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Strontium and yttrium in HgMn stars

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Abstract. Some individual Mercury-Manganese (HgMn) stars have known high abundances of Sr and Y, but other studies have found normal or undetectable abundances. We have surveyed these elements in a sample of 23 stars. In most cases the Sr lines do not suffer greatly from blending, and the resonance line Sr II λ4077 and λ4215 of multiplet (1) dominate. Yttrium has many lines visible if it is at high abundance, and we select a subset of these which are the least blended. We find that Sr ranges from ~ 3 dex above solar abundance to abundances of ~ 1 dex below solar, while Y attains overabundances of up to 4 dex, but is very difficult to detect in the hotter sample stars even if moderately overabundant.

Key words: stars: chemically peculiar – stars: abundances

1. Introduction

The list of stars analyzed for this study is from the UV abundance paper of Smith and Dworetsky (1993) who originally listed 26 stars. We omit two stars that are not HgMn stars, 36 Lyn (a magnetic Ap star) and HR 6000, a hot analogue of the HgMn stars. One other star, ϕ Phe, was omitted due to absence of good spectra. This left a sample of 22 HgMn stars as given by Dworetsky *et al.* (2007), an investigation of the abundance of Xe in HgMn stars (submitted to *Mon. Not. R. Astron. Soc.*) plus ν Cnc (total 23 stars). We also observed several normal comparison stars.

Sr (A = 38) and Y (A = 39) are of interest in nucleosynthesis studies because they (with Zr [A = 40] comprise the first blocking place in the neutron-absorption cross-sections for s-process synthesis of heavy elements in red giants (see Clayton, 1968). However, we are confident that the wide range of abundances seen by us in HgMn stars and in other types of chemically peculiar star (e.g., SrCrEu stars) is not due to unusual nucleosynthesis but rather to radiative acceleration and diffusion.

2. Observations and abundances

We used four lines of Sr II: two arising from the ground state multiplet (1), λ4077 and λ4215, and the two lines of multiplet (3) at λ 4161 and λ 4305 with excitation energies of about 3 eV (Moore, 1945). The oscillator strengths are from Brage *et al.* (1998) for $\lambda\,4077$ and $\lambda\,4215$, and from Warner (1968) for the other lines. The solar abundance is $\log A(\mathrm{Sr}) = 2.90$ (Asplund *et al.*, 2005).

For Y II lines, we searched for lines of reasonable strength which were unblended or only weakly blended. We eventually found 14 such lines in the range $\lambda\lambda\,4800$-5800. The strongest of these were $\lambda\,4883$, $\lambda\,5087$, and $\lambda\,5205$. Oscillator strengths are from Hannaford and Lowe (1982), and line broadening parameters from the Kurucz CD23 line list. The solar abundance of yttrium is $\log A(\mathrm{Y}) = 2.19$ (Asplund *et al.*, 2005).

We summarize our results in Tab. 1. The number of optical lines used, or examined (in the case of upper limits), for Sr II or Y II is given along with the abundance of each element, or an upper limit. The number of lines may be taken as a crude "quality indicator" for the result in each case. The weak-line Y II identification in 46 Aql appears to be correct but requires further confirmation; we note that Sadakane *et al.* (2001) did not observe Y II in 46 Aql, but they were not observing in a wavelength region with the strongest lines.

In Fig. 1 we show the trend of Sr abundances with T_{eff}. We treated the upper limits as if they were real data and found a highly significant correlation coefficient of -0.65 ± 0.22. The normal stars tend to have near-solar abundances, indicating that non-LTE effects may be neglected.

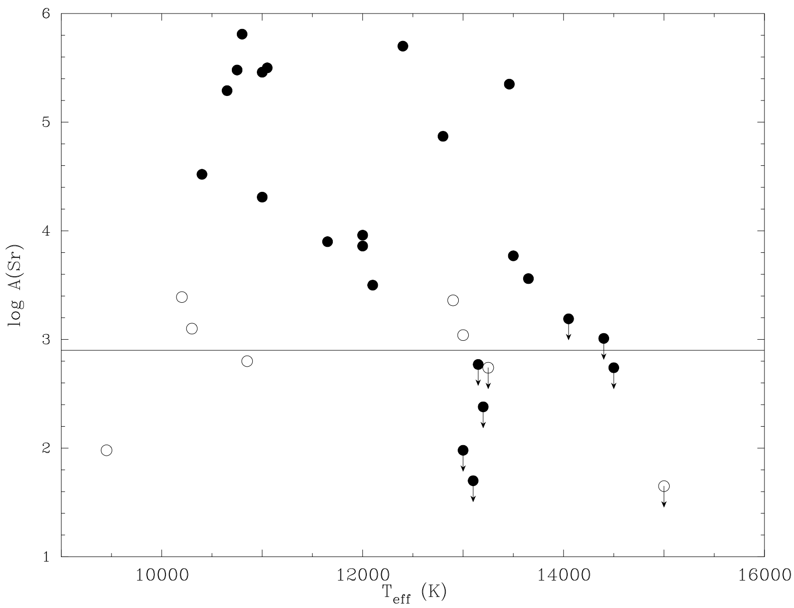

Figure 1. Strontium abundances as a function of T_{eff} in 23 HgMn stars and 8 normal stars. Arrows indicate upper limits.

Table 1. Sr and Y abundances in 23 HgMn stars; $\log A(\mathrm{H}) = 12.00$.

Element	Sr II		Y II	
Star	n	log A	n	log A
Normal Stars				
π Cet	2	≤ 2.74	2	≤ 3.41
134 Tau	2	2.80	2	≤ 3.00
τ Her	2	≤ 2.40	2	≤ 3.84
ζ Dra	2	3.36	2	≤ 3.80
α Lyr	2	1.98	2	≤ 1.53
HR 7098	2	3.39	2	≤ 2.46
21 Aql	2	3.05	2	≤ 2.60
ν Cap	3	3.23	3	2.84
HgMn Stars				
87 Psc	2	≤ 2.77	5	4.76
53 Tau	2	3.96	4	4.04
μ Lep	3	4.87	8	5.44
HR 1800	4	5.50	14	5.63
33 Gem	2	3.01	1	≤ 3.60
HR 2676	2	≤ 3.19	3	≤ 4.27
HR 2844	4	5.35	10	6.51
ν Cnc	4	4.52	8	4.70
κ Cnc	2	3.77	2	≤ 4.20
HR 4072	4	5.29	13	5.32
χ Lup	4	5.48	7	4.34
ι CrB	1	4.31	3	4.01
υ Her	2	3.92	5	4.64
ϕ Her	2	3.90	15	5.52
28 Her	4	5.46	13	5.65
HR 6997	2	≤ 3.20	3	≤ 4.70
112 Her	2	≤ 1.70	3	≤ 3.38
HR 7143	2	3.53	8	5.12
HR 7361	2	3.56	3	4.88
46 Aql	2	≤ 1.98	1	4.21
HR 7664	2	≤ 2.38	2	≤ 4.14
HR 7775	4	5.81	15	5.34
β Scl	4	5.70	13	6.12

In Fig. 2, we show the abundances of yttrium in HgMn stars. In this case, the fact that the lines do not arise from the ground state, and the cosmic rarity of the element, combine to render it undetectable in our normal star sample (with one possible exception, ν Cap). While there may be a correlation with $T_{\rm eff}$, it is far less striking than that for Sr in Fig. 1. Also, there are many more HgMn stars with only upper limits for Y II, especially at higher $T_{\rm eff}$. The correlation coefficient for $\log A$ *vs.* $T_{\rm eff}$ for all data including upper limits is -0.27 ± 0.22, which is not significant.

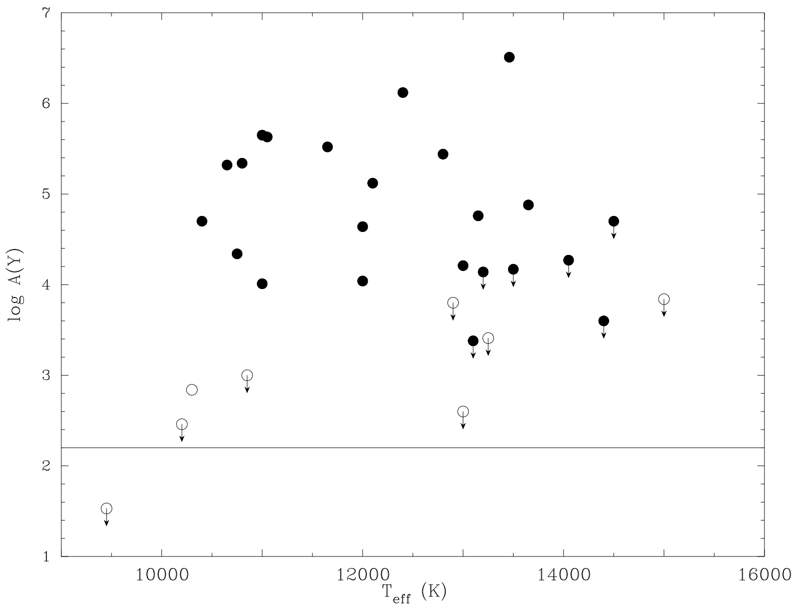

Figure 2. Yttrium abundances as a function of $T_{\rm eff}$ in 23 HgMn stars and 8 normal stars.

We also looked at whether the abundances of Sr and Y are correlated. For all stars, including as data the HgMn stellar abundances which are only upper limits, $r = 0.70 \pm 0.22$, a surprisingly strong correlation shown in Fig. 3. But for those stars with actual detections of both elements, the correlation coefficient ($r = 0.50 \pm 0.29$) is not significant. We interpret these results as indicating that low abundances of these two elements tend to be well-correlated.

Calculations of radiative acceleration were made by Hui-Bon-Hoa *et al.* (2002) for Sr and Y in a model at $T_{\rm eff} = 12\,000$, $\log g = 4.00$. The radiative accelerations for both are strongly upwards in the envelope and lower photosphere, but drop below that of surface gravity for small optical depths. Thus the

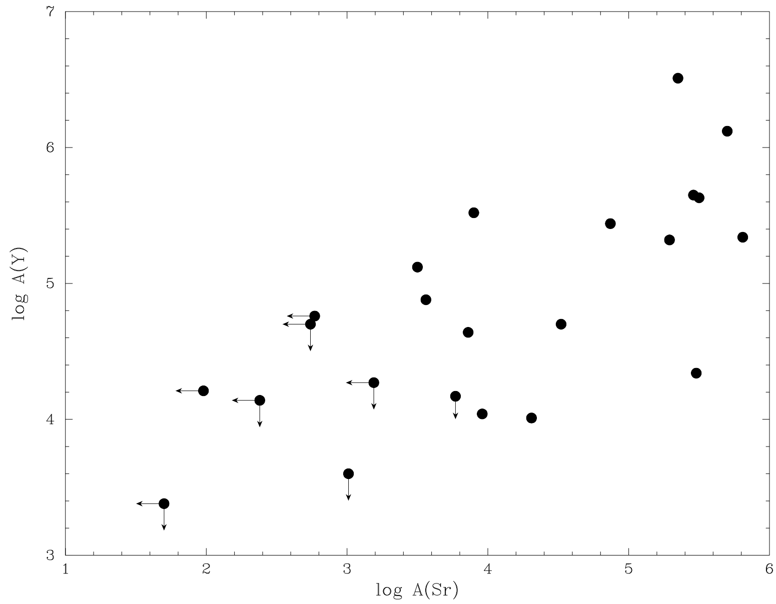

Figure 3. Correlation of stellar strontium and yttrium abundances for 23 HgMn stars. Arrows indicate upper limits; two arrows indicate the abundance is an upper limit in both elements.

observed high abundances are readily explained. It remains to be seen whether extreme low abundances of Sr in HgMn stars can be similarly explained.

3. Extreme HgMn stars

The most extreme yttrium abundance is in HR 2844, while the strongest observed lines are found in HR 1800's primary star. The southern HgMn star β Scl is also very rich in Y, as is the primary of the binary ϕ Her (Zavala *et al.*, 2007). The star with highest Sr abundance is HR 7775, which also has the strongest lines of this element. Some HgMn stars have Sr abundances definitely below the solar value, such as 112 Her and 46 Aql.

4. A note on xenon abundances

We noticed that Sr II $\lambda\,4215.519$ apparently persisted even when the line Sr II $\lambda\,4077.714$ was completely undetectable. An example of this is also given by Ryabchikova *et al.* (1996), where $\lambda\,4215.519$ has a measured equivalent width of 6.5 mÅ. We found a similar total strength for this line, but were unable to see Sr II $\lambda\,4077.714$ at all ($\leq 0.6\,\text{m\AA}$), nor did Ryabchikova *et al.* (1996) report seeing this line.

The solution to this mystery is the identification of a blend of Sr II with Xe II $\lambda 4215.62$, which has a predicted strength of $4\,\text{m\AA}$ in 112 Her from the Xe abundance in Dworetsky *et al.* (2007) and our calculated astrophysical $\log gf = -1.06$ based on the Lick observations of 46 Aql. The remaining strength of this feature in 112 Her is probably due to very weak lines of Mn II and Cr II. Strontium is at least 1.0 dex below solar abundance in both 46 Aql and 112 Her.

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References

Asplund, M., Grevesse, N., Sauval, A.J.: 2005, *ASP Conf. Ser.* **336**, 25

Brage, T., Wahlgren, G.M., Johansson, S.G., Leckrone, D.S., Proffitt, C.R.: 1998, *Astrophys. J.* **496**, 1051

Clayton, D.D.: 1968, *Principles of Stellar Evolution and Nucleosynthesis*, McGraw-Hill, New York

Dworetsky, M.M., Budaj, J.: 2000, *Mon. Not. R. Astron. Soc.* **318**, 1264

Dworetsky, M.M., Persaud, J.L., Patel, K.: 2008, *Mon. Not. R. Astron. Soc.*, in press

Hui-Bon-Hoa, A., LeBlanc, F., Hauschildt, P.H., Baron, E.: 2002, *Astron. Astrophys.* **381**, 197

Hannaford, P., Lowe, R.M.: 1982, *Astrophys. J.* **261**, 736

Kurucz, R.L.: 1994, CD-ROM 23, http://kurucz.harvard.edu/cdroms.html

Moore, C.E.: 1945, *Contrib. Princeton Univ. Obs. (Revised Multiplet Table)* **20**, 1

Ryabchikova, T.A., Zakharova, L.A., Adelman, S.J.: 1996, *Mon. Not. R. Astron. Soc.* **283**, 1115

Sadakane, K., Takada-Hidai, M., Takeda, Y., Ando, H., Aoki, W., Honda, S., Izumiura, H., Kajino, T., Kambi, E., Kawanomoto, S., Noguchi, K., Okita, K., Sato, B., Watanabe, E.: 2001, *Publs. Astr. Soc. Japan* **53**, 1223

Smith, K.C., Dworetsky, M.M.: 1993, *Astron. Astrophys.* **274**, 335

Warner, B.: 1968, *Mon. Not. R. Astron. Soc.* **139**, 115

Zavala, R.T., Adelman, S.J., Hummel, C.A., Gulliver, A.F., Caliskan, H., Armstrong, J.T., Hutter, D.J., Johnston, K.J., Pauls, T.A.: 2007, *Astrophys. J.* **655**, 1046