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Recombination line spectroscopy: the O II spectrum

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Abstract. We describe a theoretical treatment of the recombination spectrum of O II. The *ab initio* calculations are carried out in intermediate coupling which allows the distribution of population among the ^3P_J ground levels of O^{2+} to be correctly incorporated for the first time. The effects of dielectronic recombination due to states lying between the ^3P_J levels is also included. The new theory allows the strongest O II recombination lines to be used as a diagnostic of the temperature and density of the emitting region and illustrative examples are given.

Keywords. atomic processes, techniques: spectroscopic

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1. Introduction

In astrophysical ionised plasmas, weak recombination lines are increasingly being used to determine physical properties. To date, theoretical treatments of the recombination of O II, have assumed that the ^3P_J initial states of the recombining ion are populated according to their statistical weights and described by *LS*-coupling. This approximation is invalid at low electron densities.

In O II, the principal series are $2s^22p^2(^3P_{0,1,2})nlj[J\pi]$. As l increases, the appropriate coupling scheme changes from almost pure LS-coupling ($l = 0$) to pair-coupling ($l > 4$). In intermediate coupling all states are correctly treated. In addition, the $(^3P_{1,2})nl$ states with high n lie above the O^{2+} $^3P_0$ state and therefore are a source of dielectronic recombination.

In the current work we 1) allow for the distribution of population in the ground levels of the parent ion, 2) perform a full intermediate coupling treatment of the radiative capture and cascade problem, 3) extend the usual radiative recombination (RR) treatment to include dielectronic recombination (DR) due to autoionising states lying between the ^3P_J levels.

2. The Capture-Cascade Problem

The solution of the level population problem requires the calculation of bound-bound (oscillator strengths) and bound-free (photoionisation cross-sections) radiative data in intermediate coupling. These were calculated using the R-matrix method (Berrington *et al.* 1987). Recombination coefficients are computed from the photoionisation cross-section data resolved by final state, plus the fractional populations of the ground levels of the recombining ion $O^{2+}(^3P_J)$, using the approach described by Storey (1994).

3. Results

Table 1 gives the observed relative intensities of components of O II multiplet V1, normalised to λ4649, for NGC 5882 (Tsamis *et al.* 2004) and 30 Doradus (Tsamis *et al.* 2003). Results from the present work (B&S) are given at densities that best fit the observations for NGC 5882 ($3500/cm^3$) and 30 Doradus ($420/cm^3$). Results that assume statistical populations of the ^3P_J levels (SW), are also shown. The improvement in the agreement between theory and observation is marked.

Table 1

λ(Å)	NGC 5882 Obs	NGC 5882 B&S	30 Dor Obs	30 Dor B&S	SW
4638	0.49	0.34	1.00	0.89	0.21
4641	0.73	0.78	1.33	1.24	0.53
4649	1.00	1.00	1.00	1.00	1.00
4650	0.33	0.33	1.00	1.01	0.21
4661	0.34	0.36	0.88	0.93	0.27
4673	0.06	0.05	0.19	0.17	0.04
4676	0.26	0.24	0.35	0.38	0.23

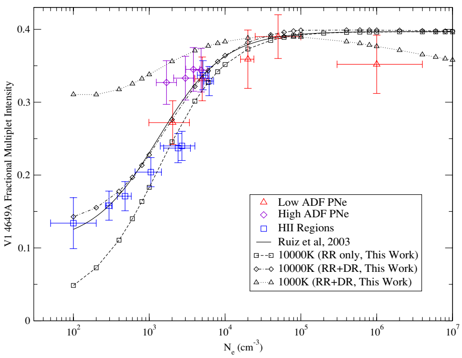

Figure 1. Intensity ratio of λ4649 relative to the V1 sum against the forbidden line density for a range of PNe and H II regions. Data sources listed by Ruiz *et al.*(2003). Includes Ruiz best fit and theoretical data from this work.

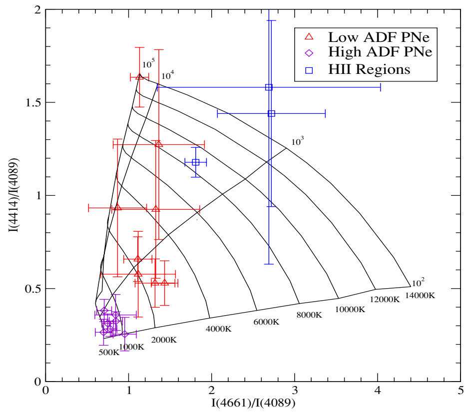

Figure 2. Using the O II lines λ4661, λ4089 and λ4414 to determine electron density and temperature. Colour and symbol coding as in Figure 1

Figures 1 and 2 show applications of our results to PN and H II region spectra.

4. Conclusions

A full intermediate coupling treatment of $O^{2+}+e^-$ recombination yields line intensity ratios in much better agreement with observation than previous work, particularly for low density nebulae. Elemental abundances derived from the new theory will therefore be more accurate and more consistent. The new theory also potentially provides a new means of determining the electron density of the emitting region from relative intensities of lines in multiplet V1 or other O II multiplets.

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