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FUSE DETERMINATION OF THE ABUNDANCES OF IRON-PEAK ELEMENTS IN THE PG 1716+426 STARS

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Abstract. We present preliminary analysis of the FUSE spectra of five PG 1716+426 stars, the subgroup of sdB stars that exhibit very low amplitude, long-period multiperiodic luminosity variations. Our aim is to investigate whether these stars display abundances of iron-peak elements which differ from those observed in the shorter-period EC 14026 stars and in non-variable sdB stars. Our preliminary results suggest that the abundances of Fe, Mn, Co and Ni in PG 1716+426 stars do not differ appreciably from those measured in our reference samples. The implications of these findings for non-adiabatic calculations which link the driving of both the long- and short-period pulsations to an opacity bump associated with a local enhancement of the abundance of iron and iron-peak elements in the envelope are briefly discussed.

Key words: stars: hot subdwarfs – stars: abundances – stars: oscillations – techniques: spectroscopic – stars: individual (PG 1716+426, PG 1627+017, PG 1338+481, PG 0101+039, PHL 457)

1. INTRODUCTION

The PG 1716+426 stars are pulsating subdwarf B stars that exhibit very low amplitude (≤ 5 mmag), long-period (2000–8000 s), multiperiodic luminosity variations. These variations are associated with high radial order g-modes. In the PG 1716+426 stars, which cluster between 20 000 and 28 000 K, the κ driving mechanism is currently thought to be similar to that which is relevant to the hotter (28 000–36 000 K), shorter-period (100–500 s) EC 14026 stars. In both classes, it has been suggested that the driving is linked to an opacity bump associated with a local enhancement of the abundance of iron and, presumably, other iron-peak elements in the envelope (Charpinet et al. 1997; Fontaine et al. 2003). This enhancement could be brought about by radiative element support, as argued by Chayer et al. (2004). Analyses of element abundances in sdB stars could be of some help in constraining current non-adiabatic models, since the mean photospheric abundances of iron-peak elements in both classes of pulsating stars might differ from those which characterize the constant sdB stars. Furthermore, the relative importance of a stellar wind might differ when one considers the sample of cool PG 1716+426 stars instead of the hotter EC 14026 stars. On that basis, it might be possible to distinguish between various groups of B-subdwarfs on the basis of the abundance of iron-peak elements.

Motivated by these considerations, we have undertaken a systematic analysis of the abundances of iron-peak elements in the PG 1716+426 stars and present here preliminary results of this work.

2. ANALYSIS AND RESULTS

Our analysis is based on high-resolution FUSE observations of a sample of five sdB stars that comprises all the PG 1716+426 observed up to now with FUSE. The basic atmospheric parameters of our target stars, as determined within the extensive analysis of the MMT sample being carried out by Chayer et al. (2003), are summarized in Table 1. For comparison purposes, we are also redetermining abundances for a sample of constant sdB stars (PG 0749+658, HD 4539, Feige 87, JL 236 and PG 1710+490, all located between 24 600 and 30 700 K), as well as for one EC 14026 star, Feige 48 ($T_{\rm eff} = 29\,600$ K). The abundances of heavy elements are determined on the basis of analyses carried out with version 201 of TLUSTY and version 48 of SYNSPEC (Hubeny & Lanz 1995; I. Hubeny 2004, private communication). In order to facilitate the comparison with our own reference samples of constant and EC 14026 stars, analyzed in LTE (e.g., Chayer et al. 2004), we use the same approximation here and treat various heavy elements as traces. The turbulent velocity is neglected and, as is standard in this type of analysis, the local continuum level is set by eye in each wavelength region.

The main results of our preliminary analysis can be summarized as follows. The PG 1716+426 stars appear to form a very homogenous group in terms of their abundances of iron-peak elements (Figure 1); the abundances by number we determine for Mn, Fe, Co and Ni are similar for our five objects and differ at most by 0.4 dex. They cluster around log (Mn/H) = −6.6, log (Fe/H) = −4.6, log (Co/H) = −7.4 and log (Ni/H) = −5.8, with typical errors of the order of 0.4 dex.

The abundances in the cooler star, PG 1627+017, are quite similar to those obtained in the slightly hotter stars of the sample. Furthermore, the lines of heavy elements in PHL 457 appear to be broader than those observed in the other stars in our sample. This suggests that some additional rotational broadening might be present. We note, in this context, that Edelmann et al. (2006a) report that PHL 457 is a member of a binary system.

Table 1. Adopted atmospheric parameters.

Star	$T_{\rm eff}/10^3$ (K)	$\log g$	log (He/H)
PG 1627+017	23.7	5.3	−2.9
PG 1716+426	27.6	5.5	−2.9
PG 0101+039	28.1	5.5	−2.8
PG 1338+481	28.1	5.4	−2.9
PHL 457	28.2	5.5	−2.5

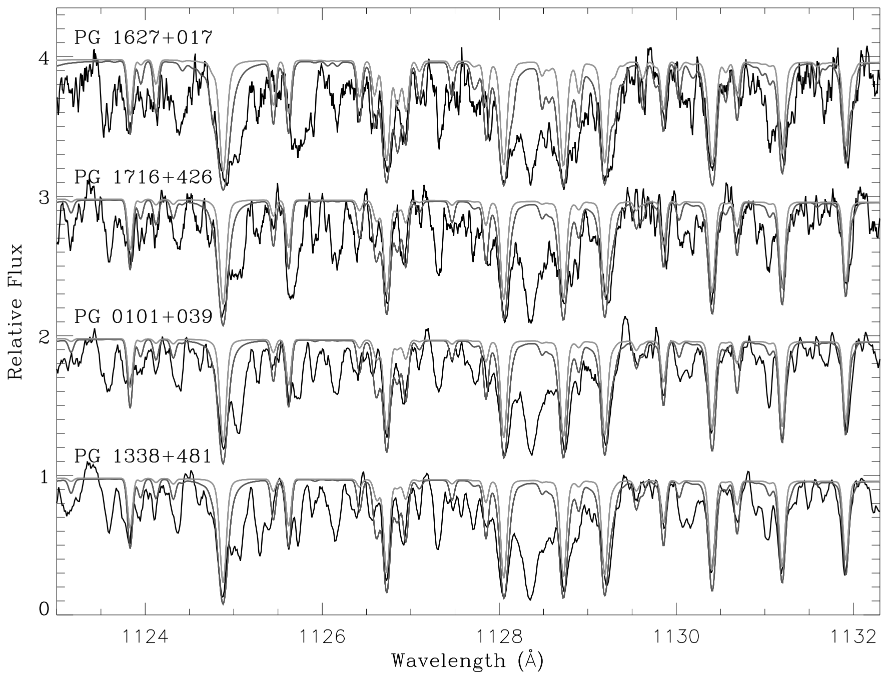

Fig. 1. Comparison between FUSE spectra of four of our program stars from 1123 to 1132 Å with synthetic spectra containing only Fe lines. This spectral region shows strong Fe III lines that correspond to transitions from the ground state $3d^6\ ^5$D to the $3d^5 4p\ ^5$P^o state. The synthetic spectra are calculated for two Fe abundances: log (Fe/H) = −4.2 (lower curve) and −5.0 (upper curve). The final Fe abundances are derived on the basis of several such regions and give a larger weight to regions with little contamination by lines of other ions.

We also carried out a comparison with the reference stars (EC 14026 and constant stars) we reanalyzed. A comparison of the four long-period variables hotter than 27 500 K with Feige 48, the EC 14026 star with similar parameters, shows that the abundances of Fe and Ni are quite similar, but that the abundances of Mn and Co appear somewhat lower (by roughly 0.4 dex) in the EC 14026 star.

A comparison of the long-period variables with the non-variables in the same temperature range shows that the abundances Fe, Mn, Co and Ni are similar in both groups. In Feige 87, recognized as a constant star with low abundances of heavy elements, there are no traces of Co and Ni, as well as lower abundances of Fe and Mn than in the PG 1716+426 stars.

As is often the case with analyses in the far-ultraviolet, the placement of the continuum represents a source of systematic error. For example, Pereira et al. (2006) have recently shown that, in the far-ultraviolet range the continuum level obtained by using a theoretical energy distribution (i) normalized at the Strömgren y magnitude and (ii) calculated at the values of $T_{\rm eff}$ and $\log g$ determined from the Balmer lines, could well lie above that used in abundance analyses. Fortunately, the impact of this work appears somewhat blunted here, since our analysis relies principally on relative, rather than absolute, abundances between various subgroups of hot B-subdwarfs.

What, then, can be said at this stage of the agreement with the abundances expected in the PG 1716+426 stars? Fontaine et al. (2006) present the first predictions of the time-dependence of the abundance of heavy elements expected in hot B-subdwarfs in the combined presence of radiative support and of a weak stellar wind. Their preliminary results suggest that there is a complex dependence of the surface abundance of heavy elements on the age; the abundance of selected heavy elements might thus not be the reliable indicator of pulsation instability it was once believed to be. While this makes the interpretation of abundances analyses such as ours and that of Edelmann et al. (2006b) less straightforward, it also suggests that abundance analyses will continue to play an important role in the near future: they will undoubtedly contribute to sorting out the interplay of the various physical processes taking place in the photospheres of hot B-subdwarfs.

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