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Fe II IN THE ORION NEBULA: SPECTROSCOPIC OBSERVATIONS AND THEORETICAL MODELS

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To create a complete numerical model of the Fe II emission we use spectroscopic observations of the Orion Nebula obtained from the Cerro Tololo Inter-American Observatory. We have identified 40 [Fe II] lines in the spectrum, allowing extensive comparisons between theory and observations.

Our current model of the Fe II atom includes all 371 levels with energies below 93487.650 cm^{-1}, or 11.59 eV. All level energies are experimental (Johansson 1978) and should be quite accurate. Our sources of radiative and collisional atomic data are described by Verner et al. (1999). Our current model includes updates to collisional strengths for transitions between the lowest 63 levels (M. Bautista, private communication). The Fe II model atom has been added into the radiative-collisional code Cloudy (Ferland et al. 1998). The basic equations of ionization and thermal balance, level populations, and radiative transfer are solved self-consistently. The Fe II level populations are obtained numerically by solving the set of balance equations. The final solution is obtained by iteration, with the feedback effects of Fe II emission on the radiative and thermal environment explicitly taken into account. We calculated a model under conditions similar to that in the Orion Nebula Baldwin et al. (1991) with improved gas-phase elemental abundances based on results from Osterbrock, Tran, & Veilleux (1992), and Rubin et al. (1991, 1992), grains and ionization by the incident continua from the four Trapezium stars are included. Using our model calculations, we compiled a list of [Fe II] lines that can be expected from the observations of the Orion Nebula in the 3498–7468 Å range (Baldwin et al. 2000). Based on this list, we identified 40 distinct forbidden lines of Fe II. We investigate the dependence of the spectrum on electron density and on pumping by the stellar continuum. Forbidden oxygen and nitrogen lines, e.g., [O II] λ3727 Å or [N II] λ6584 Å, are collisionally excited in H II regions and can be used for density diagnostics (Osterbrock 1989). The observed [Fe II] optical lines have similar excitation and ionization energies. However, the structure of the Fe II atom is much more complicated. Non-collisional excitation mechanisms, including pumping of high Fe II levels by the UV stellar continuum and subsequent downward cascades, can contribute significantly to the observed intensities of the optical [Fe II] lines. In order to determine which [Fe II] lines can be used for density diagnostics, it is first necessary to find which levels are more affected by pumping than by collisions. We do this by investigating the behavior of the level populations for conditions appropriate to H II regions (Baldwin et al. 1996, Verner et al. 1999). Our calculations show that only the very lowest levels (16 levels in 4 multiplets) are sufficiently collisionally dominated that they can be a reliable basis for density diagnostics for all conditions. These levels can be considered as collisionally excited. We have identified the pumping routes that are important in exciting the observed [Fe II] lines. The comparison between the predicted and the observed data confirms the importance of radiative pumping fluorescence for the formation of the [Fe II] emission spectra. Orion is important because it provides a relatively simple environment to test complex simulations. Our theoretical model of Fe II emission is in good agreement with the observational data.

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