The helium abundances in HgMn and normal stars[1]

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Abstract. The parameter-free model of diffusion in the atmospheres of HgMn stars (Michaud 1986; Michaud et al 1979) predicts that helium should sink below the He II ionization zone in order that diffusion of other elements may take place, and that all HgMn stars should have deficits of helium in their photospheres, with a minimum deficit of 0.3 dex. In this study, the Smith & Dworetsky (1993) sample of HgMn stars and normal comparison stars is examined, and the helium abundances determined by spectrum synthesis using échelle spectra taken at Lick Observatory and the AAT. The prediction is confirmed; all HgMn stars are deficient in He by as much as 1.5 dex. Also, two HgMn stars, HR7361 and HR7664, show clear evidence of helium stratification.

Introduction. Abundances were determined for 25 HgMn stars and 12 normal and superficially normal stars of similar $T_{\rm eff}$, using an LTE analysis. It is well-known that the effects of non-LTE can safely be ignored in the relevant temperature range. The analysis was performed for two He I lines, λ4026.2 and λ4471.5. The line profile tables of Barnard et al (1969, 1974, 1975) and Shamey (1969) were used. The abundances and estimated errors were obtained here by trial and error fits by eye to the observations. The unweighted mean for the normal stars is $\log N(\mathrm{He})/N(\mathrm{H}) = 10.98 \pm 0.05$, in excellent agreement with the standard value 10.99 (Grevesse et al 1996). (In this paper all abundances are given on the scale $\log N(\mathrm{H}) = 12.00$.) It is found that all HgMn stars have underabundances, ranging from factors of 0.3 dex at low $T_{\rm eff}$ to 1.5 dex at high $T_{\rm eff}$. These observations provide direct support for the parameter-free model.

Observations. The programme stars are listed in Table 1. Most of the observations were made with the Hamilton Échelle Spectrograph at the Lick Observatory, with fwhm resolution $R = 46\,500$. Two southern stars (ξ Oct and β Scl) were observed with the UCLES on the Anglo-Australian Telescope with nearly identical resolution. Further details of the observations and reductions, and treatment of binary stars, are the same as in Jomaron et al (1999).

Abundance of He. Auer and Mihalas (1973) showed that the He I lines used in this work can be well-approximated by LTE models for B stars in the temperature range below 15000 K. The spectrum synthesis code UCLSYN was used to calculate the abundance of He for 9 normal stars, 3 superficially-normal stars, and 25 HgMn stars. The results are shown in Table 1 and Fig 1. It is clear from this figure that all HgMn stars in this sample are deficient in He by 0.3 dex or more (usually much more). It also appears that the hotter HgMn stars have stronger He deficits than the cooler HgMn stars. Dividing them into 12 cooler and 13 hotter HgMn stars yields $\log N(\mathrm{He}) = 10.20 \pm 0.09$ for the cooler group and $\log N(\mathrm{He}) = 9.72 \pm 0.07$ for the hotter group. The statistical difference is highly significant.

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Table 1: Stellar Parameters and Helium Abundances for the Programme Stars.

Star	HD	$T_{\rm eff}$ (K)	$\log g$ (cm s^{-2})	ξ km s^{-1}	$v \sin i$ km s^{-1}	$\log N$(He) λ4471	$\log N$(He) λ4026	$\log N$(He) mean
				Normal Stars				
ν Cap	193432	10300	3.90	1.6	27	10.97 ± 0.05	10.70 ± 0.10	10.92 ± 0.05
α Lyr	172167	9450	4.00	2.0	24	10.99 ± 0.05	10.99 ± 0.10	10.99 ± 0.05
HR7098	174567	10200	3.55	1.0	11	10.90 ± 0.05	10.50 ± 0.05	10.70 ± 0.04
ζ Dra	155763	12900	3.90	2.5:	34	10.99 ± 0.05	10.99 ± 0.05	10.99 ± 0.04
134 Tau	38899	10850	4.10	1.6	30	11.05 ± 0.05	10.99 ± 0.10	11.04 ± 0.05
ξ Oct	215573	14050	3.85	0.5:	5	10.99 ± 0.10	10.99 ± 0.10	10.99 ± 0.07
τ Her	147394	15000	3.95	0.0	32	10.95 ± 0.05	10.92 ± 0.10	10.94 ± 0.05
21 Aql	179761	13000	3.50	0.2	17	11.10 ± 0.05	11.00 ± 0.10	11.08 ± 0.05
π Cet	17081	13250	3.80	0.0	25	11.20 ± 0.05	10.99 ± 0.10	11.16 ± 0.05
				Superficially Normal Stars				
21 Peg	209459	10450	3.50	0.5	4	10.90 ± 0.05	10.85 ± 0.05	10.88 ± 0.04
HR7878	196426	13050	3.85	1.0:	6	10.99 ± 0.05	10.85 ± 0.10	10.96 ± 0.05
HR7338	181470	10250	3.75	0.5	3	10.80 ± 0.10	10.65 ± 0.10	10.73 ± 0.07
				HgMn Stars				
β Scl	221507	12400	3.90	0.0:	27	9.60 ± 0.10	9.80 ± 0.10	9.70 ± 0.07
36 Lyn	79158	13700	3.65	2.0:	49	9.90 ± 0.10	9.60 ± 0.10	9.75 ± 0.07
υ Her	144206	12000	3.80	0.6	11	10.20 ± 0.05	10.20 ± 0.05	10.20 ± 0.04
HR 7361[b]	182308	13650	3.55	0.0	9	$9.5 \rightarrow 9.8$	$9.5 \rightarrow 9.8$	9.65 :
28 Her	149121	11000	3.80	0.0	8	9.75 ± 0.10	9.90 ± 0.10	9.83 ± 0.07
HR 7143	175640	12100	4.00	1.0	2	10.12 ± 0.05	10.30 ± 0.05	10.21 ± 0.04
46 Aql	186122	13000	3.65	0.0	1	9.25 ± 0.10	9.45 ± 0.10	9.35 ± 0.07
HR 7775	193452	10800	3.95	0.0	1	10.0 ± 0.30	9.50 ± 20	9.65 ± 0.17
κ Cnc	78316	13500	3.80	0.0	6	9.85 ± 0.15	9.85 ± 0.10	9.85 ± 0.08
53 Tau	27295	12000	4.25	0.0	5	9.90 ± 0.05	10.20 ± 0.10	9.96 ± 0.05
HR 7664[b]	190229	13200	3.60	0.8	8	$9.2 \rightarrow 9.7$	$9.4 \rightarrow 9.8$	9.52:
ϕ Her	145389	11650	4.00	0.4	10	10.20 ± 0.05	10.38 ± 0.05	10.29 ± 0.04
ϕ Phe	11753	10700	3.80	0.5:	13	9.80 ± 0.15	10.00 ± 0.10	9.94 ± 0.05
ν Cnc	77350	10400	3.60	0.1	13	10.30 ± 0.05	10.10 ± 0.10	10.26 ± 0.05
HR 2844	58661	13460	3.80	0.5:	30	10.00 ± 0.10	10.00 ± 0.10	10.00 ± 0.07
33 Gem	49606	14400	3.85	0.5:	22	9.50 ± 0.10	9.75 ± 0.15	9.58 ± 0.08
μ Lep	33904	12800	3.85	0.0	18	9.65 ± 0.10	10.05 ± 0.05	9.97 ± 0.05
HR 2676	53929	14050	3.60	1.0:	25	9.30 ± 0.15	9.70 ± 0.30	9.38 ± 0.13
87 Psc	7374	13150	4.00	1.5	21	10.25 ± 0.10	10.30 ± 0.10	10.27 ± 0.07
HR 6997	172044	14500	3.90	1.5	34	9.72 ± 0.05	9.85 ± 0.05	9.79 ± 0.04
HR 4072[a]	89822	10650	3.95	1.0	3.2	10.40 ± 0.10	10.40 ± 0.10	10.40 ± 0.07
χ Lup[a]	141556	10650	4.00	0.0	2.0	10.76 ± 0.04	10.70 ± 0.07	10.74 ± 0.02
ι CrB[a]	143807	11000	4.00	0.2	1.0	10.35 ± 0.10	10.42 ± 0.05	10.36 ± 0.04
112 Her[a]	174933	13100	4.10	0.0:	6	9.58 ± 0.05	9.65 ± 0.10	9.60 ± 0.04
HR 1800[a]	35548	11050	3.80	0.5	3	10.55 ± 0.05	10.45 ± 0.05	10.50 ± 0.04

[a]Binaries with two spectra (parameters refer to the primary). Explicit allowances for dilution effects have been made in this work.
[b]See text and Figs. 5 and 6 for discussion of HR7664 and HR7361.

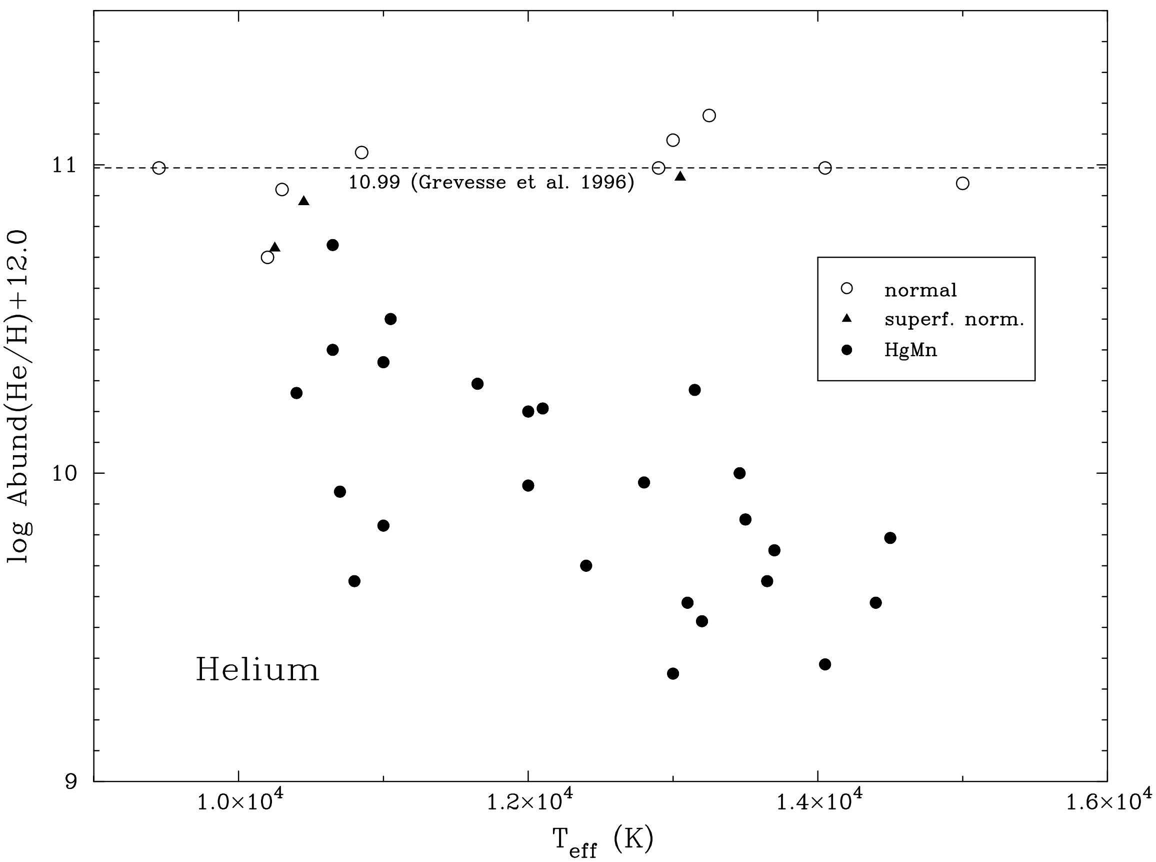

Figure 1: Helium abundances in normal stars, superficially normal stars, and HgMn stars. Points are averages of $\lambda4026$ and $\lambda4471$ profile fits. Typical errors (not shown) are ±0.06 dex. There is more depletion of He in the hotter HgMn stars than in the cooler group. In two cases, where stratification of He is suspected, the values are the means of the best fits to line centres and wings (see text).

Examples of fits to normal and HgMn stars are shown in Figs 2, 3 & 4.

Typical errors of single determinations by fitting one line were $\pm0.05 - 0.10$ dex, and consistency between $\lambda4026$ and $\lambda4471$ was of similar quality. Blends which occurred within the profile were modelled.

Depth Dependent He Abundances. In nearly all cases, the profile fits to wings and centres of the two lines were fully consistent, indicating that the modelling assumption of uniform fractional abundance of He with depth was a good one. However, two HgMn stars, HR7361 (Fig. 5) and HR7664 (Fig. 6) could not be fit to one abundance. In both cases the centre gave a good fit only for abundances about 0.3-0.5 dex lower than the fit in the wings. A model of the He abundance in these two stars with an enhanced abundance below $\log\tau = 1.0$ produced much more satisfactory fits. Although the solutions in Figs. 5c and 6c are not unique, as the actual depth distribution is probably more complicated, they are indicative of the fact that He must be considerably more depleted in the higher photosphere than in deeper layers, although it is also depleted there as well. It appears that He has left a clear trace of its downwards diffusion through the He II convection zone in these two cases.

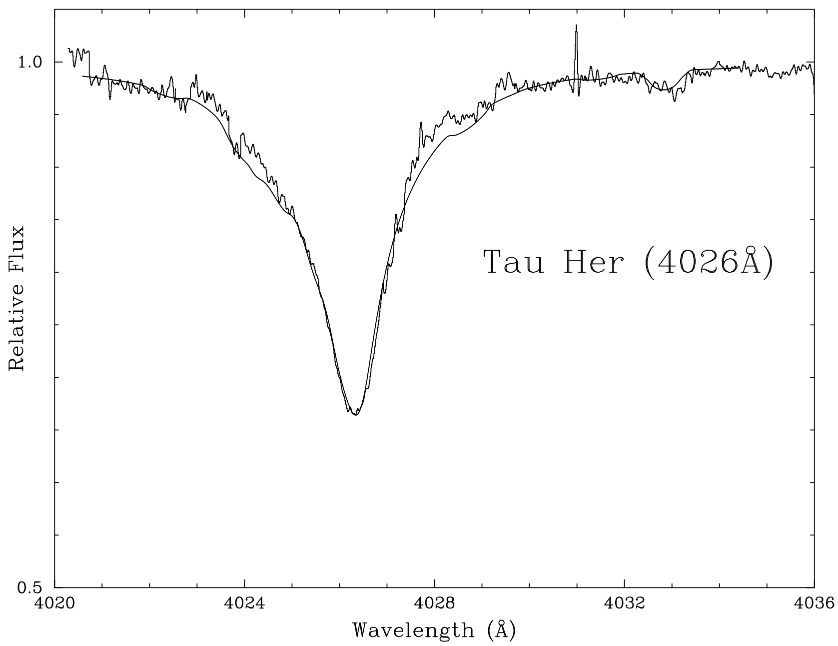

Figure 2: The line profile fit for τ Her, a normal B5 IV star with $T_{\rm eff} = 15{,}000\,\mathrm{K}$, $\log g = 3.95$, and derived He abundance 10.94.

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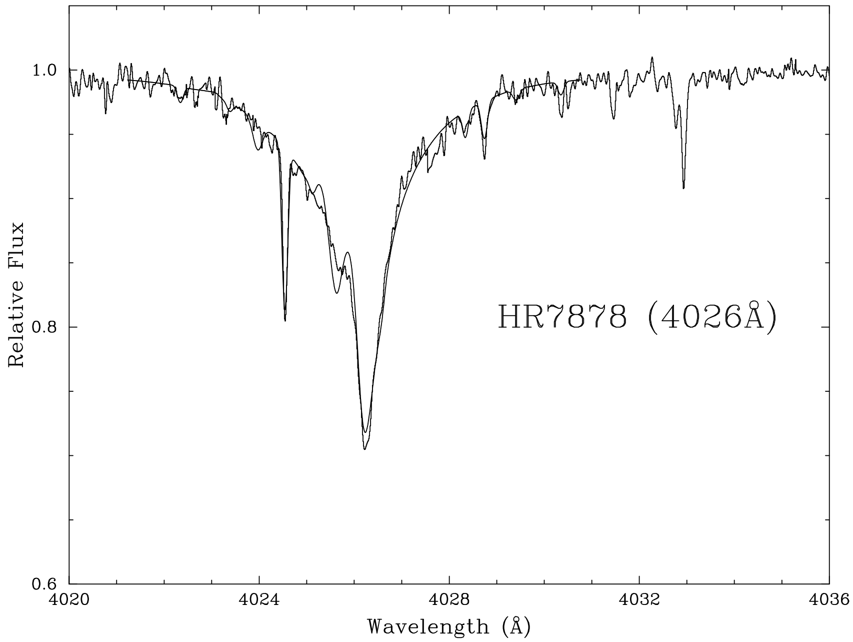

Figure 3: The line profile fit for HR7878 (B8 IIIp), a superficially normal star with $T_{\rm eff}$ = 13,050, $\log g = 3.85$, with He abundance 10.85 for λ4026.

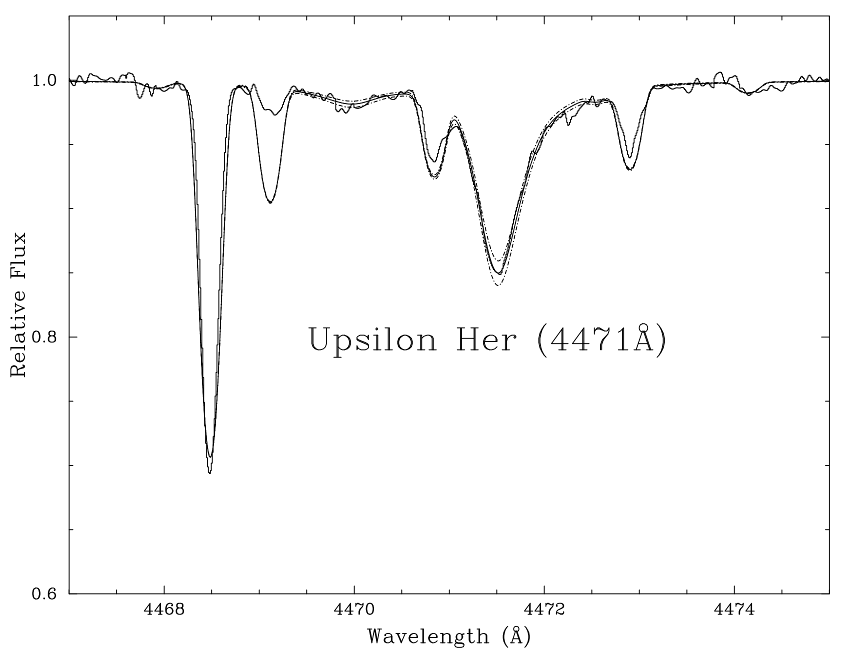

Figure 4: Best fit for HgMn star υ Her λ4471, $T_{\rm eff}$ = 12,000 K, $\log g = 3.80$, with He abundance 10.20. For illustration, the dash-dot lines indicate the profiles for changes of abundance of $\pm$0.08 dex, larger than the error estimate in this work.

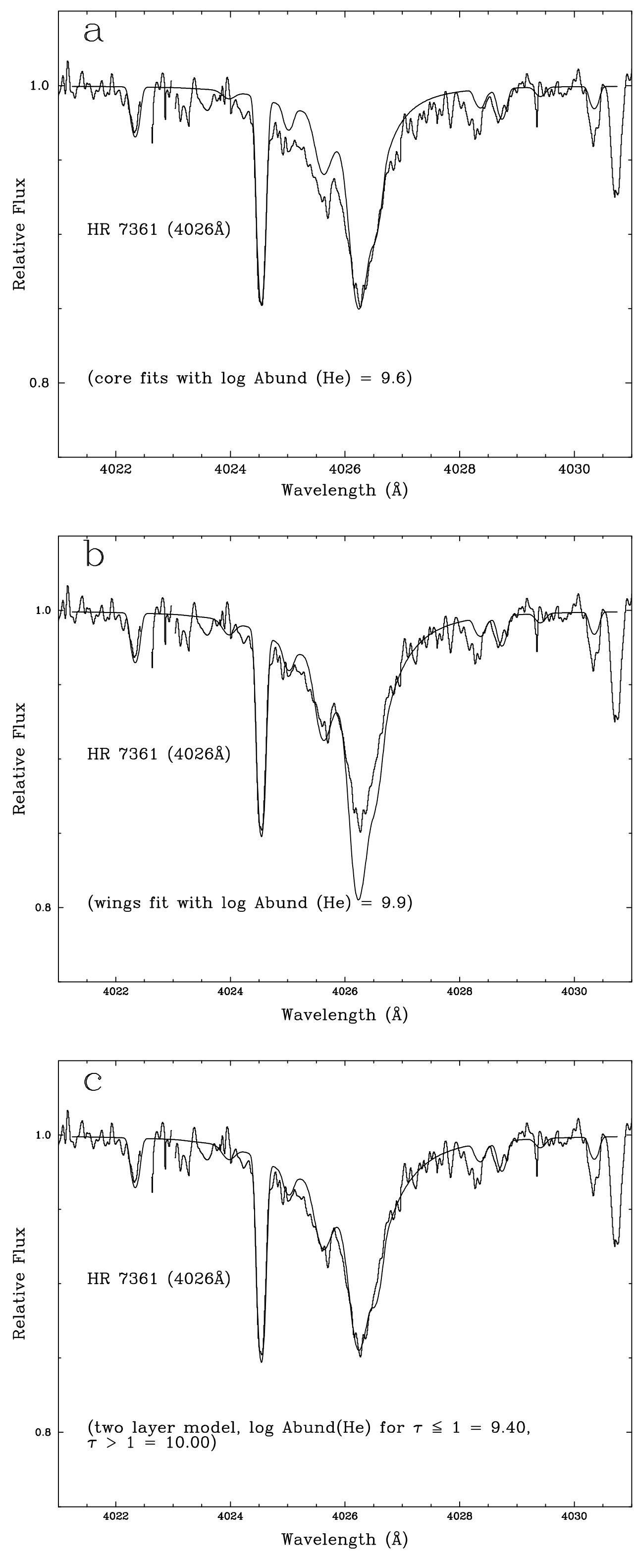

Figure 5: The centre or core (a) of $\lambda4026$ He I fits a very low He abundance in the HgMn star HR7361. The wings can only be fit with a higher abundance (b), but then the core is a bad fit. A model with a higher abundance of He below $\tau = 1$ (c) fits both core and wings reasonably well. This indicates that He is stratified, with more depletion in the upper photosphere than in the deeper photosphere.

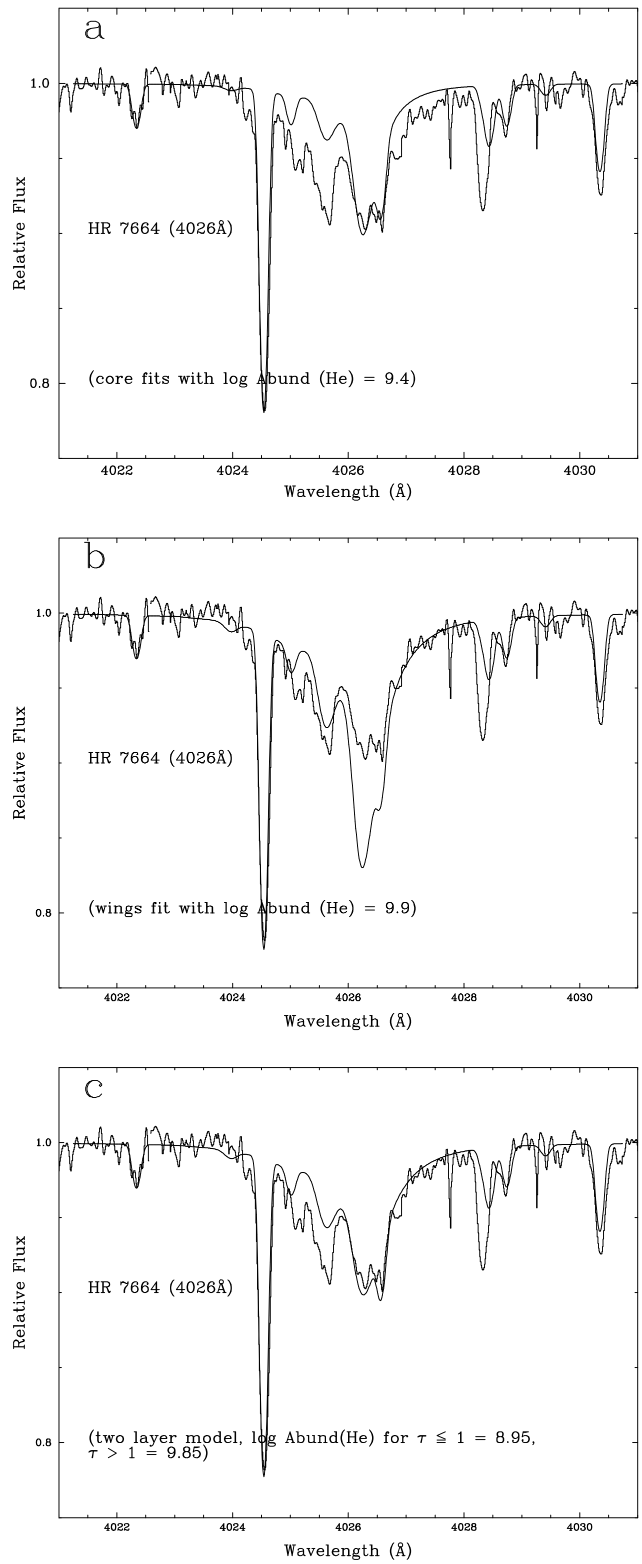

Figure 6: The HgMn star HR7664 has similar fitting problems to HR7361 shown in Fig. 5. The core (a) of λ4026 He I fits a low He log abundance, 9.4. The wings require a higher value 9.9 (b), but then the core is a bad fit. A model with a higher abundance of He below $\tau = 1$ (c) fits both core and wings reasonably well. Again, this shows that He is stratified, with more depletion in the upper photosphere than in deeper layers.