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Elemental abundance analyses with DAO spectrograms

XXVI. The superficially normal stars γ Serpentis (F6 V) and 101 Herculis (A7 V)⋆

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Abstract. Elemental abundances analyses of the superfically normal stars γ Ser (F6 V) and 101 Herculis (A7 V) consistent with previous studies of this series using photographic region spectrograms obtained with Reticon and CCD detectors produced derived values that are generally solar except for Al which is very underabundant and the rare earths which do not have the solar pattern. Similar discrepancies from solar values are seen in other superficially normal stars of this series with similar temperatures. Our results for γ Ser are in acceptable agreement with other recent studies based on different techniques and spectral regions.

Key words. stars: abundances – stars: individual: γ Ser – stars: individual: 101 Her

1. Introduction

This series has mainly studied sharp-lined non-magnetic peculiar A stars, especially the HgMn and Am stars and sharp-lined normal B, A, and F main sequence band comparison stars, to define the abundance anomalies of the former for comparison with theoretical predictions. But we are also interested in the spread of abundances among the superficially normal main sequence stars whose abundance anomalies, if any appear, at high dispersion. To see whether the sharp-lined stars were typical, we included some stars which show some rotation. As different atomic species and lines are analyzed as the effective temperature changes over the spectral type range B2 to F7, we are concerned about possible systematic errors. By extending our studies to cooler stars whose analyses often are done relative to the Sun, we can compare our results and obtain a consistency check provided both kinds of studies do not have any substantial systematic errors. Further we need the abundances of such stars for comparison with our in progress studies of the cooler Am stars.

Paper XXIII (Adelman et al. 2000), which investigated 28 And (A7 III) and 99 Her (F7 V), was our most recent paper about superficially normal late A and F type stars. By investigating two somewhat similar stars, γ Ser (F6 V) and 101 Herculis (A7 V), we increase the number of such objects consistently analyzed. In the photographic region placing their continuua can be especially difficult as in the blueward part this depends on isolated windows. This task is greatly aided by high resolution high signal-to-noise spectra. Figure 1 shows an illustrative portion of these spectra. Many of the lines in γ Ser can be seen to be blended in 101 Her.

The abundances of γ Ser (HD 142860, HR 5933), spectra type F6 V (Gray et al. 2001a), have been determined in many studies of invididual elements, e.g., Co by Adelman et al. (2000), and in several comprehensive studies such as those by Chen et al. 2000 who found $T_{\rm eff}$ = 6227 K, $\log g$ = 4.18, and [Fe/H] = −0.22, Gray et al. (2001b) who found $T_{\rm eff}$ = 6350 K, $\log g$ = 4.10, [A/H] = −0.13, and Carretta et al. (2000) who found $T_{\rm eff}$ = 6333 K, $\log g$ = 4.25, [Fe/H] = −0.26, and [A/H] = −0.22. Earlier Fuhrmann (1998) included γ Ser among the some fifty nearby F- and G-stars. He considered it a suspected binary, and gave $T_{\rm eff}$ = 6254 K, $\log g$ = 4.02, [Fe/H] = −0.19, and $v \sin i$ = 10.6 km s^{-1}. This well studied F star permits us to compare our results with those of solar type stars often analyzed relative to the Sun.

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⋆ Table 3 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/394/187

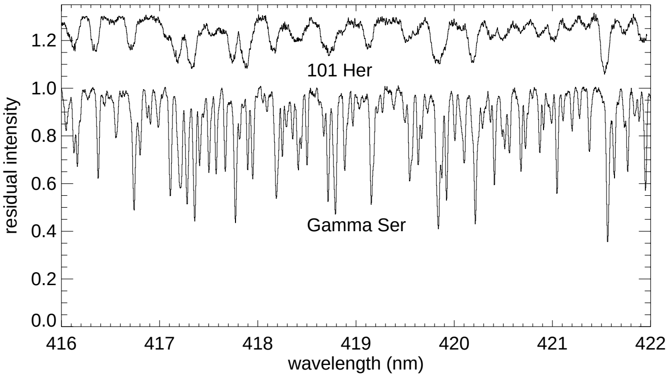

Fig. 1. The normalized spectra of 101 Her and γ Ser covering 416–422 nm. They illustrate the difficulties in locating the continuum and the relative line widths. The spectrum of 101 Her has been shifted upward by 0.3 in residual intensity for clarity.

101 Her (HD 166230, HR 6794), spectral type A7 V and $v \sin i$ = 33 km s^{-1} (Abt & Morrell 1995), is not particularly well studied. Jerzykiewicz (1993) found it was probably photometrically constant while Adelman (2001) found it was one of the least variable stars according to Hipparcos photometry. Earlier classifications indicated it as a giant (see, e.g. Cowley et al. 1969).

2. The spectra

For both stars we obtained 17 Dominion Astrophysical Observatory (DAO) 2.4 Å mm^{-1} Reticon or site 2 CCD spectrograms with a typical signal-to-noise ratio of 200 and a wavelength coverage of 67 or 63 Å, respectively. The central wavelengths between λ3830 and λ4740 had 55 Å offsets. The section centered at λ4575 for 101 Her was defective and not used. A replacement spectrogram centered at λ4588 with a spectral coverage of 147 Å was obtained with the newer site 4 CCD and measured for the missing wavelength range. Further 20 Å mm^{-1} DAO spectrograms containing the Hγ region were acquired as well as a 2.4 Å mm^{-1} spectra centered at λ5070 for γ Ser. We flat fielded the exposures with those of an incandescent lamp in the coudé mirror train as viewed through a filter to eliminate first order light. A central stop removed light from the beam to the same extent as the secondary mirror of the telescope so that the lamp and star exposures were similarly illuminated. We rectified the spectra with the interactive computer graphics program REDUCE (Hill et al. 1982) and applied a 3.5% correction for scattered light in the dispersion direction (Gulliver et al. 1996) for the Reticon and site 2 spectrograms. The scattered light for the site 4 spectrogram was removed during the extraction procedure including that in the direction of the dispersion. These corrections slightly affect our microturbulences and the final abundance values.

We fit Gaussian profiles through the spectral lines of γ Ser. For 101 Her lines with equivalent widths $\leq\approx$100 mÅ required rotational profiles, with equivalent widths $\geq\approx$14 mÅ Gaussian profiles, and with intermediate equivalent widths the profile which fit best. Rotational velocity estimates from clearly single medium strength lines near λ4481 are 9 km s^{-1} for γ Ser and 41 km s^{-1} for 101 Her. Fekel (1997) finds $v \sin i$ = 9.9 km s^{-1} and $v_{\rm macro}$ = 4.0 km s^{-1} for γ Ser. The stellar lines were identified with the general references A Multiplet Table of Astrophysical Interest (Moore 1945) and Wavelengths and Transition Probabilities for Atoms and Atomic Ions, Part 1 (Reader & Corliss 1980) as well as Huldt et al. (1982) for Ti II, Catalan et al. (1964) for Mn I, Iglesias & Velasco (1964) for Mn II, Nave et al. (1994) for Fe I, and Johansson (1978) for Fe II.

For γ Ser, clean lines of C I, Na I, Mg I, Mg II, Al I, Si II, Ca I, Sc II, Ti I, Ti II, V I, V II, Cr I, Cr II, Mn I, Mn II, Fe I, Fe II, Co I, Ni I, Ni II, Zn I, Sr I, Sr II, Y II, Zr II, Ba II, La II, Ce II, Pr II, Nd II, Sm II, Eu II, and Gd II were found. In addition lines of Si I were blended while it was difficult to measure the very strong Ca II K and H lines. There are also molecular lines which were not studied.

In the spectrum of 101 Her, we used lines of O I, Mg I, Mg II, Al I, Si II, Ca I, Sc II, Ti II, V II, Cr I, Cr II, Mn I, Mn II, Fe I, Fe II, Co I, Ni I, Ni II, Zn I, Sr II, Y II, Zr II, Ba II, La II, Nd II, Sm II, Eu II, and Gd II in our elemental abundance analysis. There are also Ca II and lines of a few other species which are probably in blends such as Si I and Ti I.

We derived the radial velocities from comparisons of the stellar and laboratory wavelengths after corrections were applied for the Earth's orbital velocity. For 18 spectrograms, our mean radial velocity was 7.20 ± 0.97 km s^{-1} for γ Ser while Abt & Biggs (1972) list values between 2.6 and 7.8 km s^{-1}. As the standard deviation of the mean for the average value is not much larger than the standard deviation of the means for individual spectra of order 0.60 km s^{-1}, at best this is weak evidence for radial velocity variability. For 101 Her, we found a mean value of −16.1 ± 2.5 km s^{-1} for 16 site 2 spectrograms which compares with values between −12.2 and −19.8 km s^{-1} compiled by Abt & Biggs (1972). Thus 101 Her is a candidate to be studied further for possible binarity. It might be possible to reduce the errors in the radial velocity by cross correlating synthetic with observed spectra.

3. The abundance analyses

Table 1 lists our effective temperature and surface gravity estimates with the last values for each star being those adopted. To get initial estimates from the homogeneous *uvbyβ* data of Hauck & Mermilliod (1980, 1998), we used the computer program of Napiwotzki et al. (1993). The uncertainties are about ±200 K and ±0.2 dex (Lemke 1989). To refine these values for γ Ser we calculated synthetic spectra of the Hγ region from ATLAS9 LTE plane parallel model atmospheres (Kurucz 1993) with Program SYNTHE (Kurucz & Avrett 1981) as well as the predicted fluxes with ATLAS9 for comparison with the observations by Schild (unpublished prior to being included in Breger 1973). As Smalley & Kupka (1997) argued that the turbulent convection theory of Canuto & Mazzitelli (1991, 1992) should be more realistic than Mixing Length theory (Castelli et al. 1997) and as Kupka (private communication) supplied the necessary subroutine for implementing Canuto-Mazzitelli convection in ATLAS9, we have used these models in the determination of the effective temperature and surface gravity.

Table 1. Effective temperature and surface gravity determinations.

Star	$T_{\rm eff}$ (K)	Log g	Method
γ Ser	6302	3.56	Napiwotzki et al. (1993) with *uvbyβ* photometry
	6300	4.25	Spectrophotometry and Hγ profile fitting, solar model, Mixing Length theory
	6300	5.00	Spectrophotometry and Hγ profile fitting, solar model, CM theory
	6300	4.00	Hγ profile fitting, solar model, iron equilibrium
101 Her	8091	3.44	Napiwotzki et al. (1993) with *uvbyβ* photometry
	8061	3.51	Photometric values corrected for offset found by Adelman et al. (2002), Mixing Length theory
	8061	3.69	Photometric values corrected for offset found by Adelman et al. (2002), CM theory

Table 2. Microturbulence determinations from Fe I and Fe II lines.

Star	Species	Number of Lines	ξ_1 (km s^{-1})	log $N/N_{\rm T}$	ξ_2 (km s^{-1})	log $N/N_{\rm T}$	gf values
γ Ser	Fe I	297	1.2	−4.58 ± 0.20	1.4	−4.61 ± 0.20	MF+KX
		250	1.2	−4.60 ± 0.19	1.4	−4.66 ± 0.19	MF
	Fe II	36	1.1	−4.54 ± 0.21	1.1	−4.54 ± 0.21	MF+KX
		adopted	1.2				
101 Her	Fe I	120	4.4	−4.61 ± 0.19	4.4	−4.61 ± 0.19	MF+KX
		107	4.4	−4.61 ± 0.19	4.4	−4.61 ± 0.19	MF
	Fe II	26	4.6	−4.62 ± 0.19	4.6	−4.62 ± 0.19	MF+KX
		adopted	4.5				

gf value references: MF = Fuhr et al. (1988), KX = Kurucz & Bell (1995).
Note: For ξ_1 and ξ_2 the abundances are found so that there is no trend of values for lines of different equivalent widths and have minimum scatter about the mean, respectively.

Smalley & Kupka (1997) found $T_{\rm eff}$ = 6269 K, log g = 4.45. The corresponding values for Mixing Length theory are also given. Our effective temperature is in the middle of the range of recent determinations, but our surface gravity is much larger the average. But we found that Fe I and Fe II lines gave substantially different abundances for this surface gravity. As our photometrically determined value of $T_{\rm eff}$ was close to the mean of many recent determinations, we adopted it. Then to find log g we demanded ionization equilibrium from Fe I and Fe II lines and considered the results for other elements with lesser weight, a process which indicated log g = 4.00. Our final values are close to those found using the infrared flux method by Smalley & Kupka (1997) $T_{\rm eff}$ = 6320 K, log g = 4.00 and also by Alonso et al. (1996) $T_{\rm eff}$ = 6233 K.

For 101 Her, which does not have good spectrophotometric values, we correct the photometric values using the mean offsets found by Adelman et al. (2002). The surface gravity is perhaps slightly smaller than one would expect for a main sequence star. We used SYNTHE (Kurucz & Avrett 1981) to compute the Hγ region and found that the observed and theoretical Hγ profiles agree well. This confirms that the effective temperature is well determined. For the best determined microtubulence following the method described below using 2 km s^{-1} odfs (opacity distribution functions), the difference between the iron abundances derived from Fe I and Fe II lines is 0.09 dex which is acceptable. But as the microturbulence was 4.4 km s^{-1} we calculated a new model with the same parameters and the odfs for 4 km s^{-1} which further improves the agreement.

The metal abundances were determined using program WIDTH9 (Kurucz 1993) with line damping constants from Kurucz & Bell (1995) or semi-classical approximations in their absence. Abundances from Fe I and Fe II lines were derived for a range of possible microturbulences whose adopted values (Table 2) result in the derived abundances being independent of the equivalent widths (ξ_1) or having a minimal scatter about the mean (ξ_2) (Blackwell et al. 1982).

For γ Ser, the derived mean abundances from Fe I and Fe II lines agree when ξ = 1.2 km s^{-1}. This value is close to 1.5 km s^{-1} of Gray et al. (2001b). For 101 Her, we find ξ = 4.5 km s^{-1} with the Fe I and Fe II line results in excellent agreement. We assumed that the helium abundances were solar. Thus to convert log $N/N_{\rm T}$ values to log N/H values −0.04 dex were added.

Table 3, the analyses of the line spectra, contains for each line the multiplet number (Moore 1945), the laboratory wavelength, the logarithm of the gf-value and its source, the equivalent width in mÅ as observed, and the deduced abundance. Source references are given at the end of this table. Letters are used in place of multiplet numbers to indicate sources other than Moore (1945): C = Catalan et al. (1964), D = Dworetsky (1971), I = Iglesias & Velasco (1964), J = Johansson (1978), K = Kurucz & Bell (1995), and N = Nave et al. (1994).

This study's abundances are compared with those of the Sun (Grevesse et al. 1996) in Table 4. Also given are the number of lines and the abundances of 28 And and 99 Her (Paper XXIII) whose values in general suggest that they are least slightly metal-poor compared to the Sun if 0.3 dex

Table 4. Comparison of derived and solar abundances.

Species	99 Her log N/H	γ Ser log N/H	Lines	28 And log N/H	101 Her log N/H	Lines	Sun
C I	−3.51	−3.60 ± 0.23	2	−3.59	...	0	−3.45
O I	...	...	0	...	−3.65	1	−3.13
Na I	−5.95	−5.77 ± 0.07	2	...	...	0	−5.67
Mg I	−5.01	−4.45 ± 0.21	2	−4.60	−4.68 ± 0.14	2	−4.42
Mg II	−4.25	−3.90 ± 0.18	2	−4.52	−4.36 ± 0.16	4	−4.42
Al I	−6.65	−6.01	1	−6.35	−6.13	1	−5.53
Si II	−4.81	−4.83 ± 0.17	2	−4.71	−4.62 ± 0.06	2	−4.45
Ca I	−6.07	−5.82 ± 0.19	12	−5.89	−5.68 ± 0.21	12	−5.64
Sc II	−8.92	−8.86 ± 0.20	6	−8.99	−8.68 ± 0.10	2	−8.83
Ti I	−7.39	−7.13 ± 0.19	41	−7.12	...	0	−6.98
Ti II	−7.22	−7.20 ± 0.21	26	−7.10	−7.06 ± 0.17	25	−6.98
V I	−8.24	−8.10 ± 0.19	17	−8.15	...	21	−8.00
V II	−8.01	−7.67 ± 0.21	9	−8.05	−7.60 ± 0.20	5	−8.00
Cr I	−6.61	−6.26 ± 0.19	85	−6.52	−6.43 ± 0.13	7	−6.33
Cr II	−6.51	−6.15 ± 0.21	18	−6.34	−6.26 ± 0.16	12	−6.33
Mn I	−7.04	−6.73 ± 0.19	27	−6.85	−6.57 ± 0.20	8	−6.61
Mn II	−6.61	...	0	−6.24	−6.38	1	−6.61
Fe I	−4.94	−4.54 ± 0.20	297	−4.71	−4.57 ± 0.19	120	−4.50
Fe II	−4.76	−4.53 ± 0.21	36	−4.64	−4.57 ± 0.19	26	−4.50
Co I	−7.31	−7.27 ± 0.15	12	−7.57	−7.22 ± 0.18	2	−7.08
Ni I	−6.22	−5.85 ± 0.20	43	−6.04	−5.70 ± 0.17	8	−5.75
Ni II	−5.78	−5.64 ± 0.13	2	−5.73	−5.46 ± 0.03	2	−5.75
Zn I	−7.84	−7.60 ± 0.19	2	−7.84	−7.62 ± 0.04	2	−7.40
Sr I	−8.94	−9.03	1	...	...	0	−9.03
Sr II	−9.61	−9.20 ± 0.03	3	−8.95	−9.20	1	−9.03
Y II	−10.02	−9.80 ± 0.20	7	−9.85	−10.22	1	−9.76
Zr II	−9.53	−9.06 ± 0.20	8	−9.51	−9.18 ± 0.22	8	−9.40
Ba II	−10.22	−9.99	1	−9.77	−9.91	1	−9.87
La II	−10.42	−10.57 ± 0.13	9	−10.87	−10.64 ± 0.08	3	−10.83
Ce II	−10.37	−10.17 ± 0.18	24	−10.20	...	0	−10.42
Pr II	−11.51	−11.11 ± 0.12	2	...	...	0	−11.29
Nd II	−10.61	−10.59 ± 0.21	14	−10.62	−9.59	1	−10.50
Sm II	−10.58	−10.39 ± 0.12	13	−10.53	−9.84	1	−10.99
Eu II	−11.87	−11.49 ± 0.05	3	−11.33	−10.31	1	−10.49
Gd II	−10.22	−10.32 ± 0.17	8	−10.91	−9.98	1	−10.88
$T_{\rm eff}$ (K)	6100	6300		7350	8061		

is considered to be a measure of significance. All Al abundances are significantly less than solar . It would be useful to study other lines of Al I to see if they also show this effect. Although 101 Her has greater rare earth abundances than the other three stars, those based on only a few lines need to be regarded with suspection. For the other three stars that the derived Eu values are so underabundant is somewhat surprising.

The 101 Her results for Nd, Sm, and Gd, which are based on only one line each, that suggest some rare earth elements are greatly overabundant need additional confirmation. Of the remaining 19 non-rare earth elements the mean underabundance of 101 Her with respect to the Sun is −0.06 ± 0.26 dex which is solar. The major exception is Al which is underabundant by −0.60 dex. We used the Mg II value rather that than for Mg I as the lines of the later species are in very heavily line blanketed regions. The values for O, Sr, Y, Ba, and Eu which depend on only one line each need confirmation. Cr I and Cr II lines give somewhat similar results while those from Ni I and Ni II lines are not in quite as good agreement. This is a difficult star to analyze due to its moderate rotation and degree of line blanketing.

For 26 species the mean overabundance for γ Ser is −0.03 ± 0.32 dex which is solar using the Mg I value as it is more reliable than that from Mg II. Al is underabundant as are Si and Eu while Sm and Gd are overabundant. The mean and the iron abundances have solar values rather than being marginally underabundant as most other recent analyses. Table 5 compares the results of this study with those of Caretta et al. (2000), which are a renalysis of Edvardsson et al. (1993), Chen et al. (1998), and Nissen et al. (2000). Our microturbulence is the smallest while our Fe abundance which depends in part on strong lines is the largest. The other three values in common with those from Caretta et al. are in good agreement. But with Chen et al. and Nissen et al. in some cases our agreement is not as good. The [Si/Fe] values have a discrepancy of 0.41 dex. Although our Si II lines have good gf values and are not subject to nLTE effects as are many Si II lines in the red, they are

Table 5. Comparison of derived γ Ser abundances.

Quantity	Caretta et al.	Chen or Nissen et al.	This Study
[Fe/H]	−0.18	−0.22	−0.04
[C/Fe]	−0.05	...	−0.09
[Na/Fe]	0.02	−0.06	−0.06
[Mg/H]	0.07	...	−0.03
[Si/Fe]	...	0.07	−0.34
[Ca/Fe]	...	0.11	−0.12
[Ti/Fe]	...	−0.12	−0.14
[Sc/H]	...	0.25	0.01
[Mn/H]	...	0.01	−0.08
$T_{\rm eff}$ (K)	6268	6227	6300
$\log g$	4.04	4.18	4.00
ξ (km s^{-1})	1.63	2.15	1.20

in a part of the spectrum strongly affected by line blanketing and so have relatively large errors.

Table 6. Influence of several sources of errors on the final abundances.

Species	$T_{\rm eff}$	$\log g$	W_λ	ξ	Total
Ca I	0.14	0.00	0.17	0.02	0.22
Ti I	0.15	0.01	0.07	0.03	0.17
Ti II	0.04	0.08	0.10	0.03	0.14
V I	0.17	0.00	0.06	0.01	0.18
Cr I	0.11	0.00	0.06	0.02	0.13
Cr II	0.02	0.07	0.09	0.05	0.13
Mn I	0.12	0.00	0.08	0.03	0.15
Fe I	0.08	0.02	0.11	0.06	0.15
Fe II	0.00	0.07	0.10	0.05	0.13
Co I	0.17	0.00	0.06	0.02	0.18
Ni I	0.11	0.00	0.09	0.03	0.15
Ce II	0.07	0.08	0.04	0.01	0.11
Nd II	0.09	0.08	0.06	0.02	0.14
Sm II	0.07	0.07	0.03	0.02	0.11

Notes: The effective temperature ($T_{\rm eff}$) was raised by 200 K, the surface gravity ($\log g$) by 0.2 dex, the microturbulence (ξ) by 0.2 km s^{-1}, and the equivalent width (W_λ) by 10%. The total error (total) is given as the sqaure root of the square sum of the individual errors.

4. Discussion

An important question concerns the uncertainties in the results for γ Ser. Canonically the smallest errors for absolute abundance analyses are thought to be about 0.20 dex (see, e.g., Gigas 1988). One can perform a sensitivity test of the abundances. Table 6 shows the changes in the 14 derived abundances based on the most lines for γ Ser. We considered the effective temperature being increased by 200 K, the surface gravity by 0.2 dex, the equivalent width scale by 10%, and the microturbulence by 0.2 km s^{-1}. For each species the total error is the square root of the square sum of the individual errors (see, e.g. Lemke 1990). These values range from 0.11 to 0.22 dex and are similar to the errors in Table 4. Differences in sensitivity are species and mean line strength dependent. In a homogeneous set of analyses for many similar stars, one can select those lines which give the most consistent results and thus reduce the resultant errors a little.

The offset in [Fe/H] of this study for γ Ser relative to those of previous studies is of concern. If we use Fe II lines only from Fuhr et al. (1988), the mean abundance is $\log {\rm Fe/H} = -4.61 \pm 0.17$, a reduction of 0.08 dex. This suggests a small systematic offset in the Fe II gf values from Kurucz & Bell (1995) relative to those in Fuhr et al. (1988). Using only the 10 Fe I lines whose equivalent widths are between 10 and 30 mÅ and whose gf values have errors less than 25% in Fuhr et al. (1988), $\log {\rm Fe/H} = -4.60 \pm 0.19$, a reduction of 0.06 dex. Thus about 0.07 dex of the offset may be due to gf values. The lack of substantial reductions of the scatter in these Fe I and Fe II determations relative to those of the entire sets of Fe I and Fe II lines also suggests that part of the scatter in each elemental abundance value is due to systematic errors in the gf values.

As the absolute gf values of the lines in the photographic are often better determined than those further to the red, the above paragraph not with standing, this is possibly a source of problems in the comparison with other studies. The results for certain species may include possible nLTE effects. But our continuum is less certain and the degree of undetected line blending probably greater than in the red. For a proper comparison with our other stars, we need to study the photographic region as many species have lines there. At our S/N ratio of 200+ and resolution of 0.072 Å (2 pixels) we reliably interpolate the continuum in the blue even in late F stars. The line density dramatically decreases as one proceeds longward of about 4630 Å at which point determining the continuum level also becomes easier. Thus studies of F type stars beginning about 4630 Å and going longward should have most of the virtues claimed for studies in the red, especially better determined continua and a sufficiently low line density so that line blending is not a major problem. Further the reduction of echelle spectrograms involve special problems including the ripple which do not affect coudé spectrograms. By analyzing the same lines as other investigators as well as those of this study, we should be better able to identify and then hopefully to eliminate sources of possible difference, including errors in the gf values. It is probably also desirable to study another well studied late F star using spectra which include the red region. However, some of the systematic errors discussed by Kurucz (2002) for solar type star studies may dominate any comparison.

In summary, our abundance study of γ Ser based on photographic region spectrograms shows decent agreement with those of other investigators who used spectra further to the red. To understand the origins of the discrepancies, it is desirable to obtain spectra of this star in the red and then analyze them consistently with those used in this paper.

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