Astron. Astrophys. 332, L33–L36 (1998)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

A HgMn companion to the Cepheid SU Cyg

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Received 2 March 1998 / Accepted 17 March 1998

Abstract. We report here the discovery of a chemically peculiar star of the HgMn type as a companion to the classical Cepheid variable SU Cyg. This is the first investigation of a HgMn star in a binary system in which a star of a more advanced evolutionary stage is the primary. The age of the Cepheid provides an estimate to the age of the chemical peculiarities which is independent of the photometric calibration of HgMn field stars. From a synthetic spectrum analysis it is determined that the HgMn star, SU Cyg B, displays the abundance deficiency for nitrogen and enhancements for manganese (+1.5 dex) and the very heavy elements mercury (+5.8 dex) and platinum (+5.0 dex). Absorption from the strong transitions Au II λ1740 and Tl II λ1908 each implies abundance enhancements of 3.0 dex. A search through the IUE and HST/GHRS spectral archives reveals several binary-Cepheid companions which are candidates for chemically peculiar stars.

Key words: stars: abundances – stars: chemically peculiar – binaries: spectroscopic – variables: Cepheids

1. Introduction

Dynamical companions to HgMn stars have up to now been detected through observations of relatively bright HgMn stars. As more sensitive techniques have emerged to study stellar duplicity, the percentage of HgMn stars in binary/multiple systems has increased to a current estimate of nearly two-thirds for the field population (Hubrig & Mathys 1996) and even higher among open clusters (Schneider 1993). This level of duplicity, while higher than that often quoted for stars of the general field population, still falls below, or rivals in the case of open clusters, estimates of more than 80% duplicity among the metallic-lined A-stars. Binarity as the origin of spectrum peculiarities has been a consideration for many years and remains today a viable condition for the chemical peculiarity phenomenon. In general, the HgMn star binaries possess short orbital periods (4–15 days), which is thought to induce rotational braking and inevitably lead to the stable atmospheric conditions that are believed required to foster diffusion processes.

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The SU Cyg (= HD 186688) multiple star system has been investigated by Evans & Bolton (1990). The primary star, component A, is a 5.9 $M_\odot$ Cepheid variable (pulsational period 3.85 days) in a long period (549.16 days) orbit with a close binary pair comprised of components (B + C). The close pair has a short period orbit with a period of 4.67 days. Component B was asserted to be a chemically peculiar star of the HgMn type based solely upon the presence of a strong absorption feature at the wavelength of the Ga II λ1414 Å resonance transition in low-dispersion IUE spectra (Evans 1995). Although this Ga II transition is observed to exhibit great strength in many HgMn stars its presence is neither unique to the HgMn star class nor ubiquitous among its members (Takada-Hidai et al. 1986). Knowledge of component C is limited to a mass estimate of about 2 $M_\odot$. Its contribution to the spectrum is overwhelmed at optical and ultraviolet wavelengths by the other components.

We report here the positive identification of SU Cyg B as a HgMn star. A comparison of its IUE high-dispersion spectrum with similar spectra of both chemically normal and peculiar stars is convincing in that it shows many of the features found among the cooler HgMn stars. Such features include, but are not limited to, lines of the very heavy elements Pt and Hg. We proceeded to fit the IUE spectrum with synthetic spectra, as described below. The extent of the line enhancements found for these ions is comparable to the most extreme enhancements noted among HgMn stars, and shows that by the young age of this stellar system the chemical peculiarities are fully developed.

2. Spectrum analysis

We have investigated the abundance of elements that are often peculiar in the spectra of the HgMn stars. In general, this implies the very heavy elements (Pt, Au, Hg, Tl, Bi) in addition to the usually deficient nitrogen and enhanced manganese. Other elements heavier than the iron group are also known to show enhanced lines, but either lack intrinsically strong vacuum ultraviolet lines or the abundance levels required to be noticed in lower-resolution, low S/N spectra, such as from the IUE high-dispersion mode. However, one exception is Ga II λ1414. We did not analyse this line as the noise characteristics of the spectrum would not permit a definitive result. This line is observed in the IUE low-dispersion spectrum (SWP 25573) at a strength that is comparable to strong enhancements in HgMn stars, essentially an abundance enhancement of approximately three orders of magnitude. We also mention that our synthetic spectrum analysis of several Si I/II lines in the 1850 Å region did not reveal an abundance enhancement, and thus we are able to dismiss the possibility that the B component is a Si-rich star.

Abundances were determined by fitting the observed IUE high-dispersion spectrum (SWP 28590) with spectra generated with the SYNTHE code (Kurucz 1993). The spectra have been listed by Evans & Bolton (1990), although the measurements in this paper use the version reprocessed during the last year. Model atmospheres for components B and C were generated by us using the ATLAS9 code. We have decomposed the composite spectrum of the SU Cyg system by fitting single star spectra representing the Cepheid and the hottest star, and it is clear that essentially no flux is contributed from the Cepheid at wavelengths shorter than 2000 Å. Therefore, we have ignored component A in the synthetic spectrum analysis. For component B the temperature (T_{eff} = 12200 K) was taken from the spectral type from Evans (1995) and a gravity of log g = 4.0 was assumed. For component C its estimated mass of 2 $M_{\odot}$ is that of an early A type main sequence star, which we approximate by the parameters T_{eff} = 9500 K and log g = 4.0. For both stars a turbulent velocity of zero km s^{-1} was assumed and a solar elemental abundance distribution was used to generate the model atmospheres. No spectral information regarding component C was ever recovered other than a required flux in the analysis of the saturated Hg II λ1942 Å line. The spectrum of component C was coadded to that of B at levels of ten and five percent for the calculations in the regions centered at 1940 and 1740 Å, respectively, and was offset from the component B spectrum by +36 km s^{-1}. The observed line widths are dictated by the instrumental broadening and not by the stellar rotation. Thus, the rotational velocity of component B is less than v*sin*i = 15 km s^{-1}. We have used the representative value of 5 km s^{-1} for both components B and C.

The atomic line data were taken from Kurucz (1993) with the exceptions of the very heavy elements. For these elements we have used the line data, including the effects of hyperfine structure and isotopic shifts, which have been used in analyses of high-resolution spectra of chemically peculiar stars obtained with the Goddard High Resolution Spectrograph (GHRS) onboard the Hubble Space Telescope (HST). These data are for Pt III and Au II λ1740 (Wahlgren et al. 1995), Hg II λ1942 (Leckrone et al. 1991), Tl II λ1908 (Leckrone et al. 1996; Johansson et al. 1996), Bi II λ1902 (Wahlgren et al. 1994), and Bi II λ1437/ Bi III λ1423 (Wahlgren et al., in preparation).

We address the analysis of the elements individually.

Pt: The effective temperature of component B is sufficiently high to produce observable spectral lines from both the singly and doubly ionized states. The strongest lines of Pt II (λ1777,

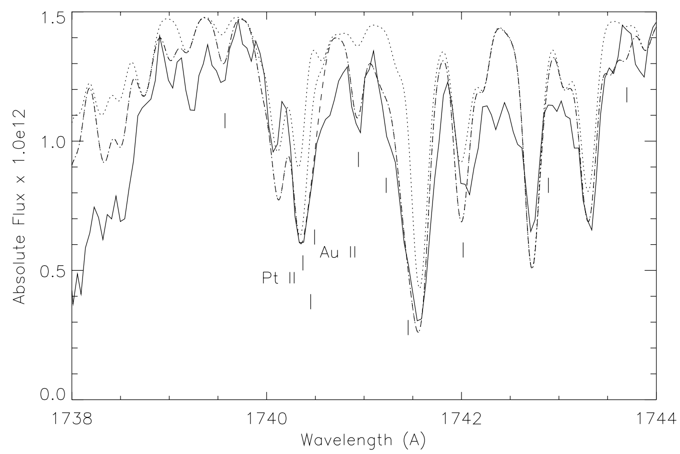

Fig. 1. Pt II/III and Au II in SU Cyg B. Observation (solid) compared against best fit abundances (dashed), best fit Pt with solar Au, and solar abundances (dotted). Unlabeled lick marks identify Pt III lines.

2144) were not useable due to the noise levels found within the orders of the echelle at the locations of these wavelengths. We observed the effects of a group of Pt II/III lines that had been studied in the spectra of the HgMn stars κ Cnc and χ Lupi (Wahlgren et al. 1995). Fig. 1 identifies the positions of eight Pt III lines and a single, unclassified Pt II line. An abundance enhancement of 5.0 dex above the solar value is required to achieve a good fit to the strongest blended features in the center of the figure. Fig. 1 also depicts the effects of an increased manganese abundance by 1.5 dex. This manganese enhancement is an averaged enhancement based upon Mn II features observed in all regions analysed.

Au: Absorption from the strong line of Au II λ1740 is determined to be consistent with an upper limit abundance enhancement of 3.0 dex. This line is blended with lines of Pt II/III. However, its appearance is similar to other gold-enhanced HgMn stars observed at this resolution (Wahlgren et al. 1993). The study of HgMn stars at higher resolution shows that this feature does not contain significant unidentified lines. The unaccounted absorption observed just longward of the Au II line is similarly unaccounted for in other spectra, and the high-resolution spectra show this absorption to be well separated from the gold line. Absorption lines from Au II/III are also observed at other wavelengths, but have not been included in this analysis due to the lack of oscillator strength data.

Hg: The obvious presence of the Hg II λ1942 line is the most convincing evidence for the enhancement of the heavy elements. Fig. 2 compares the observation with synthetic spectra representing solar abundance levels and enhanced mercury at levels of [Hg/H] = +5.8 and +5.6 dex. The derived mercury enhancement is extremely large and requires caution in its interpretation. The continuum determination may contribute to this uncertainty; however, the line width is not consistent with an enhancement of less than +5.6 dex, given a reasonable uncertainty in the continuum level. The depth of the saturated Hg II line could not be properly modeled without an additional flux, which we have modeled by including the reasonable flux amount

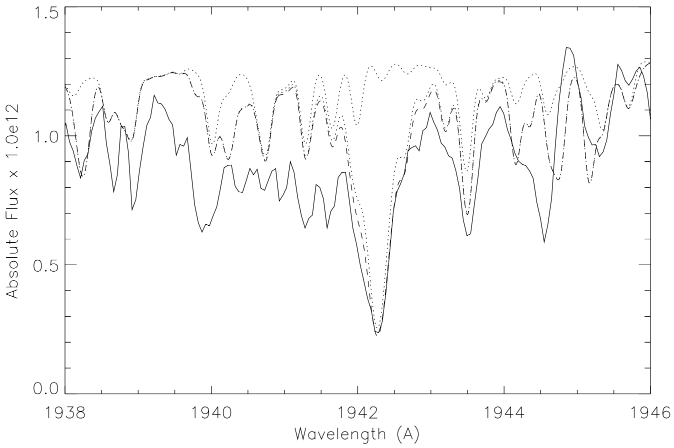

Fig. 2. Hg II λ1942 in SU Cyg B is presented in a comparison of the observation (solid line) and synthetic spectra corresponding to the best fit Hg and Mn abundances (dash), slightly reduced Hg abundance, and solar abundances (dotted).

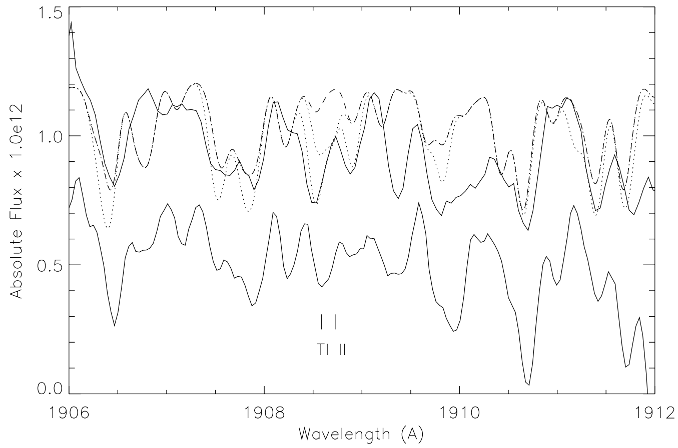

Fig. 3. Upper: Observation (solid) compared with solar (dashed), best fit Tl and Mn, and Tl with solar Mn abundances (dotted). Lower: IUE spectrum of χ Lupi.

of 10% from component C. The Hg II λ1649 resonance line is also observed in our spectrum. However, it is placed rather near the edge of an order and has an increased noise level. The enhanced line profile of the synthetic spectrum is consistent with the envelope of the noise.

Tl: In the spectrum of SU Cyg B the Tl II λ1908 line is veiled by absorption from Mn II lines. Fig. 3 presents the observed spectrum and computed spectra for the cases of a) solar thallium abundance, b) [Tl/H] = +3.0, and c) [Tl/H] = +3.0 with [Mn/H] = +1.5. Below this comparison is the IUE spectrum of the HgMn star χ Lupi (SWP 4688), for which the Tl II lines are not blended with Mn II as the manganese abundance is rather solar-like in this star. Note that the computed Tl II profile for SU Cyg B is similar in strength and shape to the observed feature in χ Lupi. The abundance of thallium in χ Lupi has been found to be [Tl/H] = +3.8 from analysis of GHRS high resolution spectra (Leckrone et al. 1996).

Bi: Our search for bismuth consisted of modeling the lines Bi II λ1437, 1902 and Bi III λ1423. Absorption by these lines was not detected at enhancement levels greater than [Bi/H] = +2.0 dex, as limited by the data quality. The nature of the λ1902 feature resembles that found in χ Lupi, determined to have a bismuth abundance of (Bi/H) = +2.1 (Wahlgren et al. 1994).

N: The strong lines N II λ1742, 1745 are observed in the spectrum at strengths representative of an abundance deficiency of 1.0 dex, which is similar in magnitude to deficiencies found in other HgMn stars (Roby & Lambert 1990). A consistent abundance for both lines could not be determined due to a combination of noise and line blending uncertainities.

3. Discussion

The development of spectrum peculiarities in warm stars is postulated to arise from the diffusion of ions in an environment in which the force of gravity is essentially in balance with radiative forces arising from within the star. But do stars reach the main sequence with enhanced line strengths or are the requisite conditions developed during the early main sequence phases? If the former is true, then it might be expected that the beginnings of enhanced line strength would be observable in pre-main sequence stars. For the latter case we might expect the chemically peculiar stars to be found after the ZAMS phase. Theoretical scenarios predict that spectral peculiarities can develop over time scales of less than 10^6 years (Michaud et al. 1976), but the actual onset of peculiarities, as influenced by magnetic fields, rotation, and turbulence for example, is undetermined. The observational evidence is inconclusive regarding this question, although AR Aur has been suggested to be a pre-main sequence star showing HgMn characteristics (Nordström & Johansen 1994). HgMn stars have been observed in several open clusters having lifetimes of less than 10^8 years (Schneider 1993), and photometric (Woolff & Preston 1978) and astrometric (North et al. 1997) investigations of field stars find HgMn stars throughout the main sequence. The detection of a HgMn star dynamically coupled to the more evolved Cepheid allows us to assign an age to the HgMn star with an accuracy not possible for a single field star or HgMn star that is a primary in a binary system. The model dependent age of SU Cyg A is 1.0×10^8 years, based upon the evolutionary tracks of Schaller et al. (1992).

The positive identification of SU Cyg B as a HgMn star awakens an awareness to the possibility of chemically peculiar companions to other Cepheids To further the statistics on this issue we searched the IUE archives for low-dispersion spectra of Cepheids having B-type companions. Table 5 from Evans (1995) lists 12 Cepheids having companions within the spectral type range B3–A0. Of these 12 stars SU Cyg displays the strongest 1414 Å feature, while the systems U Aql and T Mon show a weak feature at this wavelength. The remainder of the stars in this list presented no obvious isolated absorption feature at this wavelength. However, the noise characteristics of the data and the nature of the line spectrum resulting from elemental abundances and temperature may mask Ga II absorption. As one such example the HgMn star χ Lupi possesses a strong Ga II feature in HST/GHRS spectra (Brandt et al., in preparation) yet does not display a distinct absorption feature at 1414 Å in IUE low-dispersion spectra (SWP 38389). We find the companion to the Cepheid W Sgr to exhibit a χ Lupi-like spectrum. Therefore, we can not exclude chemical peculiarity from the other systems.

In addition to the IUE spectra, there are five binary Cepheids for which GHRS spectra exist. These data were obtained with the G3 first-order grating at a resolving power of approximately R = $\lambda/\delta\lambda$ = 25000 for the spectral region 1839–1879 Å, and are generally of low signal-to-noise. Spectral lines of Pt II (Reader et al.1990) and Pt III (Ryabtsev et al. 1993) were identified in a high signal-to-noise G3 spectrum of χ Lupi and subsequently searched for in the binary Cepheid spectra. The systems T Mon and V350 Sgr display many spectral characteristics similar to χ Lupi, including absorption at wavelengths of platinum lines. For the remaining systems (U Aql, Y Car, and V636 Sco) the signal level was too low to make definitive conclusions. The coincidences are intriguing, in particular for T Mon due to the possible presence of Ga II λ1414.

A point to be remembered is that SU Cyg is a multiple star system. The Cepheid is sufficiently distant from the HgMn star to not have had any influence upon the development of peculiarities. On the other hand, the short period orbit containing the companion probably has been circularized, and likely influenced the rotation rates of the two hot stars. The significance of SU Cyg may therefore not be as a peculiarity chronometer as much as a harbinger for the nature of the binarity that may be required. If proximity is paramount, then further investigation of HgMn stars among Cepheids will uncover a large percentage of triple star systems.

Acknowledgements. GMW gratefully acknowledges the financial support of the Royal Swedish Academy of Sciences, and NRE the support from the AXAF Science Center, NASA Contract NAS8-39073.

References

Abt, H., 1979, ApJ 230, 485

Evans, N.R., 1995, ApJ 445, 393

Evans, N.R., Bolton, C.T., 1990, ApJ 356, 630

Hubrig, S., Mathys, G., 1996, A&AS 120, 457

Johansson, S., Kalus, G., Brage, T., Leckrone, D.S., Wahlgren, G.M., 1996, ApJ 462, 943

Kurucz, R.L., 1993, SYNTHE Synthesis Programs and Line Data, (Kurucz CD-ROM No. 18)

Leckrone, D.S., Wahlgren, G.M., Johansson, S., 1991, ApJ 377, L37

Leckrone, D.S., Johansson, S., Kalus, G., Wahlgren, G.M., Brage, T., Proffitt, C.R., 1996, ApJ 462, 937

Michaud, G., Charland, Y., Vauclair, S., Vauclair, G., 1976, ApJ 210, 447

Nordström, B., Johansen, K.T., 1994, A&A 282, 787

North, P., Jaschek, C., Hauck, B., et al., 1997, in Proceedings of the ESA Symposium 'Hipparcos-Venice '97, ed. B. Battrick, ESA SP-402, p. 239

Reader, J. Acquista, N., Sansonetti, C.J., Sansonetti, J.E., 1990, ApJS 72, 831

Roby, S.W., Lambert, D.L., 1990, ApJS 73, 67

Ryabtsev, A.N., Wyart, J.-F., Joshi, Y.N., et al., 1993, Physica Scripta 47, 45

Schaller, G., Schaerer, D., Meynet, G., Maeder, A., 1992, A&AS, 96, 269

Schneider, H., 1993, in Peculiar Versus Normal Phenomena in A-Type and Related Stars, ed. M.M. Dworetsky, F. Castelli, & R. Faraggiana, ASP Conf. Ser 44, 639

Takada-Hidai, M., Sadakane, K., Jugaku, J., 1986, ApJ 304, 425

Wahlgren, G.M., Leckrone, D.S., Johansson, S., Rosberg, M., 1993, in ASP Conf. Ser. 44, 121

Wahlgren, G.M., Brage, T., Gilliland, R.L., et al., 1994, ApJ 435, L67

Wahlgren, G.M., Leckrone, D.S., Johansson, S., Rosberg, M., Brage, T., 1995, ApJ 444, 438

Wolff, S.C., Preston, G.W., 1978, ApJS 37, 371