Density Effects in Na-He/H_2 and Ca^+-He Collisional Profiles

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Abstract

Traces of heavy metal in cool DZ white dwarfs may be attributed to the accretion of circumstellar dust. This dust is thought to originate from the tidal disruption of some rocky material. They provide a unique opportunity to study the composition of extra-solar planetary systems. The determinations of precise atmospheric parameters and abundances require accurate description of the line profiles of the identified features. The theory of spectral line shapes, especially the unified approach we have developed, makes possible accurate models of stellar spectra that account both for the centers of spectral lines and their extreme wings in one consistent treatment. We present absorption spectra of Na-He and Ca^+-He for the conditions prevailing in cool white dwarfs and unified line profiles of sodium perturbed by H_2 from the optical to the infrared spectral range.

Introduction

Infrared observations with the Spitzer space telescope discovered infrared excesses in DA and DB white dwarfs. In the mean time high resolution spectroscopy reveals the presence of heavy elements in the spectra of many white dwarfs (reclassified as DAZ and DBZ) [1].
The studies of observed cool DZ white dwarfs in the Sloan Digital Sky Survey (SDSS) by [2] showed extremely broad resonance lines of ionized calcium and magnesium in the optical and ultraviolet region. They pointed out the need for more accurate line profile calculations than Lorentzian profiles. The lines are significantly broadened due to collisions with helium and the wings extend as much as 1000 Å either side of line core.
Through their blanketing effect these lines have a dominant influence on the model structure and thus on the determination of atmospheric parameters and element abundances.

Theory

A unified treatment of the shape of pressure-broadened absorption line from near resonance to the far wing is obtained using autocorrelation formalism. Complete details and the derivation of the theory are given by [3]. This treatment includes finite duration of collision and requires the knowledge of molecular potentials, that is, the binary interaction between the radiating and the perturbing atom or molecule as a function of their separation. To evaluate an atomic spectral line shape, we compute a Fourier Transform written formally as

$$I(\Delta\omega) = \frac{1}{\pi} Re \int_0^{+\infty} \Phi(s) e^{-i\Delta\omega s} ds$$

Here the correlation function Φ is not for a single isolated atom, but for an ensemble of sources each experiencing a different microscopic environment with a different temporal history during the radiative process. The well-developed theory of spectral line shapes allows us to compute the function

$$\Phi(s) = e^{-n_p g(s)}$$

in which the density of perturbers is expressed explicitly, and the function $g(s)$ depends only on single collisions [4].
The decay of the autocorrelation function $\Phi(s)$ with time leads to atomic line broadening. It depends on the density of perturbing atoms n_p and on their interaction with the radiating atom. Fundamentally we are able to calculate a spectrum in this way for any atom given the temperature, density, and composition of the gas in which it is found.
Moreover, the impact approximation determines the asymptotic behavior of the unified line shape correlation function. In this way the results described here are applicable to a more general line profile and opacity evaluation for the same perturbers at any given layer in the photosphere.
Much effort has been expended in accurate determination of the shape of pressure broadened alkali resonance lines for brown dwarf and extra-solar planet atmospheres [5, 6, 7].
In the PHOENIX implementation of alkali lines perturbed by helium and molecular hydrogen, the line opacity is calculated by splitting the profile into a core component, which is describing the interactions at intermediate and long distance with a Lorentzian shape, and the far wings for close interactions that can produce detunings up to several 1000 Å. The latter is computed using an expansion of the autocorrelation function in powers of density, developed to the third order. This method, successfully applied under the conditions of brown dwarf atmospheres can be applied to the conditions of cool white dwarf atmospheres until n_{He}= 10^{21} atoms cm^{-3}.
http://mygepi.obspm.fr/ allard/tables.html.

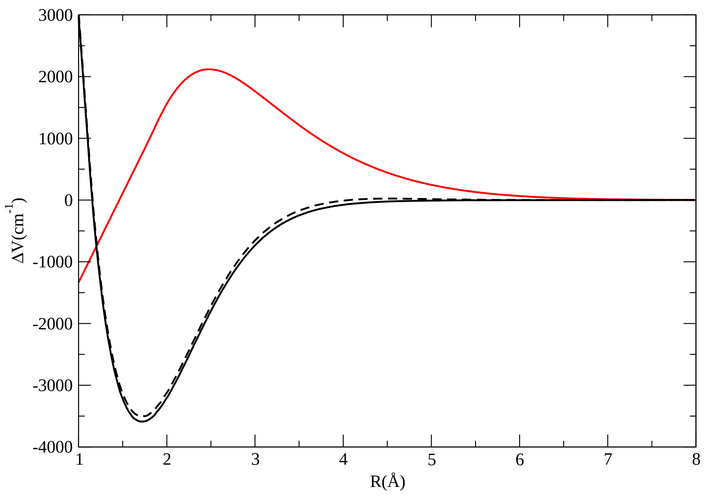

Figure 1 presents $\Delta V(R)$ for the Na–He (red curve) and Ca^+–He (black curves) molecules including spin-orbit coupling.

Resulting profiles

Collision-broadened lines show features that arise from the changed structure of the radiating atom in the presence of another atom. As such, their presence is sensitive to the conditions of the radiating system and reveal the composition, temperature, and pressure of the source. Spectral line satellites have been seen in stars of extreme variety – on the Lyman series of hydrogen emitted by white dwarfs, and on alkali lines in brown dwarf stars only a few times Jupiter's mass [6].
Blue satellite bands in Na-He/H_2 profiles are correlated with maxima in the excited B state potentials and can be predicted from the maxima in the difference potentials ΔV (Fig. 1) for the $3p$ B-$3s$ X transition [8].
In the case of CaII-He the minimum in ΔV (Fig. 1) for the $4p$ A-$4s$ X transition leads to quasi-molecular lines Ca^+He at 0.45 μm (Fig. 3) on the red wing of the CaII H and K resonance lines [9].
When the atomic density is as high as (n_{He}=1×10^{21} cm^{-3}) the radiating atom may undergo a close collision simultaneous with more than one perturber.
Satellites on Na and K due to broadening by H_2, have been measured in the laboratory [10]. Line shape theory, with the aid of such laboratory confirmation, is a tool for exploring the extremes of density and temperature in stellar atmospheres. We have extended this work to transitions between excited states in [11]. Unified line profiles of sodium perturbed by H_2 from the optical to the infrared spectral range are shown in (Figs. 4-5).

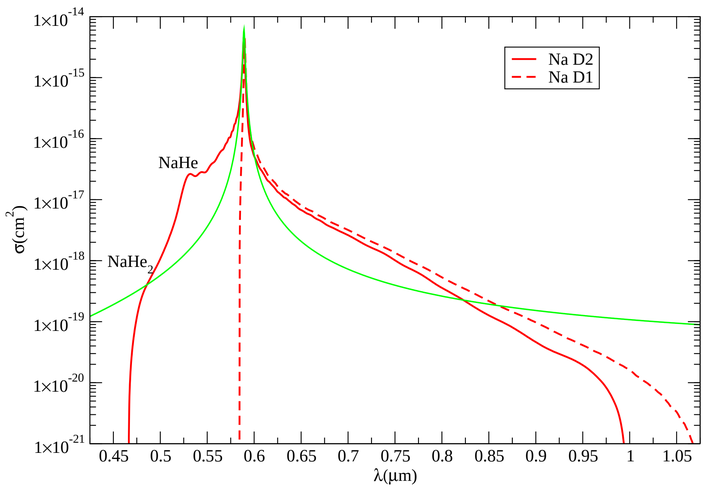

Figure 2
Absorption cross section of the Na D1 and D2 resonance lines perturbed by He for (T= 6000K, n_{He}=1× 10^{21} cm^{-3}). Green curve for corresponding Lorentzian for the D2 line.

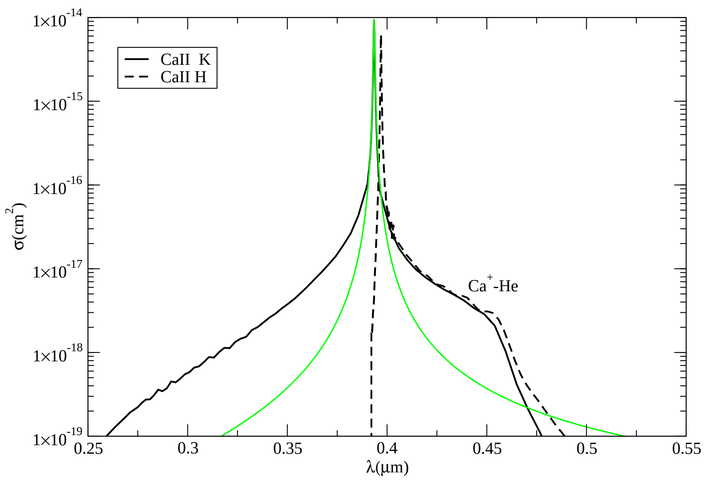

Figure 3
Absorption cross section of the CaII H and K resonance lines for T= 6000K. Green curve for corresponding Lorentzian for the K line.

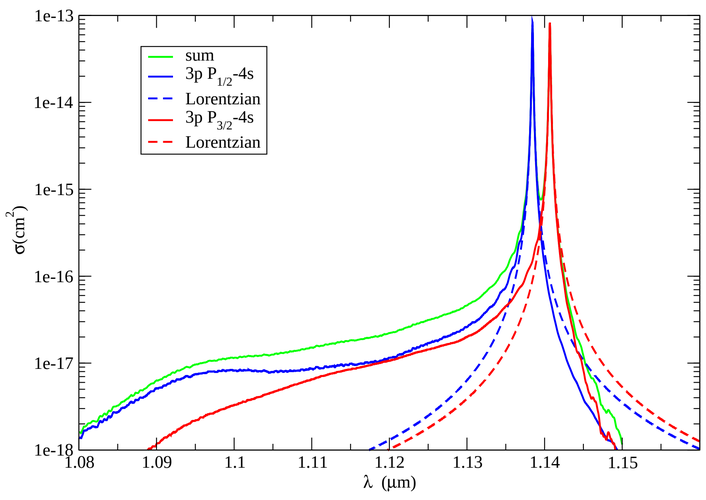

Figure 4
Absorption cross section of the 3p $P_{1/2,3/2}$-4s lines of Na perturbed by H_2. (T= 1000K, n_{H_2}=1×10^{19} cm^{-3}). Dashed lines for corresponding Lorentzians.

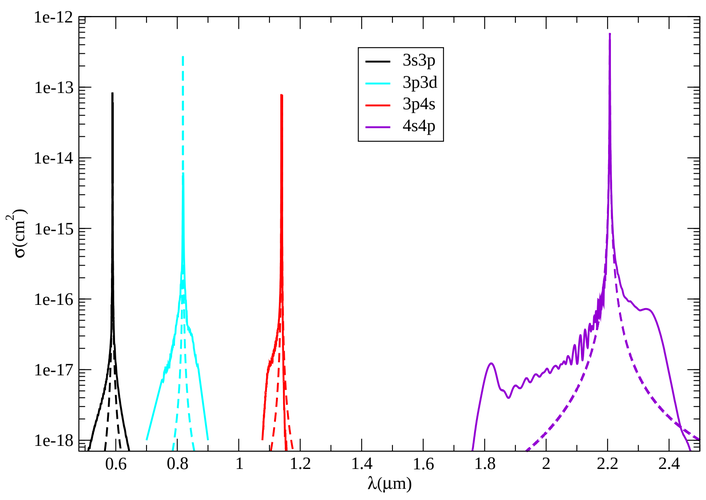

Figure 5
Absorption cross section of the 3s-3p, 3p-3d, 3p-4s, 4s-4p lines of Na perturbed by H_2. (T= 1000K, n_{H_2}=1×10^{19} cm^{-3}). Dashed lines for corresponding Lorentzians.

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