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Letter to the Editor

Indication of singly ionized helium in the white dwarf GD 229

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Abstract. We comment on the applicability of the stationary line argument recently used by Jordan et al. (1998) to account for the unusual absorption features in the observed optical spectra of GD 229. Moreover, we provide an alternative explanation based upon the existence of neutral and singly ionized atomic helium atoms as the main elements comprising the atmosphere of this magnetized white dwarf star.

Key words: stars: white dwarfs – stars: magnetic fields – stars: individual: GD 229 – stars: individual: LB 11146B

1. Introduction

A recent interesting paper (Jordan et al. 1998) has presented a rough match for the observed optical spectrum of GD 229 using "stationary line" (Angel 1978) components of neutral atomic helium (He). Based upon linear and circular polarization measurements by Schmidt et al. (1996), this atypical magnetized white dwarf star was thought to have He as the dominant element in the atmosphere, and the polarization measurements suggested that the magnetic field strength exceeded $10^9\,\mathrm{G} = 1000\,\mathrm{MG}$. The work of Jordan et al. (1998) not only appears to confirm the presence of He but also determines the strength of the magnetic field sustained by the star, at approximately 300–$700\,\mathrm{MG}$, slightly lower than the value suggested by the polarization experiments. In this brief report, we comment on these results and present an alternative interpretation of the anomalous absorption features of GD 229 based on the existence of both He and singly ionized helium (He^+).

2. Background

Stationary transitions are those whose wavelength passes through maxima and minima for a given interval of magnetic field strength which approximates the suspected variation of the field strength across the stellar disk. This interpretation of the optical spectral absorption features of stars in terms of the stationary line components of atomic systems has been extremely successful in interpreting the unusual features of certain magnetized white dwarfs, like Grw+70°8247 (Angel et al. 1985). This technique, however, is hampered by the poor theoretical understanding of the electronic structure of simple atomic systems in strong external fields. Unfortunately, only the spectrum of the simplest element, hydrogen, has been adequately treated (Rosner et al. 1984; Ruder et al. 1994). Therefore, precise calculations of the spectrum of other light elements, like He, would greatly help to understand the composition of the atmospheres of other compact stellar remnants. Progress has recently been made in determining some transition wavelengths of neutral He in fields up to $10^6\,\mathrm{MG}$ with unprecedented accuracy (Jones et al. 1998; Becken et al. 1998) although oscillator strengths were not obtained with an equivalent degree of precision. Detailed modeling for helium-rich magnetized white dwarf atmospheres has therefore not been possible to date, and an analysis using stationary lines, like that presented in Jordan et al. (1998), remains the most viable, albeit crude, theoretical treatment.

The stationary line matching argument, however, is quite subjective; spectral lines which are extremal are aligned with observed absorption features without considering the influence of the dipole matrix elements or the physical environment present in the star. As Jordan et al. (1998) state, however, the two strongest absorption features in the observed spectrum can not be consistently matched with their numerical results (which include many excitations of neutral helium, but only for a limited subset of possible symmetries). Our results for neutral helium (Jones et al. 1998), computed for fewer excitations but a greater variety of symmetries, also fail to account for many of these prominent spectral components. We do not exclude the possibility that these features may be accounted for by transitions in He not considered by Jordan et al. (1998) and Jones et al. (1998).

3. Contributions from He^+

In this work we propose the additional presence in GD 229 of He^+ ($Z = 2$), whose spectral properties can be obtained by

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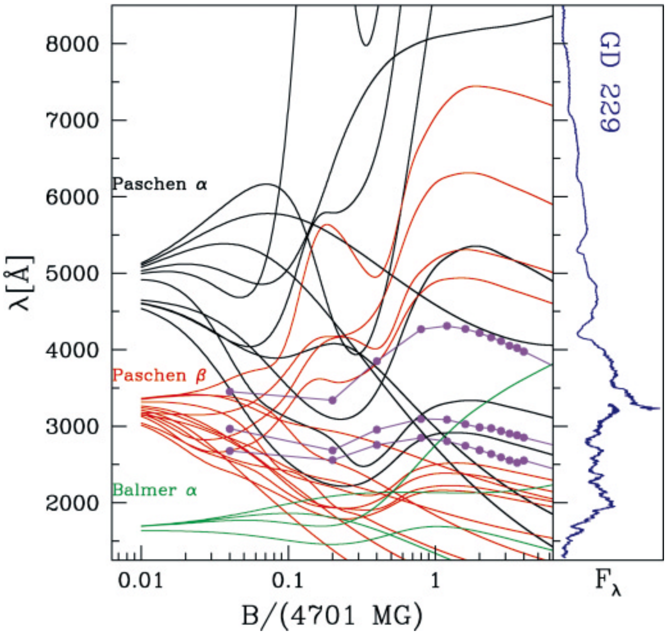

Fig. 1. Stationary line components of singly ionized atomic helium as a function of applied magnetic field strength. Atomic data for He^+ was taken from Rosner et al. (1984). Three stationary lines arising from neutral helium (lines with dots) are from Jones et al. (1998), using the stationary transitions $(1s3p)^3P_0 \to (1s2s)^3S$, $(1s4p)^3P_0 \to (1s2s)^3S$ and $(1s4p)^3P_{-1} \to (1s2s)^3S$. The right panel shows the observed flux from the white dwarf GD 229 (Schmidt et al. 1990, 1996).

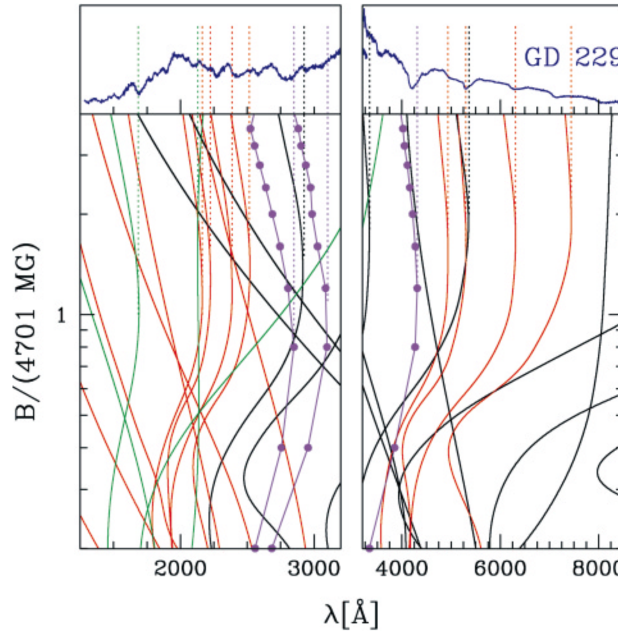

Fig. 2. Stationary line components of singly ionized and neutral helium as in Fig. 1. The arrows indicate the magnetic field range 4100–9400 MG, which approximates the variation of the field across the stellar disk. The top panel shows the observed flux from the white dwarf GD 229 (Schmidt et al. 1990, 1996).

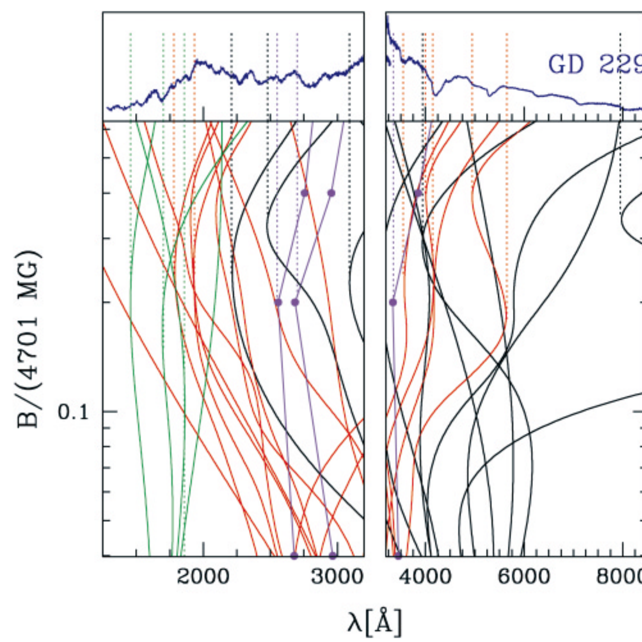

Fig. 3. Stationary line components of singly ionized and neutral helium. The arrows indicate the magnetic field range 700–1600 MG.

scaling the energies for atomic hydrogen (Rosner et al. 1984) ($Z = 1$). The scaling law for the energy reads (Surmelian et al. 1974)

$$E(Z, \beta) = Z^2 E(Z = 1, \beta/Z^2), \tag{1}$$

where $\beta = (B/B_0)$ is the magnetic field parameter in terms of $B_0 = 4701\,\mathrm{MG}$. The "stationary" lines thus obtained are shown in Fig. 1, coming from Balmer α (change in principal quantum number, n_p, from 3 to 2), Paschen α ($n_p = 4 \to 3$) and β ($n_p = 5 \to 3$) transitions, along with three stationary lines from He (Jones et al. 1998). Examination of the spectrum suggests two possible magnetic field regimes. The first is shown in Fig. 2, where we have drawn lines corresponding to extremal values in the optical spectrum for magnetic fields in the range 4100–9400 MG, for which we see a crude match to the observed flux (top panel). The second possible matching is displayed in Fig. 3, which shows another set of extremal values for a smaller range of magnetic fields, about 700–1600 MG, which almost overlaps the range suggested by Jordan et al. In particular, notice that the most pronounced absorption features around 4100 Å and 5600 Å could be accounted for by the presence of He^+. These two matchings are more consistent with the field strength suggested by polarization experiments (Schmidt et al. 1990, 1996). We note that these crude matchings account for many of the dominant features, with the exception of those near 6500 Å and at wavelengths longer than 7000 Å, where there are many lines coming from neutral helium (Jordan et al. 1998), particularly those coming from spin singlet states, which were not considered by Jones et al. (1998). We also note that the broad feature near 5600 Å in LB 11146B (Liebert et al. 1993; Glenn et al. 1994) could be accounted for using the above stationary lines of He^+. We should emphasize, however, that this stationary line argument is qualitative.

A very relevant question concerns the possible source of He^{+}. Clearly the inferred temperature of $16–20 \times 10^3$ K is insufficient to ionize He in such a strong field (Schmidt et al. 1990, 1996). At zero field, however, a possible ionizing mechanism, which has been demonstrated experimentally, is known (Rose 1998). The $(2s2p)^1P$ state of He (excited from the ground state by a single ultraviolet photon) can decay by means of a radiationless transition to He^{+}. For large magnetic field strengths this autoionizing process has thus far not been calculated, and it is unclear whether this process (or others) can produce enough He^{+} to have an observable effect on the spectrum.

4. Conclusions

We have presented two alternative interpretations of the anomalous spectrum of the magnetic white dwarf GD 229 using stationary line components of He and He^{+}. These results indicate the possible presence of both species, but it remains an open question as to the possible origin of He^{+}. Direct comparison with observed stellar spectra is problematic; what is needed is a model of the stellar atmosphere which uses the atomic spectral information along with enough of the crucial physical behavior involved in absorption and emission in the visible stellar disk (stellar opacities), similar to studies done using the hydrogen results (Ruder et al. 1994), which were used to produce synthetic spectra. Until such an analysis is made, however, we believe that the application of stationary line arguments to GD 229 will remain somewhat uncertain.

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