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Atomic Physics of Raman Scattered He IIλ4332

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Abstract. Raman scattering of far UV photons with atomic hydrogen is important in studying the mass loss and accretion processes in many symbiotic stars. We present basic atomic physical properties for the inelastic scattering of He II 949 with a hydrogen atom, which results in Raman scattered He II 4332 blueward of H gamma. At line center of He II 949, the total scattering cross section is computed to be $\sigma_{tot} = 2.5 \times 10^{-22}$ cm^2 and the branching ratio into the level 2s is 0.12. It is proposed that comparisons of broad Balmer wings and Raman scattered He II features may provide an important diagnostic of far UV continuum around H I Lyman series.

Keywords. Binaries: symbiotic, radiative transfer, scattering

1. Introduction

The broad emission bands $\lambda\lambda$ 6830 and 7088 apparent in about a half of symbiotic stars were identified by Schmid (1989), who proposed that they are the resonance doublet O VI $\lambda\lambda$ 1032 and 1038 Raman scattered by hydrogen atoms. The scattering hydrogen atoms de-excite into $2s$ state re-emitting optical photons redward of Hα. These Raman scattered lines are very useful to probe the accretion processes of a white dwarf, which captures a fraction of material lost by the companion giant several AUs away from it.

Further investigation by van Groningen (1993) showed that far UV He II emission lines arising from $2n \rightarrow 2$ transitions are Raman scattered by atomic hydrogen to form weak and broad features blueward of hydrogen Balmer lines. Explicitly, He II$\lambda\lambda$1025 and 972 are Raman scattered to form He IIλ6545 and He IIλ4850, respectively. These scattered features have been found in the symbiotic stars including RR Tel and V1016 Cyg and in some young and compact planetary nebulae such as IC 5117 and NGC 6790 (Kang *et al.* 2012, Lee *et al.* 2006).

The symbiotic star V1016 Cyg shows another Raman scattered He IIλ4332 formed by inelastic scattering of He IIλ949 (Lee 2012), for which we provide basic atomic physical properties in this contribution.

2. Calculation and Result

The scattering process of a photon with an atomic electron is described by the second order time-dependent perturbation theory. The cross section, known as the Kramers-Heisenberg formula, is given by a sum over bound np states and an integral over free $n'p$ states of matrix elements of the dipole operator weighted by the conserved energy term.

When a line photon of He IIλ949 is incident upon a hydrogen atom in the ground state, the final state of the hydrogen atom can be one of $1s, 2s, 3s, 3d, 4s$ and $4d$ states as a result of electric dipole interactions. Therefore, we need to compute the six cross

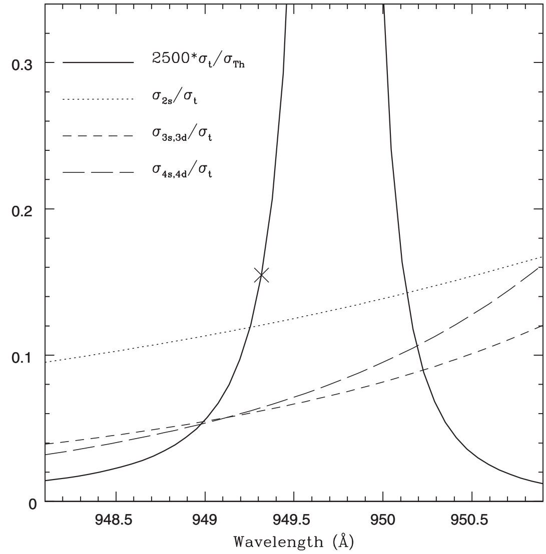

Figure 1. Total scattering cross section and branching ratios near HI Lyδ. The solid line shows the total cross section in units of σ_{Th} multiplied by a factor 2500. The other lines represent the branching ratios into the states $3s-3d$ and $4s-4d$. The cross show the total scattering cross section of 2.5×10^{-22} cm^2 at emission center $\lambda = 4340.381$ Å of He IIλ949.

sections corresponding to the six final states in order to simulate the radiative transfer of He IIλ949 line photons.

In Fig. 1 we show the total scattering cross section and branching ratios near Lyδ. The cross in the figure shows the line center wavelength of He II λ949, where the total scattering cross section is $\sigma_{tot}\sim 386\sigma_{Th} = 2.57\times10^{-22}$ cm^2. This value is much smaller than the corresponding values of 6.2×10^{-21} cm^2 and 9.1×10^{-22} cm^2 for He II λ1025 and He II λ972, respectively. The formation of Raman scattered He II features in a large range of scattering optical depths may be useful to probe the velocity field and the geometric structure of the giant wind.

The branching ratios near Lyγ is approximated as

$$r_2(\lambda) = 0.123 - 22.4(1-\lambda/\lambda_0)$$
$$r_3(\lambda) = 0.0672 - 34.5(1-\lambda/\lambda_0)$$
$$r_4(\lambda) = 0.0640 - 23.5(1-\lambda/\lambda_0),$$

up to the first order of $\Delta\lambda/\lambda_0$, where λ_0 is the center wavelength of Lyγ.

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