.14	+0.39	−0.03	+0.15	+0.01	1
HD 161796	−0.31	+0.20	+1.17	+0.38	+0.71	−0.05	+0.72	−0.23	1
HD 70379	−0.31	+0.42	+0.38	+0.34	+0.01	−0.17	+0.34	+0.40	2

[1] Luck et al. (1990).
[2] Reddy (1996).

TABLE 8

Important [X/Fe] Ratios for HR 4912 and a Few Well-Known Post-AGB and Halo Giants

Star	[Fe/H]	[C/Fe]	[N/Fe]	[O/Fe]	[S/Fe]	[Ca/Fe]	[Zn/Fe]	[*s*/Fe]	References
HR 4912	−1.10	−0.17	+0.50	+0.84	+0.30	+0.02	+0.24	−0.30	1,2
SAO 239853	−0.90	+0.49	+0.60	+0.72	+0.49	+0.40	+0.20	−0.20	3
IRAS 180955+2704	−0.82	+0.32	+0.76	+0.59	+0.50	+0.08	+0.07	−0.60	4
HD 47603	−1.70	+1.70	+1.70	+1.60	+1.30	+0.70	+0.40	−0.20	5,6,7
HD 44179	−3.30	+3.30	+3.30	+2.90	+1.70				3

[1] Luck et al. (1983).

[2] This work.

[3] Van Winckel (1995).

[4] Reddy (1996).

[5] Luck and Bond (1984).

[6] Bond and Luck (1987).

[7] McCarthy et al. (1996).

employs the parallax given in the *Bright Star Catalogue* (Hoffleit and Jascheck 1982), then the distance would be only 100 pc. We are inclined to regard the parallax values with caution. Alternatively, the large distance modulus might have been caused by circumstellar extinction. This star deserves a very comprehensive multiwavelength study.

HR 4912 is a semiregular variable of a long period but small amplitude of light variations. Arellano Ferro (1981) found a period of 44 days. The Hα profile has strong emission components on both wings. The infrared flux is detected (Table 1) but it is not particularly strong for this object. Submillimeter fluxes are reported by van der Veen et al. (1994) but they are near the detection limit. An absolute magnitude of −3.7 can be inferred from the strength of the O I triplet measured on high-resolution spectra (Arellano Ferro et al. 1991). From the spectroscopic determination of gravity, Luck et al. (1983) estimated $M_v \sim -4$. Our present spectroscopic study also indicates a similar value. In the present work we found almost the same value of atmospheric parameters. Considering the fact that it is a variable star, finding the same values of $T_{\rm eff}$ and $\log g$ is strange, but then the amplitude of the variations is not very large and it is possible that the spectra of ours and those of Luck et al. (1983) were obtained at similar phases.

Luck et al. (1983) did a chemical-composition study and suggested that this star is a semiregular variable, situated at the top of the AGB evolving towards the white-dwarf regime. After the detection of infrared fluxes in many high-galactic-latitude stars, many searches have been made to identify post-AGB objects among field stars. Several post-AGB stars have been identified, for example, HD 52961, HD 46703, and BD +39°4926. Abundance data have been compiled to define the abundance pattern found in post-AGB stars. It is found that for many well-known post-AGB objects, their abundance pattern correlates with the elemental depletions observed in the interstellar medium (Venn and Lambert 1990; Bond 1991; Van Winckel et al. 1992). The elements with higher condensation temperature ($T_c > 1200$ K) are strongly depleted in their atmospheres whereas the elements like Zn and S having smaller condensation temperatures ($T_c < 600$ K) are largely unaffected. In fact, for stars whose abundances are affected by the dust-condensation process, these two elements may be better indicators of metallicity. These elements are neither affected by the CNO cycle nor are easily condensable ones.

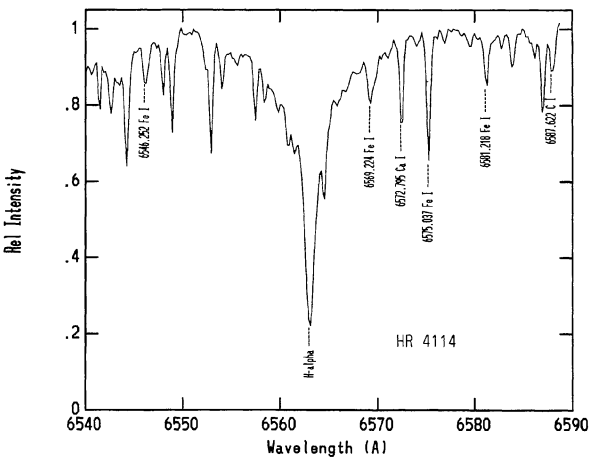

FIG. 2—Spectrum of HR 4114 in Hα region.

Our present study of HR 4912 covers these two elements. In Table 8 we have presented, the [X/Fe] for several elements for HR 4912 and a few post-AGB stars. HD 44179 is a very metal-poor post-AGB star. It is obvious from the table that the abundance pattern of HR 4912 is quite similar to those of oxygen-rich post-AGB stars SAO 239853 and IRAS 18095+2704. Much larger values of [S/Fe] and [Zn/Fe] are found in post-AGB stars with C/O > 1. Some of these carbon-rich post-AGB stars show *s*-process enrichment.

HR 7671 is metal poor by a factor of 10–15. This deficiency is shared by all Fe group elements Ca, Sc, Ti, Cr, Fe, and Ni. Our atmospheric parameters are in very good agreement with $T_{\rm eff} = 6600$ K, $\log g = 1.0$ and $V_t = 2.8$ derived by Luck et al. (1990). The investigation of Luck et al. is more extensive than ours, covering more elements. They reported this star to be slightly deficient in C and O, *s*-process elements to be enhanced and Li abundance of $\log \epsilon({\rm Li}) = 2.3$ that is unusually high. This star does not possess a very large infrared flux.

5. PHOTOMETRIC IRON ABUNDANCES

It is shown by Arellano Ferro and Mantegazza (1996) that the photometric estimations of the iron content of a yellow supergiant star can be made with reasonably good accuracy from the Strömgren m_1 and β indices. Since the present work derives spectroscopic [Fe/H] for a number of stars, it was considered important to see how well the two

TABLE 9

$uvby\beta$ Data of Program Stars

Star	V	$b-y$	m_1	c_1	β	References
HR 3229		0.657	0.416	0.329		7
		0.660	0.399	0.392		7
	5.070	0.683	0.438	0.390	2.584	8
HR 4114	3.82	0.179	0.142	1.173	2.739	1
	3.824	0.191	0.163	1.331	2.744	5
		0.192	0.158	1.344		7
		0.183	0.179	1.326		7
	3.826	0.187	0.165	1.325	2.744	10
	3.80	0.185	0.159	1.370	2.730	9
HR 4912	6.782	0.468	0.143	1.023	2.590	9
HR 5165	5.604	0.538	0.238	0.566	2.591	8
HR 7671	6.46	0.424	0.170	1.033	2.611	1
	6.34	0.435	0.060	1.105		2
	6.351	0.389	0.016	1.201	2.613	3,4
	6.371	0.394	0.025	1.174	2.603	5
		0.394	0.068	1.113	2.630	6
	6.404	0.403	0.040	1.128	2.628	10
HR 8470	5.58	0.321	0.195	0.789	2.674	1
	5.592	0.308	0.195	0.738	2.662	3,4
		0.317	0.182	0.743	2.670	11
HD 114520		0.272	0.154	0.576	2.686	11

[1] Stokes (1972).
[2] Danzinger and Faber (1972).
[3] Gronbech and Olsen (1976).
[4] Gronbech and Olsen (1977).
[5] Olsen (1983).
[6] Fernie (1986).
[7] Manfroid and Sterken (1987).
[8] Mean values in Arellano Ferro et al. (1990).
[9] Gray and Olsen (1991).
[10] Eggen (1992).
[11] Mendoza and Arellano Ferro (1993).

estimates agree, and whether these stars could serve as calibrators for future empirical calibrations. Table 9 contains the Strömgren indices of the seven stars under study and their sources are listed for completness. It is clear from the V and $b-y$ indices that mid- to long-term intrinsic variablity can be found in these supergiants. Indeed HR 4114 is listed as a probable variable in the *Bright Star Catalogue* (Hoffleit and Jaschek, 1982) while the variability of HR 4912 and HR 7671 has been discussed by Arellano Ferro (1981) and Fernie (1986), respectively. We have averaged all the available indices and used those mean values to calculate the $\delta[m_1]$ parameter defined by Arellano Ferro and Mantegazza (1996).

Figure 3 shows the position of the seven stars in our sample on the [Fe/H]-$\delta[m_1]$ empirical calibration derived by Arellano Ferro and Mantegazza (1996), that has an uncertainty of ±0.33 dex. The solid curve is a quadratic fit to photometric [Fe/H] as a function of $\delta[m_1]$ given in Arellano Ferro and Mantegazza (1996). The meaning of various symbols are explained in the figure caption. It can be seen that within the errors of determinations (0.33 for photometric estimates and about 0.2 for the spectroscopic ones), the agreement between the two estimates of [Fe/H] is generally good. HR 4114 and HR 5165 are located a little far from the calibration. The discrepancy can be understood for HR 4114 since it is a variable object and the mean value of its photometric indices may not necessarily be the equilibrium value. Second, the calibration made using a young disk object may not be a very appropriate one for HR 4114 if it is an evolved object. For HR 5165 no obvious explanation is at hand. It is clear, however, that given the present uncertainties of the photometric calibration, from the m_1 and β indices alone, one may not be able to estimate the low iron content of some stars, such as HR 4114. Further investigations in this field are needed.

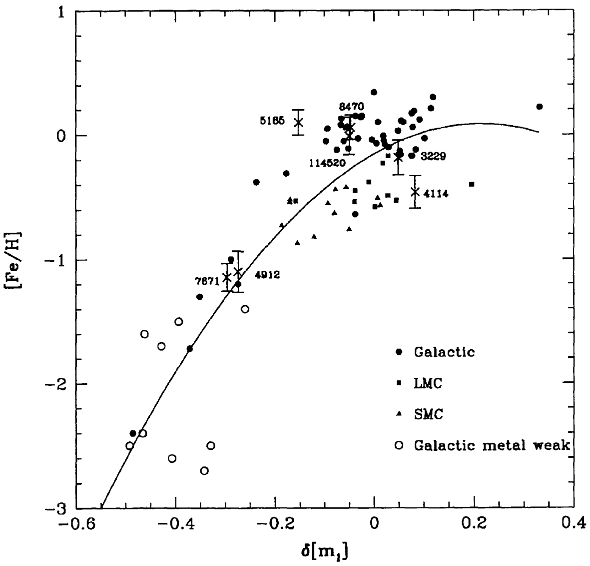

FIG. 3—Empirical photometric calibration [Fe/H]-$\delta[m_1]$ taken from Arellano Ferro and Mantegazza (1996). The crosses and error bars represent the spectroscopic iron abundances and standard errors reported in Tables 4–8. The numbers are HR identifications, except for HD 114520. Other symbols represent supergiant stars as coded in the legend. Solid curve is a quadratic fit (see Arellano Ferro and Mantegazza 1996 for details).

6. CONCLUSIONS

We find that two stars of our sample, HR 5165 and HD 114520, are not yellow supergiants of high galactic latitude as considered earlier, but are subluminous giants belonging to the galactic disk. HR 4114 has abundances similar to those of the post-AGB stars 89 Her, HD 161796, and HD 70379. This star has the largest infrared flux in our sample although Hα only very mildly suggests a shell structure. HR 4114 is a potential post-AGB candidate, but a more detailed investigation is required to confirm it.

The abundance pattern of the semiregular variable HR 4912 is very similar to that found in oxygen-rich post-AGB stars.

HR 3229 and HR 8470 are young bright giant members of the galactic disk.

The photometric predictions of [Fe/H] match well with the present spectroscopic determinations which shows that these stars can be used as calibrators for future empirical calibrations of photometric abundances.

S.G. wishes to thank the Third World Academy of Sciences for a travel grant under a South-South fellowship that primarily supported her visit to the University of Guanajuato, Mexico. S.G. also wishes to thank the Department of Astronomy of the University of Guanajuato for covering living expenses incurred at Guanajuato. We are grateful to Dr. G. González for getting the spectra of HR 5165, HD 114520, and HR 4912 at the McDonald Observatory and to Ms. T. Sivarani for getting a spectrum of HR 4114 from V.B.O. Kavalur at our request. S.G. is indebted to Professor D. L. Lambert for hospitality at the Deptartment of Astronomy, University of Texas at Austin. We are also grateful to Ms. Sandra Rajiva for her help in the manuscript preparation. This work was partially supported by CONACyT (México) through Grant Nos. E9203-1219, F113E9201, and F689E9411. This work has made use of the SIMBAD database operated at CDS, Strasbourg, France.

REFERENCES

Arellano Ferro, A. 1981, PASP, 93, 351

Arellano Ferro, A., and Madore, B. F. 1986, ApJ, 302, 767

Arellano Ferro, A., and Mantegazza, L. 1996, A&A, 315, 542

Arellano Ferro, A., Giridhar, S., and Goswami, A. 1991, MNRAS, 250, 1

Arellano Ferro, A., Parrao, L., Schuster, W. J., González-Bedolla, S., Peniche, R., and Peña, J. H. 1990, A&A, 83, 225

Bidelman, W. P. 1993, in Luminous High-Latitude Stars, ASP Conf. Ser. 45, 49, ed. D. D. Sasselov

Bond, H. E., and Luck, R. E. 1987, ApJ, 312, 203

Bond, H. E. 1992, Nature (London), 356, 474

Conlon E. S., 1993, in Luminous High-Latitude Stars, ASP Conf. Ser. 45, 33, ed. D. D. Sasselov

Danzinger, I. J., and Faber, S. M. 1972, A&A, 18, 428

Eggen, O. J. 1992, AJ, 103, 1381

Fernie, J. D. 1986, ApJ, 301, 302

Giridhar, S., and Arellano Ferro, A. 1995, RMxA&A, 31, 23

Giridhar, S., Rao, N. K., and Lambert, D. L. 1994, ApJ, 437, 476

Giridhar, S. 1983, JA&A, 4, 75

Gratton, R. G., Focardi, P., and Bandiera, R., 1989, MNRAS, 237, 1085

Gray, R. O., and Olsen, E. H. 1991, A&AS, 87, 541

Gronbech, B., and Olsen, E. H. 1976, A&AS, 25, 213

Gronbech, B., and Olsen, E. H. 1977, A&AS, 27, 443

Gustafsson, B., Bell, R. A., Eriksson, K., and Nordlund, A. 1975, A&A, 42, 407

Hoffleit, D. and Jascheck, C. 1982, Bright Star Catalogue (New Haven, Yale University Observatory)

Hoffleit, D., Saladyga, M., and Wlasuk, P. 1983, A Supplement to the Bright Star Catalogue (New Haven, Yale University Observatory)

Kodaira, K., Greenstein, J. L., and Oke, J. B. 1970, ApJ, 159, 485

Lambert, D. L., and Ries, L. M. 1981, ApJ, 248, 228

Lambert, D. L., Heath, J., Lemke, M., and Drake, J. S. 1996, ApJ, 103, 183

Luck, R. E. 1994, personal communication

Luck, R. E., and Bond, H. E. 1984, ApJ, 279, 729

Luck, R. E., and Wepfer, G. G. 1995, AJ, 110, 2425

Luck, R. E., Bond, H. E., and Lambert, D. L. 1990, ApJ, 357, 188

Luck, R. E., Lambert, D. L., and Bond, H. E. 1983, PASP, 95, 413

Manfroid, J., and Sterken, C. 1987, A&AS, 71, 539

Martin, G. A., Führ, J. R., and Wiese, W. L. 1988, J. Phys. Chem. Ref. Data, 17, S3, 1

McCarthy, J. K., Uglesich, R. R., and Lambert, D. L. 1996, unpublished

McWilliam, A. 1990, ApJ, 74, 1075

Mendoza, E. E., and Arellano Ferro, A. 1993, AJ, 106, 2524

Reddy, B. E. 1996, Ph.D. thesis, Bangalore University, India

Olsen, E. H. 1983, A&AS, 54, 55

Sneden, C. 1973, Ph.D. thesis, University of Texas at Austin

Stokes, N. R. 1972, MNRAS, 159, 165

van der Veen, W. E. C. J., Waters, L. B. F. M., Trams, N. R., and Matthews, H. E. 1994, A&A, 285, 551

Van Winckel, H. 1995, Ph.D. thesis, Katholike Universiteit Leuven, Belgium

Van Winckel, H., Mathis, J. S., and Waelkens, C. 1992, Nature (London), 356, 500

Venn, K. A., and Lambert, D. L. 1990, ApJ, 363, 234

Wilson, R. E. 1953, General Catalogue of Stellar Radial Velocities (Washington D.C., Carnegie Institute), p. 601