Four new HgMn stars: HD 18104, HD 30085, HD 32867, and HD 53588 (Research Note)

R. Monier^{1,2}, M. Gebran³, and F. Royer⁴

¹ LESIA, UMR 8109, Observatoire de Paris, Place J. Janssen, 92195 Meudon, France

² Laboratoire Lagange, Université de Nice Sophia, Parc Valrose, 06100 Nice, France
 e-mail: Richard.Monier@unice.fr

³ Department of Physics and Astronomy, Notre Dame University-Louaize, PO Box 72, Zouk Mikael, Lebanon

⁴ GEPI, Observatoire de Paris, Place J. Janssen, 92195 Meudon, France

Received 16 March 2015 / Accepted 10 April 2015

ABSTRACT

Context. We have discovered four new HgMn stars while monitoring a sample of apparently slowly rotating superficially normal bright late-B and early-A stars in the northern hemisphere.

Aims. Important classification lines of Hg II and Mn II are found as conspicuous features in the high resolution SOPHIE spectra of these stars ($R = 75\,000$).

Methods. Several lines of Hg II, Mn II and Fe II were synthesized using model atmospheres and the spectrum synthesis code SYNSPEC48, including hyperfine structure of various isotopes when relevant. These synthetic spectra were compared to high-resolution observations of these stars that have a high signal-to-noise ratio to derive abundances of these key elements.

Results. The four stars are found to have distinct enhancements of Hg and Mn, which shows that they are not superficially normal B and A stars, but are new HgMn stars and need to be reclassified as such.

Key words. stars: abundances – stars: atmospheres – stars: chemically peculiar – stars: early-type

1. Introduction

We have recently undertaken a spectroscopic survey of all apparently slowly rotating bright early-A (A0-A1V) and late-B stars (B8-B9V) observable from the northern hemisphere. The incentive is to search for rapid rotators seen pole-on or new chemically peculiar B and A stars that have thus far remained unnoticed. The abundance results for the A0-A1V sample have been published in [Royer et al. \(2014\)](#). The selection criteria were a declination higher than -15° , spectral class A0 or A1 and luminosity class V and IV, and magnitudes V brighter than 6.65. The B8-9 sample employs the same criteria, except for the V magnitude brighter than 7.85 because these B stars are intrinsically brighter in the V band where SOPHIE reaches its highest efficiency. Most of the stars of that B8-9 sample (40 stars) have just recently been observed in December 2014. A careful abundance analysis of the spectra with a high resolution and high signal-to-noise ratio (S/N) of the A stars sample has allowed sorting out the sample of 47 A stars into 17 chemically normal stars (whose abundances do not depart by more than ± 0.20 dex from solar values), 12 spectroscopic binaries, and 13 chemically peculiar stars (CPs), five of which are new CP stars. The status of these new CP stars still needs to be fully specified by spectropolarimetric observations to address their magnetic nature or by exploring new spectral ranges that we had not explored in this first study. Indeed, the abundance analysis of the A stars sample in [Royer et al. \(2014\)](#) only relied on four spectral regions: 4150–4300 Å, 4400–4790 Å, 4920–5850 Å, and 6000–6275 Å, avoiding Balmer lines and atmospheric telluric lines.

We have now started to examine the A0-A1V and B9-B8V samples in the region of the red wing of the H ϵ line to search for the Hg II 3983.93 Å line and also the spectral range 4125–4145 Å, which harbors the Mn II line at 4136.92 Å next to the Si II doublet (multiplet 2). The Hg II 3983.93 Å line and the Mn II line at 4136.92 Å lines with appreciable strengths are the signatures of an HgMn star ([Jaschek & Jaschek 1995](#)). Note that, a priori, only one of these two elements (Mn or Hg) is sufficient to identify a new HgMn star because both elements may be distributed in different spots and may not be simultaneously visible to the observer at a given time (see [Hubrig et al. 2012](#) for a complete review). In our A and B stars samples, we found that four stars unambiguously show the Hg II line at 3984 Å and the Mn II line at 4136.92 Å (and several other strong Mn II lines). These are HD 18104 (B9V), HD 30085 (A0IV), HD 32867 (B8V), and HD 53588 (B9V). A bibliographic query of the CDS for each of these stars revealed very few publications (about ten references each). HD 30085 was ascribed a spectral type A0IV in the survey of [Cowley et al. \(1969\)](#) of bright A stars (observed with prismatic dispersion of 125 Å mm⁻¹ around H γ), and the authors did not mention any peculiarity in the spectrum. The other three B stars do not appear in [Cowley's](#) classification (1972) of the bright B8 stars. The purpose of this research note is to report on the detection of the Hg II 3983.93 Å line and strong Mn II lines as well in these four stars that are currently classified as “normal”. We have also determined estimates of the iron, manganese, and mercury abundances using spectrum synthesis to quantify the enhancements of these elements in these stars.

Table 1. Observation log.

Star ID	Spectral type	<i>V</i>	Observation date	Exposure time (s)	<i>S/N</i>
HD 18104	B9	6.85	2014-12-16	800	136
HD 30085	A0IV	6.35	2013-12-11	1200	269
			2012-13-03	800	216
HD 32867	B8V	7.48	2014-12-16	2100	170
HD 53588	B9V	7.20	2014-12-17	1350	158

2. Observations and data reduction

The four stars have been observed at Observatoire de Haute Provence using the high-resolution ($R = 75\,000$) mode of the SOPHIE echelle spectrograph (Perruchot et al. 2008) at three different epochs: February 2012, December 2013, and December 2014. The three late-B stars have been observed only once in December 2014. The A0IV star HD 30085 was observed twice, in February 2012 and December 2013. The coaddition of the two exposures for HD 30085 yields a coadded spectrum whose *S/N* is about 300. The three late B stars observed in December 2014 have lower *S/N* ratios ranging from 136 to 170. The observations log is displayed in Table 1. The data were automatically reduced to produce 1D extracted and wavelength calibrated échelle orders. Each reduced order was normalised separately using a Chebychev polynomial fit with sigma clipping, rejecting points above or below 1σ of the local continuum. Normalised orders were merged, corrected by the blaze function, and resampled into a constant wavelength step of about $0.02\text{ \AA}$ (see Royer et al. 2014, for more details).

Radial velocities were derived from cross-correlation techniques, avoiding the Balmer lines and the atmospheric telluric lines. The normalised spectra were cross-correlated with a synthetic template extracted from the POLLUX database¹ (Palacios et al. 2010) corresponding to the parameters $T_{\text{eff}} = 11\,000\text{ K}$, $\log g = 4$, and a solar metallicity. A parabolic fit of the upper part of the resulting cross-correlation function yielded the Doppler shifts, which were then used to shift spectra to rest wavelengths. The radial velocity of HD 30085 is found to be the same within its accuracy at the two different epochs of observations: $V_{\text{rad}} = 8.27 \pm 0.20\text{ km s}^{-1}$. We only searched for line profile variability in the lines of Hg II and Mn II. The individual spectra of HD 30085 were coadded and the difference of each spectrum with the mean spectrum was computed. This difference was then ratioed to the estimated noise level σ of the local continuum. We considered real variations only if the absolute value of the difference was found to be higher than 3σ . We failed to find any real line profile variations or radial velocity variations above three σ of the noise level for HD 30085.

3. Hg II and Mn II lines in the four stars

Two spectral regions were used to establish the HgMn nature of the four stars. First, the red wing of H ϵ , which lies in order 3, harbours the Hg II λ 3983.93 $\text{\AA}$ line and several Zr II and Y II lines that are expected to be strengthened in HgMn stars. Jäschek & Jäschek (1995) emphasised that the Hg II 3983.93 $\text{\AA}$ line is absent from the spectra of normal late-B stars. Second, the region from 4125 $\text{\AA}$ to 4145 $\text{\AA}$ (order 6) contains the Mn II line at 4136.92 $\text{\AA}$ redwards of the Si II doublet (multiplet 2). In a HgMn star, the Mn II line at 4136.92 $\text{\AA}$ should be strong, but

Fig. 1. Detection of the Hg II line at 3984 $\text{\AA}$; its rest wavelength location is depicted as a vertical line in the spectra of the four stars. The spectra have been offset from each other for clarity. The Hg II line is absent from the spectrum of the comparison star HD 42035.

it should be absent from any comparison normal late B-type star. Furthermore, the lines of Mn II at 4206.37 $\text{\AA}$ and 4252.96 $\text{\AA}$ should also be enhanced in the spectra of HgMn stars (Gray & Corbally 2009).

Figure 1 displays order 3 for the four stars and a comparison star, HD 42035 (a normal B9 V star of our sample) and the location as a vertical line of the rest wavelength of the Hg II 3983.93 $\text{\AA}$ line (Multiplet 2), Fig. 2 displays the Mn II line at 4136.92 $\text{\AA}$ longwards of the Si II doublet (Multiplet 2) at 4128.07 $\text{\AA}$ and 4130.88 $\text{\AA}$. The Hg II 3983.93 $\text{\AA}$ line and the Mn II 4136.92 $\text{\AA}$ are clearly present in the four spectra of the four stars and absent in the comparison star HD 42035. The equivalent width of the Hg II 3983.84 $\text{\AA}$ line ranges from 64 m $\text{\AA}$ to 132 m $\text{\AA}$, which is well in the range quoted for HgMn stars (from 50 m $\text{\AA}$ up to 300 m $\text{\AA}$ typically in Jäschek & Jäschek 1995). The equivalent width (EW) of the Mn II line at 4136.92 $\text{\AA}$ ranges from 47.4 m $\text{\AA}$ up to 93.6 m $\text{\AA}$ in the four stars, but this Mn II line is absent from the spectrum of the comparison star HD 42035. The Mn II lines at 4206.37 $\text{\AA}$ and 4252.96 $\text{\AA}$ are also prominent features in the spectra of all stars. The EWs of 4206.37 $\text{\AA}$ ranges from 66.7 m $\text{\AA}$ to 117.4 m $\text{\AA}$, in agreement with Kodaira & Takada (1978), who found a mean EW of about 100 m $\text{\AA}$ for the 4206.37 $\text{\AA}$ line for a group of HgMn stars. The EW of 4252.96 $\text{\AA}$ ranges from 75 m $\text{\AA}$ up to 122.4 m $\text{\AA}$. The comparison of the spectra of the four stars to that of the normal stars in these key regions leads us to propose that these stars are new HgMn stars and should be reclassified as such.

4. Abundance determinations

4.1. Fundamental parameter determinations

For the three B stars, we adopted the effective temperatures and surface gravities derived by Huang et al. (2010) from fitting the Hy profiles. Two B stars, HD 18104 and HD 53588, do not have Strömgren photometry, which precludes using the UVBYBETA procedure developed by Napiwotzky (1993) to derive their fundamental parameters. We therefore used the effective temperature and surface gravity derived in Huang et al. (2010) by fitting the Hy profile for the three stars for consistency. For HD 30085, the effective temperature and surface gravity were derived from Strömgren photometry in Royer et al. (2014), and a spectrum

¹ <http://pollux.graal.univ-montp2.fr>

Fig. 2. Detection of the Mn line at 4136.92 Å; its rest wavelength location is depicted as a vertical line in the spectra of the four stars. The spectra have been offset from each other for clarity. The Mn II line is absent from the spectrum of the comparison star HD 42035.

Table 2. Stellar fundamental parameters.

Star ID	T_{eff}	$\log g$	$v \sin i$ (km s ⁻¹)	V_{rad} (km s ⁻¹)
HD 18104	11074	3.67	46.0	12.07
HD 30085	11300	3.95	23.0	8.20
HD 32867	13149	3.86	37.0	13.97
HD 53588	12351	3.88	48.0	12.03

synthesis of its H γ profile was run to confirm these parameters. The adopted effective temperatures, surface gravities, and projected equatorial velocities are displayed in Table 2.

4.2. Model atmospheres and spectrum synthesis calculations

Plane-parallel model atmospheres assuming radiative equilibrium and hydrostatic equilibrium were computed using the ATLAS9 code (Kurucz 1992). The linelist was built from Kurucz (1992) gfhyperall.dat², which includes hyperfine splitting levels. A grid of synthetic spectra was computed with SYNSPEC48 (Hubeny & Lanz 1992) to model the Hg II, Mn II, Fe II, and Si II lines. Computations were iterated by varying the unknown abundance until minimisation of the chi-square between the observed and synthetic spectrum was achieved. The microturbulent velocities were assumed to be 0 or 0.5 km s⁻¹, in agreement with most analyses of HgMn stars whose atmospheres are thought to be very quiet.

4.3. Derived iron, manganese, and mercury abundances

The iron abundances were derived by using several Fe II lines of multiplets 37, 38, and 186 in the range 4500–4600 Å, whose atomic parameters are critically assessed in NIST³ (these are C+ and D quality lines). These lines are widely spaced, and the continuum is fairly easy to trace in this spectral region. Their synthesis always yields consistent iron abundances from the various transitions with very little dispersion. The iron abundance is

Table 3. Abundance determinations.

Star ID	Chemical element	Laboratory wavelength (Å)	$\left[\frac{N_{\text{elem}}}{N_{\text{solar}}} \right]_{\odot}$
HD 18104	Fe II	4500–4550	2.5 ± 0.5
HD 30085	Fe II	4500–4550	2.5 ± 0.5
HD 32867	Fe II	4500–4550	2.0 ± 0.5
HD 53588	Fe II	4500–4550	2.5 ± 0.5
HD 18104	Mn II	4136.92	50 ± 4.5
HD 30085	Mn II	4136.92	40 ± 4.0
HD 32867	Mn II	4136.92	350 ± 32.0
HD 53588	Mn II	4136.92	150 ± 14.0
HD 18104	Hg II	3983.87	$40\,000 \pm 2800$
HD 30085	Hg II	3983.87	$32\,000 \pm 2000$
HD 32867	Hg II	3983.87	$130\,000 \pm 9100$
HD 53588	Hg II	3983.87	$300\,000 \pm 27\,000$

probably the most accurately determined of the three abundances derived here. We find that the four stars show only mild enhancement in iron, about 2 to 2.5 solar. The Fe II, Mn II, and Hg II abundances and their estimated uncertainties for the four selected stars are collected in Table 3 (the determination of the uncertainties is discussed in Royer et al. 2014).

The manganese abundances were derived from two C+ quality lines, λ 4206.368 Å and 4259.191 Å, whose hyperfine structure is published in Holt et al. (1999). The individual transitions were added to our initial lineslist using the wavelengths, oscillator strengths, and angular momenta from Table 1 in Holt et al. (1999). We did not use the other two Mn II lines at 4326.644 Å and 4348.396 Å analysed by Holt et al. (1999) because they fall in the blue and red wings of the H γ line where the continuum is more difficult to locate. After the hyperfine structure of 4206.368 Å and 4259.191 Å were properly taken into account, these two Mn II lines yielded very consistent abundances that were significantly lower than when the hyperfine structure was ignored (up to a factor of ten lower). Manganese enrichments range from 40 up to 350 solar and appear to slowly increase with effective temperature, the two coolest stars (HD 18104 and HD 30085) around 11 000 K having the lowest manganese enrichment (40–50 $\odot$), while the hottest star, HD 32867, is the most enriched. This agrees with the correlation of manganese abundances with the effective temperature reported by Smith & Dworetzky (1993) using ultraviolet lines of Mn II for a large number of HgMn stars.

The mercury abundances were derived from the Hg II 3983.93 Å line in NIST (multiplet 2) but including the hyperfine structure of the various isotopes as provided in Dolk et al. (2003). We used the wavelengths and oscillator strengths for each transition as presented in their Table 2 for the case of a terrestrial isotopic mixture. The other line of Hg II that might be present in the spectra of HgMn stars is that of multiplet 4 at 6149.48 Å, but it appears to be blended in all four stars with the Fe II line at 6149.25 Å so that we did not use this line for abundance analysis. Dolk et al. (2003) assumed a terrestrial isotope mixture for mercury, which may not occur in the HgMn stars we investigate. Note that the 3983.93 Å line is blended with two lines, Cr I 3983.897 Å and Fe I 3983.960 Å, which contribute no absorption at the temperatures of the late-B stars we study here (this is easily verified by removing the Hg II hyperfine transitions from the line synthesis and by checking that no absorption is computed for the appropriate iron abundance for any of these stars). The

² <http://kurucz.harvard.edu>

³ <http://www.nist.gov>

Fig. 3. Comparison of the observed Hg II 3983.93 Å line profile of HD 32867 to a synthetic profile computed for an overabundance of 130 000 solar. The vertical line depicts the location of the rest wavelength of the Hg II line.

Hg overabundances range from 32 000 to 300 000 solar, where again the coolest stars tend to have lower Hg enhancement than the hotter stars. The uncertainties on these abundances are believed to be of the order of $\pm 2000 \odot$ to $\pm 27 000 \odot$. The synthetic spectrum reproducing the best the Hg II profile for HD 32867 for a 130 000 solar overabundance of Hg is compared to the observed profile rectified to the red wing of H ϵ in Fig. 3. Only the mean spectrum of HD 30085 is of sufficient quality to examine the structure of the line core. In the two observations of this star, the core of the 3983.93 Å line appears to be fairly flat and extending from 3893.90 ± 0.02 Å to 3984.07 ± 0.02 Å, which roughly corresponds to the positions of the transitions of the heaviest isotopes ^{200}Hg and ^{204}Hg . The accuracy of the wavelength scale is achieved by using four control lines on each side of the Hg II line: shortwards of the Zr II line at 3982.025 Å, the Y II line (M 6) at 3982.59 Å, and longwards of the Zr II lines at 3984.718 Å and 3991.15 Å: after correcting for the radial velocity of HD 30085, the centres of these lines are found at their expected laboratory locations to within ± 0.02 Å. These two isotopes appear thus to contribute most of the absorption in HD 30085, as is the case in the majority of the coolest

HgMn stars (White et al. 1976), whereas they only contribute a small fraction of the terrestrial mixture.

5. Conclusions

We have found four new HgMn stars from the inspection of the H ϵ wing and a few Mn II lines. We provide for the first time estimates of the overabundances of Fe, Mn, and Hg in these stars, which were until now considered as normal. They clearly must be reclassified as HgMn stars. The detection of these new HgMn stars is quite important because they only represent about 8% for the coolest B-type stars around B9 and B8 (Wolff & Preston 1978). We expect to find other new HgMn stars by extending our survey to the late-B stars of the southern hemisphere. Each of these stars will be the subject of a detailed abundance analysis, which we plan to publish in the near future.

Acknowledgements. We thank the referee, S. Hubrig, whose comments resulted in many improvements. We also thank the OHP night assistants for their helpful support during the three observing runs.

References

- Cowley, A. 1972, *AJ*, **77**, 750
- Cowley, A., Cowley, C., Jасhek, M., & Jасhek, C. 1969, *AJ*, **74**, 375
- Dolk, L., Wahlgren, G. M., & Hubrig, S. 2003, *A&A*, **402**, 299
- Gray, R., & Corbally, J. C. 2009, *Stellar spectral classification* (Princeton University Press), 133
- Huang, W., Gies, D. R., & Mc Swain, M. 2010, *ApJ*, **722**, 605
- Hubeny, I., & Lanz, T. 1992, *A&A*, **262**, 501
- Hubrig, S., González, J. F., Ilyin, I., et al. 2012, *A&A*, **547**, A90
- Holt, R., A., Scholl, T. J., & Rosner, S. D. 1999, *MNRAS*, **306**, 107
- Jасhek, C., & Jасhek, M., 1995, *The behavior of chemical elements in stars* (Cambridge University Press), 111
- Kodaira, K., & Takada, M. 1978, *Ann Tokyo Obs, second Ser.*, **17**, 79
- Kurucz, R. L. 1992, *Rev. Mex. Astron. Astrofis.*, **23**, 45
- Napiwotzki, R., Schoenberger, D., & Wenske, V. 1993, *A&A*, **268**, 653
- Palacios, A., Gebran, M., Josselin, E., et al. 2010, *A&A*, **516**, A13
- Perruchot, S., Kohler, D., Bouchy, F., et al. 2008, in *Ground-based and Airborne Instrumentation for Astronomy II*, eds. J. S. McLean, & M. M. Casali, *Proc. SPIE*, **7014**
- Royer, F., Gebran, M., Monier, R., et al. 2014, *A&A*, **562**, A84
- Smith, K. C., & Dworetzky, M. M. 1993, *A&A*, **274**, 335
- White, R. E., Vaughan, A. H., Preston, G. W., & Swings, J. P. 1976, *ApJ*, **204**, 131
- Wolff, S. C., & Preston, G. W. 1978, *ApJS*, **37**, 371