Multiplicity of chemically peculiar stars

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Summary. Recently, with the goal to study multiplicity of chemically peculiar stars, we carried out a survey of 40 stars using diffraction limited near infrared (IR) imaging with NAOS-CONICA (NACO) at the VLT. Here, we announce the detection of 27 near IR companion candidates around 25 late B-type chemically peculiar stars exhibiting strong overabundances of the chemical elements Hg and Mn in their atmospheres. A key point for the understanding of the abundance patterns in these stars may be connected with binarity and multiplicity. It is intriguing that more than half of the sample of HgMn stars studied previously by speckle interferometry and recently using the adaptive optics system NACO belong to multiple systems.

1 Introduction

Chemically peculiar (CP) stars are main sequence A and B type stars in the spectra of which lines of some elements are abnormally strong or weak. The class of CP stars is represented by roughly three subclasses including magnetic Ap and Bp stars, metallic-line Am stars and HgMn stars which are late B-type stars showing extreme overabundances of Hg (up to 6 dex) and/or Mn (up to 3 dex). Among the magnetic Ap stars the rate of binaries is 43% [1]. The main result of this most recent study of multiplicity of magnetic stars is that, statistically, the orbital parameters of Ap stars do not differ from those of normal stars, except for an almost complete lack of orbital periods shorter than 3 days. The studies of the evolutionary state of magnetic Ap stars in binaries indicate that all of them are rather old main sequence stars and are well evolved from the zero-age main sequence (e.g. Wade et al. (1996) [2]), fully in agreement with results of the study of single magnetic Ap stars by Hubrig et al. (2000) [3].

The number of double-lined spectroscopic binary (SB2) systems among magnetic Ap stars is abnormally low (only 3 SB2 systems are known to date) and no eclipsing binary comprising a magnetic Ap star has ever been identified. The rate of binaries is much smaller among magnetic Bp stars, $\sim$20%, and only two double-lined eclipsing binaries have recently been discovered: HD 123335 was discussed by Hensbergen et al. (2004) [4] and AO Vel by González et al. (2005) [5]. A total of six magnetic Bp/Ap stars are known to be multiple and are listed in the Multiple Star Catalogue of Tokovinin (1997) [6].

The metallic-line Am stars show an overabundance of heavy elements and an underabundance of Ca and Sc. A very high fraction of these stars, at least 90%, are SB systems with orbital periods between 2.5 and 100 days.

HgMn stars are rather young objects and many of them are found in young associations like Sco-Cen, Orion OB1 or Auriga OB1. HgMn stars do not have strong large-scale organized magnetic fields and exhibit marked abundance anomalies of numerous elements. In contrast to Bp and Ap stars with large-scale organized magnetic fields, they generally do not show overabundances of rare earths, but exhibit strong overabundances of heavy elements like W, R, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi. Another important distinctive feature of these stars is their slow rotation ($\langle v \sin i \rangle \approx 29\,\mathrm{km\,s^{-1}}$, Abt et al. (1972) [7]). The number of HgMn stars decreases sharply with increasing rotational velocity [8]. Evidence that stellar rotation does affect abundance anomalies in HgMn stars is provided by the rather sharp cutoff in such anomalies at a projected rotational velocity of 70–80 $\mathrm{km\,s^{-1}}$ [9].

The mechanisms responsible for the development of the chemical anomalies of HgMn stars are not fully understood yet. A key point for the understanding of the abundance patterns may be connected with binarity and multiplicity. More than 2/3 of the HgMn stars are known to belong to spectroscopic binaries [10]. Quite a number of HgMn stars belong to triple or even quadruple systems [11, 12]. Out of 30 SB HgMn stars observed in speckle interferometry, 15 appear to have more than two components. Indirect evidence for the presence of a third component was found in four other HgMn SBs (HD 11905, HD 34364, HD 78316 and HD 141556) on the basis of spectroscopic and photometric arguments. Further evidence that other HgMn stars frequently are members of multiple systems is inferred from the results of the ROSAT all-sky survey. X-ray emission was detected through this survey in 12 HgMn stars (7 SB1s, 3 SB2s and 2 for which no radial velocity data are available). Previous X-ray observations with the Einstein Observatory and theoretical estimates had suggested that stars in the spectral range B2–A7 are devoid of any significant X-ray emission. In most cases when emission had been detected in such stars, it was found to originate from a cool companion. This suggests that the X-ray emission found in HgMn SBs does not originate from the HgMn primary. From observations investigating late-B X-ray sources using the ESO 3.6-m with ADONIS [13] we found faint companions for 4 HgMn stars that were part of the X-ray selected late-B stars observed, strengthening this interpretation.

In the catalogue of multiple stars by Tokovinin (1997) [6], which compiles data on 612 stellar systems of different spectral types, we found four additional multiple systems containing HgMn stars. It is especially intriguing that if the relative frequency of HgMn stars in multiple systems is studied, every third system with a primary in the spectral range between B6 and B9 involves an HgMn star. These observational results clearly show that the study of multiple systems with an HgMn component is of prime interest for star formation. In the following we report our results of the recent study of multiplicity of this amazing class of objects using NACO K-band imaging.
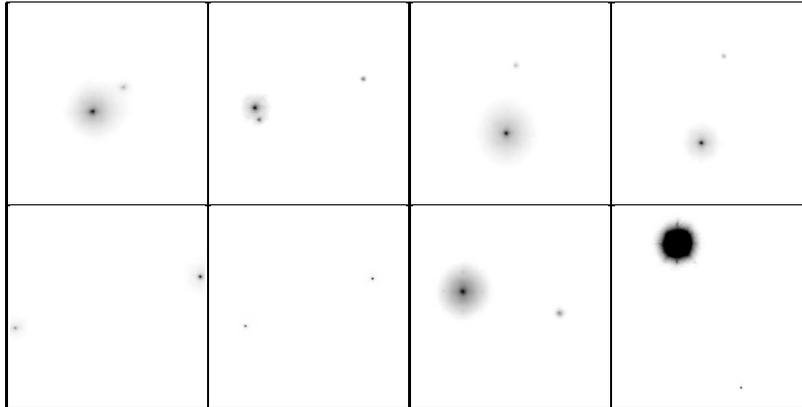
2 Observations

Observations of 40 HgMn stars have been carried out with NACO in service mode from October 2004 to March 2005. We used the S13 camera, to be able to discover practically all components down to K=14 with a signal-to-noise ratio of the order of 12.

Here, we announce the detection of 27 near IR companion candidates in eight binaries, 16 triple and one quadruple system. The detected companion candidates have K magnitudes between $5^{\mathrm{m}}5$ and $13^{\mathrm{m}}5$ and angular separations ranging from $0''1$ to $7''3$ (7-1500 AU).
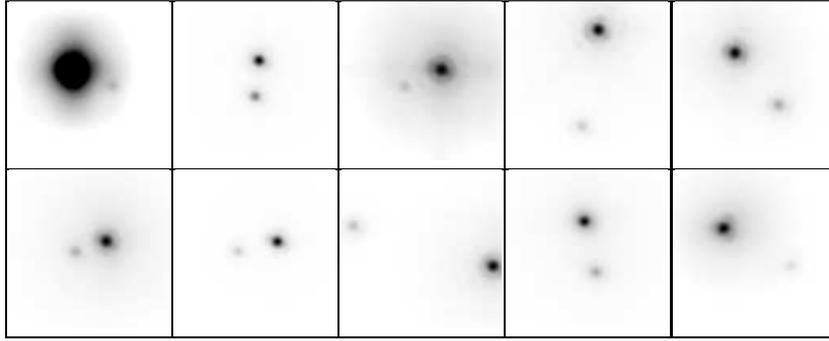
In Figs. 1–3 we show adaptive optics K-band images obtained with NACO. The field of view displayed was selected according to the angular distances of the companions. The intensity scale was adjusted to visualize the respective companions.

One of our NACO targets, the HgMn star HD 75333, has already been observed in May 2001 with the adaptive optics system at Keck II. The Keck images of this system have been presented in Hubrig et al. (2005) [14]. These observations revealed that this star has two low-mass companions in a binary system at a separation of $1''34$. This system is not displayed in Figs. 1–3, since the separation between the two low-mass companions in the binary system is only $0''06$. The diffraction limit for NACO installed at the 8 m telescope is lower than that for Keck II, hence these companions do not appear resolved in our NACO images. In Fig. 4 we show the distribution of the projected separations for the studied multiple systems with HgMn primaries. For most of the systems the separations are smaller than 100 AU.
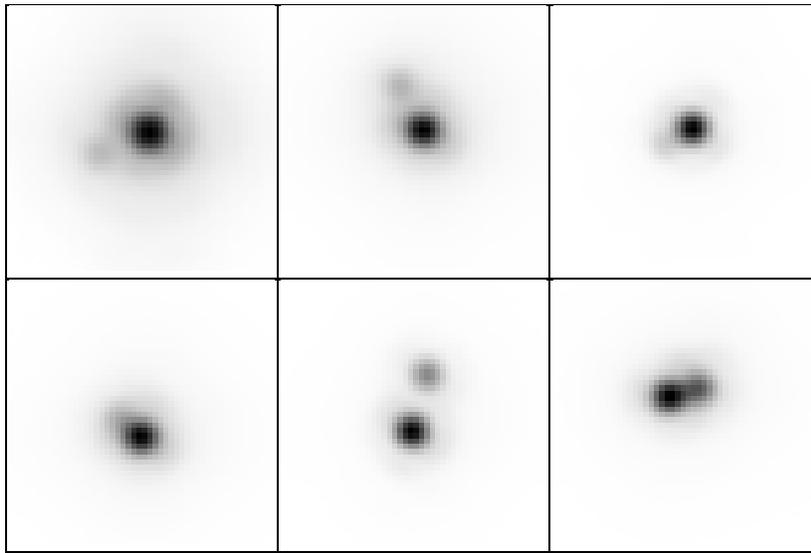
If all detected IR objects around the HgMn stars are true companions, the resulting multiplicity rate is 68%. In Table 1 we present the list of the observed HgMn stars. Their visual magnitudes and spectral types were retrieved from the SIMBAD data base. In the last column we give some remarks about their multiplicity.
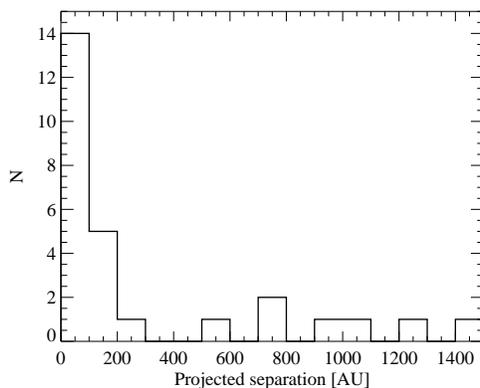

Fig. 1. NACO images of the wide systems in our sample. Upper row from left to right: HD 32964, HD 34880, HD 36881 and HD 53929. Lower row from left to right: HD 120709, HD 129174, HD 165493 and HD 178065. The field of view in each frame is $7.95'' \times 7.95''$.

Fig. 2. NACO images of the intermediate systems in our sample. Upper row from left to right: HD 33904, HD 35548, HD 53244, HD 59067 and HD 73340. Lower row from left to right: HD 78316, HD 101189, HD 110073, HD 158704 and HD 221507. The field of view in each frame is $1.33'' \times 1.33''$.

Fig. 3. NACO images of the close systems in our sample. Upper row from left to right: HD 21933, HD 28217 and HD 29589. Lower row from left to right: HD 31373, HD 33647 and HD 216494. The field of view in each frame is $0.66'' \times 0.66''$.

Fig. 4. Distribution of the projected separations for the studied systems with HgMn primaries.

Table 1. List of HgMn stars observed with NACO.

HD	V	Sp. Type	Remarks	HD	V	Sp. Type	Remarks
1909	6.6	B9IV	SB2	70235	6.4	B8Ib/II	
7374	6.0	B8III	SB1	71066	5.6	A0IV	vis. binary
19400	5.5	B8III	vis. binary	71833	6.7	B8II	vis. binary
21933	5.8	B9IV	IR comp.	72208	6.8	B9	SB2
27295	5.5	B9IV	SB1	73340	5.8	B8	IR comp.
28217	5.9	B8IV	vis. binary + IR comp.	75333	5.3	B9	two IR comp.
29589	5.4	B8IV	SB1 + IR comp.	78316	5.2	B8III	SB2 + IR comp.
31373	5.8	B9V	IR comp.	101189	5.1	B9IV	IR comp.
32964	5.1	B9V	SB2 + IR comp.	110073	4.6	B8II/III	SB1 + IR comp.
33904	3.3	B9IV	IR comp.	120709	4.6	B5III	IR comp.
33647	6.7	B9V	SB2 + IR comp.	124740	7.9	A	SB2
34880	6.4	B8III	SB1 + two IR comp.	129174	4.9	B9	SB1 + IR comp.
35548	6.6	B9	SB2 + IR comp.	141556	4.0	B9IV	SB2
36881	5.6	B9III	SB1 + IR comp.	144661	6.3	B8IV/V	SB1
49606	5.9	B7III	SB1	144844	5.9	B9V	SB2
53244	4.1	B8II	SB1 + IR comp.	158704	6.1	B9II/III	SB2 + IR comp.
53929	6.1	B9.5III	SB1 + IR comp.	165493	6.2	B7.5II	SB1 + IR comp.
59067	5.9	B8	IR comp.	178065	6.6	B9III	SB1 + IR comp.
63975	5.1	B8II	SB1	216494	5.8	B8IV/V	SB2 + IR comp.
65950	6.9	B8III		221507	4.4	B9.5IV	IR comp.

3 Discussion

The results of our study clearly confirm that HgMn stars are frequently found in multiple systems. It is especially intriguing that out of the 40 HgMn stars in the sample studied only two stars, HD 65950 and HD 70235, are not known to belong to a binary or multiple system. However, companionship can not be established based on K photometry alone, and confirming the nature with a near infrared spectrograph is essential for establishing their true companionship. Our program to carry out NACO K-band spectroscopy of the discovered IR-candidate companions has been scheduled at the VLT in service mode for the period October 2005 to March 2006. Using these observations we will be able to determine the mass of the IR companions much more accurately, and explore the physics in their atmospheres by comparison of observed and synthetic spectra. Since the HgMn type primaries have all Hipparcos parallaxes ($\sigma(\pi)/\pi < 0.2$), their age is known, and assuming coevality we will have an unprecedented set of data for the confirmed very young or even PMS companions.

We would like to note that our observations contribute not only to the understanding of the formation mechanism of HgMn stars but also to the general understanding of B-type star formation. An interesting result about the combination of long- and short-period systems has been presented by Tokovinin a few years ago [15]. He suggested that the fraction of SBs belonging to multiple systems probably depends on the SB periods. It is much higher for close binaries with 1 to 10 day periods than for systems with 10 to 100 day periods. The statistics of multiple systems is still very poor and much work remains to be done. The proposed survey of binarity and multiplicity of HgMn stars will help to understand the connection between close binaries and multiplicity, and especially the formation of close binary systems. To find out which role membership of HgMn stars in multiple systems plays for the development of their chemical peculiarities, it would be important to compare the ranges of periods, luminosity ratios, and orbital eccentricities, as well as hierarchy of multiples with the same characteristics of normal late B systems.

A further remarkable feature of HgMn spectroscopic binaries is that many of them have orbital periods shorter than 20 days. However, binary periods of less than three days are absent, while they are quite common among normal late B systems. Interestingly, from a survey of the Batten et al. catalogue [16] limited to systems brighter that V = 7, it appears that only six normal B8 and B9 stars are known to be members of SBs with orbital periods between 3 and 20 days. Four of them are very fast rotating with $v \sin i$ values of the order of $100 \, \mathrm{km \, s^{-1}}$ and more, i.e. much faster than typical HgMn stars. For the remaining two systems no information on the rotational velocity could be found in the literature.

In some binary systems with an HgMn primary, the components definitely rotate subsynchronously [17]. It is striking that the majority of these systems have more than two components. Probably the most intriguing and most fundamental question is whether all late-B close binaries with subsynchronously rotating companions belong to more complex systems.

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