A&A manuscript no.
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07 (02.12.2; 08.01.3; 08.05.3; 08.13.2; 08.16.4; 08.23.1)

ASTRONOMY AND ASTROPHYSICS
4.3.1998

Ultra-high excitation features in hot white dwarfs: A DAO and three DO stars discovered by the Hamburg Schmidt survey*

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Received date; accepted date

Abstract. We report on the discovery of four hot white dwarfs, one DAO (HS 2115+1148) and three DO (HS 0158+2335, HS 0727+6003 and HS 2027+0651). The spectra of these stars exhibit shallow metal absorption lines from ultrahighly excited ionization stages (C V, C VI / N VI, N VII / O VII, O VIII, Ne IX, Ne X) with ionization energies ranging from 392eV to 1362eV. We propose that they are formed in a stellar wind, explaining their asymmetric shape. However, the He II line spectra of the three DOs as well as the Balmer–line spectrum of the DAO are peculiar and cannot be fitted by static NLTE model atmospheres.

These stars increase the number of hot degenerate stars showing this phenomenon to six, this is the first time it is observed in a hydrogen–rich star. Thus, these six stars might constitute a new spectral subclass of hot white dwarfs suffering mass–loss from a hot and fast wind.

Key words: line: identification – stars: atmospheres – stars: evolution – stars: mass–loss – stars: AGB and post-AGB – stars: white dwarfs

1. Introduction

The Hamburg-Schmidt objective prism surveys, aiming at a complete sample of bright quasars in the northern sky (HQS, Hagen et al. 1995) and on the southern hemisphere (HES, Wisotzki 1994), also provide a very rich source of faint ($13 \lesssim B \lesssim 17$) blue stars. Optical follow-up spectroscopy of the stellar component has revealed numerous interesting individual stars, for a recent review see Dreizler et al. (1994). Among these are extremely hot helium–rich white dwarfs and PG 1159 stars with effective temperatures exceeding 100 000 K. In this *Letter* we report on the discovery of four very exceptional objects (HS 0158+2335, HS 0727+6003, HS 2027+0651, and HS 2115+1148) whose optical spectra reveal absorption lines observed recently in two similar objects (HE 0504−2408 and HS 0713+3958, Werner et al. 1995). The spectra of these two stars are dominated by broad, shallow and partly asymmetric metal absorption lines from ultrahighly excited ionization stages (C V, C VI / N VI, N VII / O VII, O VIII, Ne IX, Ne X). Additionally, symmetric lines of He II are observed. Werner et al. (1995) interpret these objects as hot DO white dwarfs surrounded by an extremely hot, fast wind causing the blue shifted, asymmetric lines of highly ionized metals. This picture is, however, only the first step toward our understanding of these stars, since neither the DO spectrum nor the wind features could yet be modeled successfully with our non–LTE atmosphere code.

As described in the next sections, the stars we report on here also show these highly ionized metal lines probably formed in an extremely hot wind, however, with much weaker line strengths. Very remarkable is the fact that this phenomenon seems to be restricted not only to helium–rich white dwarfs but can also be observed in a hydrogen–rich white dwarf.

2. Observations and line identifications

All stars we present here, HS 0158+2335, HS 0727+6003, HS 2027+0651, and HS 2115+1148, were observed during our follow–up spectroscopy of the stellar component of the Hamburg–Schmidt survey. Observations were obtained with the TWIN spectrograph mounted to the

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* Based on observations collected i) at the German-Spanish Astronomical Center, Calar Alto, operated by the Max-Planck-Institut für Astronomie Heidelberg jointly with the Spanish National Commission for Astronomy, ii) with the International Ultraviolet Explorer satellite.

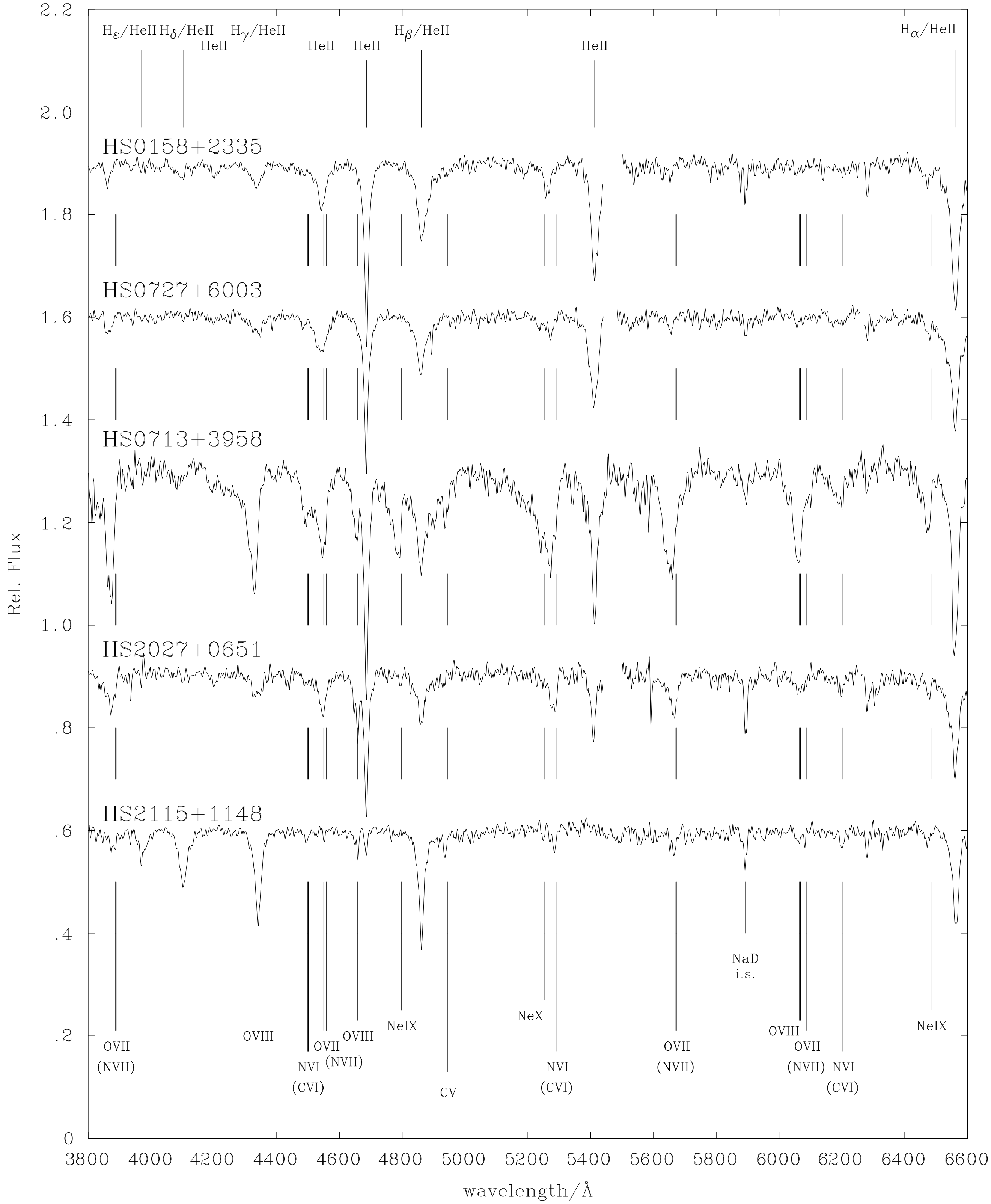

Fig. 1. Normalized optical spectra of HS 0158+2335, HS 0727+6003, HS 2027+0651, and HS 2115+1148 compared to a previously detected object of this class (HS 0713+3958). Note the absorptions from ultrahigh-excited C, N, O ions and even Ne IX and Ne X lines. Positions of these lines are marked and labeled at the bottom. Hydrogen and helium line centers are marked at the top

Calar Alto 3.5m telescope equipped with Tek#11 and Tek#12 chips (1024x1024 24 μ pixel). Wavelength coverage is 3800–7200 Å with a resolution of 3 Å. Details of the observations as well as coordinates and B magnitudes are given in Table 1. Magnitudes were derived from calibration of the Schmidt plates obtained during the Hamburg survey with an uncertainty of $\approx 0\overset{\mathrm{m}}{.}5$.

Table 1. Coordinates, magnitudes, and log of optical observations

star	RA (1950)	DEC (1950)	B	Date y-m-d	$t_{\rm exp}$ min
HS 0158+2335	01 58 38.8	+23 35 25	16.6	95jan24	120
HS 0727+6003	07 27 00.4	+60 03 57	15.8	95jan23	50
HS 2027+0651	20 27 05.2	+06 51 04	16.9	94sep23	100
HS 2115+1148	21 15 54.1	+11 48 53	16.5	94sep25	59

The optical observations of the four stars are compared in Fig. 1 to one of the previously detected stars exhibiting the extremely highly ionization features (HS 0713+3958). This comparison shows that all these objects show signatures of extremely highly ionized material, however, in a less drastic form than in HS 0713+3958 and HE 0504−2408. Table 2 lists the identifications made in the spectra of the four stars of Δn=1 or Δn=2 transitions arising from extremely highly ionized C, N, O and Ne ions. The ionization potentials (392-1362 eV) require temperatures in excess of 500 000 K, which is far too high for normal white dwarf atmospheres. As in HS 0713+3958 and HE 0504−2408 the highly ionized lines are blue shifted and slightly asymmetric suggesting that these lines are formed in a hot wind.

Some features are blended with ions typically present in spectra of hot DO white dwarfs or PG 1159 stars (C IV, N V, O VI). The line at 5290 Å could be due to high lying O VI transitions. We would then, however, expect to see the 3s-3p doublet at 3811 and 3834 Å as well which cannot be identified. Similarly the line at 4658 Å can be attributed to C IV, but other prominent C IV lines should then be visible, too. We therefore discard these identifications with lower excited lines, since also unblended lines of highly ionized metals are visible in all four stars.

No He I line (e.g. 4471Å or 5876Å) is detectable in any of the stars pointing at high effective temperatures (> 80 000 K). The He II Pickering series ($4 \rightarrow$ n) and the hydrogen Balmer series show a strong decrement so that the higher series members are not visible. Additionally, the wings of these lines are so broad that they must originate from an atmosphere with a high gravity typical for white dwarfs (log g=7–8). The He II absorption line spectrum of the DOs is peculiar, because the equivalent widths of 4686 and 6560Å are about twice as strong as in "normal" hot DO stars while the other optical He II equivalent widths are close to "normal". The same phenomenon was observed for HS 0713+3958 and HE 0504−2408. As in the case of the latter two stars a fit of the DO spectrum with our static plane–parallel non–LTE model atmospheres fails. The strong He II 4686 Å and lower Pickering series members cannot be reproduced with any of our models. The higher Pickering series members could be fitted with models of cool DOs ($\approx$ 60 000 K). At such low temperatures the He I lines would be clearly visible which is, however, not the case. At temperatures high enough for the absence of He I none of the He II lines can be reproduced (see also Werner et al. 1995). As in the case of HS 0713+3958 and HE 0504−2408 we propose the lower He II lines to be affected by the hot wind.

The Balmer line spectrum of HS 2115+1148 is similar to that of other hot DAO spectra. We used a χ^2 fit–program, kindly provided by Rex Saffer (Baltimore), adapted to our needs by one of us (R.N.), to determine effective temperature, surface gravity and helium abundance from a simultaneous fit to all hydrogen and helium lines. A comparison with H/He non–LTE model atmospheres formally results in an effective temperature of 67 000 K, a surface gravity of log g=6.9 and a helium abundance of log (He/H)=-2.8. Nevertheless, a consistent fit is also not possible here (Fig. 2). This stars shows a severe form of the Balmer line problem also observed in other hot DAO white dwarfs (Napiwotzki & Rauch 1994). Napiwotzki (1993) demonstrated by independent temperature determinations that a fit to Hγ and Hδ give reliable effective temperatures while the lower Balmer line series members are then predicted far too shallow. The discrepancy increases with increasing effective temperature, "normal" DAO stars at an effective temperature of 70 000 K would, however from our experience, be affected less drastically. Very recently, Werner (1995) demonstrated that the Balmer line problem can be solved in "normal" DAOs by the inclusion of very detailed model atoms of C, N, and O. Test calculations showed, however, that this is not the case in HS 2115+1148. This indicates that the photospheric spectrum of HS 2115+1148 is similarly affected by the wind as in the case of the DO stars. The derived parameters should therefore be regarded as a rough estimate only.

An ultraviolet spectrum of HS 0727+6003 (SWP 49577) was obtained with the IUE satellite in the low dispersion mode. The He II 1640 Å line is detectable. Seven more transitions of extremely highly ionized C and O are expected in the IUE range, due to the low resolution they are, however, not visible.

3. Conclusions

Following the arguments of Werner et al. (1995), our line identifications imply that we found four new stars exhibiting extremely hot and fast winds originating from hot white dwarfs. It is remarkable that for the first time highly ionized absorption features have been detected in a hydrogen–rich white dwarf (the DAO star HS 2115+1148).

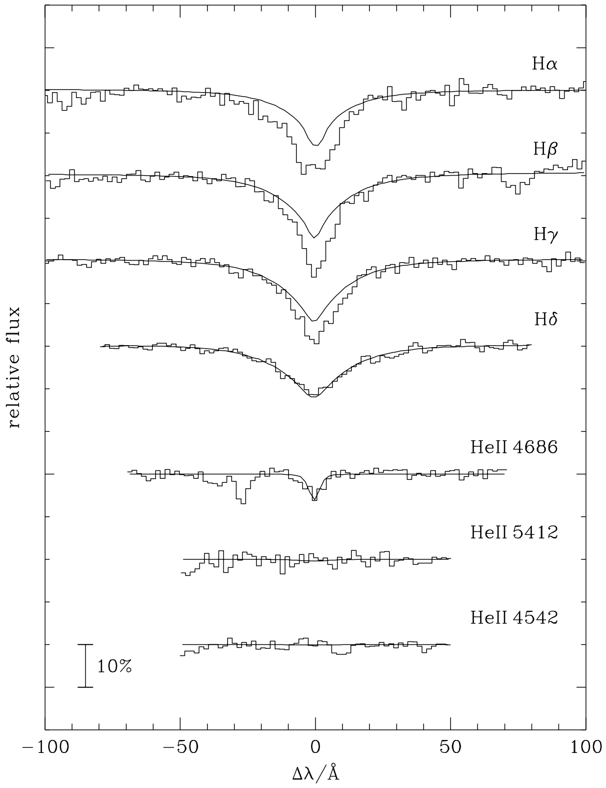

Fig. 2. HS 2115+1148 compared to the best "fit" model atmosphere: $T_{\rm eff}$=67000 K, log g=6.9 and log (He/H)=-2.8. Except Hδ no lower Balmer line can be reproduced by the model

Hence the phenomenon is not restricted to DO stars but might be a common phase at the beginning of the white dwarf cooling sequence. The wind features are weaker than in the previously detected stars HE 0504−2408 and HS 0713+3958. Whether this is due to different wind temperatures, densities or compositions cannot yet be decided. Our interpretation can qualitatively explain the spectrum of these stars, details are, however, far from understood. Non–LTE calculations with static plane–parallel model atmospheres can neither reproduce the very highly ionized lines nor the He II absorption lines (Werner et al. 1995). Future calculations for expanding atmospheres will show if it is possible to have a wind which is on the one hand dense enough to show the extremely highly ionized ions in absorption and is on the other hand still transparent enough to exhibit lines of photospheric origin (high n He II Pickering lines). The peculiar strengths of He II 4686 Å and 6560 Å in our DOs and also the low Balmer lines in the DAO are reminiscent of the winds of early type stars of lower gravity, where Hα and He II, 4686 Å are primary wind diagnostic lines (Kudritzki & Hummer, 1991). Hence it is likely that they are severely "contaminated" by the winds in our DOs and in the DAO too.

We expect the extremely hot wind to be a X-ray source. Due to the large distances of these stars, none of them is found in ROSAT or EUVE catalogs.

Table 2. Line identifications in HS 0158+2335, HS 0727+6003, HS 2027+0651, and HS 2115+1148. Uncertain identifications are marked with a colon. Wavelengths are from theoretical predictions (Garcia & Mack 1965) except for the C V (Moore 1970), N VI, O VII and Ne (hydrogenic). C VI / N VI and N VII / O VII blends are unresolved

ion	transition λ/Å	HS 0158 +2335	HS 0727 +6003	HS 2027 +0651	HS 2115 +1148
C V	4945				X
C VI	5291[d]		X	X	X
	4499		X		X
	6201			X	X
N VI	5293[d]		X	X	X
	4501		X		X
	6204			X	X
N VII	3887	X	X	X	X
	4550[a]	X	X	X	X
	5669	X	X	X	X
	6085	X	X	X	X
O VII	3889	X	X	X	X
	4558[a]	X	X	X	X
	5673	X	X	X	X
	6088	X	X	X	X
O VIII	4340[a,b]		:	:	
	4658[c]			X	X
	6068			X	X
	6064			X	X
Ne IX	4797	:		X	
	6484	X	X	X	X
Ne X	5252	X	:		:

[a] blend with He II [b] blend with H I
[c] blend with C IV [d] blend with O VI

The number of DOs showing this phenomenon has thus increased to five, which is a significant fraction of all known DO white dwarfs (22). This and the detection of such a wind surrounding a DAO white dwarf suggests that it is a much more common phenomenon than previously thought. The completed Hamburg survey will provide a statistically complete sample of white dwarfs, which then allows to estimate the space densities for these stars. First evidence for significant (temporarily) mass loss from stars close to the white dwarf cooling sequence came from the outburst observed in central star of the planetary nebula Lo4 (Werner et al. , 1992a), for which a mass loss rate of $10^{-7.3}$ $M_\odot$/yr was deduced (Werner et al. , 1992b). Assuming that the mean mass loss rate of these white dwrafs is slightly below that of Lo4, rougly 0.01 $M_\odot$ is lost within the ≈ 10^6 years cooling down to 50 000 K. Future model calculations with expanding non–LTE model atmospheres will provide mass–loss rates.

Acknowledgements. We thank Stefan Haas (Bamberg) for obtaining the IUE spectrum. S. Dreizler was supported by the DFG under grant He 1356/16-2. We thank the DFG for travel grants to the Calar Alto observatory. Calculations were performed on the CRAY Y-MP of the Leibniz Rechenzentrum München. The Hamburg Schmidt Survey is supported by the DFG through grants RE 353/11 and RE 353/22.

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