DENSITY SENSITIVE C II LINES IN COOL GIANT STARS

Robert E. Stencil
Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards, Boulder, CO 80309

and

Kenneth G. Carpenter
Department of Astronomy, Ohio State University Columbus, OH 43210

ABSTRACT

The density sensitivity of the emission lines within the UV 0.01 multiplet of C II near 2325 Å has been examined in additional late type giants and supergiants with deep LWR high dispersion exposures. The new data support the original contention based on these lines that noncoronal red giants possess geometrically extended chromospheres.

INTRODUCTION

Given the complexity of the spectra of late type post main sequence stars, it is crucial that spectroscopic methods be established which can unambiguously determine basic atmospheric parameters, such as the electron density. One such density diagnostic involves the mid-UV intercombination lines of C II, multiplet UV 0.01 near 2325 Å (Stencel et al. 1981). By iterating between three observed line ratios within the multiplet and atomic theory, a self-consistent set of atomic parameters which fit the observations was derived. These lines exhibit a density sensitivity between $10^7$-$10^9 \text{ cm}^{-3}$. In that study, except for the solar chromosphere which provided the high density limit, all of the stars considered were late K and M giants and supergiants which are inferred to lack solar-like corona on the basis of their low upper limits of soft X-ray emission (Ayres et al. 1981a).

We have endeavored during the fourth year of IUE operations to extend the observational sample across the cool half of the H−R diagram, particularly to explore the so-called Linsky and Haisch (1979) division between giant stars with and without transition regions (TR) and coronae. To this end, we have observed three coronal type stars: Beta Dra (G2 Ib−II), Beta Gem (K0 III) and 56 Peg (K0 IIp + wd). The latter is an interacting binary and must be cautiously compared with single stars (cf. Schindler et al. 1982). In addition, we have observed Epsilon Gem (G8 Ib) and Epsilon Peg (K2 Ib) to extend the survey of C II] in the spectra of noncoronal stars.
OBSERVATIONS

Figure 1 displays the 2320-2330 Å region of spectrum in the five new observations, plus a comparison with the previously observed, high signal-to-noise (S/N), strong C II lines in Alpha Ori (M2 Iab). The figure also indicates the exposure times used for these LWR echelle mode observations during 1981. The wavelength scales are those provided by the IUESIPS, and given the small range of THDA (13±1°C), suggest real velocity shifts. The primary member of the multiplet, near 2325.4 Å appears to have been detected in each case, except perhaps in Beta Dra where a strong continuum has swamped much of the emission. The ratio of 2325.4 Å/2328.1 Å (R1) theoretically decreases with increasing electron density, while the ratios 2325.4 Å/2326.9 Å (R2) and 2324.7 Å/2326.9 Å (R3) both increase with increasing electron density. On this basis we can derive some preliminary density estimates, limited largely by the low S/N:

<table>
<thead>
<tr>
<th>Star</th>
<th>Spectral Type</th>
<th>Radial Velocity</th>
<th>C II Ratios</th>
<th>Log N_e</th>
</tr>
</thead>
<tbody>
<tr>
<td>β Dra</td>
<td>G2 Ib-II</td>
<td>-20 km s⁻¹</td>
<td>1.8</td>
<td>2.3</td>
</tr>
<tr>
<td>β Gem</td>
<td>K0 III</td>
<td>+3</td>
<td>2.2</td>
<td>4.8</td>
</tr>
<tr>
<td>56 Peg</td>
<td>K0 IIp+wd</td>
<td>-24</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>ε Gem</td>
<td>G8 Ib</td>
<td>+11</td>
<td>3.2</td>
<td>2.3</td>
</tr>
<tr>
<td>ε Peg</td>
<td>K2 Ib</td>
<td>+5</td>
<td>2.5</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Improvements in the use of the C II ratios for accurate density determinations must await more accurate atomic parameters for C II, as well as higher S/N observations which will become possible with the High Resolution Spectrograph on the Space Telescope in the mid-1980s.

INFERENCES

The ratios of the 1335 Å resonance lines of C II to the intercombination lines is sensitive to T_{exc}. Among coronal type giants like Beta Dra and Beta Gem, the lines of C II near 1335 Å are clearly present. Among the noncoronal giants, the resonance lines of C II are much weaker and often blended with fluoresced CO emission (Ayres et al. 1981b). These resonance lines are computed to form in the lower TR in the Sun (≤20,000 K), but our calculations for giant stars suggest significant contribution to the line flux from the chromospheres. We are typically finding upper limits to the T_{exc} for noncoronal giant stars, of 5000-7000 K. Physically, the emission measure suggests that in order to obtain significant flux from the intercombination lines when the resonance lines are weak or absent (low T_{exc}), formation in an extended chromosphere is required. Solving for the line emissivity of C II 0.01 requires an accurate ionization equilibrium, which is difficult to compute in the turbulent and partially-ionized chromospheres of red giants. However,
because the C II UV 0.01 lines are not self-reversed, we can adopt an optically thin approximation, and the emitting layer thickness (cm) can be expressed as a function of the observed flux, distance factors and the ionization-excitation populations which involve an exponential of inverse $T_{\text{exc}}$. Thus, coronal type giants like Beta Dra and Beta Gem which have solar like $T_{\text{exc}}$ are deduced to have thin C II emitting layers ($r \ll R_\star$). The noncoronal giants with low $T_{\text{exc}}$ are deduced to have very large C II emitting layers ($r > R_\star$). Although the calculations require improvements and generalization, it is encouraging that this evidence concurs with parallel data from radio and narrow band speckle interferometry observations which also point to extended chromospheres among noncoronal giants and supergiants (cf. Stencel 1982). The evidence for a discontinuous change in chromospheric extent between coronal and noncoronal giants must be a crucial clue to the mechanism of rapid mass loss (cf. Mullan and Stencel — this volume).

LINES OF Si II UV 0.01

Multiplet UV 0.01 of Si II which occurs between 2330–2350 Å also appears in emission in the spectra of our observed stars. We have examined line ratios in this multiplet to look for any correlation they may exhibit against the C II derived densities, and find little evidence for such. Presumably chromospheres can easily populate the upper level of UV multiplet 1 of Si II (which is only 1.5 eV above the upper level of UV 0.01), in contrast to populating the upper levels of UV 1 of C II, which are 4.0 eV above UV 0.01.

ACKNOWLEDGMENTS

We wish to thank R. F. Wing, J. L. Linsky and C. Jordan for useful discussions, along with the staff of the IUE Observatory for their generous assistance. This work was supported in part by NASA grant No. NAG5-82 for which we are grateful.

REFERENCES

Figure 1. The C II intersystem lines in several late-type stars.