Establishing the link between HgMn and PGa stars

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Abstract We discuss most recent spectroscopic and spectropolarimetric observations of the star HD 19400 representative of the group of PGa stars. Our high-spectral-resolution study of abundances, line profile variability, and the longitudinal magnetic field of HD 19400 discloses a remarkable similarity between this group and the group of HgMn stars.

1. Introduction

The mid to late-main sequence B-type stars contain several groups of chemically peculiar stars, among them classical magnetic Bp stars, HgMn stars, and PGa stars. The classical magnetic peculiar Bp stars, which include Si and He-weak Bp stars, are usually characterised by large overabundances of Fe-peak and rare-earth elements. They possess non-axisymmetric large-scale magnetic fields of up to a few kG and display on their surfaces chemical spots of different elements. On the other hand, the presence of weak magnetic fields on the surface of late-B type stars with HgMn peculiarity, the so-called HgMn stars, has been controversial during the last two decades. Our recent measurements of magnetic fields in HgMn stars with the moment technique, using spectral lines of several elements separately, revealed the presence of a weak longitudinal magnetic field, a quadratic magnetic field, and the crossover effect on the surface of several HgMn stars (Hubrig et al. 2012 [1]).

The aspect of inhomogeneous distribution of some chemical elements over the surface of HgMn stars was first discussed by Hubrig & Mathys (1995 [2]). From a survey of HgMn stars in close spectroscopic binaries, it was suggested that some chemical elements might be inhomogeneously distributed on the surface, with, in particular, preferential concentration of Hg along the equator. Recent studies revealed that not only Hg, but also many other elements, most typically Ti, Cr, Fe, Mn, Sr, Y, and Pt, are concentrated in spots of diverse size, and different elements exhibit different abundance distributions across the stellar surface (e.g., Hubrig et al. 2006 [3]; Briquet et al. 2010 [4]; Korhonen et al. 2013 [5]). Moreover, an evolution of the abundance spots of several elements at different time scales was discovered in two additional HgMn stars, HD 11753 and AR Aur. Briquet et al. (2010 [4]) and Korhonen et al. (2013 [5]) reported the presence of dynamical spot evolution over a couple of weeks for the SB1 system HD 11753, while Hubrig et al. (2010 [6]) detected a secular element evolution in the double-lined eclipsing binary AR Aur. Our recent spectroscopic and polarimetric studies of HgMn stars suggest the existence of intriguing correlations between the strength of the magnetic field, abundance anomalies, and binary properties (Hubrig et al. 2012 [1]). However, not much is known about the origin of anomalies in the hotter extension of the HgMn stars, the PGa stars, with rich P II, Mn II, Ga II, and Hg II spectra, and effective temperatures of about 14 000 K and higher. In this work, we present a spectroscopic study of the typical PGa star HD 19400.

2. The spectrum of the PGa star HD 19400

We recently downloaded two high-resolution, high S/N HARPSpol spectra of the PGa star HD 19400 from the ESO archive to study the presence of a magnetic field and an inhomogeneous distribution of overabundant elements on the stellar surface. A careful inspection of the polarimetric spectra of HD 19400 acquired on two consecutive nights in 2011 revealed the presence of anomalous flat-bottom line profiles belonging to overabundant elements, reminiscent of profile shapes observed in numerous HgMn stars. Magnetic field measurements using the moment technique introduced by Mathys (e.g. 1991 [7]) disclosed the presence of a weak mean longitudinal magnetic field of the order of a few tens of Gauss, similar to weak fields

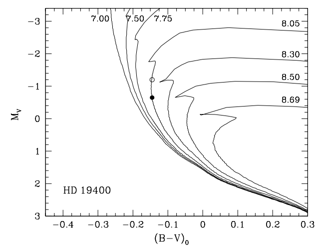

Figure 1. The position of HD 19400 in the H-R diagram. The filled circle corresponds to the position obtained using the Hipparcos parallax, while the open circle corresponds to spectroscopic $T_{\rm eff}$ and $\log g$ (Leone et al. 1997 [10]).

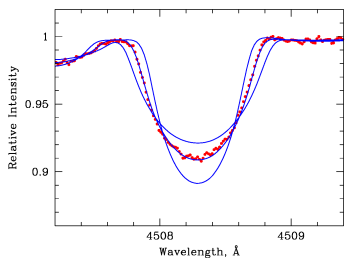

Figure 2. Determination of the v sin i value for HD 19400. Solid blue lines correspond to profiles calculated with v sin i = 25, 30, and 35 km s^{-1}. The observed line profile is shown by red dots.

detected in a number of HgMn stars (e.g., Mathys & Hubrig 1995 [8]; Hubrig et al. 2012 [1]). To date, HD 19400 is the only PGa star for which a search for the presence of a magnetic field and an inhomogeneous element distribution has been carried out. The position of HD 19400 in the H-R diagram is presented in Fig. 1.

As shown in Fig. 2, the v sin i value of 30 km s^{-1} was estimated from fitting a synthetic spectrum to the observed profile of the Fe II λ4508.3 Å line, which has a low Landé factor.

The HARPSpol spectra observed on two consecutive nights on December 15 and December 16, 2011, show tiny variations in the line shapes. In Fig. 3 we present these weak variations in several line profiles. Moreover,

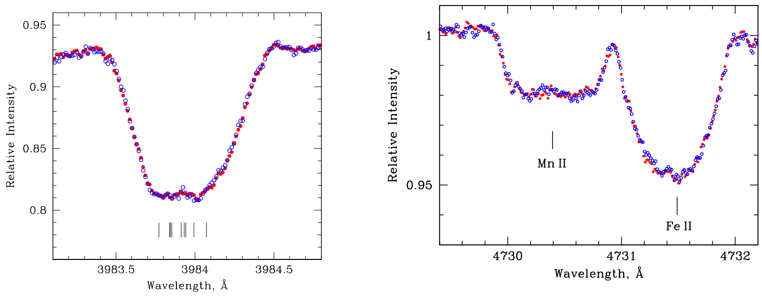

Figure 3. Observations of line profiles belonging to three different elements are highlighted for different nights by open and filled circles. *Left:* The Hg II λ3984 Å line together with the indicated isotopic/hyperfine structure. *Right:* Profiles of Mn II and Fe II lines in the spectral region around 4730.5 Å.

Fig. 3 clearly shows that the shape of the line profiles belonging to Hg II and Mn II strongly deviates from the rotationally broadened Fe II profiles, indicating an inhomogeneous distribution of at least these elements on the stellar surface.

3. Synthesis of line profiles of Hg II and Mn II taking into account the isotopic and hyperfine structure

In Fig. 4 we present synthetic spectra in the spectral regions containing the Hg II λ3984 Å and Mn II λ4206 Å lines. Synthetic line profiles have been calculated using Kurucz models, the current version of the MOOG code (Sneden 1973 [9]), atmospheric parameters of Leone et al. (1997 [10]), and $v_{\rm t} = 0.2$ km s^{-1}. Obviously, neither the impact of isotopic/hyperfine structure of Hg on the profile shape, nor the hyperfine structure of the Mn II lines can produce the observed flat-bottom line profiles.

4. Appearance of line profiles in typical HgMn stars

Similar flat-bottom line profiles belonging to overabundant elements are frequently observed in typical HgMn stars. In Fig. 5, we present UVES spectra of the eclipsing binary AR Aur with a HgMn primary, obtained a few years ago.

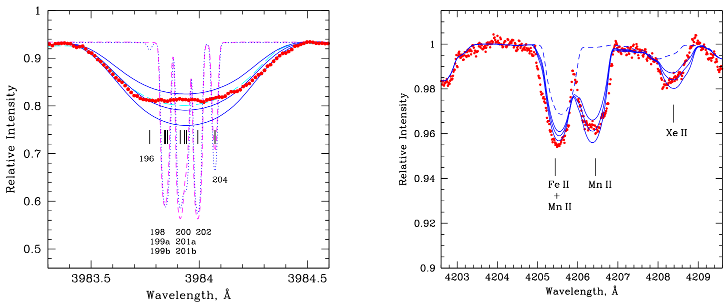

Figure 4. *Left:* Synthetic spectrum in the region around the Hg II λ3984 Å line. *Right:* Synthetic spectrum in the region around the Mn II λ4206 Å line. Red points correspond to observations, while solid blue lines indicate the synthetic spectra calculated for different abundances of Hg (for $\log\epsilon(\mathrm{Hg}) = 5.7$, 6.0, 6.3) and of Mn (for $\log\epsilon(\mathrm{Mn}) = 7.20$, 7.25, 7.30). The blue dotted line in the figure on the left side represents a terrestrial isotopic mixture (Dolk et al. 2003 [11]) without broadening, while for the magenta short dash line we assume the isotopic composition obtained by Castelli & Hubrig (2004 [12]) for the HgMn star HD 175640. The long dash cyan line represents the Hg II line profile calculated without consideration of hyperfine structure and isotopic composition. The short dashed blue line in the figure on the right side presents the synthetic spectrum calculated with solar abundances of Mn and Xe (Anders & Grevesse 1989 [13])

5. Conclusions

Due to a small number of detailed high-resolution, high S/N spectropolarimetric studies of PGa stars, the link between the chemically peculiar groups among the mid to late main sequence B-type stars is not understood yet. Apart from our recent study of HD 19400, no other information on spectral variability and the presence of magnetic fields in PGa stars currently exists. Our study of the PGa star HD 19400 indicates a spectral behaviour very similar to that of HgMn stars showing the presence of chemical spots and weak magnetic fields. Future high S/N, high-resolution spectropolarimetric observations of PGa stars are important to firmly establish the link between PGa and HgMn stars.

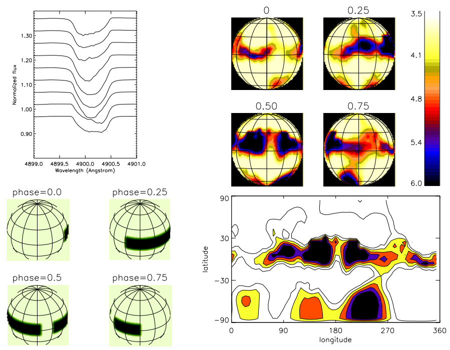

Figure 5. *Left:* Observed Y II λ4900 Å line variations in UVES spectra of the eclipsing binary AR Aur with a HgMn primary. Using a direct Doppler imaging method, the flat-bottom Y II profiles can be explained by the presence of a Y II fractured equatorial ring (Hubrig et al. 2006 [3]). *Right:* A surface Y II abundance distribution similar to a fractured equatorial ring was detected using the Doppler imaging inversion code iAbu (Savanov et al. 2009 [14]).

Acknowledgements. N.A.D. acknowledges support of the PCI/MCTI, Brazil, under the Project 302350/2013-6 and the Saint Petersburg State University, Russia, under the Project 6.38.73.2011.

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