GHRS OBSERVATIONS AND ANALYSIS OF THE O I AND C I RESONANCE LINES IN THE UV SPECTRUM OF α ORI (M2 IAB)

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INTRODUCTION

The resonance lines of both O I (near 1304 Å) and C I (near 1656 Å) are typically strongly in emission in the far-UV spectrum of cool stars. However, in the prototypical M-supergiant α Ori (M2 Iab), these lines are remarkably weak, while other transitions from the same upper energy levels (O I UV 146 near 1641 Å and C I UV 32 near 1993 Å) are stronger in emission, despite their much lower oscillator strengths. The resonance lines of both O I and C I are blended with lines of other species and progress in understanding this flux deficiency is difficult because of the low resolution of existing IUE and GHRS data. We therefore obtained medium resolution GHRS spectra of α Ori to resolve blended lines and allow detailed study of this phenomenon.

OBSERVATIONS

We have used the Goddard High Resolution Spectrograph (GHRS) to obtain spectra of O I and C I lines in the far-UV spectra of α Ori at two different epochs: (1) April 1991 and (2) September 1992. The data shown in Figure I were obtained with the medium resolution gratings (R=20,000), except for those from epoch (1) near 1300 Å, which are from the G140L grating (R=1,000). Data from epoch (2) have been scaled up by a factor of 1.5 to enforce agreement with both the S I (UV 11) line flux at 1667 Å and with the 1635 - 1675 Å continua in the data from epoch (1). The difference in observed flux level is likely due to poor centering of the star in the GHRS aperture during the epoch (2) observations, combined with a general decline in overall UV-visible flux as reported by Dupree
FIGURE I Spectra from April 1991 (solid) and Sept. 1992 (dotted).

(private comm.) during this time interval. The O I UV 146 and UV 2 fluxes show an even more severe decrease, indicating a larger O I flux variation.

The O I (UV 2) emission is weak or absent during epoch (1) – it is difficult to tell which, due to the low resolution of the G140L spectrum. The C I (UV 2) lines are seen in absorption. However, despite the weakness of these resonance lines, the O I (UV 146) and C I (UV 32) lines are seen in strong emission.

In the epoch (2) observations, the R=20,000 spectrum reveals O I resonance lines to be present in emission, but very weak. The 1290 - 1310 Å region is seen to be dominated by Fe II emission features, with the O I and S I lines contributing relatively minor amounts to the flux.

ATMOSPHERIC MODELS AND NLTE TRANSFER CALCULATIONS

Since interstellar absorption by the O I and C I lines cannot account for the observed weakness/absence of emission (Carpenter et al. 1990), what can? Our approach begins with the analysis of simple calculations from model atmospheres which can account for well-understood lines which are collisionally-excited. We constructed two atmospheric models which can (within a factor of two) account for the observed fluxes of lines of Mg II, C II, and Si II. Two models were made in order to investigate effects of redenning, using $A_V = 0.25$ and $A_V = 0.0$. The models of Basri, Linsky, and Eriksson (1981) and Hartmann and Avrett (1984)
were used as starting points for the creation of homogeneous, one-dimensional, plane-parallel atmospheres. The resulting models were used to investigate line formation processes under representative conditions. They are not intended as models of the actual atmospheric structure. Full NLTE radiative transfer and hydrostatic equilibrium equations were solved for H, C, N, O, Mg, Si, Fe, and S. Judge’s atomic models and MULTI (Carlsson, 1986) were used to perform the computations (details will be given elsewhere). Note that no “background” line or dust opacity is treated in these calculations.

RESULTS OF MODEL CALCULATIONS

(1) Model atmospheres can be constructed in which collisionally excited lines have computed fluxes within a factor of two of those observed. (2) The O I resonance lines, excited by H Lyβ, are always ~ 10^1 to 10^2 times stronger than observed, but the 1641 Å line is weaker than observed. (3) The S I line fluxes near 1820 Å, excited by H Lyα, agree to within a factor of three of the observed fluxes. (4) The C I resonance multiplet is weakly in emission, in contrast to the observed absorption, and the 1993 Å line is weaker than observed. (5) O I photons are destroyed by absorption in bound-free continua formed in the thick chromosphere. A possible explanation for the weakness of the O I resonance lines then arises: The observed 1641 Å and 1993 Å line fluxes require higher optical depths than present in the models, depths where the resonance lines of O I can be destroyed by absorption in the background (Si I) photoionization continuum. Furthermore, absorption of O I resonance line photons by the fluoresced species S I, Fe II and CO, which have substantial optical depths in these models, must also contribute.

This picture falls within the realm of physical processes encountered in standard atmosphere theory. Outside of this, the calculations can be used to show that small dust/gas ratios in the chromosphere (column masses near 10^-2 g cm^-2), using opacities 100 times smaller than canonical circumstellar values of \( \kappa(1\mu) \sim 20 \text{ cm}^2\text{g}^{-1} \) (scaled up for UV wavelengths), can easily destroy resonance line photons. The existence of such dust (interesting but difficult to prove) would indicate gross inhomogeneities. The calculations do not include effects of the circumstellar shell. A synthetic line absorption spectrum computed for an overlying 500 K slab with a column mass of 2.3 \times 10^{-5} g \text{ cm}^{-2} indicates that chromospheric emission in C I UV 2 (and by analogy O I UV 2) might be hidden by circumstellar line absorption. We are undertaking further computations.

REFERENCES

Carlsson, M. 1986, Uppsala Astronomical Observatory, Report No. 33