THE PECULIAR ABUNDANCE PATTERN OF THE NEW HG-MN STAR HD 30085

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Abstract. Using high-dispersion, high-quality spectra of HD 30085 obtained with the echelle spectrograph SOPHIE at l'Observatoire de Haute Provence, we show that this star contains strong lines of the *s*-process elements Sr II, Y II and Zr II. Line syntheses of the lines yield large overabundances of Sr, Y, Zr which are characteristic of HgMn stars. The Sr-Y-Zr triad of abundances is inverted in HD 30085 compared to that in our solar system. The violation of the odd-even rule suggests that physical processes such as radiative diffusion, chemical fractionation and others must be at work in the atmosphere of HD 30085, and that the atmosphere is stable enough to sustain them.

Keywords: stars: individual, stars: Chemically Peculiar

1 Introduction

HD 30085, currently assigned a spectral type of A0 IV, is one of the 47 northern slowly-rotating early-A stars stars studied by Royer et al. (2014). It shows strong lines of Mn II and Hg II, and recently Monier et al. (2015) synthesized several lines of Mn II, Fe II and Hg II which are present in spectra observed with SOPHIE, using model atmospheres and spectrum synthesis that include hyperfine structure of various isotopes where relevant. The synthetic spectra were adjusted iteratively to the observed high-resolution, high signal-to-noise spectra in order to derive the abundances of those elements. The analysis yielded over-abundances of 40 times solar for Mn and 32000 times solar for Hg, thus demonstrating unquestionably that the star needs to be re-classified as an HgMn star. In this paper we focus on lines of Sr, Y, Zr which are also strong in the spectrum of HD 30085, and derive the element abundances.

2 Observations and reduction

HD 30085 was observed twice at l'Observatoire de Haute Provence in February 2012 and December 2013, using the high-resolution mode (R =75000) of SOPHIE. Three 15-minute exposures were obtained in February 2012 and coadded to create a mean spectrum with a $\frac{S}{N}$ ratio of about 316. A single 20-minute exposure was acquired in December 2013, with a $\frac{S}{N}$ of ∼300.

3 Lines of Sr II, Zr II and Y II in HD 30085

The strongest lines of Sr II, Y II and Zr II in our line catalogue are conspicuous in the SOPHIE spectra of HD 30085. They are listed in Table 1 along with the measured equivalent width and derived abundance for each transition. Only a few of these lines are unblended; most of the blends are with lines of Cr II, Mn II and Fe II, whose abundances were derived in Monier et al. (2015). Fig. 1 displays the resonance-line profile of Sr II at 4305 Å and that of Zr II at 4496 Å to illustrate their strengths and the overabundances of those species.

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Lines used for abundance analysis					
Wavelengths (Å)	Identification	Multiplet	EW	Abundance	Comment
4077.71	Sr II	M 2	74.0	40 ⊙	blend
4161.80	Sr II	M 3	11.0	40 ⊙	
4215.52	Sr II	M 2	64.7	40 ⊙	blend
4305.45	Sr II	M 3	14.6	40 ⊙	
4177.53	Y II		46.0	300 ⊙	blend
4235.73	Y II		18.3	300 ⊙	
4309.63	Y II		42.1	250 ⊙	blend
4358.73	Y II		31.8	300 ⊙	blend
4398.01	Y II		49.6	250 ⊙	blend
4422.59	Y II		32.9	500 ⊙	blend
4682.32	Y II		15.1	300 ⊙	blend
4823.30	Y II		16.1	275 ⊙	blend
4883.68	Y II		50.9	500 ⊙	
4900.12	Y II		49.4	500 ⊙	blend
5205.72	Y II		48.2	500 ⊙	
5497.41	Y II		31.4	500 ⊙	blend
5662.93	Y II		51.2	500 ⊙	
4443.00	Zr II		27.4	200 ⊙	
4457.43	Zr II		10.0	100 ⊙	
4496.98	Zr II		22.2	200 ⊙	
5112.30	Zr II		12.6	150 ⊙	

Table 1. The strongest lines of Sr II, Y II and Zr II in HD 30085
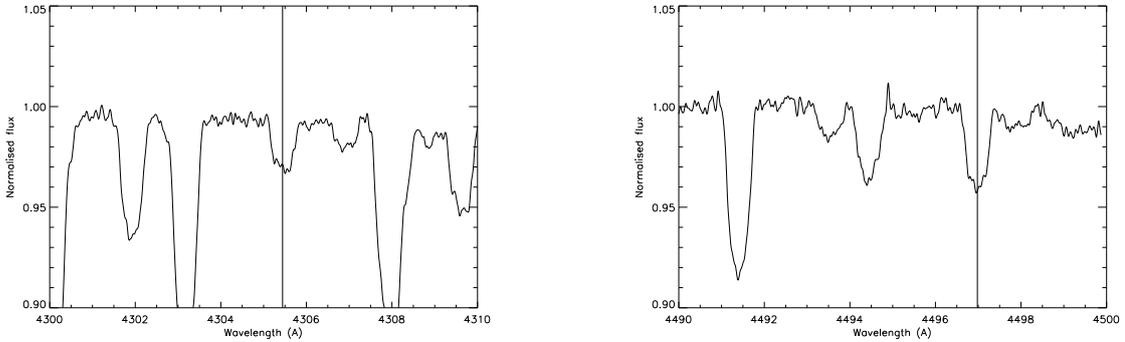
Fig. 1. Left: Sr II line at 4305 Å (left). **R**ight: Zr II line at 4496 Å (right).

4   Model atmospheres and spectrum synthesis

The effective temperature $T_{\rm eff}$ and surface gravity $\log g$ of HD 30085 were first evaluated using Napiwotzky et al's (1993) *uvbybeta* calibration of Stromgren's photometry. The derived values were $T_{\rm eff} = 11300 \pm 200$ K, $\log g = 3.95 \pm 0.25$.

First a plane-parallel model atmosphere assuming radiative equilibrium and hydrostatic equilibrium was computed using the ATLAS9 code (Kurucz 1992), but with the linux version that uses the new ODFs maintained by F. Castelli on her website*. A line-list was built by starting from Kurucz's (1992) "gfhyperall.dat" file [†], which includes hyperfine splitting levels, and was upgraded by appealing to the NIST Atomic Spectra Database

‡ and the VALD database operated at Uppsala University (Kupka et al. 2000)[§]. A grid of synthetic spectra was then computed with SYNSPEC48 (Hubeny & Lanz 1992), specifically to model the Sr II, Y II and Zr II lines. We adopted a projected rotational velocity $v_e \sin i = 26$ km s^{-1} and a radial velocity $v_{rad} = 8.20$ km.s^{-1} from Royer et al. (2014). In Fig. 2, the observed line-profile of Y II at 5662.93 Å is compared with the synthetic one computed for an overabundance of Yttrium of 500 ⊙; that overabundance provided the best fit to the observed profile.

5   Evidence for Sr-Y-Zr excesses

The abundances of Strontium, Yttrium and Zirconium that were derived from each analysed transition are listed in Table 1. The four lines of Sr II yielded a consistent overabundance of 40 ⊙. In contrast, the Y II lines yielded overabundances ranging from 250 ⊙ to 500 ⊙, the scatter in the values probably reflecting inacuracies in the atomic data of those elements. Similarly, the Zr II lines yielded overabundances ranging from 100 to 200 ⊙. We thus find that Y is more abundant than Sr and Zr in HD 30085, which is the opposite of what is observed in the solar system.
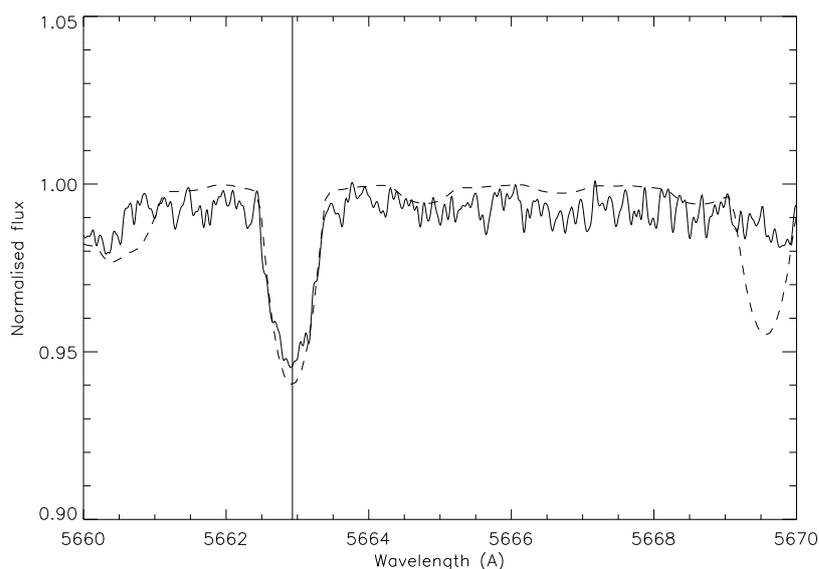
Fig. 2. Synthesis of the Y II line at 5662 Å (observed: thick line, synthetic: dashed lines for a 500 ⊙ overabundance)

6   Conclusions

Lines of Sr II, Y II and Zr II are enhanced in HD 30085. Line synthesis reveals large overabundances in these s-process elements, Y being more abundant than Sr and Zr. This violation of the odd-even rule shows that the Sr-Y-Zr triad of abundances is inverted in HD 30085 compared to the solar system pattern. It strongly suggests that physical processes such as radiative diffusion and chemical fractionation are at work in the atmosphere of HD 30085, and that its atmosphere is stable enough for long enough to sustain such processes. Sr, Y and Zr are of interest for nucleosynthetic studies because they comprise the first blocking place in the neutron absorption cross-section for s-process syntheses of heavy elements in red giants. We conclude that HD 30085 has overabundances of Sr, Y, Zr which are characteristic of an Hg-Mn star. A detailed abundance analysis of other elements in this star is currently in progress in order to complement the abundances reported here.

[‡]http://physics.nist.gov/cgi-bin/AtData/qlinesform
[§]http://vald.astro.uu.se/ vald/php/vald.php

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