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FIRST DETECTION OF IONIZED HELIUM ABSORPTION LINES IN INFRARED K BAND SPECTRA OF O-TYPE STARS

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ABSTRACT

We have obtained high signal-to-noise, moderate-resolution *K* band spectra of two early O-type main-sequence stars, HD 46150 O5 V, and HD 46223 O4 V, in the Rosette Nebula. We report the detection, for the first time, of the 2.189 μm He II line in O-type stars. Also detected is the 2.1661 μm Brγ line in absorption. The 2.058 μm He I line appears to be present in absorption in both stars, although its appearance at our resolution is complicated by atmospheric features. These three lines can form the basis for a spectral classification system for hot stars in the *K* band that may be used at infrared wavelengths to elucidate the nature of those luminous stars in otherwise obscured H II and giant H II regions.

Subject headings: infrared: stars — stars: early-type

1. INTRODUCTION

Our scientific interest in *K* band spectroscopy is to identify, classify, and clarify the character of the OB that are found in heavily obscured giant H II (GH II) regions of our Galaxy. Such stars may well be among the *youngest* massive stellar objects and dominate the energetics of such regions. Unfortunately, the typically heavy extinction of 10 to 20 magnitudes (or more) in the visual region has precluded optical photometry or spectroscopy of the exciting stars. However, in the near-infrared *K* band centered at 2.2 μm, the dust extinction is only 10% of that in the visible (Rieke & Lebofsky 1985). An opportunity to study the stars of highly reddened regions now awaits exploitation. For example, *H* and *K* band photometry of stars in the GH II region W51 using area scans has been given by Little et al. (1989). With the advent of the new IR array detectors, extensive photometry of other obscured H II regions is now beginning in earnest; *JHK* imaging of M17 has been published by Lada et al. (1991).

Relatively moderate-resolution, low signal-to-noise spectroscopy is sufficient to detect *emission* lines in the *K* band (e.g., in Galactic Wolf-Rayet stars: Hillier, Jones, & Hyland 1983). McGregor, Hyland, & Hillier (1988) have obtained *JHK* band spectroscopy of a number of early-type high-luminosity stars in the LMC, many showing Brγ and He I 2.058 μm lines in emission. These stars had been pre-selected as showing emission features in the optical. Their spectral classifications are B supergiants or WN9/Of types; some stars appear to be luminous blue variables (LBV) according to McGregor (1989). Curiously, *K* band spectra of 10 hot stars in the Galactic center also show these same lines in emission (Krabbe et al. 1991). Are such objects also anomalous B supergiants, WN9/Of types, or LBV stars? Are these phenomena common among obscured GH II regions?

What do *normal* O and luminous B stellar spectra look like in the *K* band? There is plenty of *JHK* photometry for hot stars, for example Castor & Simon (1983). Curiously, there is as yet *no* published observational spectroscopy for *normal* OB stars, nor have detailed non-LTE predictions yet been made for lines in this region (according to D. Mihalas and L. Anderson 1992, private communication). We have now obtained spectra of two well-known early O-type stars, HD 46150 and HD 46223, in the Rosette Nebula (Mon OB2 association) for the purpose of attempting to detect the He II 2.189 μm line. HD 46223 lies very close to the ionization center of the Rosette (Schneps, Ho, & Barrett 1980). Observations from the *International Ultraviolet Explorer* by Garmany et al. (1981) show that stellar winds from HD 46223 alone are sufficient to account for the well-known 20 km s^{-1} overall expansion of the nebula. HD 46150 too has a substantial wind. HD 46223 is also responsible for driving ionization fronts which "light up" or "etch" primordial giant molecular cloud clumps in the SE quadrant of the Rosette (Block, Dyson, & Madsen 1992).

2. OBSERVATIONS

Observations were made at the United Kingdom 3.8 m Infrared Telescope (UKIRT) on Mauna Kea, on the night of 1992 November 9 (UT), using the facility spectrometer CGS4. A 75 lines mm^{-1} grating was employed; it was set to cover the wavelength band 2.03–2.45 μm at a nominal spectral resolving power of $R \approx 290$ after processing. Wavelength calibration was achieved via measurement of the spectrum of an argon arc lamp. A spectrum of a standard star BS 2421 (γ Gem) was observed prior to the observations of HD 46150 and HD

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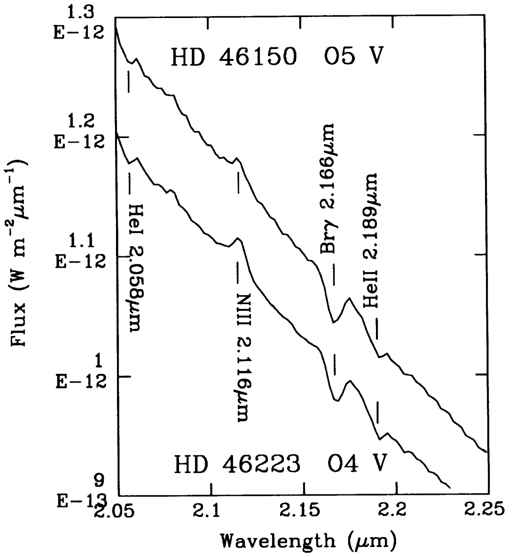

FIG. 1.—Fluxed *K* band spectra of two early O type stars with line identifications indicated. The flux of HD 46223 has been multiplied by a factor of 1.18 to allow the spectra to be shown together.

46223. In subsequent data reduction, BS 2421 was assumed to have a *K* magnitude of 1.90 and effective blackbody temperature of 9500 K. The spectrum of the standard star, of type A0 V, contained a prominent broad Brγ absorption line, which was artificially removed prior to ratioing. All spectra were obtained in the stare/nod mode, with the nod position being roughly 36″ along the slit direction.

The *K* band magnitudes of HD 46150 and HD 4623 are 6.42 and 6.68, respectively (Castor & Simon 1983), and the exposure times 120 s for both stars. The resultant signal to noise was quite high, ≳300.

The fluxed, but not extinction-corrected spectra of HD 46150 and HD 46223 are shown in Figure 1. The ionized helium 2.189 µm line is positively identified and detected in O stars for the first time. As can be seen by inspection, the 2.1661 µm Brγ, 2.058 µm He I, and 2.189 µm He II (7–10) lines are all in absorption (the He I feature may still be partially contaminated by atmospheric lines). Given the spectral resolution we have available, these absorption features are unresolved, inasmuch as the rotational broadening is only about 100 km s^{-1} from optical studies for each star (Conti & Ebbets 1977).

The measured equivalent widths were found to be about 2.4 ± 0.2 Å for the Brγ lines of both stars. The weaker He II lines were measured to be about 1.0 ± 0.2 Å. The equivalent width of the He I lines are still more uncertain due to the problem with telluric features, but are between 0.5 and 1.0 Å. These helium line strengths in Å are both larger than the corresponding lines in the optical; in W_λ/λ units they are comparable. Even more surprising was the finding that the He I lines are nearly similar in strength to the He II feature. In the optical region, O stars of such early spectral type have only very weak He I lines, but then the 2.058 µm He I is the leading singlet transition (analogous to the 1.083 µm He I triplet).

Despite their shallow appearance, the helium lines in HD 46223 and HD 46150 are unmistakeably real. If we are to believe these absorption lines, then we must also believe that the shallow *emission* feature at 2.117 µm is real. While a possible transition near this position is the 2.1125 µm (4–3) He I line, detected in early B-type, high-luminosity stars (McGregor et al. 1988), we do not believe this is the line we see. It would be very difficult to understand why this He I line would be seen in emission when the lower energy 2.058 µm He I line appears in absorption. The line has a larger offset (by 0.005 µm) from the expected wavelength than the other lines identified (accurate to 0.002 µm). J. Drew (1992, private communication) has informed us that she has observed a strong emission line at 2.116 µm in a number of Of and O-type supergiant stars, which she identifies as N III (8–7). We believe this also applies to our O-type stars, which both show 4634,4640 N III emission in the optical. Conti (1973) finds emission line equivalent widths of 0.3 and 0.07 Å, respectively, for 4640 N III in HD 46223 and HD 46150. Similarly, our *K* band values are 2.0 ± 0.5 and 0.5–1.0 Å. Quite a number of early O-type stars show optical N III lines in emission but He II in absorption [Walborn 1971 calls this type O((f))], exactly as we observed here.

3. DISCUSSION

It should now become possible to use these *K* band lines and follow the precepts for quantitative classification of O stars by Conti & Alschuler (1971). These authors used optical line ratios of 4471 Å He I and 4541 Å He II. One could thus utilize the analogous line ratios for 2.058 µm He I and 2.189 µm He II (10–7). There is also Brγ which we have shown to be in absorption in (at least some) main-sequence O-type stars, even those with very strong winds. By analogy with the behavior of 1.0047 µm P δ, Brγ may come into emission in the most luminous O stars (I. Howarth 1992, private communication). Similarly, the singlet 2.058 µm He I line should be very strong in B stars, and weaken in the O stars, by analogy with the triplet 1.083 µm He I. The 2.189 µm He II line should be in absorption in all O-type stars, but absent in B stars. The He I and He II line ratio may provide the key that would enable classification of O and B stars in the *K* band. Before this can be done, however, additional spectra of known OB stars will have to be obtained and a quantitative comparison undertaken. Higher spectral resolution than we have used here would be preferable, especially to disentangle the blending of atmospheric features with the He I line. It should be noted that the Rosette H II region does not include a strong nebular contribution to He I and Brγ. Nebular emission in these transitions is most certainly going to be a problem in younger and denser H II and GH II regions (such as the Galactic center: Krabbe et al. 1991). That problem can probably be allowed for by using long-slit spectroscopy so that the nebular contribution can be subtracted from the stellar features.

Spectroscopy of the hottest stars in GH II regions heretofore hidden from spectral analysis should now enable us to type their upper main sequences. The quantity and quality of the hot star components will have an important impact on our understanding of those starburst episodes which are still shrouded in their initial birth clouds of dust and gas. Do these extremely young stars have the spectra of *normal* OB stars? Are many of them linked to CO emission peaks of giant molecular clouds? Lada et al. (1991) suggest that many OB stars in M17 have circumstellar disks from their IR photometry. If so, characteristic double-peaked stellar emission profiles should be observed in the Brγ and 2.058 µm He I lines. Are such line features really present? High-resolution *K* band spectroscopy can answer such questions.

Even though our two O stars have strong stellar winds, the 2.058 μm He I and Brγ lines are in absorption. The high terminal velocity radiatively driven winds are thus optically thin in these transitions and we are observing their stellar photospheres in the *K* band. This is to be contrasted to those Galactic center exciting stars where 2.058 μm He I and Brγ are in emission. Their winds must be optically thick in the *K* band lines. We suspect that their terminal velocities are correspondingly lower, due either to their LBV nature, or possible extreme youth (i.e., stars approaching or at the ZAMS).

Finally, it has not escaped our notice that *K* band spectroscopy might play a role in helping us to understand the nature of the hot star content of very luminous but very dusty *IRAS* "starburst" galaxies.

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