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Elemental abundances in the Hg-Mn star γ Corvi

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Abstract. Spectral data obtained at ESO, Observatoire de Haute-Provence and with the IUE covering the 120 - 910 nm spectral range allowed us to determine the abundances of 21 elements in the atmosphere of the moderately fast rotating Hg-Mn star γ Corvi. We find that helium, carbon, nitrogen, magnesium, aluminium, silicium, sulfur, chromium, iron and nickel are underabundant with respect to solar values. Beryllium, boron, calcium, phosphorus, titanium, manganese, copper, zinc, gallium and yttrium are overabundant by factors up to 2.5 dex. The oxygen abundance is found to be solar. This pattern is not unusual among Hg-Mn objects.

Key words: stars: abundances – stars: chemically peculiar – stars: individual: γ Crv – ultraviolet: stars

1. Introduction

It is well known that the HgMn stars exhibit very diverse abundances of many elements, and especially of the iron-peak elements (Smith and Dworetsky, 1993). Several hypotheses have been made to explain this pattern of abundance anomalies, such as the accretion of metal-enriched supernovae ejecta (Guthrie, 1967), or selective accretion of interstellar matter (Havnes and Conti, 1971). So far the most promising explanation is the radiative diffusion mechanism originally proposed by Michaud and since developed and refined to produce a self-consistent stellar model (Michaud, 1970, 1986). The abundance anomalies patterns are however quite diverse and we propose to extend this research to one of the fastest rotators in this category.

γ Corvi (Gienah=HD106625=HR4662) is, according to the Bright Star catalogue (D. Hoffleit and C. Jaschek, 1979), a B8 III star of visual magnitude $m_v = 2.60$. Until 1971, this bright object had not been recognized as a Hg-Mn star (Cowley and Crawford, 1971). The Cowleys (Cowley and Cowley, 1971) explained this late recognition as due to a rather large rotational velocity for this class of stars, which hampers moderate spectral anomalies being noticed. These peculiarities became however more evident when ultraviolet spectra were obtained.

Faraggiana and van der Hucht (1975) noted an overabundance of Mn and a slight underabundance of Mg, Si, Ni, and Cr. Cowley and Aikman (1980) with their "line statistics method", proposed an underabundance of 0.67 dex for Cr and 0.05 for Fe while Mn was overabundant by 0.61 dex. Boron and beryllium have been found overabundant by 1.30 and 2.65 dex (Sadakane et al., 1985) while the same authors (1988) claim an overabundance of zinc of 1.5 dex with respect to solar values. These various works based on narrow portions of the spectra lead to non-solar values which need to be confirmed and refined by a more extensive investigation.

Table 1. General characteristics of the observations

Date	Region (nm)	Detectors
January 22, 1983	110 - 210	SWR19063 (IUE)
January 22, 1983	180 - 320	LWR15091 (IUE)
May 18, 1975	353 - 503	IIa-O
May 20, 1975	460 - 614	IIa-D
June 16, 1994	840 - 872	CCD (Thomson)
June 20, 1994	760 - 801	CCD (Thomson)

2. Observational data

Our study is based upon several sources (Table 1) which cover a large part of γ Corvi's spectrum.

Two high-resolution IUE spectra (SWR 19063 and LWR 15091), albeit fairly noisy, taken on January 22, 1983 have been kindly de-archived and recalibrated for us by J.van Santvoort. High resolution (3 Å/mm) spectra (numbered H1356 and H1357) had been obtained at the coudé spectrograph of the ESO 1.52-m telescope by M. de Groot in May 1975. They cover the 353 nm - 503 nm region (IIa-O plate), and the 460 nm -614 nm region (IIa-D). These plates have been scanned at the Brussels Observatory in 1990 and reduced using the IHAP procedure.

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Table 2. Comparison of different fundamental parameters determinations

Source	Temperature (K)	Log g (c.g.s)
this paper	12000.	3.5
Cowley & Aikman (1975)	12300.	-
Code et al. (1976)	12444.	3.7
Sadakane et al. (1988)	12000.	3.3
Norris (1970)	12759.	-

The red part of the spectrum has been covered by two spectra obtained at Observatoire de Haute-Provence on June 20, 1994. They were obtained with the Carelec spectrograph at the Cassegrain focus of the 193-cm telescope (Lemaître et al., 1990). They cover the regions 760 nm - 801 nm, and 840 nm to 872 nm.

3. Overview of the spectrum

At first glance, the spectrum of γ Crv shows no strong differences in the visible with other objects of similar spectral type and luminosity class. The wide hydrogen Balmer wings are cut by weak metallic lines and two HeI lines appear at 402.6 and 447.1 nm. Between 358.5 and 535 nm we note 17 lines belonging to Cr II with equivalent widths not exceeding a few thousandths of nanometers (Multiplets 11, 12, 18, 19, 25, 26, 29, 30, 31, 44, 183). Likewise, 17 lines belong to FeII multiplets ($n^o s$ 20, 22, 27, 37, 38, 42, 43, 49, 126, 154, 173, 186) and Ti II is well represented (especially multiplets 11, 13, 19, 31, 34, 40, 41, 50, 51, 61, 72, 82, 92, 93, 104, 105, 114, 115). In the visible region, other ions present are Si II, Ca II and Zr II. A number of features may be attributed to the rare earth ions Sm II, Gd II, Hf II, Eu II, but they all blend with lines of elements mentioned above, so that their presence cannot be ascertained, except for Ce II which shows a number of unblended lines. Characteristic lines of Mn II are seen at 420.6, while the Hg II line at 398.4 nm appears in the wing of Hϵ with an equivalent width of 8 x 10^{-4}nm. All these ionic lines, with central depths never exceeding 2 or 3% are not well suited for comparison with computed spectra.

In the ultraviolet, line features are much more conspicuous but severely blended. As a guide for identifications, the spectra of two stars of neighbouring temperatures (π Ceti and ν Cap), described by Artru et al. (1989) have been used. In this spectral region it is clear that Fe II line strengths are below normal. We relied also on the averaged and higher quality spectra of these authors to draw a continuum level otherwise difficult to define on our noisy spectrum. In the red region, nothing distinguishes γ Crv from objects of the same spectral type if we except the presence of a relatively strong feature at 851.3 nm which could be attributed to the λ 8513.57 La I line.

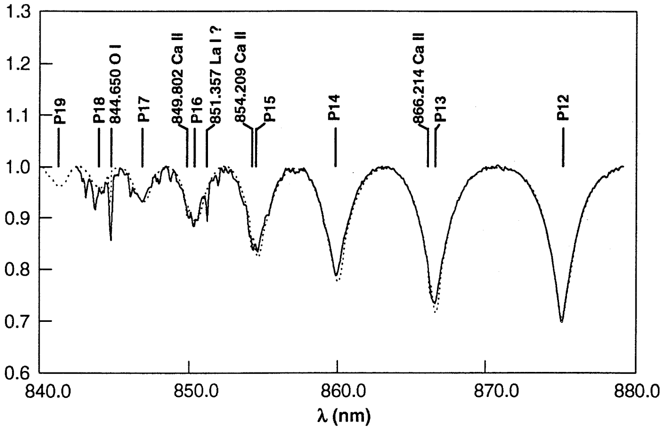

Fig. 1. Comparison between observed (line) and theoretical (dots) profiles of the higher members of the Paschen serie

4. LTE spectrum synthesis

The spectrum synthesis is based on the Kurucz models (Kurucz, 1979, 1993) and the continuum opacities are computed using several ATLAS 6 subroutines. When no reference to Stark broadening was found for the principal lines we used the "simple theoretical prediction" method proposed by Freudenstein and Cooper (1978). For subordinate lines we used the scaled classical expression with a scaling factor found in Kurucz's line lists. Hydrogen line opacities are evaluated with the semi-empirical method due to Edmonds, Schlüter and Wells (1967). Helium line absorptions are obtained from the SYNSPEC code (Hubeny et al., 1985), which includes all the BCS calculations (Barnard et al., 1974) for line broadening.

Alterations of line profiles due to axial rotation were computed with a code proposed by Delcroix (1974), improving the method proposed by Underhill (1968). Finally, resulting line profiles are convoluted with gaussian instrumental profiles appropriate to the various spectrographs.

5. Fundamental atmospheric parameters

The effective temperature was determined using the Strömgren *uvby* color indices system. We adopted $T_{\rm eff}$ = 12000 K. Surface gravity has been estimated from comparison of computed and observed hydrogen line profiles. The hydrogen H_δ line, convoluted with a 36 km s^{-1} rotational velocity (Guthrie, 1981) indicates a log g = 3.5 (cgs), and this value is confirmed by the observed profiles of the higher Paschen lines, as can be see on Fig. 1 (Frémat et al., 1996). Table 2 gives a comparison of our adopted atmospheric parameters with values found in the literature.

As absolute fluxes of γ Crv were available from various sources, we checked that these parameters agree with the spectral energy distribution from 92 to 560 nm. Far ultraviolet data are taken from OAO-2 data (Meade and Code, 1980), continued by TD1 fluxes (Macau-Hercot et al., 1978), while the visible data are available in Breger's compilation (1976). These data are displayed in Fig. 2 together with the computed fluxes.

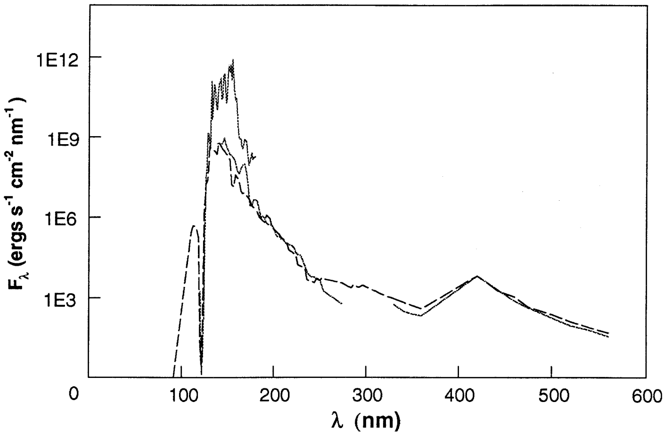

Fig. 2. The computed flux from 92 to 560 nm (dashed) compared to the observed one (solid line). The observed fluxes at Earth from OAO-2 spectrograph (Meade and Code, 1980) (120 to 180 nm), from the TD1 satellite (Macau-Hercot et al., 1978) (130 to 274 nm), and from Breger (1976) (330 to 580 nm) have been multiplied by $206264806^2/\pi\theta^2$ (mas) to adjust to the computed F_λ flux. Best fit is obtained for $\theta = 0.79$ mas

The agreement is quite acceptable and futhermore, the angular diameter of 0.79 milliarcseconds (mas), deduced from these data is in fair concordance with Hanbury's et al. (1974) value of 0.75 ± 0.06 mas.

6. Atomic data

Atomic data play an important role in the accuracy of the results of the spectral synthesis. We tried to find, when possible, the most recent observed or calculated values available at this time. Our choices are described in Table 3 for each spectral regions we studied.

Most of the abbreviations used to design the origin of the *gf* values are taken from Morton (1991): APBK85 (Ansbacher et al., 1985), CT89 (Curtis & Theodosiou, 1989), GMNP86 (Goldbach et al.,1986), GMN89 (Goldbach et al., 1989), HCKBMH91 (Haar et al., 1991), L69 (Lawrence, 1969),MFW88 (Martin et al., 1988), NPS81 (Nussbaumer et al., 1981), NS81a (Nussbaumer & Storey, 1981), NS84 (Nussbaumer & Storey, 1984), OH89 (Ojha & Hibbert, 1989), SL66 (Savage & Lawrence, 1966), T86 (Theodosiou, 1986), T89 (Theodosiou, 1989), WM80 (Wiese & Martin, 1980), YTS87 (Yu Yan et al, 1987), ZSM77 (Zeippen et al., 1977). The other references are HLGBW82 (Hannaford et al., 1982), K93 (Kurucz, 1993), LPS88 (Luo et al., 1988) and QB93 (Quinet & Biémont, 1993), for the gf values, and L83 (Lakićenić, 1983), GR74 (Griem, 1974) and SBS71 (Sahal-Bréchot & Segre, 1971) for the collisional broadening of lines. We may hope that the carefully selected values of the atomic parameters allow us to correctly reproduce the blends in the spectral windows investigated.

Indeed our Fig. 3 shows that, as far as the noise permits to judge, the agreement with the observed spectrum in the 152.4-153.6 nm region is sufficiently good to show clearly the under-

Table 3. Atomic parameters used in the spectral synthesis.

Element	Spectral region (nm)	n	Source of gf values	Collisionnal profile reference
HeI	401.0 - 403.2	1	QB93	BCS
	446.4 - 447.7	1	QB93	BCS
BeII	312.7 - 313.3	2	WM80	GR74
BII	136.0 - 136.5	1	WM80	GR74
CI	155.2 - 156.2	4	HCKBMH91	
	127.4 - 128.2	19	GMN89, NS84	GR74
CII	133.0 - 134.0	2	NS81a, YTS87	SBS71
NI	149.1 - 150.4	3	GMNP86	GR74
OI	130.0 - 130.8	3	ZSM77	GR74
MgII	173.6 - 175.6	2	K93	
	447.8 - 449.1	1	K93	GR74
AlII	166.3 - 167.6	1	WM80	
AlIII	185.9 - 186.0	2	K93	
SiII	125.7 - 126.8	2	LPS88	SBS71
	152.5 - 153.7	2	LPS88	SBS71
SiIII	130.0 - 130.8	2	K93	
PII	153.4 - 153.8	2	SL66	
	154.1 - 154.6	2	SL66	
SI	125.3 - 126.0	2	K93	
SII	125.3 - 126.0	2	L69,OH89	
CaII	392.9 - 393.7	1	T89	
TiII	401.0 - 403.2	1	K93	
	456.8 - 457.5	1	K93	
TiIII	145.3 - 145.8	1	K93	
CrII	200.2 - 200.7	14	K93	
MnII	173.6 - 175.6	1	K93	
	178.4 - 179.1	1	K93	
	257.3 - 257.8	1	MFW88	
FeII	159.9 - 161.7	16	K93,NPS81	
	163.9 - 165.1	18	K93	
	178.4 - 178.9	4	K93	
	423.1 - 424.3	1	K93	
NiII	136.9 - 137.6	2	K93	
	173.6 - 175.6	2	K93	
	178.4 - 179.1	1	K93	
CuII	135.8 - 136.0	1	T86	L83
ZnII	206.0 - 206.5	1	CT89	
GaIII	149.1 - 150.4	1	APBK85	
	152.5 - 153.7	1	APBK85	
YII	417.0 - 418.2	1	HLGBW82	

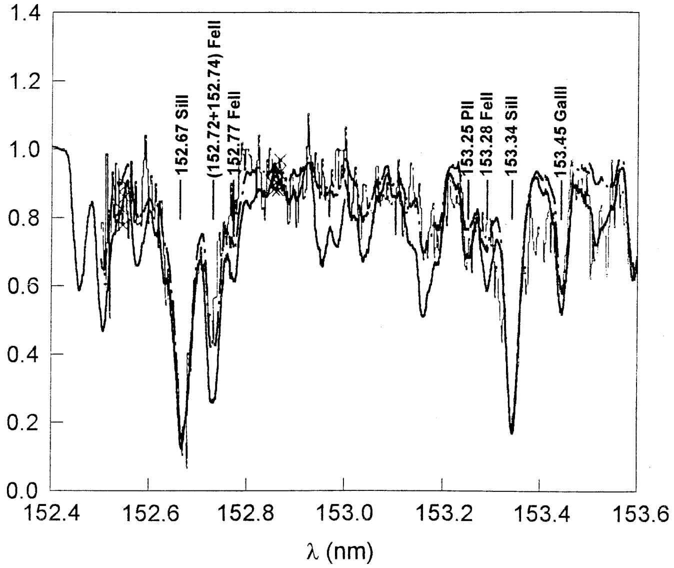

Fig. 3. Comparison of observed (thin line) and theoretical (thick and broken lines) spectra. The adopted abundances are as in Table 4 (broken line). The thick line represent the spectrum as computed with a solar abundance for iron

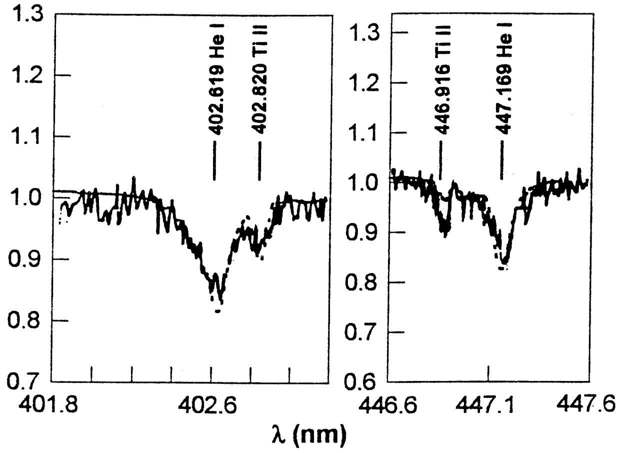

Fig. 4. Comparison of observed (straight line) and theoretical (broken line) for the He I lines at 402.6 and 447.1 nm

abundance of iron (broken line), while a solar abundance would lead to stronger lines (thick line).

7. Discussion

Table 4 shows the observed abundances in γ Corvi and those observed in the Sun.

The helium abundance has been derived from the best defined lines in the blue-violet part of the spectrum at 402.62 and 447.15 nm. The agreement shown on Fig. 4 has been obtained with a helium abundance 0.7 times the solar value and thus indicates a slight underabundance of this element in γ Crv.

Table 4. Elemental abundances. The references between parentheses are related to: (1) Sadakane et al. (1985), (2) Faraggiana & van der Hucht (1975),(3) Cowley & Aikman (1980), (4) Lamers et al. (1980), (5) Sadakane et al. (1988) and (6) Tadaka-Hidai et al. (1986).

Element	Abundances in γ Corvi (N_H = 12.00)		Solar
	This paper	Literature	
He	10.84		10.99
Be	3.65	3.80 (1)	1.15
B	3.60	3.90 (1)	2.60
C	7.86		8.56
N	6.75		8.05
O	8.93		8.93
Mg	7.38		7.58
Al	5.17		6.47
Si	6.85	↓ (2)	7.55
P	6.35	↑ (2)	5.45
S	6.81		7.21
Ca	6.54		6.36
Ti	5.99		4.99
Cr	5.07	5.00 (3);↓ (2)	5.67
Mn	6.09	6.00 (3)	5.39
Fe	6.95	7.50 (3);⊗ (4)	7.55
Ni	4.95	↓ (2)	6.25
Cu	5.21		4.21
Zn	5.70	1.50 (5)	4.60
Ga	3.83	≦3.58 (6);↑ (2)	2.88
Y	3.94	≦5.00 (3)	2.24

⊗: the central intensity of λ2548 FeII is 0.62 of its "normal" value
↓: found to be underabundant
↑: found to be overabundant

This very small deficiency is remarkable since most of the Hg-Mn stars had much lower helium abundances and that the diffusive models proposed by Michaud (1981) require that before any other diffusive processes take place, a substantial decrease occurs in helium. The large overabundances of Be, B, Mn, Zn, Ga and Y are confirmed; the underabundance of Ni is shown to reach 2 dex. Oxygen is found to be solar, but this is not the case for carbon and nitrogen, the latter being deficient by 1.3 dex. While the overabundance in zinc is predicted by Michaud's diffusive model, there is only a small number of anoumalously zinc-rich Hg-Mn stars (Smith, 1994). Carbon deficiencies are occasionnally found in Hg-Mn stars, while the nitrogen underabundance is observed in most of them (Smith and Dworetsky, 1990). Aluminium was also found to be underabundant in γ Corvi and in nearly all Hg-Mn stars (Faraggiana and Gerbaldi, 1990). We have been able to quantify the deficiency in silicium as well as the overabundance of phosphorus. The underabundance of sulfur is marginal. As far as iron is concerned the deficiency is about 0.6 dex as shown on Fig. 3, in disagreement with Cowley and Aikman (1980). Our value, which is derived from the stronger lines in two ultraviolet multiplets should have a higher accuracy than values obtained from weak rotationnally broadened lines in the visible. Let us note that our abundance leads nevertheless to a very good fit with Fe II line we observe at 423.3nm. We show that the deficiency in nickel is rather severe and uncommon for this type of star while the overabundance of copper is currently observed (Smith, 1994). Abundances versus

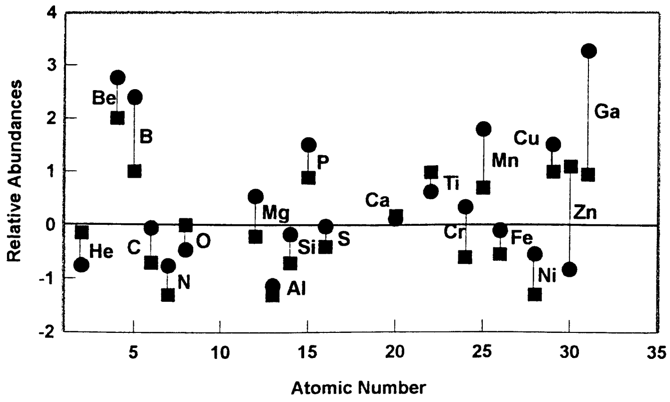

Fig. 5. Variation of the elemental abundances in γ Corvi (squares) and of the average abundances observed in a wide sample of Hg-Mn stars (circles) (Tadaka-Hidai, 1991) relatively to the Sun as a function of A

effective temperature for iron peak elements have been analysed by Smith and Dworetsky (1993). As far as Fe and Cr are concerned, the abundances in γ Crv fall within the expected trends, but on one side, the overabundance of Mn is milder than that for stars of similar temperatures, and on the contrary, the nickel content is about the lowest one observed in Smith and Dworetsky's sample.

8. Conclusions

Our results are summarized on Fig. 5, where the abundances, taken logarithmically relatively to the solar values, have been recharted as a function of the atomic number.

This figure also shows, on the same scale, the average abundances (Tadaka-Hidai, 1991) measured on a wide sample of Hg-Mn stars. Most of the chemical peculiarities measured in the atmosphere of γ Corvi are of the same order than those observed in Takada-Hidai's figure. We note the relatively high helium content for a Hg-Mn star observed in γ Corvi.This result was confirmed when we compared the observed equivalent widths of the $\lambda\lambda$ 4026 and 4471 He I lines observed in this star with those measured by Norris (1971) and Heasley, Wolff and Timothy (1982) for normal B type stars. We checked the validity of our fundamental parameters by computing a theoretical spectra from 92. to 560. nm using a Kurucz (CDROM) model atmosphere. The results were then compared (Fig.2) with several observations: from 130. to 274. nm we used the TD1 observations (Macau-Hercot et al., 1978), from 330. to 580. nm we took Breger's (1976) magnitudes and from 120. to 180. nm we used the OAO spectrograph fluxes (Meade & Code, 1980). On base of the TD1 observations and our calculations, we determined a semi-empirical value for the angular diameter of γ Corvi. Our determination is in fair agreement with the observed value (Hanbury et al., 1974).

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