Identification of the [Al II] Forbidden Line at 2661 Å in the Spectrum of RR Telescopii

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1. Introduction

The forbidden ($J = 2$) and intercombination ($J = 1$) components of the $2s^2 \ 1S - 2s2p \ 3P_J$ and $3s^2 \ 1S - 3s3p \ 3P_J$ multiplets in Be-like CIII and NIV, and Mg-like SiIII, respectively, provide well known electron density diagnostics for gaseous nebulae, including symbiotic stars and planetary nebulae. Keenan et al. (1992b) calculated the forbidden to intercombination line ratio for Mg-like Al II, but were only able to marginally identify the [Al II] forbidden line in the IUE spectra of two gaseous nebulae. Better quality spectra obtained by the Goddard High Resolution Spectrograph (GHRIS) on the Hubble Space Telescope (HST) are used here to make a definite identification of the forbidden [Al II] line.

2. Atomic Data

The model ion for Al II consisted of the five energetically lowest fine-structure levels, namely $3s^2 \ 1S$, $3s3p \ 3P_{0,1,2}$ and $3s3p \ 1P$. Electron impact excitation rates calculated by Aggarwal & Keenan (1998) using the R-matrix code of Berrington et al. (1978) are employed in the analysis. For Einstein A-coefficients, the calculations of Tayal & Hibbert (1984) and Hibbert & Keenan (1987) based on configuration interaction wavefunctions are adopted, apart from the value for the $3s^2 \ 1S - 3s3p \ 3P_1$ intercombination line, where the measurement of Johnson, Smith & Parkinson (1986) is preferred.

Using these atomic data in conjunction with the statistical equilibrium code of Dufton (1977), relative Al II level populations and hence emission line strengths were generated for a range of electron temperatures ($T_e = 5000 - 30000 \ K$) and densities ($N_e = 10 - 10^8 \ cm^{-3}$). Details of the procedures involved and approximations made may be found in Dufton (1977) and Dufton et al. (1978). Given uncertainties of typically less than 10 per cent in the adopted atomic data, we estimate that the derived theoretical line ratios should be in error by at most 15 per cent.
3. Results and Discussion

Keenan et al. (1999) showed that in GHRS spectrum Z2QM010XT, the Al II intercombination line at $\lambda$ 2669.95 Å is asymmetrical. They fitted it using a two component model with a wavelength separation of $0.263 \pm 0.020$ Å ($30 \pm 2$ km s$^{-1}$). Crawford et al. (1999) have noted that the nebular [O III] 4363 Å line profile in RR Tel also shows a two-component structure, comprising a strong low density feature ($\log N_e \leq 5.5$), and a weak high density wing ($\log N_e \geq 8$), redshifted by approximately 28 km s$^{-1}$.

Kaufman & Hagan (1979) predict a vacuum wavelength for the [Al II] line of 2661.15 Å, 8.80 Å away from the Al II feature. An inspection of Fig. 2 of Keenan et al. (1999) reveals the presence of an emission feature $8.89 \pm 0.08$ Å from the low density Al II component. Keenan et al. predict the absence of a high density component in the [Al II] line profile, as for $\log N_e \geq 8$ their predicted forbidden to intercombination line ratio is $\leq 0.0002$. Although the line is quite weak, it appears to be symmetrical as expected.

The measured intensity ratio of this feature to the low density component of the intercombination line is $R = 0.027 \pm 0.003$, which for an adopted electron temperature of $T_e = 13,000$ K (Hayes & Nussbaumer 1986) implies $\log N_e = 5.8 \pm 0.2$. This density is in excellent agreement with the values found for RR Tel from line ratios in ions formed at similar temperatures to Al II. For example, Hayes & Nussbaumer (1986) measured a value of the Si III line ratio I(1883 Å)/I(1892 Å) = 0.03, which implies $\log N_e = 6.0$ from the diagnostic calculations of Keenan et al. (1992a).

The good agreement between the predicted and observed wavelengths, and the similarities of the densities derived from $R$ and other spectral diagnostics, provides strong evidence that we have detected the [Al II] line at a vacuum wavelength of 2661.06 ± 0.08 Å. This is the first time (to our knowledge) that the line has been reliably identified in an astronomical or laboratory spectrum.

References