MODELING THE ULTRAVIOLET PHOTOSPHERIC SPECTRUM OF COOL STARS: α ORI (M2 IAB)

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INTRODUCTION

Little attention has, as yet, been paid to the potential utility of the ultraviolet (UV) spectrum of cool stars in the determination of photospheric parameters independent of optical-infrared data. This is, in part, due to the large number of chromospheric emissions in this spectral region, which make study of the photosphere difficult. However, we are intrigued by the possibility of extending the windows of visibilty into the photosphere to shorter wavelengths than traditionally explored to counter the problems posed by the extreme molecular opacities that occur in the coolest stars longward of 4500 Å. Our previous work on α Boo (K2 Ib) (Carpenter & Wahlgren 1990) and γ Cru (M3 III) (Wahlgren & Carpenter 1990) utilizing IUE spectra convinced us that understanding the UV photospheric spectrum was necessary for studying the chromospheric emissions. With the higher resolution and signal-to-noise spectra obtained by the Goddard High Resolution Spectrograph (GHRS), we can now explore the UV photospheric features on their own merits for information such as elemental abundances, molecular absorption, and ultimately line diagnostics that give information on the stellar gravity and effective temperature.

OBSERVATIONS

The GHRS team has obtained complete wavelength coverage of the α Ori spectrum from 2000 - 3300 Å using the first-order, intermediate resolution G270M grating (R = 20000 - 35000) of the GHRS onboard the Hubble Space Telescope. This atlas supplements the far-UV spectral data (1200 - 2000 Å) previously obtained by Carpenter et al. (1993). Signal-to-noise levels are typically 100 for strong emission features and 50 - 65 in the ‘continuum’ longward of 2800 Å.

PHOTOSPHERIC MODELING

We chose the photospheric parameters from the work of Lambert et al. (1984) to initiate our study. Their parameters of $T_{eff} = 3800$ K, log $g = 0.0$, with solar elemental abundances, determined from analyses of infrared atomic and molecular transitions, are identical to one of the models of Brown et al. (1989)
which we have employed. The microturbulent velocity of 4 km sec\(^{-1}\) derived by
Lambert et al. is not incorporated into the model atmosphere but is included in
our synthetic spectrum calculations. To match the line profiles it was necessary
to broaden the theoretical spectrum with a macroturbulent velocity of 14 km
sec\(^{-1}\), but a slightly lower velocity of 12 km sec\(^{-1}\) may be more appropriate
for some features. Synthetic spectra created for other effective temperature
and gravity combinations showed that some spectral features were better fit by
\(T_{\text{eff}}\) of 3600 K. Models hotter than 3800 K and those with log \(g\) = 1.0 were
clearly inconsistent with the data, although the UV photospheric spectrum is
not particularly sensitive to small changes in gravity for this star.

The modeling procedure was first carried out for the longest wavelengths
of our data, from 3200 to 3300 Å. This segment of the spectrum is not known
to contain strong molecular absorptions and presents few strong emission lines.
Therefore, contamination of the photospheric spectrum is minimal. The program
SYNTHE (Kurucz, private communication) was used to generate the synthetic
spectrum. Atomic line data included both the theoretical and experimental
compilations of Kurucz. Figure 1 presents a reasonably good fit of the theory to
the observation over a limited, but representative, wavelength interval. A scale
factor of 1.43E-12 was required to fit the GHRS flux scale by the SYNTHE
flux. Applying this model at shorter wavelength regions requires an increase
in the scale factor in order to attain the same 'continuum' level. This can be
interpreted as a relative decrease of the photospheric contribution to the total
light compared to that from chromospheric emissions (both discrete and continuous).
Below 3000 Å the fits are markedly worse as a result of an increase in the
number of strong chromospheric Fe II emissions. Near 2800 Å the photospheric
contribution is approximately half of the total flux level and at 2600 Å it may
only be at the 20 % level.

![Graph](image.png)

**FIGURE I** Observed (solid) and synthetic (dashed) spectra for \(\alpha\) Ori.
EMISSION LINE INTERPRETATIONS

A major concern in the interpretation of the UV photospheric spectrum is contamination by emission lines arising from physical processes occurring in the chromosphere (both thermal and non-thermal). We illustrate the problem of interpreting the weaker, apparently normal-appearing spectral lines that have been filled-in by emission. In Figure 1 are identified (by asterisks) several Fe I absorption features that are observed to be weaker than in the synthetic spectrum. Investigation into these transitions finds that they all originate from lower energy levels approximately 19000 cm$^{-1}$ above the ground state level and are excited up to levels near 51000 cm$^{-1}$. The energy difference of 3.80 to 3.85 eV corresponds to the energy differences found in the Fe II (6, 7) multiplets. The strong Fe II $\lambda 3227.732$ Å emission line profile includes two transitions from Fe I (157), and pumps the Fe I atoms to higher energy states. Weak fluorescence processes will act to fill-in the absorption spectrum, as observed. Many instances of weakened Fe I absorption features are found between 3200 and 3300 Å. Pumping of Fe I, followed by collisional processes, may then lead to many Fe I higher levels being populated and result in many weakened absorption lines.

A possible alternate explanation for many of these weakened Fe I transitions lies in the uncertainties of the oscillator strengths. The f-values used here for the highly excited Fe I transitions are all computed using a Cowan code and atomic energy levels measured in the laboratory. However, if difficulty exists in labeling the energy levels, as a result of their separation being comparable to the errors in measuring the positions of those levels, then the calculations for gf-values will be incorrect because of improper configuration interaction. Errors of this type have been identified for the uppermost labeled levels of Cr II and Fe II (Johansson, Leckrone, & Wahlgren, paper in preparation) and might be expected for Fe I. Rectifying the problem of improper labeling will lead to improved calculations of gf-values that, by f-sum rules, will be either weaker or stronger than originally computed. The observations at this point appear to systematically show weakening of the lines, which favors fill-in of the lines by the fluorescence process outlined above, but further laboratory work is required to more accurately measure the Fe I energy levels.

REFERENCES


PART I
(continued)

RESULTS OF RECENT SPACE MISSIONS
(ROSAT)