Peculiar Versus Normal Phenomena in A-Type and Related Stars
ASP Conference Series, Vol. 44, 1993
M.M. Dworetsky, F. Castelli, and R. Faraggiana (eds.)

NON-LTE ANALYSIS OF CNO LINES IN VEGA

YOICHI TAKEDA
Institute of Astronomy, The University of Tokyo,
Mitaka, Tokyo, 181 Japan

ABSTRACT Non-LTE calculations for neutral C, N, and O are performed to determine the accurate abundances of these elements in the atmosphere of Vega by taking the non-LTE effects realistically into consideration. It is shown that C and O are mildly deficient by ~0.2–0.3dex while N shows an appreciably large underabundance by ~0.8dex.

1. INTRODUCTION

It is nowadays believed that Vega, the well-known A0V star, has a kind of abundance anomaly. That is; any of the recent spectroscopic analyses indicate an appreciable metal-deficiency in the atmosphere of this star. The key to an understanding of this abundance peculiarity (e.g., in connection with the characteristics of λ Bootis stars) may be the abundances of important light elements such as C, N, and O. Therefore, our aim is to determine the accurate photospheric abundances of these elements based on the statistical-equilibrium calculations which allow us to take the non-LTE effect realistically into consideration.

2. NON-LTE CALCULATIONS

The procedure of the non-LTE calculation is basically the same as that described in Takeda(1991), which is founded on the method of accelerated lambda iteration (ALI). Regarding the atomic data necessary for constructing the model atoms, we relied mostly on the extensive compilation of Kurucz and Peytremann(1975). As a result of the conventional treatment that lines belonging to the same multiplet are adequately combined into one radiative transition, our atomic models comprise 2351/2119/294 radiative transitions and 129/119/86 terms for (neutral) C/N/O. Owing to the distinguished superiority of the ALI method, we could treat *all of these explicitly* without any difficulty. As to the model atmospheres, we adopted two Kurucz's(1979) line-blanketed models (with T_{eff}=9500K and logg=4.0) which differ in metal-content as $[X/X_{\odot}]$=0.0 (1× model) and −1.0 (1/10× model), hoping that the metallicities of these two models adequately encompass that of Vega ([Fe/H]~−0.6; see, e.g., Gigas 1986). With regard to the microturbulent velocity, we assumed a depth-independent value of $2\mathrm{km \cdot s^{-1}}$, which was used also in abundance determinations after calculating the non-LTE departure coefficients.

3. ABUNDANCES

The results of the derived abundances are presented in tables I(C), II(N), and III(O), where $\Delta\log\varepsilon$, $\log\varepsilon$, and $\log\bar{\tau}$ denote the abundance correction ($\log\varepsilon_{NLTE}-\log\varepsilon_{LTE}$), the non-LTE abundance ($\log\varepsilon_{NLTE}$), and the mean depth of line-formation defined by equation(1) in Takeda(1992), respectively. [The first and the second column in the tables show the multiplet number and the term combination (term numbers are designated in increasing order of excitation potentials).] The gf values used for the analysis were taken from Stürenburg and Holweger(1990), Hibbert et al.(1991), and Wiese et al.(1966) for C, N, and O, respectively. Regarding the observational data of equivalent widths, we adopted the values published by Lambert et al.(1982). From these tables, we obtain $\log\varepsilon$(C)=8.38±0.12, $\log\varepsilon$(N)=7.52±0.14, and $\log\varepsilon$(O)=8.64±0.14 for the 1× model; and $\log\varepsilon$(C)=8.31±0.18, $\log\varepsilon$(N)=6.98±0.13, and $\log\varepsilon$(O)=8.50±0.17 for the 1/10× model. [Note the particularly large metallicity-dependence in the case of N. It is also worth to mention that our results for C (1× model) agree well with those of Stürenburg and Holweger(1990)]. Considering the amount of metal-deficiency (~−0.6dex), we may conclude the CNO abundances of Vega to be $\log\varepsilon$(C)~8.3–8.4, $\log\varepsilon$(N)~7.2, and $\log\varepsilon$(O)~8.6; that is, *C and O are only mildly underabundant by ~0.2–0.3dex while N shows a rather large deficiency by ~0.8dex as compared to the Sun.* This is an interesting and important observational fact, which has to be reasonably explained by any theories attempting to understand the abundance peculiarities of Vega. It should finally be pointed out that the present result, such light elements being underabundant in Vega, does not conform to the general characteristics of λ Bootis stars (showing normal or slightly overabundant C, N, and O; cf. Baschek and Slettebak 1988), in spite of the similar amount of deficiency in other heavier elements.

https://doi.org/10.1017/S0252921100020947 Published online by Cambridge University Press

Table I. Carbon abundances from CI lines.

RMT	l-u	λ(Å)	χ(eV)	$\log gf$	W_λ(mÅ)	$\Delta\log\varepsilon$	$\log\varepsilon$	$\log\bar{\tau}$	$\Delta\log\varepsilon$	$\log\varepsilon$	$\log\bar{\tau}$
						(1× model)			(1/10× model)		
1	5-9	10691.2	7.49	+0.33	280	-0.80	8.38	-2.29	-0.88	8.32	-2.10
1	5-9	10683.1	7.48	+0.06	254	-0.71	8.48	-2.15	-0.84	8.37	-1.98
1	5-9	10685.4	7.48	-0.29	218	-0.55	8.59	-1.94	-0.69	8.44	-1.80
1	5-9	10729.5	7.49	-0.43	153	-0.28	8.26	-1.49	-0.38	8.08	-1.41
1	5-9	10707.4	7.48	-0.43	169	-0.35	8.38	-1.61	-0.47	8.19	-1.51
1	5-9	10754.0	7.49	-1.60	38	-0.07	8.34	-0.56	-0.10	8.19	-0.54
3	5-11	9111.88	7.49	-0.40	186	-0.39	8.44	-1.61	-0.52	8.23	-1.48
3	5-11	9088.51	7.48	-0.51	168	-0.33	8.40	-1.47	-0.45	8.20	-1.37
5	5-25	4826.73	7.49	-2.31	5	-0.03	8.24	+0.02	-0.04	8.12	+0.02
5	5-25	4817.33	7.48	-2.53	6	-0.03	8.53	+0.01	-0.04	8.42	+0.01
6	5-26	4771.75	7.49	-1.70	23	-0.03	8.34	-0.07	-0.04	8.23	-0.07
6	5-26	4766.62	7.48	-2.40	6	-0.03	8.40	+0.03	-0.04	8.29	+0.02
6	5-26	4775.87	7.49	-2.20	7	-0.03	8.28	+0.02	-0.03	8.17	+0.02
6	5-26	4762.54	7.48	-1.94	15	-0.03	8.37	-0.02	-0.04	8.25	-0.02
11	6-23	5380.32	7.68	-1.68	19	-0.01	8.37	-0.19	+0.20	8.48	-0.24
12	6-27	5052.16	7.68	-1.49	31	-0.01	8.43	-0.20	+0.19	8.52	-0.28
17	6-47	4228.33	7.68	-2.22	9	-0.01	8.54	+0.15	+0.10	8.55	+0.14
20	8-19	10541.2	8.54	-1.29	32	-0.03	8.61	-0.52	+0.35	8.88	-0.70
20.01	8-21	10123.9	8.54	-0.11	118	-0.12	8.34	-1.18	*****	****	*****
22	8-40	6587.64	8.54	-1.34	11	-0.02	8.33	-0.36	+0.19	8.43	-0.39
25.02	9-30	7116.99	8.65	-0.68	21	-0.04	8.06	-0.51	-0.02	7.98	-0.51
25.02	9-30	7119.67	8.64	-0.95	21	-0.04	8.32	-0.51	-0.02	8.24	-0.51
26	9-31	7115.19	8.64	-1.03	21	-0.04	8.40	-0.51	-0.02	8.32	-0.51
26	9-31	7113.18	8.65	-0.87	20	-0.04	8.22	-0.50	-0.02	8.14	-0.50
26	9-31	7111.48	8.64	-1.20	14	-0.04	8.37	-0.46	-0.02	8.29	-0.46

Table II. Nitrogen abundances from NI lines.

RMT	l-u	λ(Å)	χ(eV)	$\log gf$	W_λ(mÅ)	$\Delta\log\varepsilon$	$\log\varepsilon$	$\log\bar{\tau}$	$\Delta\log\varepsilon$	$\log\varepsilon$	$\log\bar{\tau}$
						(1× model)			(1/10× model)		
1	4-8	8683.40	10.33	+0.116	70	-0.29	7.43	-0.57	-0.88	6.82	-0.54
1	4-8	8686.16	10.33	-0.273	39	-0.24	7.46	-0.37	-0.79	6.88	-0.33
1	4-8	8718.84	10.34	-0.337	38	-0.24	7.51	-0.37	-0.80	6.93	-0.33
1	4-8	8711.71	10.33	-0.221	52	-0.28	7.56	-0.45	-0.83	6.98	-0.40
1	4-8	8703.26	10.33	-0.299	47	-0.26	7.58	-0.42	-0.82	7.00	-0.37
2	4-9	8216.32	10.34	+0.147	68	-0.28	7.37	-0.51	-0.85	6.78	-0.48
2	4-9	8210.71	10.33	-0.668	16	-0.20	7.39	-0.20	-0.74	6.83	-0.18
2	4-9	8184.85	10.33	-0.296	26	-0.36	7.54	-0.65	-0.97	6.91	-0.62
2	4-9	8188.01	10.33	-0.290	23	-0.35	7.48	-0.64	-0.96	6.84	-0.61
3	4-10	7468.31	10.34	-0.171	46	-0.38	7.71	-0.69	-0.99	7.08	-0.66
3	4-10	7442.30	10.33	-0.386	30	-0.33	7.68	-0.58	-0.92	7.06	-0.55
3	4-10	7423.64	10.33	-0.713	21	-0.31	7.82	-0.53	-0.91	7.20	-0.50
7	5-11	9392.79	10.69	+0.328	81	-0.37	7.55	-0.71	-0.65	7.25	-0.88
8	5-12	8629.24	10.69	+0.090	53	-0.27	7.46	-0.43	-0.57	7.14	-0.48
8	5-12	8594.00	10.68	-0.320	16	-0.20	7.26	-0.24	-0.53	6.91	-0.24
8	5-12	8655.87	10.69	-0.603	9	-0.20	7.28	-0.21	-0.52	6.94	-0.21
18	8-17	10114.6	11.76	+0.778	53	-0.25	7.52	-0.60	-0.80	6.96	-0.57
18	8-17	10112.5	11.76	+0.623	47	-0.24	7.60	-0.56	-0.78	7.05	-0.53
18	8-17	10108.9	11.75	+0.443	36	-0.23	7.62	-0.50	-0.76	7.07	-0.47

Table III. Oxygen abundances from OI lines.

RMT	*l*–u	λ(Å)	χ(eV)	log*gf*	W_λ(mÅ)	Δlogε	logε	log$\bar{\tau}$	Δlogε	logε	log$\bar{\tau}$
						(1× model)			(1/10× model)		
1	4–6	7771.83	9.15	+0.333	235	−1.02	8.78	−2.42	−1.37	8.52	−2.35
1	4–6	7774.05	9.15	+0.186	402	−0.96	8.77	−2.17	−1.34	8.46	−2.04
		7775.27		−0.035							
4	5–7	8446.23	9.52	+0.175	405	−0.62	8.48	−1.55	−0.87	8.24	−1.46
		8446.63		−0.047							
		8446.12		−0.524							
8	6–10	9260.80	10.74	−0.025	168	−0.37	8.62	−1.17	−0.50	8.46	−1.08
		9260.71		+0.085							
		9260.67		−0.268							
8	6–10	9262.64	10.74	+0.401	199	−0.40	8.52	−1.23	−0.56	8.36	−1.13
		9262.53		+0.197							
		9262.44		−0.393							
8	6–10	9265.87	10.74	+0.69	175	−0.40	8.34	−1.25	−0.53	8.19	−1.17
		9265.79		+0.100							
		9265.69		−0.75							
10	6–18	6155.90	10.74	−1.158	83	−0.07	8.67	−0.44	−0.12	8.61	−0.42
		6155.88		−1.047							
		6155.87		−1.399							
		6156.68		−0.731							
		6156.66		−0.934							
		6156.64		−1.524							
10	6–18	6158.09	10.74	−0.445	59	−0.08	8.63	−0.52	−0.12	8.57	−0.50
		6158.08		−1.031							
		6158.06		−1.877							
12	6–27	5329.03	10.74	−1.83	30	−0.04	8.75	−0.17	−0.07	8.71	−0.16
		5329.02		−1.72							
		5329.01		−2.077							
		5329.61		−1.407							
		5329.60		−1.61							
		5329.59		−2.203							
12	6–27	5330.66	10.74	−1.124	22	−0.03	8.71	−0.21	−0.08	8.66	−0.20
		5330.65		−1.71							
		5330.64		−2.55							
21	7–19	7002.12	10.99	−0.78	44	−0.07	8.77	−0.52	−0.15	8.69	−0.50
		7002.09		−1.53							
		7002.07		−2.70							
		7001.82		−1.05							
		7001.79		−1.53							
		7002.14		−1.40							

REFERENCES

Baschek, B., and Slettebak, A. 1988, A&A, **207**, 112.
Gigas, D. 1986, A&A, **165**, 170.
Hibbert, A., Biémont, E., Godefroid, M., and Vaeck, N. 1991, A&AS, **88**, 505.
Kurucz, R.L. 1979, ApJS, **40**, 1.
Kurucz, R.L., and Peytremann, E. 1975, Smithsonian Astrophys. Obs. Spec. Rept., No.362.
Lambert, D.L., Roby, S.W., and Bell, R.A. 1982, ApJ, **254**, 663.
Stürenburg, S., and Holweger, H. 1990, A&A, **237**, 125. [Erratum in A&A **246**, 644 (1991).]
Takeda, Y. 1991, A&A, **242**, 455.
Takeda, Y. 1992, A&A, **253**, 487.
Wiese, W.L., Smith, M.W., and Glennon, B.M. 1966, *Atomic Transition Probabilities Vol.I)* *– Hydrogen Through Neon, NSRDS–NBS4*, (U.S. Government Printing Office, Washington, D.C.).

https://doi.org/10.1017/S0252921100020947 Published online by Cambridge University Press

DISCUSSION (Takeda)

LEMKE: Do you find any different abundance corrections for the oxygen triplet lines at 7773 Å and the forbidden line at about 6300 Å?
TAKEDA: Unfortunately, the forbidden line O I 6300 Å for Vega was not observed by Lambert et al. (1982), on which my analysis was based. However, according to my NLTE analysis for Procyon (α CMi), using the data of Tomkin and Lambert (1978), the abundance corrections $\Delta \log \epsilon$ turns out to be ≈ 0.0 for 6300 Å and ≈ 0.3 for 7773 Å, which results in the mutually consistent non-LTE abundances $\log \epsilon_{NLTE}$ (6300) $\approx \log \epsilon_{NLTE}$ (7773).
HUBENY: Were C II levels considered in your NLTE study of C I? NLTE in C II may influence considerably the departure coefficients of the C I levels.
TAKEDA: C II levels were considered in the conservation equation of total number of atoms. But I assumed the equality of departure coefficients for these levels. This is a reasonable assumption, since the C II levels which affect the results for C I are several low-excitation terms which are only collisionally coupled with each other (because they are of the same parity). That is, collisional shuffling leads to the equality of b-values for these terms. It should be noted that most of the C II population occupies these low-excitation states, as the other levels are located above about 10 ev. They are also the parent terms of all C I levels. Therefore, my assumption is valid and does not cause serious problems. But it is true that b-values of the high-excitation C II levels (e.g., upper levels of the strong resonance lines) depart significantly from those of the low-excitation C II levels, although they do not affect the results for C I due to the reasons just mentioned.
HUBENY: A word of caution: carbon is the second most important continuous opacity source in the A-type atmospheres (and the most important one in the far UV), so treating carbon as a trace element may be dangerous.
TAKEDA: I quite agree with you. Improved treatment of the photoionizing radiation fields are desirable.

https://doi.org/10.1017/S0252921100020947 Published online by Cambridge University Press