New Lyman $\alpha$ opacities and consequences on stellar spectra

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Abstract. We present new theoretical calculations of the total profile of the atomic hydrogen Lyman $\alpha$ spectral line perturbed by collisions with neutral hydrogen atoms and protons. The variation of the radiative dipole moment during the collision is taken into account. This leads to an increase in the amplitude of the main spectral line satellites.

1. Introduction

Close collisions with neutral hydrogen and protons are responsible for the appearance of satellite features at 1600 Å and 1405 Å in the Lyman $\alpha$ wing associated with free-free quasi-molecular transitions of $H_2$ and $H_2^+$. These features have been observed in UV spectra of certain stars obtained with the spectrograph of IUE and HST. The stars which show Lyman $\alpha$ satellites are:

– DA white dwarfs,
– Old Horizontal Branch stars of spectral type A,
– Peculiar spectral type A stars of Population I, the $\lambda$ Bootis stars.

The last two have the distinctive property of poor “metal” content. In the observed UV spectra of DA white dwarf stars, $\lambda$ Bootis stars, and laboratory plasmas, the strength of the contributions to the Lyman $\alpha$ wing caused by...
neutral collisions relative to the contributions caused by charged perturbers depends very strongly on the ionization balance of hydrogen, and thus, through the Saha equation, on the stellar parameters $T_{\text{eff}}$ and $\log g$. As a consequence of its dependence on the degree of ionization, the shape of the Lyman $\alpha$ wing is a very sensitive tool for determining these parameters once accurate absorption coefficients for the line wing are known.

2. New Profile Calculations

Previous theoretical calculations of line profiles were based on a unified line profile theory assuming a constant radiative dipole moment during the collision (Allard et al., 1994).

However, the assumption that the dipole moment is constant during the collision may be questionable and the theoretical results are improved by including the effect of the variation of the radiative dipole moment during the collision. The theoretical approach is described in Allard et al., 1998a.

Numerical calculations show that large changes in the intensity of the satellites may occur when the variation of the dipole moment is important in the region of internuclear distance where the satellite is formed Allard et al., 1998b.

This leads to a significant increase in the amplitude of the main spectral line satellites. Results of these calculations are shown in Table 1. The dipole moment variation increases the amplitude by a factor 2 for the 1405 Å satellite and by 1.5 for the 1600 Å satellite.

As a consequence, when theoretical Lyman series profiles are to be used in the diagnostics of stellar parameters, the variation of the dipole moment must be included in order to obtain a reliable analysis.

<table>
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<th>1405 satellite</th>
<th>1600 satellite</th>
<th>1405/1600 ratio</th>
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</thead>
<tbody>
<tr>
<td>constant</td>
<td>$4.12 \times 10^{-9}$</td>
<td>$2.3 \times 10^{-10}$</td>
<td>17.9</td>
</tr>
<tr>
<td>variable</td>
<td>$8.73 \times 10^{-9}$</td>
<td>$3.4 \times 10^{-10}$</td>
<td>25.7</td>
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<tr>
<td>variable/constant</td>
<td>2.11</td>
<td>1.48</td>
<td></td>
</tr>
</tbody>
</table>

3. Comparison of IUE Observations with Theoretical Spectra

New theoretical profiles have been included by Kurucz in the computation of synthetic spectra of $\lambda$ Bootis stars (Allard et al., 1998c). A comparison with an IUE
Figure 1. Comparison of an observed IUE spectrum of λ Bootis with theoretical models with and without the variation of dipole moment.

Figure 2. Comparison of the observed 1600 Å region with theoretical profiles with and without the variation of dipole moment. The experiment is a measurement of the optically thin emission from atomic hydrogen compressed and heated by the shock wave from a laser-produced plasma at a neutral density of approximately \(10^{19} \text{ atoms/cm}^3\).
observation shows that these last improvements are essential to a quantitative interpretation of the spectra and to determination of atmospheric parameters (Figure 1).

4. Comparison of laboratory observations with Theoretical profiles

The observation of the far wing of Lyman $\alpha$ due to neutral atom and ion collisions in a laser-produced hydrogen plasma also confirms that the variation of the radiative dipole moment is an important factor in determining the far wing emission of Lyman $\alpha$. The observed shape of the satellite is in good agreement with the variable $D(R)$ theory; the constant $D$ theory underestimates the strength of the satellite. Both theories predict oscillatory structure between the satellite and the line Figure 2.

Acknowledgments. The computations of potentials and dipole transition moments were performed on the CRAY of the computer center IDRIS and on the CONVEX of the computer center of the Observatoire de Paris. The work at the University of Louisville is supported by a grant from the U.S. Department of Energy, Division of Chemical Sciences, Office of Basic Energy Sciences, Office of Energy Research. R.K. gratefully acknowledges support through grants from the CNRS.

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