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Investigation of Atomic and Molecular Spectrum of g Herculis

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Abstract: *In this study, the line identifications of g Herculis (g Her), which is M6III red giantstar,wereinvestigated. The line identifications of thestarwere made by using the Moore Multiplet Table. Astronomic properties of thestarwere madeto find database Simbad by using Hipparcos Catalogue. Spectrumanalysis of the star was made by software Image Reduction and Analysis Facility (IRAF).*

Keywords: *g Her, IRAF, red giant star*
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I. INTRODUCTION

The aim of observing and surveying the spectra of stars is to have knowledge about that star.The age of the star, mass, chemical composition, etc. are in this knowledge.The total mass is the main determinant of the development of the star.It depends on the mass at the end of the star.According to the stage of evolution in which a star is in the process of evolution, it is changing many properties such as diameter, temperature, chemical composition, mass and many features like this.The most important stages of the star evolution are known as the Main sequence and the Red giant branch.The position of these stages is determined by the mass of the star. The g Her (M6 III) studied in this study is in the red giant branch.This star is one of the coolest (T_{eff}=3250 K)SRb (semi-regular) variable stars and has a mass, perhaps as great as (4$M_{\odot}$).

In the literature, there areworks for different resolutions, wavelengths, spectrum region and telescopes for g Her.These studies can be sorted:Spectral energy distributions and effective temperature scale of M giant stars have been determined. This study has been applied a method of band model opacity to red giant stars of relatively low effective temperature (M-giant stars) [1].The Outer atmospheres of the coolest M giants (ρ Persei, 2 Centauri, g Herculis, θ Apodis and R Lyrae) have been examined at Ultraviolet spectrum region. The chromospheric spectrum found to contain a plethora of Fe II lines, whose relative strengths are strong, affected by saturation and fluorescence, and a few lines of C I, C II, Mg I, Mg II, Al II, Fe I and Cr II. The chromospheric spectra of ρ Persei, R Lyrae, 2 Centauri and g Her have been found to be remarkably similar [2]. Non-LTE (NLTE) calculations of semiempirical chromospheric models have been presented for 30 g Her (M6 III). The semiempirical models have been described here are constrained by two high-resolution IUE spectra recording the line profiles of the C II] UV0.01 intersystem lines near 2325 Å, the Mg II *h* and *k* lines near 2800 Å, and the Mg I resonance line at 2852 Å [3].

In the study,atomic and molecular specrumof g Herculishave examined. There were not many studies in theinvestigated literature except for those given in our article for g Her.Our goal is to contribute to the literature and to provide information about g Her for wide wavelength range.

II. OBSERVATION

The line identifications of the star were made by using Moore Multiplet Table [4]. Astronomic properties of the star were made to find database Simbad by using Hipparcos Catalogue [5].The atomic and molecular spectrum of g Herculis for5260-8560Å wavelength rangeexamined. The observation information is given Table 1 for g Her.Some observations for g Her made in the past are given in Table2.

Table 1. The observation information for gHer

Telescope	B-V	Exposure Time (sec)	Resolving Power (λ/Δλ)	Period	Instrume	CCD
RTT150	*1.28*	*400*	*40,000*	*89.2*	*Coude-Echelle*	*ANDOR*

Table 2. Some of g Her observations [3]

Wavelengths (Å)	Date (U. T.)	Telescope	Resolving Power (λ/Δλ)	Exposure Time (sec)
2500-3200	*1988 June 16*	*IUE*	*500*	*300*
2500-2900	*1988 June 16*	*IUE*	*10,000*	*2400*
2300-3100	*1988 june 17*	*IUE*	*10,000*	*52800*
3922-3975	*1989 Aug 13*	*McMath*	*21,000*	*9000*
8488-8590	*1989 Aug 14*	*McMath*	*23,000*	*120*
4181-4248	*1989 Aug 27*	*McMath*	*21,000*	*120*
6540-6600	*1992 Apr 20*	*McMath*	*45,000*	*300*

III. IMAGE REDUCTION AND ANALYSIS FACILITY (IRAF)

The accuracy of the spectral analysis results for a star depends on the quality of the observational data analyzed and the reliability of the atomic data used to make the methods used in the analysis current and accurate. The crude spectrum image for the g Her is given in Figure 1.

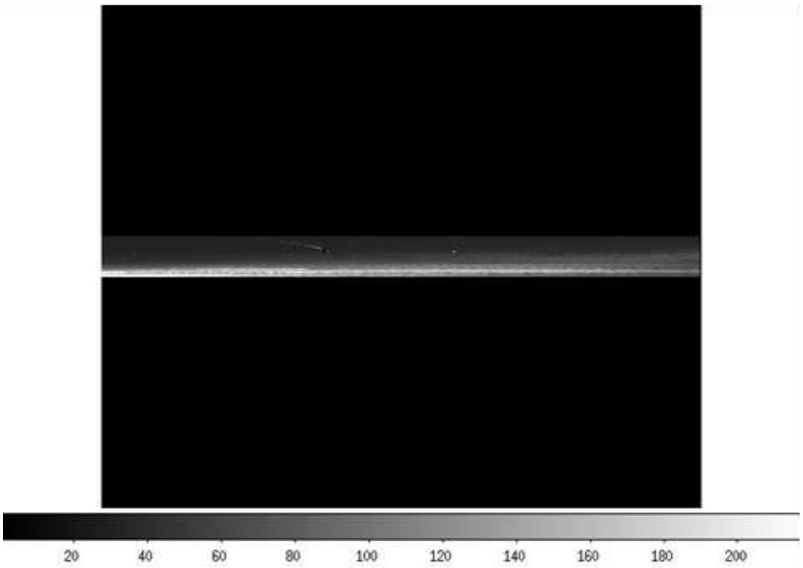

Fig.1. The crude spectrum image for the g Her

Spectrum analysis of star (such as preliminary reduction, reduction, wavelength calibration) was made using by IRAF. There are some rules that must be followed during the reduction process of Echelle spectra.It is necessary to make some adjustments which are caused by the CCD. The most important are dark, bias and flat calibrations [6]. The average bias, dark, and flat images are given in Figure 2, 3, 4.

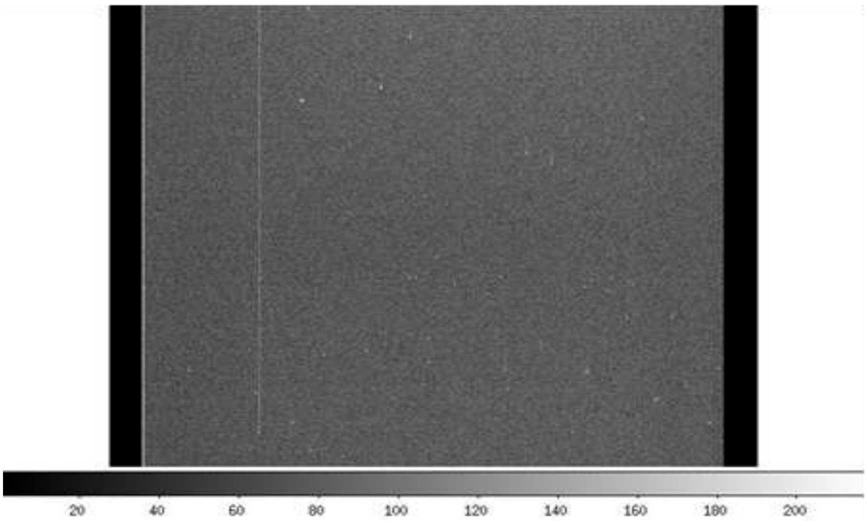

Fig.2. The average bias image

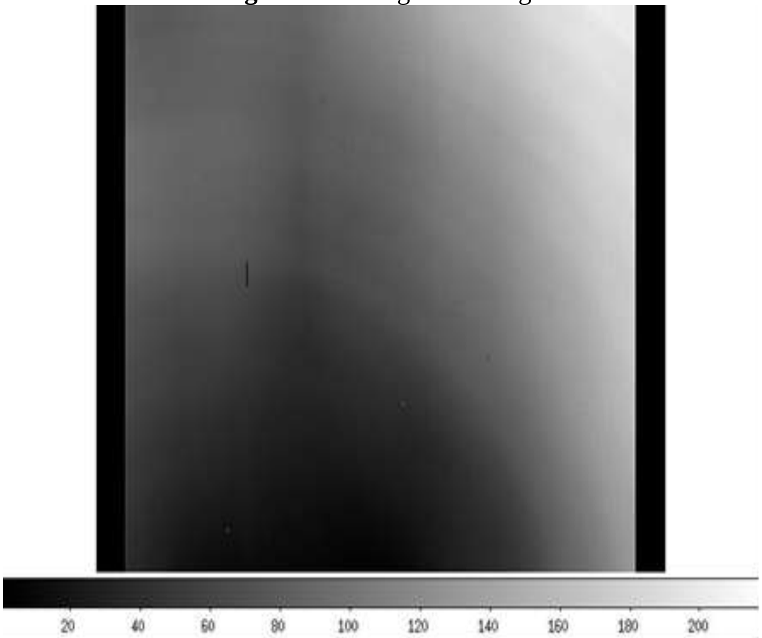

Fig.3. The average dark image

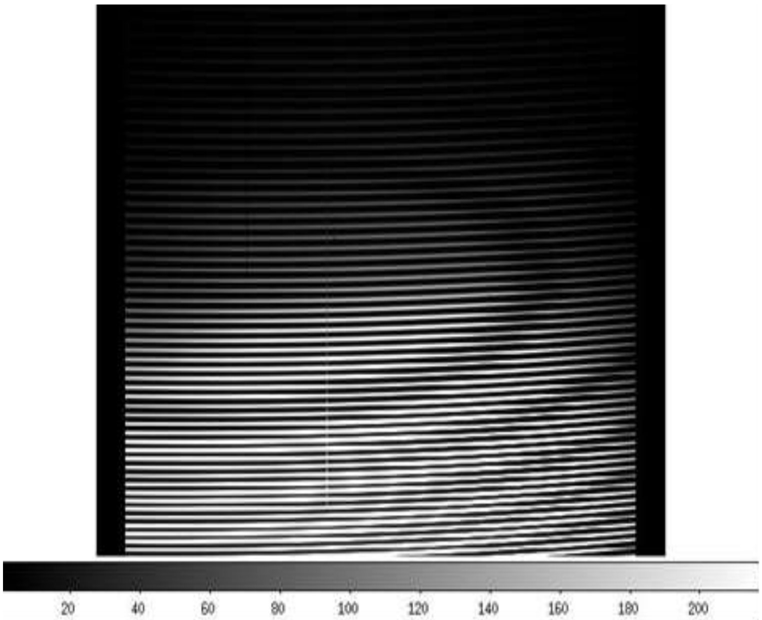

Fig.4. The average flat image

IV. RESULTS AND DISCUSSION

In the study, atomic and molecular spectrum of g Herculishave examined for 5260-8560Å wavelength interval.The most important feature of M-type stars is the predominance of TiO molecules in their spectra.Especially, the visual spectrum is dominated by the typical TiO to bands characterizing the M spectral type. The spectra of M-type stars have metal lines because the effective temperature is low. Molecules are also found in the spectrum of these typestars. Because molecules can bind only at low temperatures.

The M-type stars, strong absorption bands of TiO and metallic lines do not exist at wavelengths shorter than 4000 Å [7]. In our work, TiO bands were found inwavelengths bigger than 4000Å.In the study, recognition of spectral lines for g Herculiswas made by IRAF. The spectrum line diagnostics were done by selecting clean and smooth apertures. Some apertures for g Her spectrum is given Figure 5;6;7; 8 and 9.

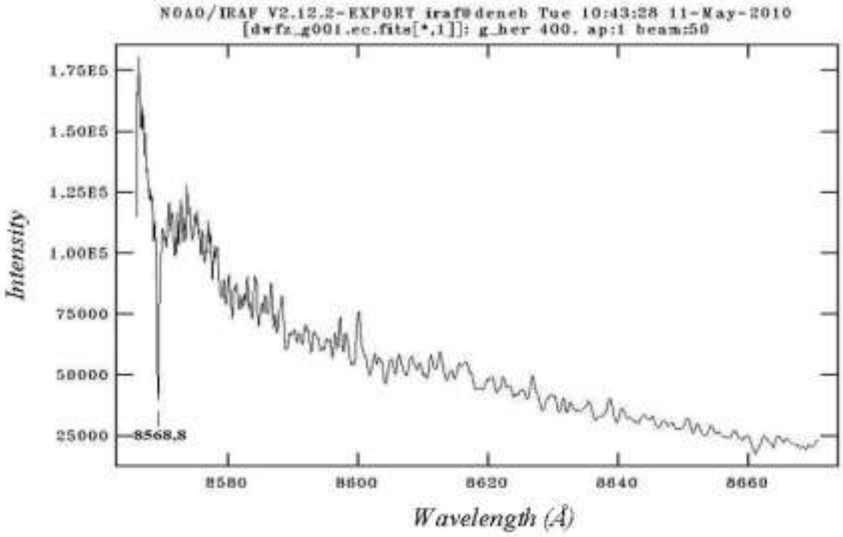

Fig. 5. The first aperture of g Her spectrum

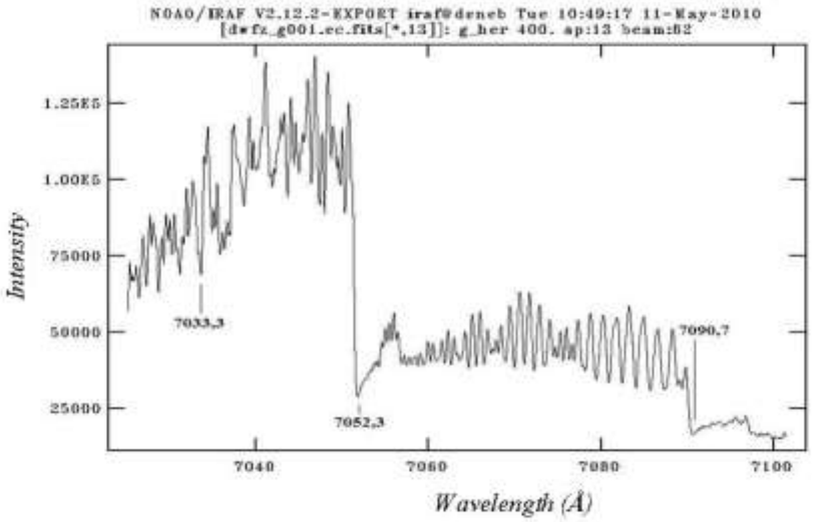

Fig. 6. The 13th aperture of g Her spectrum

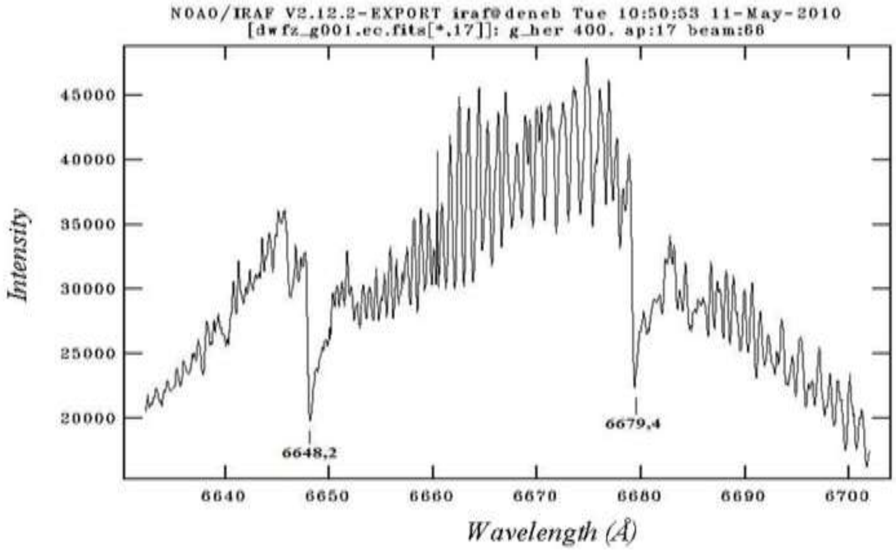

Fig. 7. The 17th aperture of g Her spectrum

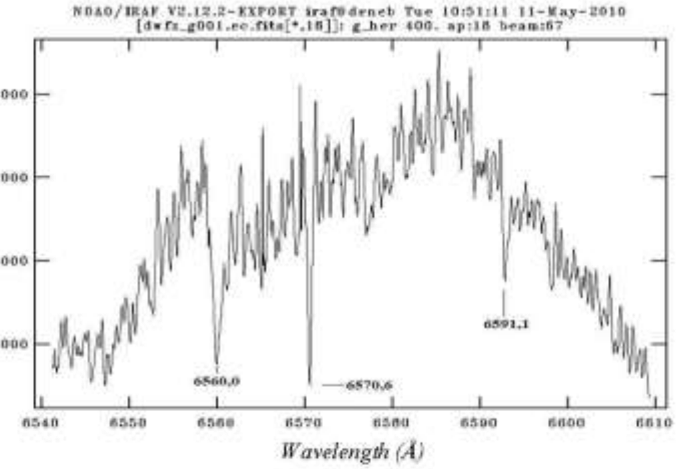

Fig. 8. The 18th aperture of g Her spectrum

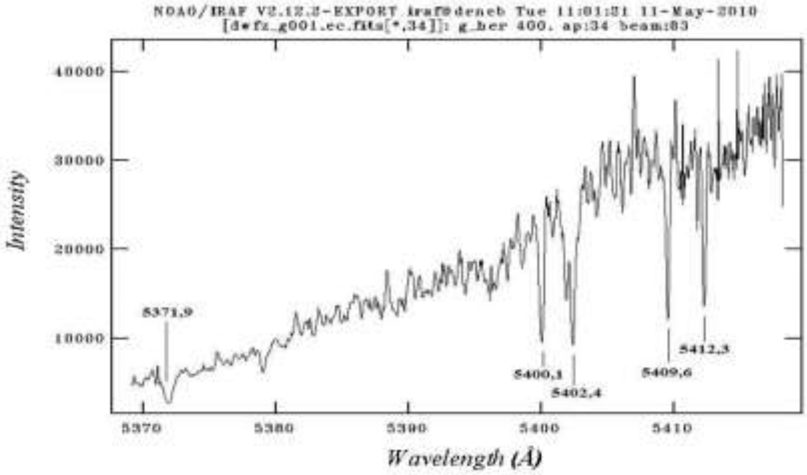

Fig. 9. The 34th aperture of g Her spectrum

TiO bands become stronger at wavelengths shorter than 9000 Å in stars which have M6 and M7 spectral species.The TiO bands in these species are weak at around10,000 and 10,300 Å .This band comes to the visible level in the stars of M3 spectral type and M is intensified by the increase of spectral.Therefore, M spectral class is a useful criterion for determining.However, inM spectral type stars is also foundVO band. This band becomes dominant for M7 and M8-9 spectral species [8].The atomic, molecular and ionic spectral lines of g Her is given in Table 3.In study of Luttermoser 1994 is obtained Ca I 6573 Å and H_α~6562.5 Å. In this work is obtained Ca I 6570.6 Å and H_α 6560 Å.According to these results, there is about 2.4 Å deviation.This deviation is added to the wavelengths. It is estimated that the cause of this deviation is due to the radial velocity of the star.In this work, TiO band head determined by using the study of Valenti *et al.* 1998 [9]. The atomic, molecular, and ionic spectral lines determined by using Multiplet Table [4]. Therefore, the multiplet number is not specified for TiO band heads. In Table 3. λ_{obs}; observation wavelength and λ_{Lab}; it is likely the wavelength of the lines. So λ_{Lab}, may correspond to more than one line. As seen in Table 3. in the atmosphere of g Her were found to be definitely present in the dominant Fe I, and Ti I.The number of more than one ionized element is low because the effective temperature is low.In addition, TiO band, which are characteristic of these spectral class stars: 5950.565 Å, 8198.659, and 8414.957 Å for g Her.The spectrum obtained from the celestial bodies is important in obtaining a lot of information about them.The lines seen on the spectrum are closely related to the star temperature.The effective temperature of the celestial body is a clear determinant of what elements, molecules, or ions may be on it.For example, metal lines are not visible at high temperatures when present at low temperatures. Because, metals cannot bond at high temperatures.At low temperatures, atoms are found at the base level and electrons are closest to the nucleus. When the temperature israised ionized atoms form.Molecules do not form at very high temperatures. In short, metals, molecules, and molecular bands are found in stars with low effective temperatures.

Table 3. The atomic, molecular and ionic spectral lines for g Her

λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No	λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No
8568.8+2.4	8571.8 Fe I	1272	7492.2+2.4	7494.72 Fe I	33
8454.1+2.4	8455.24 Cr I 8457.10 Ti I	56 141	7477.2+2.4	7479.06 O I 7479.70 Fe II	55 72
8436.4+2.4	8438.93 Ti I	224	7474.4+2.4	7476.40 Fe I 7476.45 O I 7476.92 Fe I	1251 55 1004
8421.1+2.4	8423.10 Ti I	150	7422.8+2.4	7425.12 Fe II 7425.64 F I	209 1
8412.4+2.4	8414.08 Fe I 8414.957 TiO Band Head	1154	7381.8+2.4	7384.96 Fe I	1308
8304.4+2.4	8306.115 H 8306.80 Si I	12 19	7358.7+2.4	7361.39 V I 7361.56 Ti I 7361.59 Al I	117 212 11
8294.9+2.4	8297.58 Cr I	297	7309.3+2.4	7311.02 F I 7311.101 Fe I 7311.26 Fe I	5 1077 1105
8290.9+2.4	8293.527 Fe I	623	7275.9+2.4	7278.48 Fe I 7278.72 Hf II	1274 111
8286.9+2.4	8287.38 Cr I 8290.62 Cr I	298 298	7271.4+2.4	7273.20 S II 7273.77 Ti I	18 212
8211.3+2.4	8213.02 Mg I	28	7176.9+2.4	7179.16 Fe II	72
8196.4+2.4	8198.87 V I 8198.951 Fe I 8198.659 TiO Band Head	30 1154	7090.7+2.4	7093.10 Fe I	1189
8151.4+2.4	8151.95 Co I 8160.15 Al II	193 118	7052.3+2.4	7054.042 Co I 7054.62 Gd II	140 130
8150.8+2.4	8151.95 Co I 8160.15 Al II	193 118	7033.3+2.4	7035.86 Ti I	307
8126.9+2.4	8129.32 Fe I	265	6968.9+2.4	6971.95 Fe I	404
7883.1+2.4	7885.00 Ti I 7885.26 S II	34 68	6882.8+2.4	6885.07 O II 6885.772 Fe I	45 1173
7877.4+2.4	7879.75 Fe I	1306	6843.6+2.4	6846.60 Gd II 6846.97 O II	94 45
7752.5+2.4	7754.70 F I	4	6781.2+2.4	6783.27 Fe I 6783.71 Fe I 6783.75 C II	206 205 14
7745.7+2.4	7748.281 Fe I 7748.37 Gd II 7748.93 Ni I	402 142 156	6766.9+2.4	6769.62 Ba II 6769.66 Fe I	8 1226
7743.1+2.4	7745.05 S II 7745.48 Fe I	70 1305	6753.7+2.4	6756.56 Fe I 6756.61 A II	1120 20
7592.6+2.4	7592.74 He II	6	6679.4+2.4	6681.03 Cl II 6681.23 Gd II 6681.34 Fe I	38 94 1155

Table 3.-Continued

λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No	λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No
6648.2+2.4	6648.08 Fe I 6653.41 N I	13 20	6148.9+2.4	6151.509 V I	33
6591.1+2.4	6593.878 Fe I	168	6140.9+2.4	6143.0623 Ne I 6143.23 Zr I	1 2
6570.6+2.4	6572.781 Ca I 6572.900 Cr I 6574.238 Fe I	1 16 13	6129.3+2.4	6131.005 Mn II 6131.30 Si I 6131.54 Si I 6131.86 Si I 6131.917 Mn II	13 30 30 30 13
6560+2.4	6562.817 H_{α}	1	6090.2+2.4	6092.13 S II 6092.814 Ti I	20 153
6495.5+2.4	6497.689 Ti I	102	6080+2.4	6082.431 Co I 6082.718 Fe I	169 64
6419.6+2.4	6420.47 N I 6421.355 Fe I 6421.507 Ni I	23 111 258	6064.1+2.4	6066.32 Al II 6066.44 Al II	92 92
6414+2.4	6416.905 Fe II 6416.94 Fe I	74 1253	5953.1+2.4	5955.12 Fe I 5955.37 Zr I 5955.682 Fe I	1233 3 1106
6320.5+2.4	6322.165 Ni I 6322.693 Fe I 6322.98 Fe III	249 207 3	5948.3+2.4	5950.13 Fe I 5950.91 A I 5950.565 TiO Band Head	1200 12
6303.9+2.4	6306.047 Sc I 6306.17 Hf II 6306.19 Fe I	3 81 1230	5875.1+2.4	5877.26 Gd II 5877.770 Fe I	94 1083
6221.3+2.4	6223.994 Ni I	228	5872.9+2.4	5875.6 Fe III 5875.618 He I 5875.650 He I 5875.989 He I	- 11 11 11
6210.4+2.4	6212.04 Fe I 6212.30 Ti II	1142 108	5864.5+2.4	5866.453 Ti I	72
6172.8+2.4	6175.158 Fe II 6175.424 Ni I	200 217	5849.6+2.4	5852.19 Fe I 5852.4878 Ne I	1178 6
6162+2.4	6162.172 Ca I 6163.42 Ni I 6163.560 Fe I 6163.5939 Ne I 6163.758 Ca I	3 230 64 5 20	5826.4+2.4	5828.00 N IV	15
6156.9+2.4	6159.409 Fe I	1175	5804.4+2.4	5806.31 Cr II 5806.56 La II 5806.727 Fe I 5806.75 Si II 5806.77 Sc II	31 90 1180 8 21

Table 3.-Continued

λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No	λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No
5797.8+2.4	5800.02 Fe II 5800.229 Ba I 5800.48 Si II	165 9 8	5594.9+2.4	5597.21 Gd II 5597.87 Cr I 5597.92 Ti I	95 239 229
5796.6+2.4	5797.352 V I 5797.445 Ti I 5797.53 Cr I 5797.57 La II 5797.76 Zr I 5791.81 Fe II 5797.912 Si I 5798.000 Cr I 5798.194 Fe I 5798.46 Cr I 5798.905 V I	142 309 185 4 4 165 9 185 982 17 142	5587.2+2.4	5589.00 Fe I 5589.384 Ni I	1160 205
5736.4+2.4	5738.22 Fe I 5738.286 Mn I 5738.554 Cr I	1084 - 227	5584.3+2.4	5586.007 V I 5586.16 Gd II 5586.763 Fe I	85 78 686
5730.2+2.4	5732.29 Fe I 5732.72 Fe II 5732.86 Fe I	1313 57 1055	5535.4+2.4	5537.11 Ni I 5537.756 Mn I	188 4
5665.4+2.4	5667.164 Sc II 5667.67 Fe I	29 209	5471.7+2.4	5474.09 Fe I 5474.228 Ti I 5474.449 Ti I 5474.734 Nd II	1314 108 259 82
5663.7+2.4	5666.64 N II 5666.78 Ni I 5666.837 Fe I	3 233 1053; 1060	5460.6+2.4	5463.282 Fe I 5463.38 Hf II 5463.974 Cr I	1163 14 204
5599.5+2.4	5601.285 Ca I	21	5453.4+2.4	5455.09 Fe I 5455.14 La I 5455.433 Fe I 5455.613 Fe I 5455.80 Cr II 5455.815 Nd II	627 3 1145 15 50 83

Table 3.-Continued

λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No	λ_{obs} (Å)	λ_{Lab} (Å)	Multiplet No
5451.2+2.4	5453.255 Ni I 5453.338 Co I 5453.646 Ti I 5453.81 S II 5453.98 Fe I	231 194 108 6 1064	5351.6+2.4	5354.01 Co I 5354.66 Cr II 5354.67 Ta I	91 29 6
5435.3+2.4	5437.19 Fe I	1145	5349.9+2.4	5352.000 O V 5352.046 Co I	13 172
5432.5+2.4	5434.527 Fe I	15	5346.2+2.4	5348.069 Mn I 5348.319 Cr I 5348.40 Hf II 5348.67 Gd I	36 18 22 6
5412.3+2.4	5414.089 Fe II 5414.91 Fe I	48 874	5298.1+2.4	5300.012 Ti I 5300.41 Fe I 5300.749 Cr I	74 1240 18
5409.6+2.4	5412.56 Fe I 5412.80 Fe I	1237 1162	5297.2+2.4	5299.00 O I 5299.278 Mn II 5299.85 Hf II	26 11 14
5402.4+2.4	5404.23 Ti I 5404.12 Fe I 5404.144 Fe I 5404.87 O I 5404.95 Ta I	259 1145 1165 53 13	5275.3+2.4	5277.31 Fe I 5277.32 Fe I 5277.40 Zr I 5277.59 Fe I 5277.68 Al II	1149 584 27 983 67
5400.1+2.4	5402.000 Co I 5402.113 Fe II 5402.27 Fe III 5402.51 Ta I 5402.57 Lu I 5402.69 A II 5402.78 Y II	195 - - 1 2 - 35	5256.8+2.4	5259.09 Fe I 5259.38 La II 5259.62 C II 5259.743 Pr II 5259.976 Ti I	1149 21 30 35 298

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