Mercury and platinum abundances in mercury-manganese stars

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Abstract.

We report new results for the elemental and isotopic abundances of the normally rare elements mercury and platinum in HgMn stars. Typical overabundances can be 4 dex or more. The isotopic patterns do not follow the fractionation model of White et al (1976).

Key words: stars: abundances — stars: chemically peculiar

1. HgMn stars

The HgMn stars correspond in $T_{\rm eff}$ to the main-sequence between A0 and B6 (11 000–16 000 K). Their abundance anomalies include both overabundances (e.g., Mn, P, Ga, Sr, Hg, Pt) and underabundances (e.g., He, Al, Ni, Co). They have no detectable ordered magnetic fields like the classical Ap stars (SrEuCr or Si types). While normal A0 stars have a typical rms $v \sin i \sim 164\,{\rm km\,s^{-1}}$ (Dworetsky, 1974), HgMn stars have typical $v \sin i$ of 10–20 $\rm km\,s^{-1}$; some are as low as 2–3 $\rm km\,s^{-1}$. Smith (1996) is recommended for a more detailed overview.

2. Data

We obtained high-resolution, high S/N optical spectra of Hg II and Pt II lines for several stars with the Gecko spectrograph (R$\sim 10^5$) on the Canada-France-Hawaii Telescope, and complete spectra for many more stars with the Hamilton Échelle Spectrograph ($\lambda\lambda$3900–9000, R$\sim 5\times10^4$) at Lick Observatory.

The models for the lines are based on isotopic and hyperfine structure measurements from the literature (Engleman 1989; Dworetsky et al. 1998) and on *gf*-values from Dworetsky et al (1984) and Dworetsky (1980). We used the spectrum-synthesis codes UCLSYN (Smith 1992) and BINSYN (Smalley 1996). Best fits for two stars, HR 7775 and χ Lupi, are shown in Fig. 1, and the results for those and several other stars are summarised in Tables 1–3, where abundances are given on the scale with $\log N({\rm H}) = 12$.

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3. Hg I vs Hg II

The strongest optical lines of Hg I in these stars derive from the ^{3}S to ^{3}P transitions at λ4046, λ4358 and λ5461. Although the first of these is a contaminant of the Pt II λ4046 feature, the other two are clearly present in several stars.

Table 1 shows the abundance of Hg I derived for five stars using the lines λ4358 and λ5461 and compares them with the abundance derived for Hg II using the summed isotopes of the λ3984 line (CFHT data). The agreement is excellent.

Table 1. Equivalent widths and abundances of Hg in five HgMn stars

Star	Hg I λ4358		Hg I λ5461		Hg II λ3984	
	log A	W(mÅ)	log A	W(mÅ)	log A	W(mÅ)
HR 7775	6.28	13	6.45	14	6.30	71
28 Her	5.60	3.5	5.80	4.5	5.72	28
ϕ Her	5.90	4	6.10	6	6.20	66
ι CrB	6.05	5	6.28	7.5	6.10	70
χ Lup	6.01	7.5	<6.50	12.5bl	6.33	46

4. Fractionation of Hg and Pt

The stellar abundances of Hg and Pt are enormous compared to the terrestrial (cosmic) abundances of Hg and Pt of 1.1 dex and 1.8 dex respectively. Even more remarkably, as noted by White et al. (1976), Cowley & Aikman (1975), and extended by Smith (1997) the abundance pattern for Hg is skewed to the heavier isotopes in the cooler HgMn stars. We confirm their results and extend them to Pt, which shows a similar behaviour.

Tables 2–3 show the isotope percentages of Hg and Pt in several stars. Whilst the Hg in χ Lupi and 28 Her is concentrated over 99% into ^{204}Hg, that in HR 7775, ϕ Her and ι CrB is not nearly as concentrated into the heavy isotopes (albeit much greater than the terrestrial mixture). The Pt anomalies can be seen to 'shadow' the Hg anomalies; stars with strong ^{204}Hg also have strong ^{198}Pt. Figs. 1 & 2 illustrate the differences between HR 7775 and χ Lupi for the Hg II and Pt II lines.

Leckrone et al (1993) found that χ Lupi Hg III lines yielded a similar isotopic anomaly to the Hg II λ3984 line, which excludes the possibility that the light isotopes were 'hiding' in a highly fractionated cloud of Hg III (Michaud, Reeves & Charland, 1974).

White et al proposed an extension of the radiative diffusion vs. gravitational settling model, *fractionation*, to explain this result. If one starts with the terrestrial mixture, by analogy with mineralogy, it can be fractionated by a constant factor $\exp(q)$ (per atomic mass unit). A strongly positive value of q (e.g., 3)

Table 2. Percentage Hg composition by isotope

isotope	ι CrB	HR 7775	ϕ Her	χ Lupi	28 Her	terrestrial
204	46.4	61.7	89.1	98.8	>99	6.87
202	38.6	37.2	10.1	1.1	<1	29.86
201	7.7	0.4	?	0.1	-	13.18
200	3.7	0.3	?	-	-	23.10
199	1.8	0.2	?	-	-	16.87
198	1.6	0.2	?	-	-	9.97
196	0.1	-	-	-	-	0.15

Table 3. Percentage Pt composition by isotope

isotope	HR 7775	χ Lupi	terrestrial
198	45	92	7.2
196	43	3	25.3
195	11	?	33.8
194	1	-	32.9
192	-	-	0.8

would push 99% of Hg into ^{204}Hg, normally a rare isotope. The parameter q is derived from the equation

$$q = \frac{log\,\alpha}{log\,e\,(A-202)} \tag{1}$$

where

$$\alpha = \frac{[N_A/N_{202}]_\star}{[N_A/N_{202}]_\odot} \tag{2}$$

A similar equation based on ^{196}Pt may be defined for Pt isotopes.

5. Results

The fractionation hypothesis does not adequately represent the best observed structures for Hg and Pt. Fig. 3 shows the predicted profiles (in HR 7775) for Hg II λ3984 and Pt II λ4061 for a constant q as deduced from the abundance ratios of the two heaviest isotopes. There is clearly not enough of the light isotopes present. In the cases of χ Lupi and 28 Her we find that the enhancements of the heavy isotope of Hg are so extreme that virtually all the Hg is in one isotope.

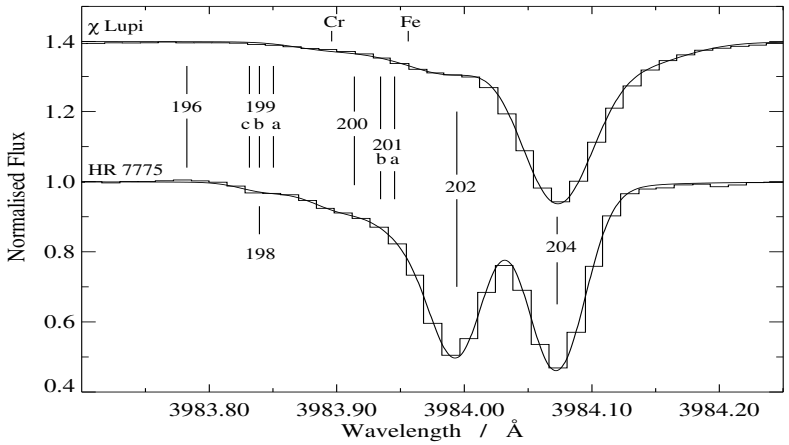

Figure 1. Comparison of Hg II profiles in HR 7775 and χ Lupi: λ3984

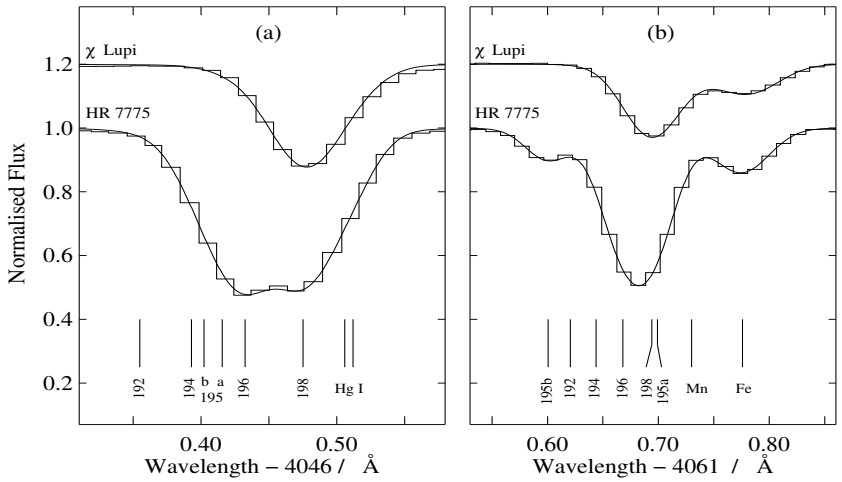

Figure 2. Comparison of Pt II profiles in HR 7775 and χ Lupi: (a)λ4046; (b)λ4061

6. Discussion

Our results contradict what was previously a largely accepted concept, namely, that the strong Hg and Pt isotopic abundance anomalies could be parameterised in a fractionation model. This is clearly not the case in at least several stars.

One (unlikely) *ad hoc* explanation is that the original abundances in these stars were different from cosmic. The fact that the Pt anomalies 'shadow' the Hg may support this view. However, while surely involving radiative diffusion and gravitational settling, any complete theory needs to take into account other factors such as the detailed flux profile of the stellar atmosphere. These exotic

abundances are now established results in need of a theoretical explanation.

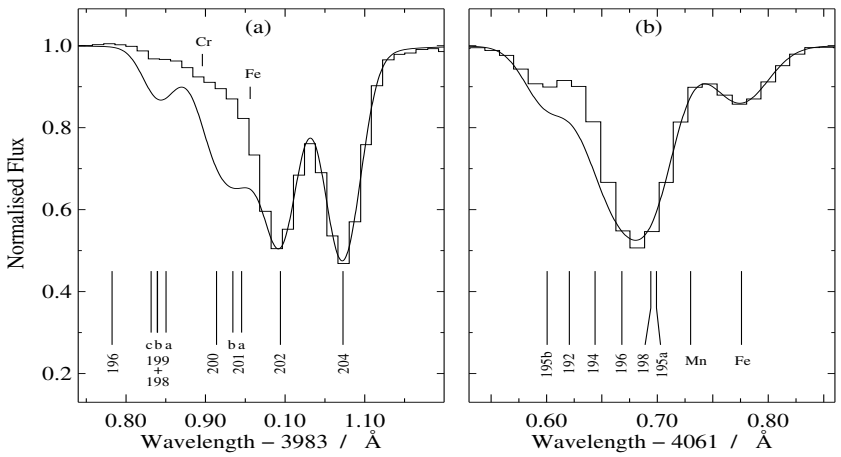

Figure 3. Observed data versus synthetic fractionation profile for HR 7775: (a) Hg II λ3984; (b) Pt II λ4061

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