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Mg line profiles for cool WD and their application in the UV

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Abstract

Since last decade there have been great advances and extremely exciting results in the search and interpretation for cool DZ white dwarfs. In the formation of their spectra, the far wings of alkaline earth metals like Ca and Mg, play an extraordinary role. We present theoretical profiles of the Mg resonance lines perturbed by He at the extreme density conditions found in the cool atmosphere of DZ white dwarfs. Atmosphere models are necessary to calculate synthetic spectra and to derive reliable parameters and the atmospheric composition for such objects. We present synthetic spectra tracing the behavior of the Mg resonance line profiles under the low temperatures and high gas pressures prevalent in the cool atmospheres of DZ white dwarfs.

1 Theory

In the atmospheres of cool white dwarfs , pressure broadening by helium is prevalent. With $n_{\rm He}$ densities above 10^{21} cm^{-3} for Ross 640 (Blouin et al., 2018), reaching 2×10^{22} cm^{-3} for vMa2 (Dufour, private communication), multiple perturber effects have to be taken into account. In dense plasmas, as in these very cool DZ white dwarfs, a reliable determination of the line profiles that is applicable in **all** parts of the line at **all** densities is the Anderson semi-classical theory (Anderson, 1952), which uses the Fourier transform of an autocorrelation function. A unified theory of spectral line broadening has been developed to calculate neutral atom spectra given the interaction and the radiative transition moments of relevant states of the radiating atom with other atoms in its environment. Complete details and the derivation of the theory are given by Allard et al. (1999). The impact approximation determines the asymptotic behavior of the unified line shape autocorrelation function. The Lorentzian width can be readily extracted, and is presented in Fig. 12 of Allard et al. (2018). This approach to calculating the spectral line profile requires the knowledge of molecular potentials with high accuracy because the shape and strength of the line profile are very sensitive to the details of the molecular potential curves describing the collisions. Our calculations are based on the very recent *ab initio* calculations of Mg^+ potentials and dipole moments (Allard et al., 2016b). The potentials of Mg–He (Allard et al., 2018) are computed by *ab initio* approaches with the MOL-

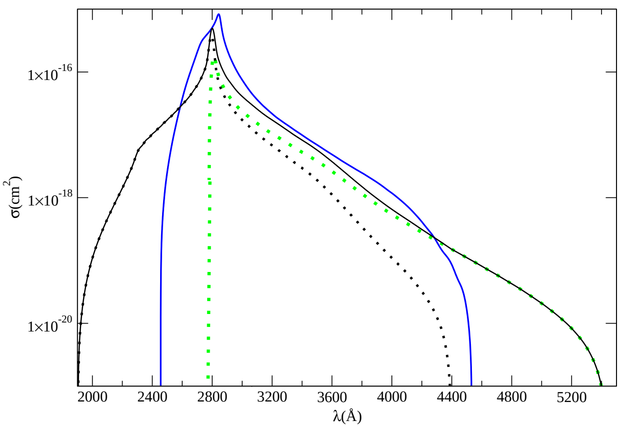

Figure 1: Theoretical absorption cross sections of the Mg lines. (T =6000 K and $n_{\rm He}$ = 10^{22} cm^{-3}). Comparison of the Mg I line (blue curve) to the sum of the two components of the Mg II line (black curve). The two components of the Mg II line are plotted in dotted lines (P3/2 black curve, P1/2 green curve).

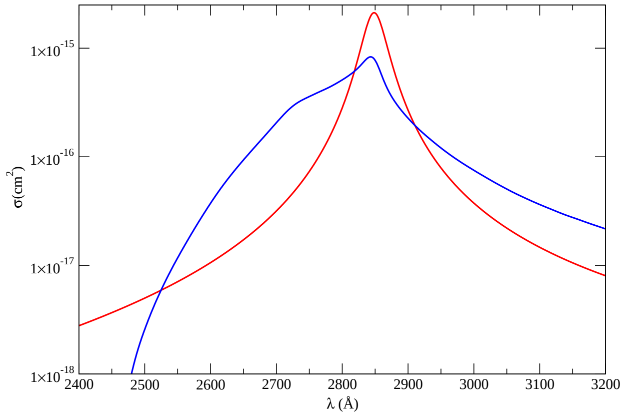

Figure 2: Theoretical absorption cross sections of the Mg I line (blue curve) compared to the Lorentzian profile (red curve). (T =6000 K and $n_{\rm He}$ = 10^{22} cm^{-3}).

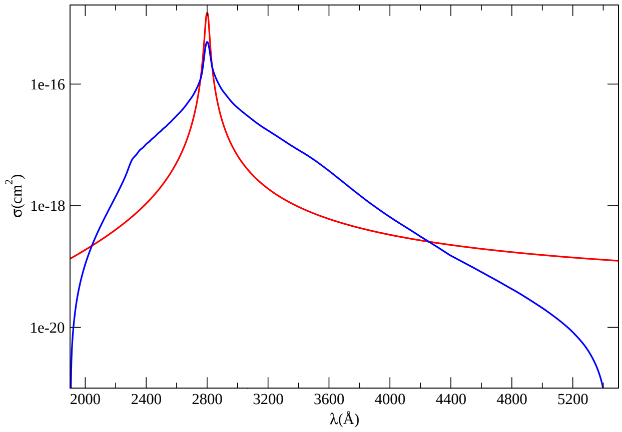

Figure 3: Theoretical absorption cross sections of the sum of the two components of the Mg II line (blue curve) compared to the Lorentzian profile (red curve). (T =6000 K and $n_{\rm He}$ = 10^{22} cm^{-3}).

PRO package (Werner et al., 2012).

2 Absorption spectra of Mg in dense helium

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.

Collisional line profiles are evaluated for $n_{\rm He}$=1× 10^{22} cm^{-3} for T =6000 K (Figs. 1 – 3). The resonance-broadened wings extend and decrease monotonically very far on the red long-wavelength side of line center. Their blue wings, however, show “satellite bands”, features that are due to the absorption of radiation during the Mg-He and Mg^+-He collisions, which are close to 2750 Å and 2300 Å for the neutral atom and the ion, respectively . The blue wings fall off very rapidly.

Since in a model atmosphere calculation the resulting line profile is the integration of the flux in all layers from the deepest to the uppermost, it is also important that the line centers be adequately represented; i.e., they can be non-Lorentzian at the high densities of the innermost layers, while Lorentzian in the upper atmosphere. In the cool white dwarfs under consideration, the helium atom density is of the order of 10^{20}-10^{21} cm^{-3} in the region of line core formation. As the line satellites are well separated from the main line, the impact approximation is still good at these densities (Fig. 11 in Allard et al. (2018)), with the understanding that it will never give a correct line wing as shown in (Figs. 2 – 3). This was also true for the H and K lines of the resonance lines of Ca II (Fig. 2 of Allard & Alekseev (2014)). When line satellites are close to the parent line as for the 3s-2p line in He_2 (Allard et al., 2012), or the Mg b triplet (Allard et al., 2016a), the situation changes drastically and leads to a complex behaviour of the dependence of the line shape.

3 Synthetic spectra

Blouin et al. (2018) have now developed an improved atmosphere model code to accurately describe cool DZ white dwarfs taking into account non-ideal high-density effects arising at the photosphere. The line profiles of the resonance lines of Mg^+ and neutral Mg have been included. Figures 4 – 5 show the relative contribution of each of these two lines to the synthetic spectra at $T_{\rm eff}$ = 8000 and 6000 K respectively. They stress the importance of accurately determining line profile calculations to evaluate the far wings of these lines. The red wing of the MgI and MgII lines extends over 1000 Å until the CaII H/K lines (Allard et al., 2018). The contribution of the blanketing on the red and blue sides is mostly due to MgII lines, since most Mg is ionized at the photosphere of the models. We report a study of WD2216-657 (LP 119-34) in Allard et al. (2018).

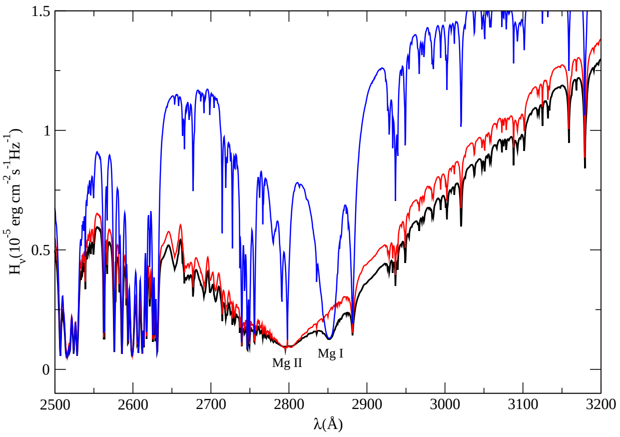

Figure 4: Synthetic spectrum computed at $T_{\rm eff} = 8000\ K$, $\log$ Ca/He $= -9$, $\log$ Fe/He $= -8.4$, $\log$ Mg/He $= -7.3$, $\log$ H/He $= -3.5$, compared to synthetic spectra computed without the MgII (in blue) and the MgI (in red) line opacity.

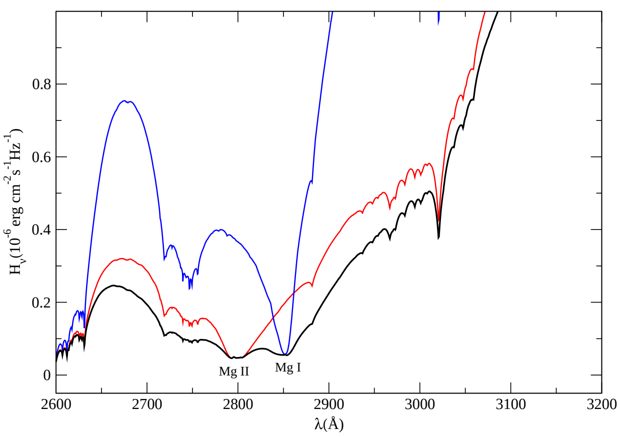

Figure 5: Synthetic spectrum computed at $T_{\rm eff} = 6000\ K$, $\log$ Ca/He $= -10.5$, $\log$ Fe/He $= -9.3$, $\log$ Mg/He $= -9.2$, $\log$ H/He $= -3.5$, compared to synthetic spectra computed without the MgII (in blue) and the MgI (in red) line opacity.

4 Conclusions

The determination of accurate opacity data of magnesium resonance lines together with an improved atmosphere model code are essential to get reliable synthetic spectra of cool DZ white dwarf stars. The broadening of spectral lines by helium needs to be understood to accurately determine the H/He and Mg/He abundance ratio in DZ white dwarf atmospheres. We emphasize that no free potential parameters or ad hoc adjustments were used to calculate the line profiles.

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