NON-MAGNETIC ANOMALOUS STARS: THE Hg-Mn STARS — A REVIEW OF ELEMENTAL ABUNDANCES —

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ABSTRACT. Abundance analyses of HgMn stars in these 15 years are compiled to clarify the abundance characteristics. NLTE abundance studies relevant to HgMn stars are also surveyed for the period of these 20 years. Discussions are made on influences of uncertainties in the atmospheric parameters and of NLTE effects upon abundance determinations, and further on establishment of abundances.

1. Introduction

The upper main sequence between spectral types of B and A is populated by a number of different types of stars which show under- or overabundances of specific elements. Preston (1974) named these stars *chemically peculiar* (CP) stars and classified them into four groups: CP1 – CP4. In this review I will confine myself to discussing on the abundances of CP3 stars, i.e., HgMn stars. I survey abundance analyses (mostly, LTE analyses) of these stars and summarize abundance characteristics. Also are reviewed non-LTE (NLTE) abundance studies relevant to HgMn stars. Then I will discuss the influences of NLTE effects and uncertainties in the atmospheric parameters upon the abundance determinations, and finally which abundances are well-established.

2. Abundance Characteristics

Before I summarize the abundance characteristics of HgMn stars, I intend to review abundance analyses which have been made and published since the last IAU Colloquium 90 on CP stars at Crimea in 1985. The compilation is intended to be complete to June 1990 and is listed in Table 1. As concerns previous reviews until the end of 1984, the readers should refer to Dworetsky's (1986) review in which other literatures can be found.

To examine the abundance characteristics, I surveyed 27 references published during the period between 1976 and June 1990 and compiled the abundances of 38 elements for 69 HgMn stars. The references are given in Table 2. Figure 1 shows the abundances [X] relative to the solar values which are taken from Anders and Grevesse (1989). From this compilation, the ranges and sizes of diversity and the average values of [X] are estimated and given in Table 3. Here the average values are estimated from the definite abundances except for upper and lower limits, and the numbers of stars used for estimates are given in the last column of Table 3. These sizes and average values are plotted in Figure 2.

G. Michaud and A. Tutukov (eds.), Evolution of Stars: The Photospheric Abundance Connection, 137–147.

Inspecting Figures 1 and 2 and Table 3, we can deduce the characteristics of abundances in HgMn stars as follows.

(A) Normal Elements

If the uncertainties of average abundances are assumed to be ± 0.5 dex, the following elements are regarded as normal although thier sizes of diversity are all larger than 1 dex: C, O, Si, S, Ca, V, Cr, and Fe. Na shows a normal abundance, but Na is omitted since it has an only result.

(B) Anomalous Elements

(1) Average abundances.

a) Elements with overabundances $\geq$ 2 dex are Be, Ga, Y, Pt, Hg, Bi, Xe, Eu, Gd, W, and Pb, where Xe, Eu, Gd, W, and Pb are less certain due to their small number of sample stars. It must be noted that Bi shows the largest overabundance of 6 dex of these elements.

b) Elements with underabundances $\leq -$ 0.5 dex are He, N, Mg, Al, Ni, and Zn, where the underabundance of N will be more enhanced if the abundance can be determined definitely in a large sample. Al shows the lowest underabundance of $-$ 1.2 dex of these elements.

(2) Sizes of diversity.

Elements with sizes $\geq$ 2 dex are Be, B, C, Sc, Ti, V, Cr, Mn, Co, Cu, Zn, Ga, Sr, Y, and Zr. Zn shows the largest size of 6 dex of these elements having definite sizes.

(3) Even-odd effect.

This effect is violated in the following sets of elements in which the signs of inequality denote the relation of abundance sizes: Cr<Mn<Fe, Fe>Co>Ni, Ni<Cu>Zn<Ga, and Sr$\lesssim$Y$\gtrsim$Zr. In Figure 2 these sets are connected by dotted lines. The violation of even-odd effect in these several cases may strongly suggest that the abundance anomaly is caused by such non-nuclear processes as diffusion.

(C) General Characteristics

a) The heavier the elements, the more enhanced the overabundances.

b) Most of the sizes of diversity distribute, independently on the atomic number Z, in the range from 1 to 3 dex.

c) The general abundance pattern of HgMn stars is more similar in the sizes of diversity and abundances to that of magnetic Ap (CP2) stars than to metallic-line A (CP1) stars (cf. Preston 1974, Boyarchuk and Savanov 1986).

3. Establishment of Abundances

I will discuss in this chapter how the errors of effective temperature ($T_{\rm eff}$) and gravity (log g) and the NLTE effects influence the abundance determination, and then which elemental abundances are well-established.

(A) Influences of Errors of $T_{\rm eff}$ and log g

The typical errors of $T_{\rm eff}$ and log g are estimated at ± 1000 K (e.g., Gerbaldi et al. 1989) and ± 0.3 dex (e.g., Takada-Hidai et al. 1986), respectively. The influences on abundance of these errors are examined for an example of the following UV resonance and two optical high-excitation lines of Ga II ion at 1414 Å and at 4251 Å and 4256 Å with lower excitation potential of 14.1 eV. Calculations of abundances are made using the model atmosphere of a typical HgMn star, ϕ Her, and its observed equivalent widths (W_λ). The model atmosphere is generated by Kurucz's ATLAS6 for the parameters, $T_{\rm eff}$ = 11600 K and log g = 3.80, taken from Adelman and Lanz (1988,eds). Observed $W_\lambda$of UV and optical lines are adopted from Takada-Hidai et al. (1986) and Takada-Hidai (unpublished data), respectively, and are as follows: $W_\lambda(1414)$ = 1050 mÅ , $W_\lambda(4251)$ = 10 mÅ , and $W_\lambda(4256)$ = 11 mÅ . A microturbulence of 0.5 km s^{-1} (Adelman and Lanz 1988,eds) is assumed in calculations by the program WIDTH6 (Kurucz, private communication).

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The abundance errors are summarized in Table 4. We can see from Table 4 that the influence of error of $T_{\rm eff}$ is smaller in the resonance line than in the high-excitation lines, while that of errors of log g is similar and small for both lines. Hence resonance line may be generally more suitable for the abundance determination than high-excitation line.

(B) NLTE Effects

At first, I compiled NLTE abundance analyses which have been made in these 20 years and are relevant to HgMn stars. They are listed in Table 5. The typical values of NLTE correction defined as (NLTE abundance) – (LTE abundance) are given in the last column of Table 5. To get information of NLTE effects on the abundances of Mg II, Ca II, Sr II, and Ba II in HgMn stars, I estimated NLTE abundaces and NLTE corrections by taking observational data and LTE abundances from Adelman's works and theoretical W_λ by NLTE calculations from Borsenberger et al. (1981, 1984). Vega is included in these calculations to see the validity of our estimates. The results are shown in Table 6.

The typical sizes and/or ranges of NLTE corrections are summarized from Tables 5 and 6, and given in Table 7 and plotted in Figure 3. Following the criteria footnoted in Table 7, I judge the degree of NLTE corrections, which is shown in the last column of this Table. Inspecting Table 7 and Figure 3, we may conclude as follows: (1) the neutral ions exhibit a tendency to suffer larger influences of NLTE effects (i.e., larger NLTE corrections) than the ionized ions; (2) there is a tendency that the heavier the elements, the NLTE corrections become smaller.

(C) Establishment of Abundances

Establishment of abundances depends on many factors in observations, data reductions, methods of abundance analyses, etc. Here I consider the following factors as criteria for their establishment in HgMn stars:

(1) observations of UV region ($\lambda \lesssim 3100$ Å),
(2) observations of optical region ($3100 \lesssim \lambda \lesssim 10000$ Å),
(3) high-quality observations with CCD or Reticon,
(4) observations of resonance lines,
(5) observations of lines and stars as many as possible,
(6) observations of ions more than two kinds with different ionization stages,
(7) NLTE analyses.

The results of these criteria are summarized in Table 8.

Evaluating these results, I pass my *personal* judgement on which elements have well- or ill-established abundances. Elements with well-established abundances are: He, Be, B, C, O, Mg, Al, Si, P, S, Ca, Sc, Ti, Cr, Mn, Fe, Ni, Zn, Ga, Sr, Y, Zr, and Hg. Elements with ill-established abundances are: N, Na, V, Co, Cu, Xe, Ba, La, Eu, Gd, Yb, W, Pt, and Bi.

4. Concluding Remarks

To establish the abundances of many elements and their characteristics in HgMn stars, the followings are, among others, required: (1) observations of unexplored elements, (2) high-quality observational data, (3) more sophisticated LTE analyses with spectral synthesis method as well as NLTE analyses, and (4) more complete laboratory data with high quality such as gf values and line lists.

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References

Adelman, S. J. 1984, *Astr.Ap.Suppl.*, **58**, 585.
Adelman, S. J. 1987, *M.N.R.A.S.*, **228**, 573.
Adelman, S. J. 1988a, *M.N.R.A.S.*, **235**, 749.
Adelman, S. J. 1988b, *M.N.R.A.S.*, **235**, 763.
Adelman, S. J. 1989, *M.N.R.A.S.*, **239**, 487.
Adelman, S. J., and Fuhr, J. R. 1985, *Astr.Ap.*, **152**, 434.
Adelman, S. J., and Gulliver, A. F. 1990, *Ap.J.*, **348**, 712.
Adelman, S. J., and Lanz, T. 1988 (eds), *Elemental Abundance Analyses* (Institute for Astronomy of the University of Lausanne)
Allen, M. S. 1977, *Ap.J.*, **213**, 121.
Anders, E., and Grevesse, N. 1989, *Geochim. Cosmochim. Acta*, **53**, 197.
Ansari, S. G. 1987, *Astr.Ap.*, **181**, 328.
Baschek, B., Scholz, M., and Sedlmayr, E. 1977, *Astr.Ap.*, **55**, 375.
Boesgaard, A. M., Heacox, W. D., Wolff, S. C., Borsenberger, J., and Praderie, F. 1982, *Ap.J.*, **259**, 723.
Borsenberger, J., Michaud, G., and Praderie, F. 1979, *Astr.Ap.*, **76**, 287.
Borsenberger, J., Michaud, G. and Praderie, F. 1981, *Ap.J.*, **243**, 533.
Borsenberger, J., Michaud, G. and Praderie, F. 1984, *Astr.Ap.*, **139**, 147.
Boyarchuk, A. A., and Savanov, I. S. 1986, in *IAU Colloquium 90, Upper Main sequence Stars with Anomalous Abundances*, ed. C. R. Cowley, M. M. Dworetsky, and C. Mégessier (Dordrecht: Reidel), p. 433.
Cugier, H., and Hardorp, J. 1988, *Astr.Ap.*, **197**, 163
Derman, I. E. 1982, *Ap.Sp.Sci.*, **88**, 135.
Dobrichev, V. M., Raikova, D. V., Ryabchikova, T. A., and Topil'skaya, G. P. 1989, *Astrofizika*, **30**, 91.
Dworetsky, M. M. 1986, in *IAU Colloquium 90, Upper Main sequence Stars with Anomalous Abundances*, ed. C. R. Cowley, M. M. Dworetsky, and C. Mégessier (Dordrecht: Reidel), p. 397.
Dworetsky, M. M., Storey, P. J., and Jacobs, J. M. 1984, *Physica Scripta*, **T8**, 39.
Faraggiana, R., Gerbaldi, M., van't Veer, C., and Floquet, M. 1988, *Astr.Ap.*, **201**, 259.
Freire, R. 1979, *Astr.Ap.*, **78**, 148.
Freire, R., Czarny, J., Felenbok, P., and Praderie, F. 1978, *Astr.Ap.*, **68**, 89.
Freire Ferrero, R., Gouttebroze, P., and Kondo, Y. 1983, *Astr.Ap.*, **121**, 59.
Freire Ferrero, R., Gouttebroze, P., and Talavera, A. 1987, *Astr.Ap.*, **173**, 315.
Gerbaldi, M., Floquet, M., Faraggiana, R., and van't Veer-Menneret, C. 1989, *Astr.Ap.Suppl.*, **81**, 127.
Gigas, D. 1986, *Astr.Ap.*, **165**, 170.
Gigas, D. 1988, *Astr.Ap.*, **192**, 264.
Guthrie, B. N. G. 1984, *M.N.R.A.S.*, **206**, 85.
Hardorp, J., Cugier, H., Koratkar, A., and Scott, J. 1986, in *New Insights in Astrophysics* (ESA SP-263), p. 377.
Heacox, W. D. 1979, *Ap.J.Suppl.*, **41**, 675.
Jacobs, J. M., and Dworetsky, M. M. 1981, in *Proc. 23rd Liège Ap. Colloquium, Upper Main Sequence CP Stars* (Liège: Université de Liège), p. 153.
Jacobs, J. M., and Dworetsky, M. M. 1982, *Nature*, **299**, 535.
Kamp, L. W. 1978, *Ap.J.Suppl.*, **36**, 143.
Kodaira, K., and Takada, M. 1978, *Ann. Tokyo Astr. obs., 2nd Ser.*, **17**, 79.
Leckrone, D. S. 1981, *Ap.J.*, **250**, 687.
Leckrone, D. S. 1984, *Ap.J.*, **286**, 725.

Leckrone, D. S. 1986, in *IAU Colloquium 90, Upper Main sequence Stars with Anomalous Abundances*, ed. C. R. Cowley, M. M. Dworetsky, and C. Mégessier (Dordrecht: Reidel), p. 109.
Lemke, M. 1989, *Astr.Ap.,* **225**, 125.
Leushin, V. V. 1988a, *Sov.Astr.,* **32**, 291.
Leushin, V. V. 1988b, *Sov.Astr.,* **32**, 430.
Lyubimkov, L. S., and Polosukhina, N. S. 1988, in *Magnetic Stars*, ed. Yu. V. Glagolevsky and J. M. Kopylov (Leningrad: Nauka), p. 183.
Mihalas, D. 1973, *Ap.J.,* **179**, 209.
Praderie, F., Boesgaard, A. M., Milliard, B., and Pitois, M. L. 1977, *Ap.J.,* **214**, 130.
Preston, G. W. 1974, *Ann. Rev. Astr. Ap.*, **12**, 257.
Ptitsyn, D. A., and Ryabchikova, T. A. 1986, in *IAU Colloquium 90, Upper Main sequence Stars with Anomalous Abundances*, ed. C. R. Cowley, M. M. Dworetsky, and C. Mégessier (Dordrecht: Reidel), p. 425
Roby, S. W., and Lambert, D. L. 1990, *Ap.J.Suppl.,* **73**, 67.
Roby, S. W., Leckrone, D. S., and Adelman, S. J. 1989, *Bull. Am. Astr. Soc.*, **21**, 1198.
Ryabchikova, T. A., and Smirnov, Ju. M. 1988, *Astr. Tsirk.*, No. 1534, p. 21.
Sadakane, K., Jugaku, J. 1981, *Pub.A.S.P.,* **93**, 60.
Sadakane, K., Jugaku, J., and Takada-Hidai, M. 1985, *Ap.J.,* **297**, 240.
Sadakane, K., Jugaku, J., and Takada-Hidai, M. 1988, *Ap.J.,* **325**, 776.
Sadakane, K., and Nishimura, M. 1979, *Pub. Astr. Soc. Japan,* **31**, 481.
Sadakane, K., Takada, M., and Jugaku, J. 1983, *Ap.J.,* **274**, 261.
Sakhibullin, N. A. 1987, *Sov.Astr.,* **31**, 151.
Severny, A. B. 1986, *Sov. Sci. Rev. E, Ap. Space Phys.*, **5**, 241.
Snijders, M. A., and Lamers, H. J. G. L. M. 1975, *Astr.Ap.,* **41**, 245.
Takada-Hidai, M. 1990, in *IAU Symposium 145, Evolution of Stars: the Photospheric Abundance connection (A Supplementary Volume of Poster Papers)*, ed. G. Michaud and A. Tutukov, in press.
Takada-Hidai, M., Sadakane, K., and Jugaku, J. 1986, *Ap.J.,* **304**, 425.
White, R. E., Vaughan, A. H., Preston, G. W., and Swings, J. P. 1976, *Ap.J.,* **204**, 131.
Zboril, M. 1990, *Bull. Astr. Inst. Czechosl.*, **41**, 44.
Zöchling, J., and Muthsam, H. 1987, *Astr.Ap.,* **176**, 75.

TABLE 1. Abundance analyses of HgMn stars during 1985 – 1990 June

Author	No. of Stars	No. of Elements	Method	Spectral Data
Sadakane et al.(1985)	25	2(B,Be)	NLTE	IUE
Adelman and Fuhr(1985)	3	24	LTE	optical
Takada-Hidai et al.(1986)	27	1(Ga)	LTE	IUE
Severny(1986)	1(χ Cnc)	2(Pb,W)	LTE	ASTRON
Leckrone(1986)	2(ι CrB,χ Cnc)	1(Fe)	LTE	IUE
Ptitsyn and Ryabchikova(1986)	1(HR562)	11	LTE	optical
Hardorp et al.(1986)	3	2(C,N)	LTE	IUE
Adelman(1987)	3	21	LTE	optical
Zochling and Muthsam(1987)	1(χ Cnc)	15	LTE	optical
Ansari(1987)	1(φ Her)	4	WCS [a]	optica
Adelman and Lanz(1988,eds)	1(φ Her)	18	LTE	optical
Adelman(1988a)	3	21	LTE	optical
Adelman(1988b)	3	22	LTE	optical
Sadakane et al.(1988)	23	1(Zn)	LTE	IUE
Ryabchikova and Smirnov(1988)	1(χ Cnc)	1(Xe)	LTE	optical
Leushin(1988a)	3	1(C)	LTE	optical
Leushin(1988b)	1(53Tau)	1(N)	LTE	optical
Lyubimkov and Polosukhina(1988)	1(α And)	10	LTE	optical
Roby et al.(1989)	2(?)	1(N)	LTE	IUE
Gerbaldi et al.(1989)	17	1(O)	NLTE	optical
Dobrichev et al.(1989)	1(χ Cnc)	1(He)	LTE	optical
Adelman(1989)	3	25	LTE	optical
Zboril(1990)	1(π[1]Boo)	11	LTE+NLTE	optical
Roby and Lambert(1990)	9	3(C,N,O)	LTE	optical

[a] WCS is the wavelength coincidence statistics method.

TABLE 2. References reviewed for abundance characteristics

Authors	Authors
Adelman (1989)	Leckrone (1981)
Adelman and Fuhr (1985)	Leckrone (1984)
Adelman and Lanz (1988,eds)	Ptitsyn and Ryabchikova (1986)
Allen (1977)	Roby and Lambert (1990)
Boesgaard et al. (1982)	Ryabchikova and Smirnov (1988)
Derman (1982)	Sadakane and Jugaku (1981)
Dworetsky et al. (1984)	Sadakane et al. (1985)
Gerbaldi et al. (1989)	Sadakane et al. (1988)
Guthrie (1984)	Sadakane et al. (1983)
Hardorp et al. (1986)	Severny (1986)
Heacox (1979)	Takada-Hidai (1990)
Jacobs and Dworetsky (1981)	Takada-Hidai et al. (1986)
Jacobs and Dworetsky (1982)	White et al. (1976)
Kodaira and Takada (1978)	

TABLE 3. Ranges and sizes of diversity and average values of [X]

Atomic No.	Element	Sun [a]	Range Min	Range Max	Size	Average	No. of Stars
2	He	10.99	-1.25	+0.4	1.65	-0.78	14
3	Li	1.16	-	-	-	-	-
4	Be	1.15	<+0.35	+4.5	>4.15	+2.70	37
5	B	2.6	<-1.85	+2.15	>4.0	+0.92	7
6	C	8.56	-1.3	+0.65	1.95	-0.12	30
7	N	8.05	-1.7	-0.2	1.5	-0.79	4
8	O	8.93	-0.8	+0.5	1.3	-0.44	21
11	Na	6.33	-	+0.2	-	+0.2	1
12	Mg	7.58	-1.3	-0.05	1.25	-0.52	34
13	Al	6.47	-2.0	-0.5	1.5	-1.15	22
14	Si	7.55	-1.0	+0.35	1.35	-0.21	33
15	P	5.45	<+0.65	+2.1	>1.45	+1.48	16
16	S	7.21	-0.75	+0.5	1.25	-0.10	13
20	Ca	6.36	-0.9	+0.7	1.6	+0.08	33
21	Sc	3.10	<-1.0	+1.6	>2.6	+0.64	20
22	Ti	4.99	-0.4	+1.6	2.0	+0.57	35
23	V	4.00	-0.7	+1.5	2.2	+0.06	7
24	Cr	5.67	<-1.0	+1.8	>2.8	+0.28	36
25	Mn	5.39	+0.2	+3.9	3.7	+1.79	37
26	Fe	7.67	-1.1	+0.6	1.7	-0.17	39
27	Co	4.92	+0.85	+3.0	2.15	+1.92	2
28	Ni	6.25	-1.65	+0.15	1.8	-0.56	21
29	Cu	4.21	<-1.2	+2.5	>3.7	+1.5	7
30	Zn	4.60	-4.0	+2.0	6.0	-0.86	19
31	Ga	2.88	<+0.2	+3.9	>3.7	+3.24	16
38	Sr	2.90	+0.2	+2.65	2.45	+1.56	26
39	Y	2.24	+1.15	+3.6	2.45	2.35	26
40	Zr	2.60	0.0	+3.7	3.7	+1.75	21
54	Xe	2.23	<+3.95	<+5.25	≶1.3	+4.71	3
56	Ba	2.13	<-0.05	<+2.9	≶2.95	+1.39	2
57	La	1.22	-	+1.6	-	+1.63	1
63	Eu	0.51	-	+4.6	-	+4.59	1
64	Gd	1.12	+1.6	+2.9	1.3	+2.24	3
70	Yb	1.08	-	+1.8	-	+1.78	1
74	W	1.11	-	+2.5	-	+2.5	1
78	Pt	1.8	<+3.0	+4.8	>1.8	+4.19	6
80	Hg	1.09	+4.1	+5.9	1.8	+5.16	28
82	Pb	1.85	-	+2.0	-	+2.0	1
83	Bi	0.71	-	+6.0	-	+6.0	1

[a] Abundance scale is log H = 12.0, and the values are taken from Anders and Grevesse (1989).

TABLE 4. Example of abundance errors of Ga produced by errors of atmospheric parameters

Quantity	Errors	Abundance Errors (dex) Resonance Line	Abundance Errors (dex) High-exc. Line
T_{eff} (K)	± 1000	± 0.08	- 0.19 + 0.25
log g	± 0.3	± 0.10	± 0.11

TABLE 5. NLTE abundance analyses relevant to HgMn stars

Ion	Reference	T_{eff} (10^3 K)	log g	ξ_t (km/s)	Typical NLTE Correction (dex)
He I	Lemke(1989)	8.8-10.9	3.45-4.5	1.2-3.0	-0.03
Be II	Boesgaard et al.(1982)	10-15	4.0	0.0	-0.4
Be I,II	Borsenberger et al.(1984)	10-15	4.0	0.0	-
Be II	Sadakane et al.(1985)	10-15	3.2-3.9	0.0	-
B II	Praderie et al.(1977)	{9.65 9.7	4.05 4.26	3.0 2.0	$\lesssim$+0.17
B II,III	Borsenberger et al.(1979)	9.65-15	4.0 4.05	0.0,3.0	-
B II	Sadakane et al.(1985)	10-15	3.2-3.9	0.0	$\lesssim$+0.2
C II	Freire(1979)	{9.65 10	4.05 4.0	1.3	-0.18
C II	Sakhibullin(1987)	15-32.5	{2.5,3.0, 4.0,4.5	0.5,10	{-0.3(optical) negligible(UV)
C I,II	Cugler and Hardorp(1988)	9.7-18.0	3.5-4.0	2.0	{0.15 - 0.85(CI) 0.11 - 0.15(CII)
O I	Baschek et al.(1977)	7.5-17.5	1,2.5,4	0.5	{-2 - -0.5(triplet) -0.4 - 0.0(visual)
O I	Faraggiana et al.(1988)	6.0-16	1,2.5,3.4	1-10	-
O I	Gerbaldi et al.(1989)	7 15	3.5,4.0	1,3.5	-2 - -0.5(triplet)
Mg I,II	Borsenberger et al.(1984)	10-15	4.0	0	-
Mg II	Snijders and Lamers(1975)	10-35	2.5,3.4	0-15	-
Mg II	Freire Ferrero et al.(1983)	{9.65 10	4.05 4.0	3 0-10	{+0.27(UV) -0.04(visual)
Mg II	Freire Ferrero et al.(1987)	10.1	4.3	1.0	-
Mg I,II	Gigas(1988)	9.5	3.90	depth-dep. (~2)	-0.03
Si II-IV	Kamp(1978)	15-35	3-4.5	0	>-0.5
Si II	Freire(1979)	{9.65 10	4.05 4.0	1.3	+1.18
Ca II	Mihalas(1973)	15-27.5	2.5,3.4	0.4	negligible (T<1.5x10^3)
Ca II	Freire et al.(1978)	{9.65 10	4.05 4.0	1	+0.70
Ca II	Borsenberger et al.(1981)	10,12.5,15	4.0	0	-
Ti II	Lemke(1989)	8.8-10.9	3.45-4.50	1.2-3.0	-0.02
Fe I,II	Gigas(1986)	9.5	3.9	depth-dep. (~2.5)	{+0.32(FeI) -0.02(FeII)
Fe I,II	Lemke(1989)	8.8-10.9	3.45-4.50	1.2-3.0	{+0.30(FeI) -0.02(FeII)
Sr II	Borsenberger et al.(1981)	10,12.5,15	4.0	0	-
Ba II	Borsenberger et al.(1984)	10,12.5,15	4.0	0	-
Ba II	Gigas(1988)	9.5	3.90	depth-dep. (~2)	+0.29

TABLE 6. LTE and NLTE abundances relative to the Sun and NLTE corrections in HgMn stars and Vega

Ion(mult) Line(Å)		HgMn stars Average (dex)	No.of stars	Ref [a]	Vega (dex)	Ref [a]	(dex)	Ref [a]	(dex)	Ref [a]	(dex)	Ref [a]
MgII(4)	LTE	-0.56	9	AD	-0.54	SN	-0.63	AG	-0.56	G	-0.56	G
4481	NLTE	-0.69	9	TH	-0.71	TH	-0.70	TH	-0.57	TH	-0.66	G
(blend)	NLTE Corr	-0.13		TH	-0.17	TH	-0.07	TH	-0.01	TH	-0.10	G
CaII(1)	LTE	+0.18	10	AD	-0.78	SN	-1.60	FC				
3934	NLTE	-0.27	10	TH	-0.69	TH	-0.36	FC				
	NLTE Corr	-0.45		TH	+0.09	TH	+0.70	FC				
SrII(1)	LTE	+1.22	10	AD	-0.79	SN						
4077	NLTE	+1.30	10	TH	-0.04	TH						
	NLTE Corr	+0.08		TH	+0.75	TH						
SrII(1)	LTE	+1.42	8	AD	-0.77	SN						
4216	NLTE	+1.56	8	TH	-0.52	TH						
	NLTE Corr	+0.14		TH	+0.25	TH						
BaII(1)	LTE	(-0.06-+2.90)	6	AD	-0.38	SN	-0.71	AG	-0.53	G	-0.53	G
4554		+1.29[b]		TH								
	NLTE	+1.04[b]	6	TH	-0.03	TH	-0.41	TH	-0.15	TH	-0.23	G
	NLTE Corr	-0.25[b]		TH	+0.35	TH	+0.30	TH	+0.38	TH	+0.30	G

[a] AD=Adelman(1984, 1987, 1988b, 1989), AG=Adelman and Gulliver(1989), FC=Freire et al.(1978), G=Gigas(1988), SN=Sadakane and Nishimura(1979), TH=this study.

[b] Values are calculated from upper limits.

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TABLE 7. Sizes, ranges, and degree of NLTE corrections

Element	Sample Stars	Ioniz. Stage	Typical Size or range of NLTE Corr (dex)	Degree of NLTE Corr [a]
He	normal A, Sirius	I	-0.03	small
Be	HgMn, normal B & A	II	-0.4(-0.7 - 0.0)	large
B	HgMn, normal B & A Vega, Sirius	II	<+0.2	moderate
C	OB, normal A & B	I	+0.5(0.15 - 0.85)	large
	Vega	II	-0.3 - 0.15	moderate
O	normal B, A, & F CP(HgMn, others)	I	-2 - 0.0	large
Mg	HgMn, Vega, Sirius	I	-0.02	small
		II	-0.04(-0.1 - 0.27)	small
Si	normal B, CP, Vega	II	-0.5 - 1.2	large
		III	>-0.5	moderate
		IV	>-0.5	moderate
Ca	HgMn, B, Vega	II	-0.45 - 0.70	large
Ti	normal A, Sirius	II	-0.02	small
Fe	normal A, Vega,	I	+0.31	moderate
	Sirius	II	-0.02	small
Sr	HgMn, Vega	II	+0.2(0.1 - 0.5)	moderate
Ba	HgMn, Vega	II	-0.3 - 0.3	moderate

[a] $|Corr| \leq 0.1$ dex ....small
$0.1 < |Corr| \leq 0.3$ dex ......moderate
$0.3 < |Corr|$........................large

TABLE 8. Achievements of observations and analyses in HgMn stars

Atomic No.	Element	UV Obs.[a]	Opt. Obs.[a]	Detector of Opt. Obs.	No. of Lines	Ionization Stage	NLTE Analysis[b]
2	He	...	O	...	~5	I	A
3	Li	...	...	...	...	...	...
4	Be	...	O(R)	(IUE)[c]	2	II	AA
5	B	O(R)	...	...	~10	II	AA
6	C	O(R)	O	Reticon	~10	I,II	A
7	N	O(R)	O	Reticon	~10	I	...
8	O	...	O	Reticon	~10	I,II	AA
11	Na	...	O(R)	...	2	I	...
12	Mg	...	O	...	~10	I,II	AA
13	Al	O(R)	O(R)	...	~5	I,II,III	...
14	Si	...	O	...	~10	I,II,III	A
15	P	...	O	...	~15	II,III	...
16	S	...	O	Reticon	~15	I,II	...
20	Ca	...	O(R)	...	3	I,II	AA
21	Sc	...	O(R)	...	~10	II	...
22	Ti	...	O	...	~70	II	A
23	V	...	O	...	~10	II	...
24	Cr	...	O	...	~50	I,II	...
25	Mn	...	O	...	~100	I,II	...
26	Fe	O(R)	O	...	~260	I,II,III	A
27	Co	...	O	...	2	I	...
28	Ni	...	O	...	8	I,II	...
29	Cu	O(R)	...	...	1	II	...
30	Zn	O(R)	...	...	1	II	...
31	Ga	O(R)	O	...	~5	I,II,III	...
38	Sr	...	O(R)	...	~5	II	AA
39	Y	...	O(R)	...	~25	II	...
40	Zr	...	O	...	~30	II	...
54	Xe	...	O	Reticon,CCD	~10	II	...
56	Ba	...	O(R)	...	1	II	AA
57	La	...	O	...	1	II	...
63	Eu	...	O(R)	...	3	II	...
64	Gd	...	O	...	5	II	...
70	Yb	...	O(R)	...	1	II	...
74	W	O	...	...	1	II	...
78	Pt	O	O	...	8	II	...
80	Hg	O(R)	O	...	5	I,II	...
82	Pb	O	...	...	1	II	...
83	Bi	O(R)	...	...	7	II	...

[a] "O" stands for the fact that observations were made, and "R" for that resonance lines were observed.
[b] "A" stands for the fact that NLTE abundance analyses were made, and "AA" for that NLTE abundance analyses were made for HgMn stars.
[c] SEC Vidicon tube is equipped.

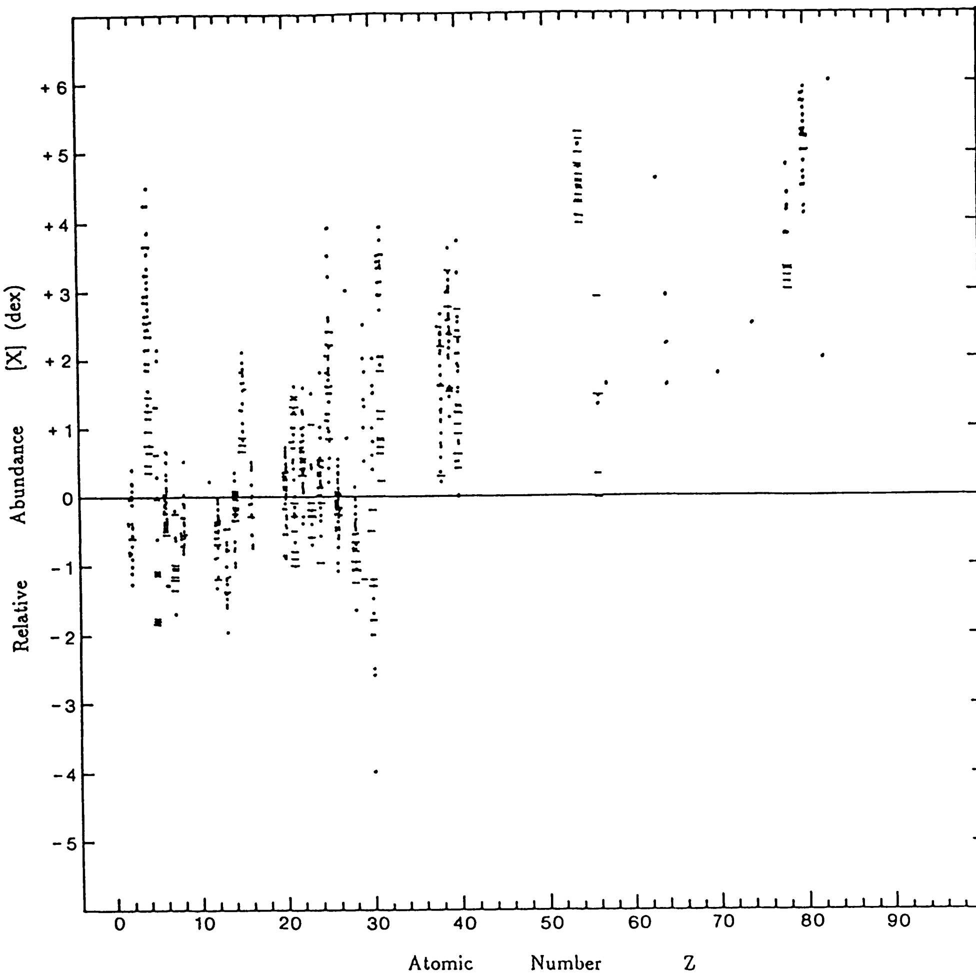

Figure 1. Observed abundances in HgMn stars. The abundances are expressed as those relative to the Sun, [X] = log X(star)/X(Sun). Dots denote definite values of abundances, while short horizontal lines like minus sign denote upper limits.

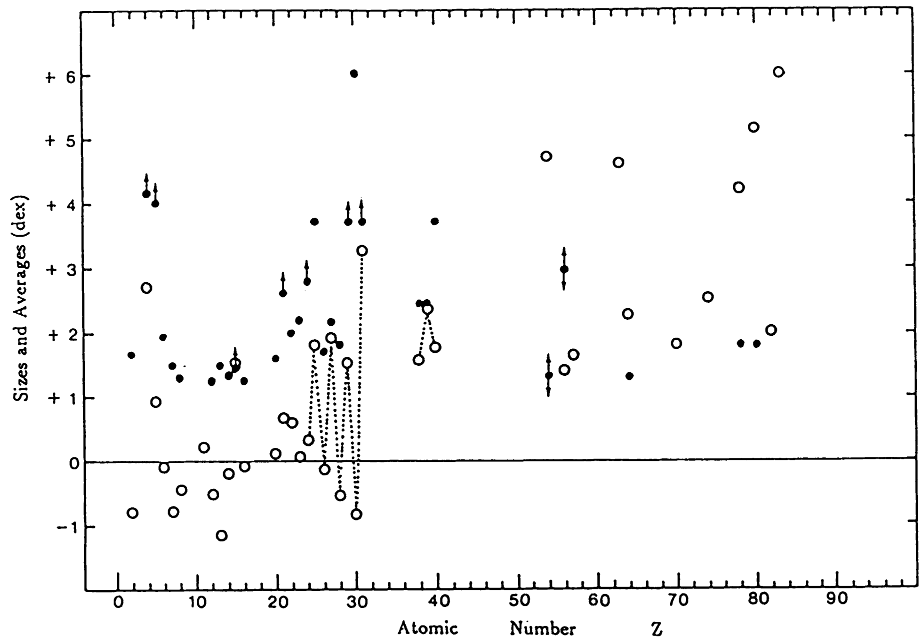

Figure 2. Average values of relative abundances and sizes of diversity observed in each abundance. Open and filled circles denote average values and sizes of diversity, respectively. Upper and lower limits in sizes are denoted by downward and upward arrows, respectively.

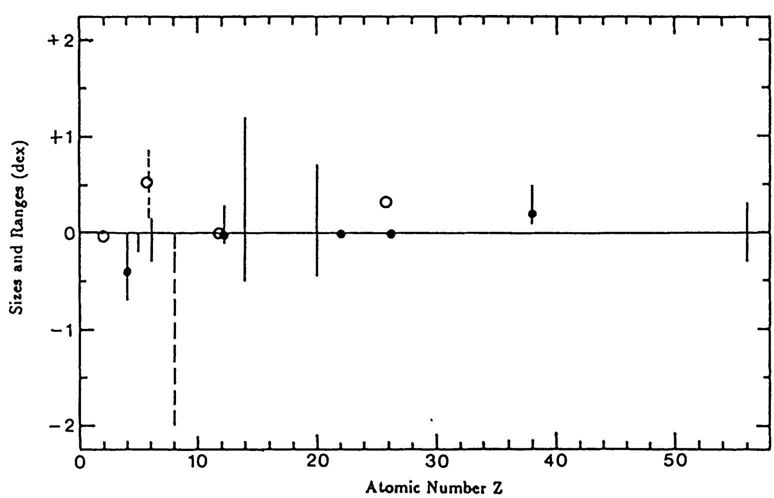

Figure 3. Typical sizes and ranges of NLTE corrections. Sizes of neutral ions and those of ionized ions are denoted by open and filled circles, respectively. Ranges of neutral ions and those of ionized ions are denoted by broken and solid lines, respectively.

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