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TEST CASE FOR THE DIAMAGNETIC EFFECT: HELIUM PECULIARITIES ON B STARS

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I. INTRODUCTION

He-peculiar stars devide into two groups: He-poor stars (B3V-B7V) and He-rich ones (B1V-B3V). There seems to be very little, if any, overlap of these two groups, in terms of spectral types (or surface temperature). Moreover, at the very upper range of the He-poor stars there is a narrow range (of Sp or Teff) in which He-3 stars are found. These stars have a larger abundance ratio of (He3/He4) compared to all other stars (Hartoog and Cowley,1979).

Peculiar stars in general exhibit periodicity in line intensity variations, interpreted in terms of (chemical abundance) spots at the stellar surface. These lines show also periodic radial velocity modulation. It is therefore puzzling that at least 3 He peculiar stars - HD 37479, HD 64740 and HD 125823 - do show intensity variation of HeI lines, but not radial velocity modulation (Groote and Hunger, 1977, Groote et. al.,1978, Norris, 1971).

We therefore ask:
(a) Why is the transition (in Sp type) from He-poor to the He-rich stars so sharp?
(b) Why do He-3 stars appear just at the transition from He-rich to He-poor stars?
(c) Can one explain the absence of radial velocity variations although well defined intensity variations are present in HeI lines?

II. OBSERVATIONS AND PAST THEORETICAL CONSIDERATIONS

Most of the He peculiar stars are photometric, spectral and magnetic variables. These variations can be understood in terms of oblique rotators. Those who do not exibit modulation are supposed to be looked pole on, or have a magnetic fields parallel to their rotation axis. A fraction of these stars show radio-emission, H alpha emission, X-rays, C IV and Si IV (sometimes rotationally modulated) spectral lines and an anisotropic stellar wind (Shore and Brown, 1990).

¿From narrow line photometry of the He I 4026 A line Pedersen and Thomsen (1977) found periodic variability in the strehgth of this line. Surprising is the absence of the He line radial velocity modulation in at least 3 stars (HD 37479, HD 64740 and HD 125823) but with well defined variations of line strength (Groote and Hunger, 1977, Groote et. al.,1978, Norris, 1971).

He-poor stars are usually explained in terms of radiative diffusion theory: since helium is scarce in spectral lines, radiation pressure on helium atoms is small compared to other elements, and therefore sinks. However, to explain He overabundances, it is necessary to invoke special stellar winds: narrow ranges of speeds and densities are needed (Vauclair,1975; Vauclair et al,1991). The supposed difference between He-peculiar and normal stars of the same Sp is explained as being the result of the atmosphere's stability in He-peculiar stars due to slower rotation - as for Ap stars. However, it is known that rotational velocities of He-pec stars are as large as those of normal stars. We now explore a completely different mechanism to explain the diversity of observed properties.

III. THE DIAMAGNETIC EFFECT (DME) AS A POSSIBLE MECHANISM FOR THE HELIUM PECULIARITIES

The observed variety of chemical pecularities do not depend on the strength of the magnetic field (Shore and Brown, 1990), so we suggest that additional factors are relevant, such as the rate of (geometric) divergence of magnetic structures. The DME could account for atmospheric structure modification due to diverging magnetic fields. In a non magnetic star the density falloff of various elements is given to the first approximation by a barometric formulae with scale heights typical to each mass and the ambient temperatures. At the poles of magnetic stars, where magnetic field lines diverge (geometrically), charged particles are pushed out from strong fields to regions of weaker fields (Fermi, 1954, Spitzer, 1962). The resulting effective gravity is reduced for charged particles compared to nonmagnetic stars. This leads to a modified barometric falloff of charged particles but at the same time nonmodified for neutral ones. In B stars hydrogen is already fully ionized.

From the Saha equation it follows that at an effective temperatures of 16 000 K helium is essentially neutral n(HeII)/n(HeI) = 0.2 while at 18 000 K helium is essentially ionized n(HeII)/n(HeI) = 2. We conclude, therefore, that (1) atmospheric altitude run of the He/H ratio will be different in magnetic vs. nonmagnetic stars; (2) the earlier vs. later magnetic B type star's atmospheres are modified in a different manner due to the DME acting only on charged particles: The effect for He depends on the degree of ionization. Therefore the sharp boundary between He-weak and He-rich stars at B3 is initially connected with the ionization state of helium and its fast change.

The observed He peculiarity depends thus on the combination of 3 factors:
(1) The degree of helium ionization;
(2) The divergence rate of magnetic field lines;
(3) The relative height of formation of helium lines vs.

that of the adjacent continuum, which is formed by recombination onto HI.

Helium underabundances are observed for cooler B stars. On these helium is essentially neutral and its barometric law is similar to that for nonmagnetic star of the same spectral class. In contrast, hydrogen is already almost fully ionized at these temperatures, which modifies the density fallof of HI, with reduced effective gravity at the magnetic poles. Continuum opacities are due to hydrogen, the continuum forming layer (photosphere) is higher compared to nonmagnetic stars than He-layer. Thus, the underabundance of helium can be understood in terms of "raising" the continuum forming layers.

Helium overabundances are observed on hotter B stars. Here helium is already ionized and its barometric law undergoes modification due to DME (as well as the hydrogen's one). Again effective gravity is reduced relative to the nonmagnetic stars. The number of helium atoms above the continuum forming layer will be larger, which leads to enhancement of helium spectral lines. The He lines are thus formed in a shell significantly higher compared that to HI adjacent continuum. He line intensity variations are possible without accompanying radial velocity modulation, provided the adjacent continuum has the proper limb darkening.

He3 overabundance is observed at the higher temperature boundary of He-poor stars. At these temperatures helium is partially ionized. He3 and He4 follow modified barometric laws, corresponding each to their mass; hence the ratio (He3/He4) rises with height. If the continuum layer is located in the region where (He3/He4) is higher than normal (compared to nonmagnetic stars) then He3 contribution in spectral lines will be enhanced in magnetic stars, relative to nonmagnetic ones.

IV. SUMMARY

We conclude that the combination of the DME with thermal properties (i.e. degree of ionization) leads to the following:
(1) He under and overabundances, with a sharp boundary between the two;
(2) the appearence of He3 overabundance just at the boundary between the two abundance classes;
(3) the appearence of He line intensity modulation without the accompanying radial velocity modulation;

Concluding, we argue that it may be possible to understand the diverse observations by one single mechanism only: the DME.

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