MODEL-ATMOSPHERE METHOD OF SPECTRUM ANALYSIS

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Abstract: The method of the model-atmosphere spectrum analysis was modified for the wider application. In this paper is described the method of corrections to the theoretical curves of growth of different microturbulent velocity values. The tables bring the theoretical curves of growth of 21 elements computed for the model atmosphere corresponding to an A0 star on main sequence.

Introduction

The origin of the Ap-stars phenomenon is not as yet explained satisfactorily. The spectroscopic observations and the analysis of them is one in desirable means to reach the advance. The study of the abundance anomalies is necessary. For determination of them we choose the method of saturation and weighting functions. As the basis we took the method described by Aller et al. (1957). The modification of this method was made in order to have a possibility of the microturbulence correction in the process of the computation. We elaborated the Algol program for the computer GIER of the Slovak Academy of Sciences. 108 theoretical curves of growth of 21 elements were computed.

In this paper we briefly describe the method used, the manner of the computation and we give the theoretical curves of growth calculated for three models of atmospheres with the effective temperature corresponding to an A0 star on the main sequence.

Method

The equivalent width of the spectral line in the method of weighting and saturation functions is given by the expression

$$W_\lambda/\lambda = \int_{-\infty}^{+\infty} MZ^*(x)\psi(Y,a)\,W_s^m(x)\,G_\lambda^0(x)\,dx = ML^*. \quad (1)$$

The meaning of the symbols used in this formula is the same as in the paper by Aller et al. (1957). The quantity M contains the abundance and it is

$$\log M = \log N_i/N_H + \log gf\lambda k + \theta_0\,\Delta\chi. \quad (2)$$

The function $Z^*(x) = Z(x)\,(1 - \exp(-h\nu/kT))$ describes the occupation of the atomic energy levels as the function of the depth in the atmosphere. The saturation function, $\psi(Y, a)$, describes the saturation of the core of the spectral line and determines the deviation of the curve of growth for moderately strong lines from that one for the weak lines:

$$\psi(Y,a) = 2\int_0^\infty H(v,a)\exp(-H(v,a)Y)\,dv/\sqrt{\pi}. \quad (3)$$

To simplify and obtain more efficiency of the method we carried out some approximation and modified the method with regard to the microturbulence. Adopted approximation is described in the paper by Zverko (1974), the corrections due to the microturbulence are derived in the next paragraph.

The coordinates of the curve of growth were calculated for five values of abscissae, which were derived from the observed value of the equivalent width by this manner: the unsaturated curve of growth is given by relation

$$W_\lambda/\lambda = \int_{-\infty}^{+\infty} MZ^*(x)\,G_\lambda^0(x)\,dx = ML^*. \quad (4)$$

Then $M' = (W_\lambda/\lambda)_{obs}/L^*$. As the abscissae of the curve of growth were adopted these values

$$\begin{aligned} M_1 &= 100\,M \\ M_2 &= 20\,M \\ M_3 &= 5\,M \\ M_4 &= M \\ M_5 &= M/2 \end{aligned} \quad (5)$$

An eventual extrapolation to the weaker lines ($M < M_5$) can be performed on the graph easily.

Microturbulence Corrections

To make better utilization of computed theoretical curves, we made the modification of the method width regard to the microturbulence in the atmosphere of the star. The basic set of the theoretical curves is computed for $\zeta_{turb} = 0$ km s^{-1}. For the particular atmosphere with $\zeta_{turb} \neq 0$, the curves can be corrected by the manner described below.

The velocity of the microturbulence enters into the equivalent width (Eq. 1) by means of the saturation function and its arguments Y and a. The last quantity – the damping constant – a is given as $a = \gamma/4\pi\Delta\nu_D$, where $\Delta\nu_D = \nu\,\zeta_0/C$ and

$$\zeta_0 = (\xi_T^2 + \zeta_{turb}^2)^{1/2}. \qquad (6)$$

As we are interested in weak and moderately strong lines lying in the flat portion of the curve of growth, single value of the damping constant is sufficient for the whole atmosphere and all lines. It can be estimated by comparison with the known atmosphere of close spectral and luminosity classes.

The quantity Y is given by the relation

$$Y(x) = Mc \int_{-\infty}^{x} Z(y)\,dy/(\zeta_T^2 + \zeta_{turb}^2)^{1/2}. \qquad (7)$$

The change of the most probable velocity, shifts the curve of growth to the new coordinates in the plane $\log M - \log W\ \lambda/\lambda$.

At first we put $\zeta_T = \zeta_{Teff}$ = const for whole atmosphere. When the curve of growth for certain value $\zeta_{turb\,1}$, was computed then, in order to obtain the new curve for the value $\zeta_{turb\,2}$, we must find the new coordinates of the point with the same saturation, i.e.,

$$Y_1 \equiv M_1/\zeta_{0_1} = M_2/\zeta_{0_2} \equiv Y_2\ , \ \text{or}$$

$$M_2/M_1 = \zeta_{0_1}/\zeta_{0_2}\ . \qquad (8)$$

As the curve of growth is drawn in the logarithmic coordinates, equation (8) we write

$$\log M_2 - \log M_1 = \log((\zeta_{Teff}^2 + \zeta_{turb\,2}^2)^{1/2}/(\zeta_{Teff}^2 + \zeta_{turb\,1}^2)^{1/2}),$$

or for $\zeta_{turb\,1} = 0$

$$\log M_2 - \log M_1 = 1/2 \log(1 + \xi_{turb\,2}^2/\xi_{Teff}^2). \qquad (9)$$

This is the correction of the coordinates of the point of the theoretical curve of growth in respect of the change of the microturbulent velocity from $\zeta_{turb} = 0$ to $\zeta_{turb} \neq 0$.

The value of the microturbulent velocity in the atmosphere can be determined either in the coarse analysis or in the fain analysis by the manner described in the paper by Zverko (1974).

Abundance Determination

If the theoretical curve of growth for the atmospherical parameters observed was computed, the calculation of the abundance of the elements is very simple.

As the abscissa of the empirical curve of growth the quantity

$$\log C' = \log gf\lambda k + \theta_0 \Delta X \qquad (10)$$

was used.

The abundance relative to the hydrogen from Eq. (2) is consequently $\log N_i/N_H = \log M - \log C'$.

The wavelength "λ" is expressed in angströms, $\log k = 3.84$, $\theta_0 = 5040/T_0$ corresponds to the region mostly contributing to the line formation. Next

$$\begin{aligned} \Delta X &= -\chi_{r-1} - \chi_{r-1,s} && \text{for } r-1,\ s \\ &= -\chi_{r,s} && r,\ s \\ &= -\chi_{r+1,s} - \chi_r && r+1,\ s, \end{aligned}$$

$r-1$, r, $r+1$ are three most important stages of the ionization, χ_r and $\chi_{r,s}$ are the ionization and the excitation potencials of the line respectively.

The curves were computed for certain values of the wavelength "λ_0" and the excitation potential "E.P.". To the same theoretical curve can be applied more of real spectral lines occurring in the certain intervals of λ and χ. The correction for the difference in the wavelengths can be estimated by the comparison of single curves and it amounts to ≈ 0.05 per 100 Å at $\log N_i/N_H$.

Tables

The theoretical curves of growth were computed for three model atmospheres. In accordance with the line identification list for 53 Aur. we selected the values of the wavelengths "λ_0" and the excitation potentials. Therefore this values do not correspond to the real spectral line in each case, but they represents the averages for whole group of the lines (sometimes for the multiplet).

Models are following:

Model I T_{eff} = 10 080 K, $\log g = 4.0$
Model II T_{eff} = 10 000 K, $\log g = 4.0$
Model III T_{eff} = 10 000 K, $\log g = 4.0$, 10× metals

The first model is from the paper by Mihalas (1966), the second and third ones are from the paper by Carbon and Gingerich (1969). This models were chosen on the basis of the atmospherical parameters determined for 53 Aur. in the paper by Zverko (1975). The integration was carried from the optical depth $\tau_{std} = 10$ to $\tau_{std} = 0.001$ (τ_{std} means the optical depth at the standard wavelength of the model).

As the most important ionisation stages were taken the neutral ($r - 1$), once (r) and twice ($r + 1$) ionized atoms. Next we put

$\theta_0 = 0.5$ for all models,

$\zeta_{turb} = 0$ km s^{-1} and $\zeta_0 = \zeta_{T_{eff}}$ = const,

$a = 0.03$ – estimated for a star on the main sequence according to Vega and Hunger (1955).

As the sources of the opacity were taken

Neutral hydrogen	$k\nu(H)$
Negative hydrogen ion	$k\nu(H)$
Neutral helium	$k\nu(He)$
H_2^+	$k\nu(H_2^+)$
Thompson scattering	δe
Rayleigh scattering	δ_R

The value $(W_\lambda/\lambda)_{obs}$, which is determinant for the computed part of the curve of growth, was taken that maximum value in the group.

The Table 1 lists the theoretical curves of growth. Each curve was computed for three models. First column contains the ion, the wavelength "λ_0" and the excitation potential "E.P." [eV], in the first, second and third line respectively. The next couples of the columns give the coordinates of the theoretical curves in the plane $\log M - \log W_\lambda/\lambda$. The number written at the same line as the designation of the ion means the ordinate of the point on the unsaturated curve (the stright line with the slope 45°) viz. for the abscissa corresponding to M_4. (For example, for the curve Mg I λ 3835 and the Model I, this abscissa is $\log M = 4.162$). In the seventh line of the group of the data of each curve is given the quantity $\log L^*$ defined by Eq.(4).

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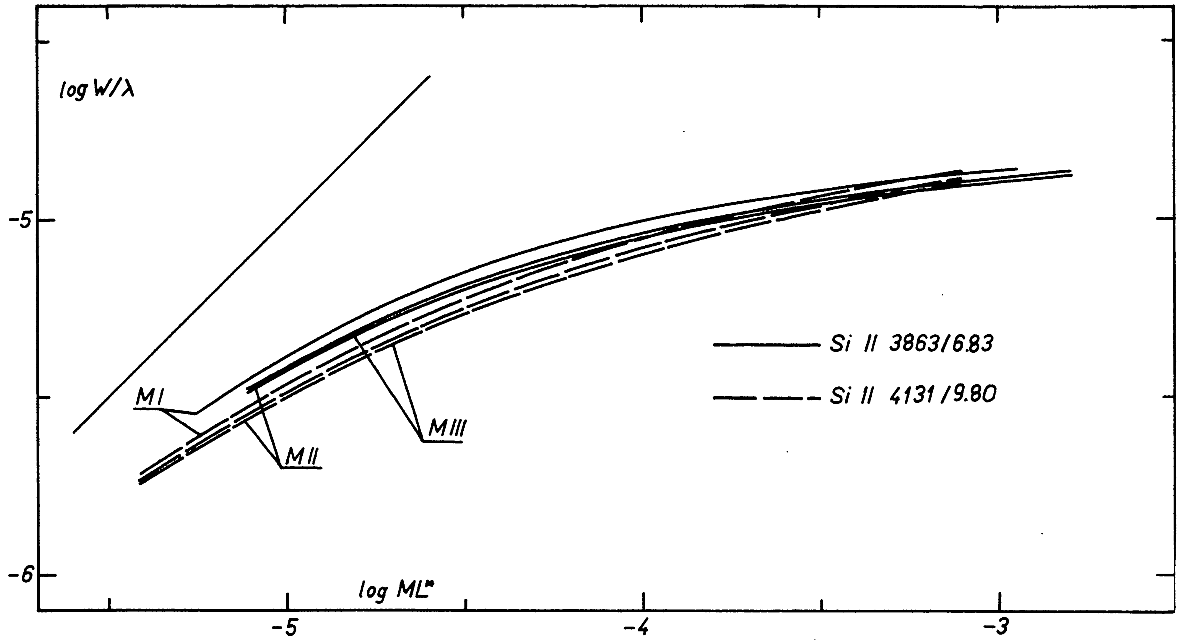

Fig. 1. The theoretical curves of growth of two lines of Si II for each of three models. The straight line with the slope 45° belongs to the unsaturated curve of growth.

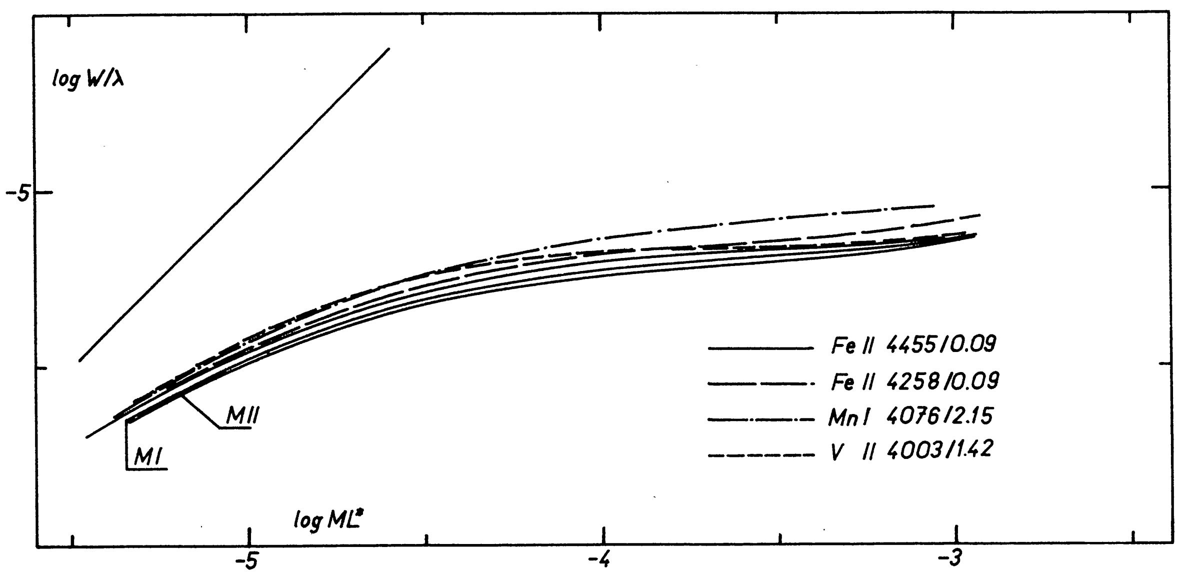

Fig. 2. The curves of growth for several of heavier elements. The unlabelled curves belong to the Model I, the straight line belongs to the unsaturated curve.

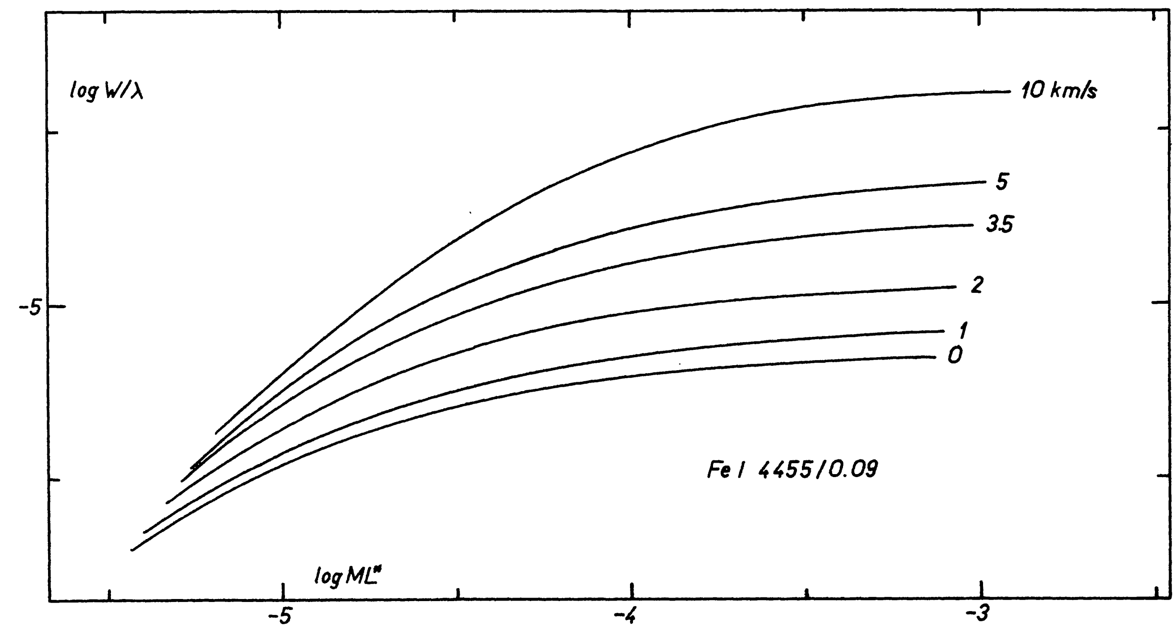

Fig. 3. The theoretical curves of growth of Fe I 4455/0.09 for several values of the velocity of the microturbulence. The curve for 3.5 km s^{-1} was used in the analysis of 53 Aur. The curves are derived from that one of Model I.

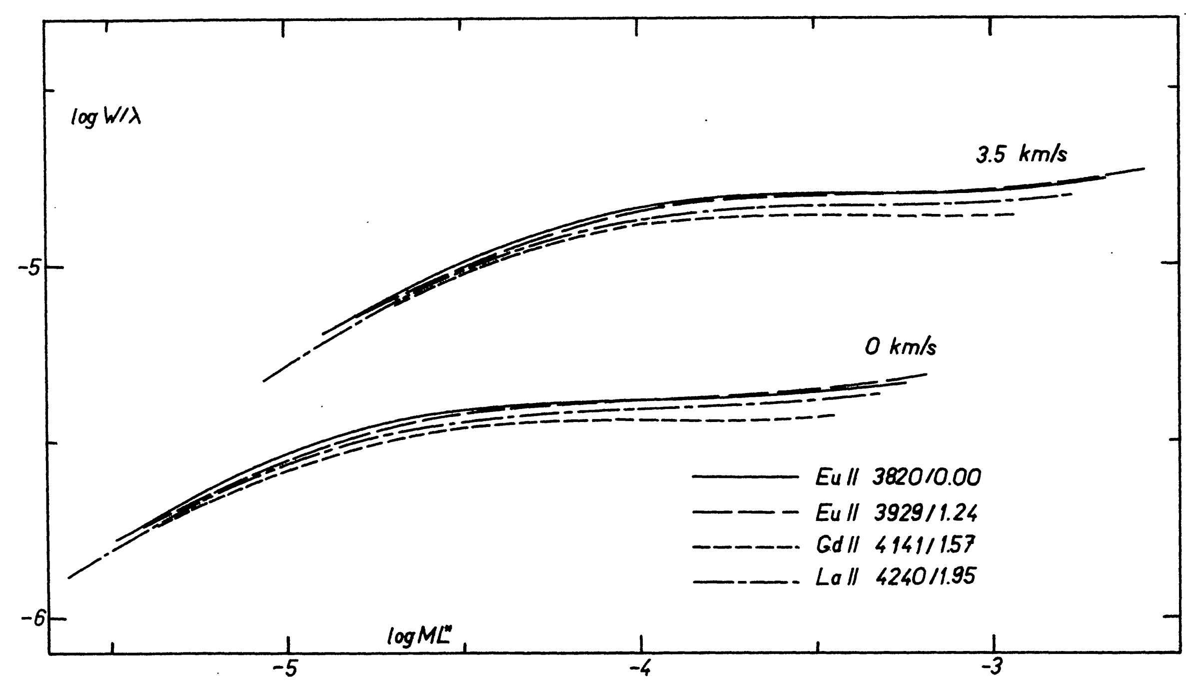

Fig. 4. The theoretical curve of growth of some rare earts, Model I. The correction in respect of the microturbulence is shown.

ŠTÚDIUM SPEKTRA METÓDOU JEMNEJ ANALÝZY

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Súhrn

Komplexné riešenie problému Ap-hviezd kladie požiadavky na získanie čo najväčšieho množstva poznatkov o ich vlastnostiach. Jednou z možností je kvantitatívna spektrálna analýza. V našej práci sme za základ zvolili metódu saturačných a váhových funkcií, kde sa teoretické spektrum porovnáva s pozorovaným pomocou kriviek rastu. Pretože okrem efektívnej teploty a hodnoty gravitačného zrýchlenia na povrchu, reálnu hviezdnu atmosféru charakterizuje aj ďalší parameter – rýchlosť mikroturbulencie, možno jedno teoretické spektrum porovnávať prakticky len s jednou reálnou atmosférou. Aby jeden rad teoretických výsledkov nemal takto obmedzené použitie, modifikovala sa metóda v tom zmysle, že hodnota mikroturbulencie sa ponechala ako voľný parameter a bola odvodená korekcia pre prechod na rozličné hodnoty rýchlosti mikroturbulencie. Korekciu súradníc teoretickej krivky rastu udáva vzťah:

$$\log M_2 - \log M_1 = \log ((\zeta^2_{T\mathrm{eff}} + \zeta^2_{\mathrm{turb}\,2})^{1/2} / (\zeta^2_{T\mathrm{eff}} + \zeta^2_{\mathrm{turb}\,1})^{1/2}),$$

pri prechode od rýchlosti mikroturbulencie $\zeta_{\mathrm{turb}\,1}$ k $\zeta_{\mathrm{turb}\,2}$.

V tabuľkách sú uvedené súradnice teoretických kriviek rastu pre všetky tri vybrané modely hviezdnych atmosfér a hodnota rýchlosti mikroturbulencie $\xi_{\mathrm{turb}\,1} = 0$. Modely odpovedajú atmosfére hviezdy spektrálneho typu A0 na hlavnej postupnosti. Pri použití tabuliek treba urobiť najprv korekciu na pozorovanú rýchlosť mikroturbulencie [z hrubej analýzy alebo spôsobom opísaným v práci Zverku (1974)], a to podľa vzťahu (9) (pre obe súradnice). Vzťahy uvedené v odstavci 4 dajú potom výsledné hodnoty.

МЕТОД ДЕТАЛЬНОГО АНАЛИЗА ИЗУЧЕНИЯ СПЕКТРОВ ЗВЕЗД

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Резюме

Метод весовых функций и функций насыщения использован для изучения спектров пекулярных звезд. Чтобы было можно использовать одну серию теоретических результатов для большого числа звездных атмосфер, мы решили считать скорость микротурбулентных движений свободным параметром и дедуцировали поправку на изменение микротурбулентных скоростей. Поправка координат теоретических кривых роста на изменение микротурбулентных скоростей дана уравнением

$$\log M_2 - \log M_1 = \log [(\zeta^2_{\text{тэф}} + \zeta^2_{\text{турб}\,2})^{1/2} / (\zeta^2_{\text{тэф}} + \zeta^2_{\text{турб}\,1})^{1/2}]$$

после перехода с одной величины $\zeta_{\text{турб}\,1}$ ко $\zeta_{\text{турб}\,2}$.

В таблице приведены координаты теоретических кривых роста, вычисленых для $\zeta_{\text{турб}\,1} = 0$. Атмосферные модели соответствуют звездной атмосфере спектрального класса A0 звезды а главной последовательности.

Table 1. Theoretical curves of growth

ION	MODEL I		MODEL II		MODEL III	
λ_0	$\log (W/\lambda)_{obs}$		$\log (W/\lambda)_{obs}$		$\log (W/\lambda)_{obs}$	
E. P.	$-\log W/\lambda$	$\log M$	$-\log W/\lambda$	$\log M$	$-\log W/\lambda$	$\log M$
	$-\log L^*$		$-\log L^*$		$-\log L^*$	
Mg I	−4.438		−4.186		−4.186	
3835	4.722	6.162	4.662	6.693	4.678	6.837
2.70	4.860	5.463	4.486	5.994	4.860	6.138
	4.931	4.861	4.917	5.392	4.936	5.536
	5.080	4.162	5.037	4.693	5.053	4.837
	5.203	3.861	5.125	4.392	5.139	4.536
	8.600		8.879		9.023	
Mg II	−4.931		−4.772		−4.772	
4434	4.856	−0.609	4.860	−0.454	4.873	−0.445
9.96	4.970	−1.308	4.973	−1.153	4.986	−1.144
	5.114	−1.910	5.100	−1.755	5.113	−1.746
	5.388	−2.609	5.335	−2.454	5.348	−2.445
	5.563	−2.910	5.489	−2.755	5.494	−2.746
	2.322		2.318		2.327	
Al I	−5.254		−5.254		−5.254	
3944	4.918	4.969	4.935	5.260	4.951	5.402
0.00	4.991	4.270	5.013	4.561	5.031	4.703
	5.142	3.668	5.161	3.959	5.177	4.101
	5.506	2.969	5.514	3.260	5.521	3.402
	5.750	2.668	5.752	2.959	5.755	3.101
	8.223		8.514		8.656	
Si II	−4.954		−4.809		−4.809	
3863	4.860	−0.630	4.863	−0.482	4.876	−0.472
6.83	4.945	−1.329	4.947	−1.181	4.961	−1.171
	5.075	−1.931	5.068	−1.783	5.082	−1.773
	5.361	−2.630	5.318	−2.482	5.326	−2.472
	5.548	−2.931	5.477	−2.783	5.487	−2.773
	2.324		2.327		2.337	
Si II	−5.111		−5.111		−5.111	
4131	4.864	−0.596	4.883	−0.640	4.903	−0.656
9.80	5.007	−1.295	5.031	−1.339	5.056	−1.355
	5.189	−1.897	5.215	−1.941	5.230	−1.957
	5.522	−2.596	5.543	−2.640	5.555	−2.656
	5.714	−2.897	5.731	−2.731	5.738	−2.597
	2.542		2.471		2.455	
Ca I	−5.371		−5.325		−5.325	
4227	5.026	5.815	5.026	6.306	5.039	6.540
0.00	5.108	5.116	5.120	5.607	5.135	5.841
	5.266	4.514	5.260	5.005	5.274	5.239
	5.626	3.815	5.597	4.306	5.603	4.540
	5.871	3.514	5.831	4.005	5.832	4.239
	9.186		9.631		9.865	
Sc I	−5.314		−5.292		−5.291	
3912	5.018	6.477	5.026	6.887	5.039	7.093
0.01	5.092	5.778	5.102	6.188	5.117	6.394
	5.232	5.176	5.244	5.586	5.257	5.792
	5.577	4.477	5.568	4.887	5.574	5.093
	5.818	4.176	5.800	4.586	5.801	4.792
	9.490		10.179		10.384	

Table 1 – continued

ION λ_0 E.P.	MODEL I log $(W/\lambda)_{obs}$ / −log W/λ	MODEL I log M / −log L^*	MODEL II log $(W/\lambda)_{obs}$ / −log W/λ	MODEL II log M / −log L^*	MODEL III log $(W/\lambda)_{obs}$ / −log W/λ	MODEL III log M / −log L^*
Sc I	−5.716		−5.620		−5.620	
4165	5.070	6.382	5.080	6.827	5.095	7.014
1.98	5.196	5.683	5.193	6.128	5.209	6.315
	5.417	5.081	5.391	5.526	5.401	5.713
	5.907	4.382	5.827	4.827	5.830	5.014
	6.180	4.081	6.090	4.526	6.091	4.713
	10.098		10.447		10.634	
Sc II	−5.458		−5.303		−5.303	
4014	5.165	−0.675	5.178	−0.269	5.188	−0.137
0.31	5.165	−1.374	5.168	−0.968	5.184	−0.836
	5.304	−1.976	5.270	−1.570	5.284	−1.438
	5.693	−2.675	5.583	−2.269	5.590	−2.137
	5.947	−2.976	5.814	−2.570	5.816	−2.438
	2.783		3.034		3.166	
Sc II	−5.181		−5.026		−5.026	
4246	5.180	−0.315	5.161	+0.094	5.166	+0.228
0.31	5.188	−1.014	5.210	−0.605	5.215	−0.471
	5.247	−1.616	5.231	−1.207	5.245	−1.073
	5.515	−2.315	5.449	−1.906	5.458	−1.772
	5.722	−2.616	5.613	−2.207	5.618	−2.073
	2.866		3.120		3.254	
Sc II	−5.246		−5.246		−5.246	
4408	5.203	−0.289	5.215	−0.039	5.222	+0.094
0.60	5.211	−0.988	5.221	−0.738	5.235	−0.605
	5.281	−1.590	5.293	−1.340	5.305	−1.207
	5.562	−2.289	5.572	−2.039	5.577	−1.906
	5.777	−2.590	5.780	−2.340	5.781	−2.207
	2.957		3.207		3.340	
Ti I	−5.754		−5.354		−5.354	
4293	5.092	6.962	5.107	7.295	5.120	7.470
0.82	5.155	6.263	5.176	6.596	5.192	6.771
	5.291	5.661	5.306	5.994	5.318	6.169
	5.626	4.962	5.636	5.295	5.640	5.470
	5.862	4.661	5.865	4.994	5.865	5.169
	10.716		10.649		10.824	
Ti I	−5.462		−5.462		−5.462	
4055	5.056	6.788	5.071	7.115	5.090	7.284
1.04	5.136	6.089	5.157	6.416	5.180	6.585
	5.305	5.487	5.327	5.814	5.337	5.983
	5.697	4.788	5.701	5.115	5.705	5.284
	5.950	4.487	5.949	4.814	5.951	4.983
	10.240		10.577		10.746	
Ti I	−5.288		−5.288		−5.288	
4469	5.093	7.155	5.109	7.479	5.123	7.647
1.45	5.158	6.456	5.178	6.780	5.194	6.948
	5.290	5.854	5.302	6.178	5.317	6.346
	5.593	5.155	5.603	5.479	5.610	5.647
	5.812	4.854	5.814	5.178	5.827	5.346
	10.443		10.765		10.935	

Table 1 – continued

ION λ_0 *E.P.*	MODEL I $\log (W/\lambda)_{obs}$ $-\log W/\lambda$	$\log M$ $-\log L^*$	MODEL II $\log (W/\lambda)_{obs}$ $-\log W/\lambda$	$\log M$ $-\log L^*$	MODEL III $\log (W/\lambda)_{obs}$ $-\log W/\lambda$	$\log M$ $-\log L^*$
Ti I	−5.089		−5.089		−5.089	
4417	5.067	7.377	5.076	7.692	5.088	7.855
1.88	5.137	6.678	5.155	6.993	5.170	7.156
	5.231	6.076	5.250	6.391	5.265	6.554
	5.485	5.377	5.497	5.692	5.505	5.855
	5.660	5.076	5.667	5.391	5.674	5.554
	10.466		10.781		10.944	
Ti I	−5.478		−5.478		−5.478	
3911	5.026	6.814	5.044	7.118	5.063	7.277
2.03	5.120	6.115	5.147	6.419	5.165	6.578
	5.298	5.513	5.320	5.817	5.330	5.976
	5.705	4.814	5.709	5.118	5.713	5.277
	5.961	4.513	5.960	4.817	5.961	4.976
	10.292		10.596		10.755	
Ti I	−5.654		−5.654		−5.654	
4059	5.062	6.724	5.084	7.024	5.100	7.181
2.30	5.180	6.025	5.201	6.325	5.217	6.482
	5.387	5.423	5.406	5.723	5.417	5.880
	5.853	4.724	5.856	5.024	5.858	5.181
	6.122	4.423	6.121	4.723	6.121	4.880
	10.378		10.678		10.835	
Ti I	−5.599		−5.599		−5.599	
4372	5.101	6.914	5.115	7.215	5.130	7.372
2.48	5.202	6.215	5.222	6.516	5.238	6.673
	5.392	5.613	5.405	5.914	5.415	6.071
	5.816	4.914	5.818	5.215	5.821	5.372
	6.086	4.613	6.075	4.914	6.076	5.071
	10.513		10.814		10.971	
Ti II	−5.705		−5.705		−5.705	
4056	5.180	−0.556	5.198	−0.355	5.212	−0.254
0.60	5.220	−1.255	5.238	−1.054	5.251	−0.953
	5.420	−1.857	5.435	−1.656	5.443	−1.555
	5.903	−2.556	5.903	−2.355	5.902	−2.254
	6.175	−2.857	6.172	−2.656	6.170	−2.555
	3.149		3.350		3.451	
Ti II	−5.581		−5.581		−5.581	
4190	5.202	−0.327	5.222	−0.138	5.235	−0.041
1.08	5.211	−1.026	5.233	−0.837	5.247	−0.740
	5.374	−1.628	5.393	−1.439	5.401	−1.342
	5.798	−2.327	5.802	−2.138	5.803	−2.041
	6.059	−2.628	6.060	−2.439	6.059	−2.342
	3.154		3.433		3.540	
Ti II	−5.265		−5.265		−5.265	
4418	5.210	+0.085	5.230	+0.276	5.240	+0.372
1.23	5.215	−0.614	5.238	−0.423	5.252	−0.327
	5.291	−1.216	5.314	−1.025	5.327	−0.929
	5.579	−1.915	5.590	−1.724	5.595	−1.628
	5.794	−2.216	5.797	−2.025	5.799	−1.929
	3.350		3.541		3.637	
Ti II	−5.266		−5.266		−5.266	
4054	5.159	+0.018	5.177	+0.188	5.188	+0.277
1.88	5.154	−0.681	5.179	−0.511	5.192	−0.422
	5.254	−1.283	5.271	−1.113	5.284	−1.024
	5.559	−1.982	5.571	−1.812	5.578	−1.723
	5.783	−2.283	5.788	−2.113	5.789	−2.024
	3.284		3.454		3.543	

Table 1 – continued

ION λ_0 *E.P.*	MODEL I log $(W/\lambda)_{obs}$ −log W/λ	 log M	MODEL II log $(W/\lambda)_{obs}$ −log W/λ	 log M	MODEL III log $(W/\lambda)_{obs}$ −log W/λ	 log M
	−log L^*		−log L^*		−log L^*	
Ti II	−5.367		−5.367		−5.367	
4420	5.199	+0.124	5.217	+0.286	5.229	+0.368
2.59	5.202	−0.575	5.225	−0.413	5.239	−0.331
	5.318	−1.177	5.336	−1.015	5.346	−0.933
	5.645	−1.876	5.653	−1.714	5.660	−1.632
	5.876	−2.177	5.879	−2.015	5.880	−1.933
	3.491		3.653		3.735	
V I	−5.546		−5.546		−5.546	
4571	5.151	6.682	5.169	7.021	5.185	7.190
0.00	5.229	5.983	5.246	6.322	5.263	6.491
	5.394	5.381	5.404	5.720	5.417	5.889
	5.783	4.682	5.784	5.021	5.789	5.190
	6.036	4.381	6.034	4.720	6.035	4.889
	10.228		10.567		10.736	
V I	−5.044		−5.044		−5.044	
4423	5.086	7.160	5.103	7.489	5.110	7.654
0.27	5.154	6.461	5.165	6.790	5.182	6.955
	5.227	5.859	5.253	6.188	5.269	6.353
	5.468	5.160	5.480	5.489	5.491	5.654
	5.633	4.859	5.642	5.188	5.649	5.353
	10.204		10.533		10.708	
V I	−4.782		−4.615		−4.615	
4119	4.981	7.388	4.941	7.860	4.954	8.017
1.07	5.084	6.689	5.097	7.161	5.111	7.318
	5.156	6.087	5.155	6.559	5.171	6.716
	5.334	5.388	5.294	5.860	5.308	6.017
	5.468	5.087	5.409	5.559	5.419	5.716
	10.170		10.475		10.632	
V II	−5.023		−5.023		−5.023	
4003	5.130	+0.079	5.143	+0.241	5.159	+0.318
1.42	5.171	−0.620	5.193	−0.458	5.209	−0.381
	5.208	−1.222	5.234	−1.060	5.246	−0.983
	5.433	−1.921	5.449	−1.759	5.460	−1.682
	5.604	−2.222	5.613	−2.060	5.620	−1.983
	3.102		3.264		3.341	
V II	−5.208		−5.208		−5.208	
3870	5.135	−0.131	5.159	+0.022	5.169	+0.098
1.68	5.145	−0.830	5.172	−0.677	5.186	−0.601
	5.225	−1.432	5.253	−1.279	5.266	−1.203
	5.519	−2.131	5.533	−1.978	5.541	−1.902
	5.734	−2.432	5.740	−2.279	5.742	−2.203
	3.077		3.230		3.306	
V II	−5.279		−5.279		−5.279	
4565	5.225	+0.117	5.243	+0.268	5.256	+0.339
2.26	5.238	−0.582	5.257	−0.431	5.273	−0.360
	5.320	−1.184	5.339	−1.033	5.350	−0.962
	5.602	−1.883	5.615	−1.732	5.623	−1.661
	5.811	−2.184	5.816	−2.033	5.820	−1.962
	3.396		3.547		3.618	

Table 1 – continued

ION λ_0 E.P.	MODEL I log $(W/\lambda)_{obs}$ −log W/λ	log M	MODEL II log $(W/\lambda)_{obs}$ −log W/λ	log M	MODEL III log $(W/\lambda)_{obs}$ −log W/λ	log M
	−log L^*		−log L^*		−log L^*	
V II	−5.481		−5.481		−5.481	
4235	5.167	−0.068	5.188	+0.049	5.198	+0.113
3.74	5.198	−0.767	5.220	−0.650	5.229	−0.586
	5.348	−1.369	5.365	−1.252	5.370	−1.188
	5.725	−2.068	5.731	−1.951	5.728	−1.887
	5.971	−2.369	5.972	−2.252	5.965	−2.188
	3.413		3.531		3.594	
V II	−5.679		−5.679		−5.679	
4301	5.163	−0.218	5.187	−0.105	5.202	−0.050
4.00	5.237	−0.918	5.258	−0.804	5.274	−0.749
	5.433	−1.519	5.448	−1.406	5.457	−1.351
	5.883	−2.218	5.886	−2.105	5.887	−2.050
	6.147	−2.519	6.146	−2.406	6.145	−2.351
	3.459		3.574		3.629	
Cr I	−5.112		−5.112		−5.112	
4275	5.092	6.237	5.108	6.563	5.119	6.728
0.00	5.141	5.538	5.160	5.864	5.175	6.029
	5.237	4.936	5.256	5.262	5.270	5.427
	5.494	4.237	5.506	4.563	5.515	4.728
	5.676	3.396	5.682	4.262	5.687	4.427
	9.349		9.675		9.840	
Cr I	−5.128		−5.128		−5.128	
4026	5.015	6.379	5.034	6.644	5.048	6.782
2.52	5.095	5.680	5.118	5.945	5.135	6.083
	5.211	5.078	5.234	5.343	5.248	5.481
	5.486	4.379	5.501	4.644	5.509	4.782
	5.677	4.078	5.685	4.343	5.689	4.481
	9.507		9.772		9.910	
Cr I	−5.065		−5.065		−5.065	
4531	5.079	6.630	5.091	6.903	5.118	7.041
2.53	5.156	5.931	5.177	6.204	5.193	6.342
	5.249	5.329	5.271	5.602	5.287	5.740
	5.490	4.630	5.504	4.903	5.514	5.041
	5.655	4.329	5.666	4.602	5.676	4.740
	9.695		9.968		10.106	
Cr I	−5.305		−5.305		−5.305	
4239	5.067	6.329	5.076	6.589	5.091	6.721
3.00	5.151	5.630	5.166	5.890	5.181	6.022
	5.281	5.028	5.307	5.288	5.322	5.420
	5.602	4.329	5.611	4.589	5.621	4.721
	5.823	4.028	5.826	4.288	5.828	4.420
	9.634		9.894		10.026	
Cr I	−5.667		−5.667		−5.667	
4185	5.099	5.951	5.117	6.211	5.124	6.351
3.07	5.207	5.252	5.232	5.512	5.240	5.652
	5.418	4.650	5.431	4.910	5.438	5.050
	5.872	3.951	5.872	4.211	5.867	4.351
	6.138	3.650	6.134	3.910	6.126	4.050
	9.618		9.878		10.016	

Table 1 – continued

ION λ_0 E.P.	MODEL I $-\log W/\lambda$	MODEL I $\log M$	MODEL II $-\log W/\lambda$	MODEL II $\log M$	MODEL III $-\log W/\lambda$	MODEL III $\log M$
	$\log (W/\lambda)_{obs}$ / $-\log L^*$		$\log (W/\lambda)_{obs}$ / $-\log L^*$		$\log (W/\lambda)_{obs}$ / $-\log L^*$	
Cr I	−5.652		−5.652		−5.652	
4492	5.127	6.107	5.143	6.365	5.160	6.494
3.36	5.241	5.408	5.260	5.666	5.276	5.795
	5.435	4.806	5.450	5.064	5.460	5.193
	5.867	4.107	5.868	4.365	5.871	4.494
	6.128	3.806	6.125	4.064	6.126	4.193
	9.759		10.017		10.146	
Cr I	−5.824		−5.824		−5.824	
4001	5.083	5.794	5.113	6.033	5.128	6.158
3.87	5.233	5.095	5.254	5.334	5.274	5.459
	5.481	4.493	5.499	4.732	5.507	4.857
	6.002	3.794	6.002	4.033	6.001	4.158
	6.282	3.493	6.276	3.732	6.274	3.857
	9.618		9.857		9.982	
Cr I	−5.341		−5.341		−5.341	
4170	5.050	6.361	5.068	6.598	5.077	6.719
4.09	5.147	5.662	5.163	5.899	5.180	6.020
	5.288	5.060	5.308	5.297	5.330	5.418
	5.623	4.361	5.634	4.598	5.643	4.719
	5.851	4.060	5.854	4.297	5.857	4.418
	9.702		9.940		10.060	
Cr II	−4.766		−4.569		−4.569	
4082	5.043	−0.251	4.994	+0.061	5.004	+0.118
3.09	5.164	−0.950	5.178	−0.638	5.192	−0.581
	5.181	−1.552	5.197	−1.240	5.213	−1.183
	5.337	−2.251	5.298	−1.939	5.312	−1.882
	5.466	−2.552	5.401	−2.240	5.412	−2.183
	2.515		2.631		2.687	
Cr II	−5.180		−5.180		−5.180	
4086	5.131	−0.607	5.149	−0.498	5.163	−0.447
3.70	5.157	−1.306	5.180	−1.197	5.190	−1.146
	5.249	−1.908	5.270	−1.799	5.282	−1.748
	5.525	−2.607	5.537	−2.498	5.549	−2.447
	5.724	−2.908	5.730	−2.799	5.735	−2.748
	2.573		2.682		2.733	
Cr II	−4.895		−4.659		−4.659	
4555	5.118	−0.117	5.062	+0.221	5.073	+0.269
4.05	5.209	−0.816	5.230	−0.478	5.250	−0.430
	5.244	−1.418	5.250	−1.080	5.267	−1.032
	5.428	−2.117	5.366	−1.779	5.381	−1.731
	5.567	−2.418	5.475	−2.080	5.486	−2.032
	2.778		2.880		2.928	
Cr II	−5.149		−5.149		−5.149	
4225	5.108	−0.393	5.128	−0.314	5.142	−0.279
5.31	5.152	−1.092	5.171	−1.013	5.188	−0.978
	5.251	−1.694	5.272	−1.615	5.289	−1.580
	5.522	−2.393	5.535	−2.314	5.548	−2.279
	5.710	−2.694	5.719	−2.615	5.725	−2.580
	2.756		2.835		2.870	

Table 1 – continued

ION λ_0 E.P.	MODEL I log $(W/\lambda)_{obs}$		MODEL II log $(W/\lambda)_{obs}$		MODEL III log $(W/\lambda)_{obs}$	
	$-\log W/\lambda$	log M	$-\log W/\lambda$	log M	$-\log W/\lambda$	log M
	$-\log L^*$		$-\log L^*$		$-\log L^*$	
Cr II	−5.208		−5.208		−5.208	
4037	5.052	−0.452	5.078	−0.394	5.096	−0.368
6.46	5.117	−1.151	5.145	−1.093	5.163	−1.067
	5.249	−1.753	5.269	−1.695	5.285	−1.669
	5.550	−2.452	5.562	−2.394	5.571	−2.368
	5.750	−2.753	5.754	−2.695	5.761	−2.669
	2.756		2.814		2.840	
Mn I	−5.079		−5.079		−5.079	
4076	5.050	6.293	5.063	6.581	5.077	6.724
2.15	5.112	5.594	5.141	5.882	5.158	6.025
	5.215	4.992	5.236	5.280	5.252	5.423
	5.468	4.293	5.482	4.581	5.497	4.724
	5.647	3.992	5.655	4.280	5.663	4.423
	9.372		9.660		9.803	
Mn I	−5.309		−5.309		−5.309	
4477	5.120	6.286	5.134	6.562	5.146	6.702
2.90	5.192	5.587	5.212	5.863	5.227	6.003
	5.314	4.985	5.333	5.261	5.347	5.401
	5.621	4.286	5.631	4.562	5.641	4.702
	5.835	3.985	5.839	4.261	5.841	4.401
	9.595		9.871		10.011	
Mn I	−5.214		−5.214		−5.214	
4260	5.074	6.301	5.087	6.574	5.104	6.713
2.91	5.149	5.602	5.169	5.875	5.184	6.014
	5.268	5.000	5.288	5.273	5.303	5.412
	5.553	4.301	5.565	4.574	5.577	4.713
	5.755	4.000	5.760	4.273	5.774	4.412
	9.515		9.788		9.929	
Mn I	−5.287		−5.287		−5.287	
4458	5.113	6.317	5.126	6.589	5.140	6.727
3.06	5.186	5.618	5.207	5.890	5.215	6.028
	5.306	5.016	5.326	5.288	5.346	5.426
	5.607	4.317	5.621	4.589	5.628	4.727
	5.818	4.016	5.822	4.288	5.825	4.426
	9.604		9.877		10.014	
Mn II	−5.305		−5.305		−5.305	
4239	5.210	−0.897	5.228	−0.753	5.242	−0.686
1.82	5.210	−1.596	5.241	−1.452	5.257	−1.385
	5.307	−2.198	5.328	−2.054	5.339	−1.987
	5.607	−2.897	5.619	−2.753	5.629	−2.686
	5.827	−3.198	5.832	−3.054	5.835	−2.987
	2.408		3.252		3.619	
Mn II	−5.371		−5.371		−5.371	
4232	5.131	−0.670	5.147	−0.596	5.163	−0.565
5.37	5.182	−1.369	5.201	−1.295	5.219	−1.264
	5.328	−1.971	5.342	−1.897	5.357	−1.866
	5.662	−2.670	5.670	−2.596	5.678	−2.565
	5.884	−2.971	5.885	−2.897	5.890	−2.866
	2.701		2.775		2.806	

Table 1 — continued

ION	MODEL I		MODEL II		MODEL III	
λ_0	$\log (W/\lambda)_{obs}$		$\log (W/\lambda)_{obs}$		$\log (W/\lambda)_{obs}$	
E.P.	$-\log W/\lambda$	$\log M$	$-\log W/\lambda$	$\log M$	$-\log W/\lambda$	$\log M$
	$-\log L^*$		$-\log L^*$		$-\log L^*$	
Fe I	−5.158		−5.036		−5.036	
4455	5.153	6.801	5.138	7.266	5.143	7.437
0.09	5.194	6.102	5.207	6.567	5.221	6.738
	5.279	5.500	5.274	5.965	5.289	6.136
	5.536	4.801	5.492	5.266	5.502	5.437
	5.720	4.500	5.648	4.965	5.654	5.136
	9.959		10.302		10.473	
Fe I	−4.930		−4.754		−4.754	
4258	5.073	6.957	5.035	7.472	5.042	7.641
0.09	5.152	6.258	5.162	6.773	5.177	6.942
	5.215	5.656	5.214	6.171	5.229	6.340
	5.420	4.957	5.366	5.472	5.380	5.641
	5.565	4.656	5.488	5.171	5.498	5.340
	9.887		10.226		10.395	
Fe I	−4.560		−4.283		−4.283	
4033	4.927	7.390	4.852	7.967	4.869	8.117
1.54	5.087	6.691	5.066	7.268	5.078	7.418
	5.131	6.089	5.134	6.666	5.150	6.816
	5.270	5.390	5.224	5.967	5.241	6.117
	5.371	5.089	5.300	5.666	5.316	5.816
	9.950		10.251		10.400	
Fe I	−6.029		−6.029		−6.029	
4277	5.042	6.127	5.196	6.413	5.212	6.553
2.60	5.204	5.428	5.354	5.714	5.368	5.854
	5.490	4.826	5.631	5.112	5.641	5.252
	6.064	4.127	6.193	4.413	6.193	4.553
	6.348	3.826	6.476	4.112	6.474	4.252
	10.156		10.442		10.582	
Fe I	−5.928		−5.928		−5.928	
4238	5.150	6.252	5.170	6.527	5.186	6.663
3.00	5.301	5.553	5.321	5.828	5.332	5.964
	5.559	4.951	5.572	5.226	5.581	5.362
	6.102	4.252	6.102	4.527	6.102	4.663
	6.382	3.951	6.380	4.226	6.378	4.362
	10.180		10.455		10.591	
Fe I	−5.614		−5.614		−5.614	
4518	5.147	6.693	5.164	6.967	5.179	7.102
3.26	5.247	5.994	5.267	6.268	5.283	6.403
	5.428	5.392	5.444	5.666	5.454	5.801
	5.838	4.693	5.841	4.967	5.845	5.102
	6.095	4.392	6.094	4.666	6.094	4.801
	10.307		10.581		10.716	
Fe I	−5.658		−5.658		−5.658	
4552	5.149	6.722	5.167	6.980	5.182	7.109
3.93	5.260	6.023	5.275	6.281	5.290	6.410
	5.449	5.421	5.466	5.679	5.476	5.808
	5.875	4.722	5.879	4.980	5.882	5.109
	6.135	4.421	6.135	4.679	6.134	4.808
	10.380		10.638		10.767	

Table 1 – continued

ION λ_0 E.P.	MODEL I log $(W/\lambda)_{obs}$ / $-\log W/\lambda$	MODEL I $\log M$ / $-\log L^*$	MODEL II log $(W/\lambda)_{obs}$ / $-\log W/\lambda$	MODEL II $\log M$ / $-\log L^*$	MODEL III log $(W/\lambda)_{obs}$ / $-\log W/\lambda$	MODEL III $\log M$ / $-\log L^*$
Fe II	−5.327		−5.327		−5.327	
3822	5.138	−0.338	5.156	−0.219	5.170	−0.165
2.33	5.152	−1.037	5.175	−0.918	5.192	−0.864
	5.270	−1.639	5.291	−1.520	5.306	−1.466
	5.604	−2.338	5.615	−2.219	5.622	−2.165
	5.835	−2.639	5.839	−2.520	5.842	−2.466
	2.989		3.108		3.162	
Fe II	−5.049		−4.838		−4.838	
4481	5.179	+0.238	5.137	+0.561	5.147	+0.613
2.82	5.238	−0.461	5.266	−0.138	5.280	−0.086
	5.276	−1.063	5.277	−0.740	5.292	−0.688
	5.493	−1.762	5.433	−1.439	5.447	−1.387
	5.655	−2.063	5.558	−1.740	5.570	−1.688
	3.287		3.399		3.451	
Fe II	−5.327		−5.327		−5.327	
4031	5.117	−0.061	5.134	+0.012	5.152	+0.040
4.71	5.160	−0.760	5.181	−0.687	5.201	−0.659
	5.301	−1.362	5.310	−1.289	5.034	−1.261
	5.624	−2.061	5.634	−1.988	5.645	−1.960
	5.844	−2.362	5.847	−2.289	5.854	−2.261
	3.266		3.339		3.367	
Fe II	−5.011		−5.011		−5.011	
3900	5.035	+0.267	5.047	+0.314	5.062	+0.333
5.92	5.101	−0.432	5.120	−0.385	5.138	−0.366
	5.200	−1.034	5.222	−0.987	5.239	−0.968
	5.449	−1.733	5.470	−1.686	5.482	−1.667
	5.622	−2.034	5.636	−1.987	5.645	−1.968
	3.278		3.335		3.344	
Fe II	−5.238		−5.238		−5.238	
4500	5.090	+0.391	5.116	+0.394	5.124	+0.407
7.82	5.181	−0.308	5.211	−0.305	5.221	−0.292
	5.327	−0.910	5.353	−0.907	5.362	−0.894
	5.624	−1.609	5.650	−1.606	5.653	−1.593
	5.813	−1.910	5.835	−1.907	5.834	−1.894
	3.629		3.632		3.645	
Co I	−4.762		−4.611		−4.611	
3877	4.983	6.919	4.957	7.392	4.967	7.552
0.50	5.095	6.220	5.102	6.693	5.116	6.853
	5.152	5.618	5.150	6.091	5.169	6.251
	5.326	4.919	5.295	5.392	5.310	5.552
	5.456	4.618	5.402	5.091	5.413	5.251
	9.681		10.003		10.163	
Co I	−4.978		−4.757		−4.757	
3998	5.052	6.804	5.000	7.336	5.011	7.491
0.98	5.118	6.105	5.125	6.637	5.139	6.792
	5.199	5.503	5.189	6.035	5.204	6.190
	5.422	4.804	5.352	5.336	5.365	5.491
	5.583	4.503	5.478	5.035	5.492	5.190
	9.782		10.073		10.248	

Table 1 – continued

ION λ_0 E.P.	MODEL I log $(W/\lambda)_{obs}$ / −log W/λ	log M	MODEL II log $(W/\lambda)_{obs}$ / −log W/λ	log M	MODEL III log $(W/\lambda)_{obs}$ / −log W/λ	log M
	−log L^*		−log L^*		−log L^*	
Co I	−5.140		−5.140		−5.140	
4002	5.067	6.746	5.083	7.037	5.097	7.180
1.98	5.126	6.047	5.146	6.338	5.164	6.481
	5.233	5.445	5.254	5.736	5.270	5.879
	5.500	4.746	5.517	5.037	5.528	5.180
	5.692	4.445	5.699	4.736	5.706	4.879
	9.886		10.177		10.320	
Co I	−4.950		−4.813		−4.813	
4548	5.080	7.237	5.060	7.648	5.071	7.783
3.02	5.171	6.538	5.176	6.949	5.191	7.084
	5.253	5.936	5.248	6.347	5.264	6.482
	5.456	5.237	5.423	5.648	5.437	5.783
	5.598	4.936	5.547	5.347	5.558	5.482
	10.187		10.461		10.596	
Co I	−5.057		−5.057		−5.057	
4448	5.095	7.097	5.106	7.370	5.117	7.506
3.05	5.168	6.398	5.187	6.671	5.201	6.807
	5.264	5.796	5.285	6.069	5.300	6.205
	5.495	5.097	5.510	5.370	5.520	5.506
	5.659	4.796	5.669	5.069	5.678	5.205
	10.154		10.427		10.563	
Ga I	−4.786		−4.606		−4.606	
4033	5.019	5.472	4.980	5.940	4.992	6.080
0.10	5.141	4.773	5.137	5.241	5.152	5.381
	5.197	4.171	5.198	4.639	5.216	4.779
	5.376	3.472	5.339	3.940	5.355	4.080
	5.501	3.171	5.438	3.639	5.451	3.779
	8.258		8.546		8.684	
Sr II	−4.487		−4.268		−4.268	
4078	5.016	−0.166	4.939	+0.415	4.949	+0.600
0.00	5.243	−0.865	5.196	−0.284	5.205	−0.099
	5.279	−1.467	5.298	−0.886	5.312	−0.701
	5.335	−2.166	5.322	−1.585	5.338	−1.400
	5.419	−2.467	5.372	−1.886	5.387	−1.701
	2.321		2.683		2.868	
Y I	−5.247		−5.247		−5.247	
4236	5.177	6.709	5.180	7.161	5.187	7.397
0.07	5.245	6.010	5.256	6.462	5.273	6.698
	5.352	5.408	5.369	5.860	5.385	6.096
	5.614	4.709	5.623	5.161	5.638	5.397
	5.804	4.408	5.807	4.860	5.813	5.096
	9.956		10.408		10.644	
Y I	−5.421		−5.421		−5.421	
4477	5.210	6.763	5.222	7.190	5.234	7.416
1.35	5.289	6.064	5.306	6.491	5.323	6.717
	5.418	5.462	5.434	5.889	5.448	6.115
	5.725	4.763	5.735	5.190	5.742	5.416
	5.945	4.462	5.947	4.889	5.949	5.115
	10.184		10.611		10.837	

Table 1 – continued

ION	MODEL I		MODEL II		MODEL III	
λ_0	$\log (W/\lambda)_{obs}$		$\log (W/\lambda)_{obs}$		$\log (W/\lambda)_{obs}$	
E.P.	$-\log W/\lambda$	$\log M$	$-\log W/\lambda$	$\log M$	$-\log W/\lambda$	$\log M$
	$-\log L^*$		$-\log L^*$		$-\log L^*$	
Y II	−5.203		−5.203		−5.203	
4310	5.303	−0.308	5.306	+0.013	5.307	+0.182
0.18	5.334	−1.007	5.349	−0.686	5.362	−0.517
	5.374	−1.609	5.386	−1.288	5.400	−1.119
	5.599	−2.308	5.613	−1.987	5.622	−1.818
	5.776	−2.609	5.782	−2.288	5.788	−2.119
	2.895		3.226		3.385	
Y II	−5.616		−5.616		−5.616	
4125	5.316	−0.759	5.327	−0.445	5.337	−0.280
0.41	5.317	−1.458	5.335	−1.144	5.349	−0.979
	5.462	−2.060	5.481	−1.746	5.489	−1.581
	5.853	−2.759	5.856	−2.445	5.858	−2.280
	6.107	−3.060	6.107	−2.746	6.106	−2.581
	2.857		3.171		3.336	
Y II	−5.110		−4.796		−4.796	
4375	5.278	−0.165	5.176	+0.463	5.184	+0.628
0.41	5.344	−0.864	5.359	−0.236	5.370	−0.071
	5.367	−1.466	5.359	−0.838	5.373	−0.673
	5.564	−2.165	5.469	−1.537	5.479	−1.372
	5.718	−2.466	5.576	−1.838	5.586	−1.673
	2.945		3.259		3.424	
Zr I	−5.850		−5.850		−5.850	
4242	5.251	6.207	5.268	6.557	5.283	6.739
0.65	5.354	5.508	5.373	5.858	5.389	6.040
	5.569	4.906	5.581	5.256	5.591	5.438
	6.047	4.207	6.047	4.557	6.049	4.739
	6.317	3.906	6.315	4.256	6.315	4.438
	10.057		10.407		10.589	
Zr II	−5.415		−5.415		−5.415	
4156	5.327	−0.436	5.339	−0.225	5.351	−0.119
0.71	5.323	−1.135	5.344	−0.924	5.359	−0.818
	5.412	−1.737	5.425	−1.526	5.439	−1.420
	5.712	−2.436	5.720	−2.225	5.728	−2.119
	5.936	−2.737	5.937	−2.526	5.940	−2.420
	2.979		3.190		3.296	
Zr II	−5.936		−5.936		−5.936	
4317	5.351	−0.897	5.371	−0.685	5.385	−0.577
0.71	5.405	−1.596	5.428	−1.384	5.441	−1.276
	5.620	−2.198	5.634	−1.986	5.642	−1.878
	6.126	−2.897	6.126	−2.685	6.126	−2.577
	6.401	−3.198	6.399	−2.986	6.397	−2.878
	3.039		3.251		3.359	
Zr II	−5.574		−5.574		−5.574	
4497	5.393	−0.470	5.408	−0.257	5.419	−0.148
0.71	5.380	−1.169	5.394	−0.956	5.409	−0.847
	5.488	−1.771	5.505	−1.558	5.517	−1.449
	5.844	−2.470	5.840	−2.257	5.844	−2.148
	6.077	−2.771	6.078	−2.558	6.078	−2.449
	3.104		3.317		3.426	

Table 1 – continued

ION λ *E.P.*	MODEL I log $(W/\lambda)_{obs}$ $-\log W/\lambda$	 $\log M$	MODEL II log $(W/\lambda)_{obs}$ $-\log W/\lambda$	 $\log M$	MODEL III log $(W/\lambda)_{obs}$ $-\log W/\lambda$	 $\log M$
	$-\log L^*$		$-\log L^*$		$-\log L^*$	
Zr II	−5.472		−5.472		−5.472	
4443	5.359	−0.306	5.378	−0.109	5.387	−0.007
1.48	5.356	−1.005	5.381	−0.808	5.396	−0.706
	5.453	−1.607	5.471	−1.410	5.483	−1.308
	5.761	−2.306	5.770	−2.109	5.776	−2.007
	5.989	−2.607	5.991	−2.410	5.992	−2.308
	3.166		3.363		3.465	
La II	−4.952		−4.952		−4.952	
4032	5.262	−0.147	5.266	+0.111	5.274	+0.246
0.32	5.406	−0.846	5.412	−0.588	5.422	−0.453
	5.395	−1.448	5.413	−1.190	5.426	−1.055
	5.538	−2.147	5.550	−1.889	5.563	−1.754
	5.659	−2.448	5.674	−2.190	5.684	−2.055
	2.805		3.063		3.198	
La II	−4.972		−4.972		−4.972	
4220	5.288	−0.093	5.292	+0.168	5.299	+0.303
0.36	5.436	−0.792	5.441	−0.531	5.450	−0.396
	5.423	−1.394	5.439	−1.133	5.452	−0.998
	5.563	−2.093	5.574	−1.832	5.586	−1.697
	5.682	−2.394	5.697	−2.133	5.706	−1.998
	2.889		3.140		3.275	
La II	−4.943		−4.943		−4.943	
3949	5.245	−0.161	5.254	+0.094	5.261	+0.227
0.40	5.391	−0.860	5.397	−0.605	5.407	−0.472
	5.388	−1.463	5.400	−1.207	5.414	−1.074
	5.527	−2.161	5.540	−1.906	5.552	−1.773
	5.649	−2.463	5.660	−2.207	5.674	−2.074
	2.782		3.037		3.170	
La II	−4.808		−4.808		−4.808	
3855	5.184	−0.024	5.195	+0.221	5.202	+0.350
0.77	5.364	−0.723	5.369	−0.478	5.385	−0.349
	5.360	−1.325	5.377	−1.080	5.385	−0.951
	5.473	−2.024	5.486	−1.779	5.500	−1.650
	5.583	−2.325	5.595	−2.080	5.605	−1.951
	2.784		3.029		3.158	
La II	−5.002		−5.002		−5.002	
4526	5.323	+0.030	5.327	+0.287	5.334	+0.420
0.77	5.472	−0.669	5.477	−0.412	5.487	−0.279
	5.460	−1.271	5.476	−1.014	5.489	−0.881
	5.597	−1.970	5.610	−1.713	5.622	−1.580
	5.718	−2.271	5.732	−2.014	5.741	−1.881
	3.032		3.289		3.422	
La II	−5.326		−5.326		−5.326	
4240	5.366	−0.264	5.373	−0.030	5.380	+0.080
1.95	5.404	−0.963	5.409	−0.737	5.421	−0.619
	5.461	−1.565	5.474	−1.339	5.489	−1.221
	5.705	−2.264	5.719	−2.038	5.728	−1.920
	5.889	−2.565	5.896	−2.339	5.901	−2.221
	3.062		3.288		3.406	

Table 1 – continued

ION λ_0 E.P.	MODEL I log $(W/\lambda)_{obs}$ −log W/λ	log M −log L^*	MODEL II log $(W/\lambda)_{obs}$ −log W/λ	log M −log L^*	MODEL III log $(W/\lambda)_{obs}$ −log W/λ	log M −log L^*
Ce II	−5.213		−5.213		−5.213	
4081	5.380	+0.199	5.390	+0.376	5.398	+0.457
0.00	5.436	−0.500	5.459	−0.323	5.473	−0.242
	5.447	−1.102	5.463	−0.925	5.478	−0.844
	5.646	−1.801	5.664	−1.624	5.674	−1.543
	5.810	−2.102	5.820	−1.925	5.827	−1.844
	3.412		3.589		3.670	
Ce II	−4.980		−4.980		−4.980	
4297	5.316	+0.514	5.330	+0.693	5.338	+0.775
0.04	5.474	−0.185	5.492	−0.006	5.505	+0.076
	5.457	−0.787	5.479	−0.608	5.494	−0.526
	5.579	−1.486	5.596	−1.307	5.609	−1.225
	5.699	−1.787	5.712	−1.608	5.723	−1.526
	3.494		3.673		3.755	
Ce II	−4.997		−4.997		−4.997	
4471	5.337	+0.578	5.350	+0.755	5.358	+0.836
0.22	5.495	−0.121	5.513	+0.056	5.527	+0.137
	5.479	−0.723	5.500	−0.546	5.515	−0.465
	5.600	−1.422	5.616	−1.245	5.627	−1.164
	5.719	−1.723	5.732	−1.546	5.742	−1.465
	3.575		3.752		3.833	
Ce II	−5.109		−5.109		−5.109	
4117	5.336	+0.403	5.346	+0.560	5.355	+0.630
0.87	5.427	−0.296	5.450	−0.139	5.464	−0.069
	5.430	−0.898	5.447	−0.741	5.462	−0.671
	5.609	−1.597	5.625	−1.440	5.638	−1.370
	5.752	−1.898	5.764	−1.741	5.774	−1.671
	3.512		3.670		3.739	
Ce II	−5.042		−5.042		−5.042	
4411	5.345	+0.579	5.354	+0.740	5.363	+0.812
0.87	5.475	−0.120	5.493	+0.041	5.507	+0.113
	5.464	−0.722	5.486	−0.561	5.501	−0.489
	5.610	−1.421	5.625	−1.260	5.639	−1.188
	5.734	−1.722	5.751	−1.561	5.762	−1.489
	3.621		3.782		3.854	
Ce II	−4.741		−4.741		−4.741	
3855	5.178	+0.595	5.193	+0.763	5.203	+0.840
0.17	5.380	−0.104	5.396	+0.064	5.409	+0.141
	5.383	−0.706	5.407	−0.538	5.424	−0.461
	5.463	−1.405	5.485	−1.237	5.500	−1.160
	5.563	−1.706	5.579	−1.538	5.593	−1.461
	3.336		3.504		3.581	
Ce II	−4.766		−4.766		−4.766	
4080	5.208	+0.689	5.223	+0.854	5.236	+0.928
0.46	5.412	−0.010	5.428	+0.155	5.440	+0.229
	5.415	−0.612	5.440	−0.447	5.456	−0.373
	5.494	−1.311	5.515	−1.146	5.531	−1.072
	5.592	−1.612	5.609	−1.447	5.623	−1.373
	3.455		3.620		3.694	

Table 1 – continued

ION λ_0 E.P.	MODEL I $\log (W/\lambda)_{obs}$ $-\log W/\lambda$	MODEL I $\log M$	MODEL II $\log (W/\lambda)_{obs}$ $-\log W/\lambda$	MODEL II $\log M$	MODEL III $\log (W/\lambda)_{obs}$ $-\log W/\lambda$	MODEL III $\log M$
	($-\log L^*$)		($-\log L^*$)		($-\log L^*$)	
Ce II	−4.987		−4.987		−4.987	
4370	5.319	+0.601	5.333	+0.766	5.335	+0.842
0.70	5.470	−0.098	5.448	+0.067	5.499	+0.143
	5.453	−0.700	5.481	−0.535	5.494	−0.459
	5.583	−1.399	5.605	−1.234	5.617	−1.158
	5.705	−1.700	5.722	−1.535	5.731	−1.459
	3.588		3.753		3.829	
Ce II	−4.968		−4.968		−4.968	
4180	5.294	+0.552	5.307	+0.713	5.315	+0.788
0.72	5.441	−0.147	5.459	+0.014	5.470	+0.089
	5.427	−0.749	5.449	−0.588	5.463	−0.513
	5.562	−1.448	5.578	−1.287	5.590	−1.212
	5.683	−1.749	5.751	−1.588	5.710	−1.513
	3.520		3.681		3.756	
Pr II	−5.034		−5.034		−5.034	
4330	5.339	+0.160	5.351	+0.348	5.357	+0.438
0.20	5.471	−0.539	5.491	−0.351	5.502	−0.261
	5.461	−1.141	5.476	−0.953	5.489	−0.863
	5.598	−1.840	5.614	−1.652	5.622	−1.562
	5.726	−2.141	5.738	−1.953	5.745	−1.863
	3.194		3.381		3.472	
Pr II	−4.941		−4.941		−4.941	
3930	5.261	+0.132	5.273	+0.306	5.281	+0.391
0.50	5.413	−0.567	5.429	−0.393	5.440	−0.308
	5.397	−1.169	5.414	−0.995	5.427	−0.910
	5.529	−1.868	5.548	−1.694	5.560	−1.609
	5.651	−2.169	5.668	−1.995	5.677	−1.910
	3.073		3.247		3.332	
Eu II	−5.184		−5.184		−5.184	
3820	5.327	−0.739	5.327	−0.463	5.334	−0.319
0.00	5.380	−1.438	5.382	−1.162	5.402	−1.018
	5.404	−2.040	5.421	−1.764	5.436	−1.620
	5.618	−2.739	5.634	−2.463	5.644	−2.319
	5.780	−3.040	5.788	−2.764	5.795	−2.620
	2.445		2.721		2.685	
Eu II	−5.115		−5.115		−5.115	
3907	5.318	−0.634	5.320	−0.358	5.324	−0.212
0.00	5.405	−1.333	5.407	−1.057	5.416	−0.911
	5.406	−1.935	5.425	−1.659	5.437	−1.513
	5.595	−2.634	5.612	−2.358	5.621	−2.212
	5.743	−2.935	5.752	−2.659	5.760	−2.513
	2.481		2.757		2.903	
Eu II	−4.444		−4.444		−4.444	
4165	5.082	+0.130	5.099	+0.408	5.108	+0.554
0.00	5.342	−0.569	5.366	−0.291	5.372	−0.145
	5.445	−1.171	5.465	−0.893	5.475	−0.747
	5.450	−1.870	5.469	−1.592	5.483	−1.446
	5.506	−2.171	5.525	−1.893	5.538	−1.747
	2.574		2.852		2.998	

Table 1 – continued

ION λ_0 *E.P.*	MODEL I log $(W/\lambda)_{obs}$ −log W/λ	MODEL I log M[1] −log L^*	MODEL II log $(W/\lambda)_{obs}$ −log W/λ	MODEL II log M −log L^*	MODEL III log $(W/\lambda)_{obs}$ −log W/λ	MODEL III log M −log L^*
Eu II	−4.339		−4.339		−4.339	
3930	5.024	+0.166	5.035	+0.438	5.046	+0.579
0.21	5.303	−0.533	5.300	−0.261	5.308	−0.120
	5.410	−1.135	5.415	−0.863	5.426	−0.722
	5.409	−1.834	5.427	−1.562	5.442	−1.421
	5.458	−2.135	5.476	−1.863	5.492	−1.722
	2.505		2.777		2.918	
Eu II	−5.170		−5.170		−5.170	
4435	5.387	−0.472	5.391	−0.191	5.395	−0.044
0.21	5.475	−1.171	5.490	−0.890	5.499	−0.743
	5.479	−1.773	5.495	−1.492	5.507	−1.345
	5.665	−2.472	5.676	−2.191	5.683	−2.044
	5.806	−2.773	5.816	−2.492	5.821	−2.345
	2.698		2.979		3.126	
Eu II	−4.257		−4.257		−4.257	
4522	5.048	+0.462	5.060	+0.743	5.071	+0.887
0.21	5.323	−0.237	5.333	+0.044	5.340	+0.188
	5.489	−0.839	5.493	−0.558	5.510	−0.414
	5.486	−1.538	5.502	−1.257	5.516	−1.113
	5.515	−1.839	5.531	−1.558	5.546	−1.414
	2.719		3.000		3.144	
Eu II	−5.117		−5.117		−5.117	
3929	5.301	−0.492	5.306	−0.243	5.313	−0.112
1.24	5.380	−1.191	5.384	−0.942	5.406	−0.811
	5.403	−1.793	5.422	−1.544	5.437	−1.413
	5.600	−2.492	5.612	−2.243	5.623	−2.112
	5.745	−2.793	5.757	−2.544	5.765	−2.413
	2.625		2.874		3.005	
Gd II	−4.680		−4.680		−4.680	
3834	5.167	+0.265	5.177	+0.448	5.189	+0.536
0.05	5.398	−0.434	5.411	−0.251	5.421	−0.163
	5.412	−1.036	5.433	−0.853	5.447	−0.765
	5.463	−1.735	5.484	−1.552	5.499	−1.464
	5.552	−2.036	5.569	−1.853	5.580	−1.765
	2.945		3.128		3.226	
Gd II	−4.278		−4.278		−4.278	
4170	5.034	+0.836	5.051	+1.014	5.063	+1.100
0.45	5.318	+0.137	5.332	+0.315	5.342	+0.401
	5.471	−0.465	5.492	−0.287	5.504	−0.201
	5.466	−1.164	5.489	−0.986	5.505	−0.900
	5.491	−1.465	5.513	−1.287	5.528	−1.201
	3.114		3.292		3.378	
Gd II	−4.522		−4.522		−4.522	
4490	5.152	+0.800	5.167	+0.963	5.178	+1.040
1.33	5.427	+0.101	5.441	+0.264	5.450	+0.341
	5.509	−0.501	5.529	−0.338	5.542	−0.261
	5.513	−1.200	5.536	−1.037	5.551	−0.960
	5.571	−1.501	5.587	−1.338	5.602	−1.261
	3.322		3.485		3.562	

Table 1 – continued

ION λ_0 *E.P.*	MODEL I log $(W/\lambda)_{obs}$ −log W/λ	 log M	MODEL II log $(W/\lambda)_{obs}$ −log W/λ	 log M	MODEL III log $(W/\lambda)_{obs}$ −log W/λ	 log M
	−log L^*		−log L^*		−log L^*	
Gd II	−5.073		−5.073		−5.073	
4141	5.330	+0.152	5.348	+0.305	5.353	+0.377
1.57	5.444	−0.547	5.464	−0.394	5.477	−0.322
	5.445	−1.149	5.468	−1.695	5.484	−0.924
	5.607	−1.848	5.628	−1.695	5.641	−1.623
	5.743	−2.149	5.761	−1.996	5.771	−1.924
	3.225		3.378		3.450	
Hg I	−4.813		−4.813		−4.813	
4358	5.259	5.385	5.272	5.783	5.285	5.978
4.87	5.466	4.686	5.478	5.084	5.491	5.279
	5.484	4.084	5.499	4.482	5.515	4.677
	5.572	3.385	5.597	3.783	5.611	3.978
	5.669	3.084	5.681	3.482	5.699	3.677
	8.198		8.596		8.891	