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Abundance Anomalies of Carbon and Nitrogen in the IUE Spectra of Algol-type Interacting Binaries

I. Introduction

There are two primary ways in which the products of nucleosynthesis in stellar interiors may appear at the surface of a star. These are mixing and/or loss of the original unburned stellar envelope. In interacting binaries, overflow can contribute dramatically to envelope loss. The simplest abundance anomalies to be expected from nuclear burning of hydrogen, helium, or carbon would be under or over abundances of H, He, C, O, Ne, and Mg. In addition, it is expected that carbon is initially severely depleted while nitrogen is enhanced during hydrogen-burning via the CNO cycle in stars above 2 solar masses. Other, more subtle anomalies are also expected and elements heavier than magnesium can be created during very late evolution by nuclear burning in massive stars. Consequently, it is expected that abundance anomalies of various kinds should occur in interacting binaries where or both stars have lost significant amounts of mass.

The cool subgiant or giant in the classical Algol systems might be expected to show abundance anomalies since up to 80% or 90% of the original mass may have been lost in some cases. Parthasarathy, Lambert, and Tomkin (1983) find that [Fe/H] = 0.0 ± 0.3, [C/Fe] = -0.5, and [N/Fe] = +0.5 for the secondaries of U Cep and U Sge. In addition, [C/Fe] = -0.5 for the very low mass secondary of S Cnc. In comparision with average field giants, [C/Fe] = 0.25 ± 0.1 and [N/Fe] = +0.5 ± 0.1 for these systems. The observed over abundance of nitrogen is significantly less than expected from CNO nucleosynthesis while carbon should be 10 - 100 times less abundant than observed. It was proposed that after some mass loss from the original primary star, mixing between the core and envelope dilutes the enhancement of nitrogen and the corresponding carbon deficiency.

It is normally impossible to observe the secondary star's spectrum with sufficient resolution to allow accurate abundance analysis because the primary star dominates the spectrum. Since the primary star has presumably accreted matter from the secondary star, abundance anomalies might be expected in its atmosphere. Cugier and Hardorp (1988a,b) have investigated the [C/H] and [N/H] ratios in many B-type single stars and the [C/H] ratio in a number of Algol system primaries. They proposed that rapid rotation can cause large scale mixing and desired to test this hypothesis. Of 108 single stars, only 5 showed nitrogen anomalies but these were uncorrelated with carbon abundances. No clear cut dependence on projected rotational velocity was detected, although two of the most rapidly rotating stars, α Leo and ² Aqr, showed the lowest carbon abundances; 0.07 and 0.02 times the solar values, respectively. The Algols δ Lib, RS Vul, and U Sge had solar carbon abundances as did the B-type binary u Her. The Algol systems TX UMa, β Per, Tau, and U CrB exhibit carbon under abundance of factors of 1.8 - 2.1 with respect to the sun. Non-LTE (Local Thermodynamic Equilibrium) effects were investigated and would lead to [C/H] values larger than the LTE values by 0.10 - 0.15.

Tomkin and Lambert (1989) determined the chemical composition of the primary star in the low activity Algol system R CMa which has a very low mass secondary component. They found [C/H] = 0.0 ± 0.2, [N/H] = 0.4 ± 0.2, [O/H] = 0.3 ± 0.3, [S/H] = 0.1 ± 0.2, and [Fe/H] = 0.1 ± 0.1. It is concluded that the previous mass transfer in R CMa must have been non-conservative and/or that mixing occurred. Considering all of the assumptions involved, it is difficult to be certain wherther or not any abundnace anomalies have been detected in classical Algol systems. In most Algol systems absorption lines of Si IV, C IV, and sometimes N V are detected outside of eclipse. These ions are often detected in emission during the totality phase of primary eclipse (Plavec 1989). In the dynamic Algols the emission lines are always detectable. Peters and Polidan (1984) analyzed the C IV absorption in several classical Algol systems and concluded that carbon is about 10 times under abundant. However, C IV emission lines detected during totality in Algols are almost always the strongest emission lines (Sahade 1986). McCluskey and Sahade (1987) have suggested that C IV emission is filling in the C IV absorption, causing it to mimic under abundance. Gimenez and Claret (1989) study the irradiation of Algol secondaries by the hot primary star and find that the irradiated spectra can be very different than the normal spectrum and that some absorption lines can be filled-in by emission.

An interesting Algol system is V 356 Sgr (A2 II + B3/4 V; P = 8.896 days), which had been observed with the International Ultraviolet Explorer and Voyager. Polidan (1988) detected no C IV emission during the total eclipse of the B-star by the A-star and no carbon was detected in the A-star's ultraviolet spectrum. Si IV and N V emission are quite strong during totality. Perhaps the A-star really is carbon-deficient.

In this report we discuss the measurement of the equivalent widths of the C II, C IV, and N V resonance doublets in standard stars and Algol-type binaries.

II. Discussion

Table 1 lists equivalent widths of the resonance doublets of C II, C IV, and N V for 26 standard stars with spectral types from O9.5 - A5 and of luminosity classes III, IV, and V. Table 2 lists the same quantities for 23 Algol-type interacting binaries within the same spectral and luminosity class range. All measurements were made from high resolution IUE spectra at the GSFC Regional Data Analysis Facility.

Table 1 shows that for normal B-type stars N V does not appear for spectral types later than B2.5 with one exception. The B3 V star HD 32630 has N V absorption features much stronger than expected whereas the C II and C IV features are within the normal range of strengths for B3 V stars. The reason for this great strength of the nitrogen resonance doublet is unknown. The resonance doublet of C IV is detectable in absorption in spectral types as late as B6. No obvious anomalies are present in the C II and C IV line strengths for the standard stars with the exception of the B 2.5 IV star HD 35708 in which C IV is much weaker than normal although C II appears normal. These results are in good agreement with earlier work, e.g. Slettebak and Carpenter (1983).

In the Algol binaries, as indicated in Table 2, the C II line strength are in general very similar to those found in the standard stars. Only in SX Aur (B3 V) is it a little weaker than normal. The strongly interacting binary AX Mon (B2 III) shows considerable excess in strength of C II, C IV, and N V lines. This is probably due to extensive mass flow.

The C IV resonance doublet is stronger than it is in the standard stars in about 66% of the Algol binaries observed. It is seen in spectral types as late as B9. The N V absorption is also stronger in about 40% of the Algol systems than in standard stars and is observed in spectral types as cool as B8.

III. Conclusion

The C II resonance doublet provides a relatively good indicator of carbon abundance since it is considerably less influenced by mass flow effects than most other strong ultraviolet lines in B-type stars. A comparison of C II equivalent widths in 26 standard stars and 23 Algol binaries shows that in general the carbon abundance in these two groups does not differ by more than a factor of 2.

The C IV and N V line strengths are very sensitive to mass flow and will not provide good abundance determinations until a detailed understanding of the physical conditions in which they are formed becomes available. It is of interest to note that the C IV and N V line strengths in many Algol systems are similar to those observed in Be stars. A more detailed discussion of these results is being prepared for publication.

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Table 1
Standard Stars -- Equivalent Widths

HD	Sp	T	C II	C IV	N V
15371	B5	IV	2.88	0.49/0.36	absent
32630	B3	V	2.76	0.54/0.32	1.26/0.67
34816	B0.5	IV	0.90	1.92/1.29	0.37/0.34
35039	B2	IV	1.42	0.81/0.50	0.32/0.20
35708	B2.5	IV	1.66	0.15/0.16	0.30/0.19
36512	B0	V	1.14	2.37/2.00	0.42/0.28
36959	B1	V	1.20	0.35/0.27	0.40/0.22
36960	B0.5	V	1.08	2.00/1.60	0.52/0.30
38666	O9.5	V	1.04	3.72/2.71	0.90/0.46
39060	A5	V	1.96	absent	absent
39283	A2	V	2.41	absent	absent
50707	B1	IV	1.16	0.87/0.60	0.20/0.14
53929	B9.5	III	2.27	absent	absent
74280	B3	V	1.76	0.50/0.47	absent
80007	A2	IV	1.81	absent	absent
89021	A2	IV	1.81	absent	absent
90994	B6	V	2.46	0.35/0.28	absent
97633	A2	V	1.84	absent	absent
128345	B5	V	2.67	0.43/0.32	absent
183324	A0	V	2.56	absent	absent
188665	B5	V	2.46	0.44/0.25	absent
209952	B7	IV	2.90	absent	absent
214994	A1	IV	2.27	absent	absent
215573	B6	IV	3.00	absent	absent

Table 1 continued
Standard Stars -- Equivalent Widths

HD	Sp T	C II	C IV	N V
222661	B9.5 V	2.37	absent	absent
224686	B9 IV	2.94	absent	absent

Table 2
Algol Binaries -- Equivalent Widths

HD	Name	Sp T		C II	C IV	N V
1486	TV Cas	B9	V	2.79	0.41/0.40	
3369	π And	B5	V	2.62		
6882	Phe	B6	V	2.33		
19356	β Per	B8	V	2.33	0.25/0.20	0.23/0.13
25204	Tau	B3	V	2.02	0.26/0.26	0.29/0.19
29365	HU Tau	B8	V	2.37	0.24/0.15	0.38/0.34
33357	SX Aur	B3	V	1.16		
44701	IM Mon	B5	V	2.19	0.23/0.19	
45910	AX Mon	B2	III	3.30	2.75/2.60	2.33/1.57
50846	AU Mon	B5	V	2.24	0.32/0.20	0.65/0.36
72754		B8	I	2.17	0.80/0.51	0.42/0.24
76805		B5	V	2.15		
93033	TX UMa	B8	V	2.40	0.42/0.34	0.39/0.36
93206	QZ Car	B0	I	1.87		
134687	e Lup	B3	III	1.89		
136175	U CrB	B6	V	2.12	0.29/0.25	0.23/0.17
151676	V1010 Oph	A5	V	3.60		
151890	μ Sco	B1.5	V	1.42	0.42/0.42	
156633	u Her	B2	IV	1.52	0.86/0.42	0.27/-
173787	V356 Sgr	B3	V	1.56	0.64/0.41	
180939	RS Vul	B5	V	2.77	0.91/0.61	0.64/0.39
181182	U Sge	B7	V	2.30	0.76/0.50	
185507	σ Aql	B3	V	2.24		