

# Chemical composition and fundamental parameters of roAp stars

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**Abstract.** Element abundances of three roAp stars, HD 166473, HD 203932, and HD 217522, were determined using Kurucz model atmospheres with metal abundances scaled to solar ones and the results were compared with data from the literature concerning three further roAp stars, normal B and A stars and two  $\lambda$  Bootis stars. Up to 38 elements could be identified and therefore, this work represents the most complete chemical investigation hitherto published, which can be summarized as follows:

- all investigated roAp stars have a similar abundance pattern,
- the overabundances of rare earth and other heavy elements are comparable to cool non-pulsating Ap-stars,
- iron belongs to the most deficient and cobalt to the most enhanced elements in the group of the iron peak elements, and
- the light elements carbon, nitrogen, and oxygen are less abundant than in atmospheres with abundances scaled to the Sun.

Beside an unexpected possible relation between effective temperature and metallicity of roAp stars, no outstanding differences from non-pulsating Ap stars could be detected. This statement, however, suffers from the lack of comparably detailed investigations of the latter.

**Key words:** Stars: abundances – Stars: atmospheres – Stars: chemically peculiar

## 1. Introduction

Rapidly oscillating Ap (roAp) stars are a subgroup of the CP2 stars, which oscillate with non-radial, high overtone, low order acoustic  $p$ -modes with the axis of oscillation aligned with the axis of the magnetic field (Kurtz 1982). A still open question is concerned with the excitation mechanism for roAp stars and other physical parameters which distinguish them from non-pulsating CP stars.

## 2. Observations

Six EMMI echelle spectra were obtained by G. Mathys with the NTT at ESO in June 1992. Two different cross-disperser gratings covered the entire spectral

range from 4200 to 8100 Å. The spectral resolution is about  $\mathcal{R} = 24000$ , the typical signal-to-noise ratio per pixel is about 200 in the continuum.

All reductions of the observations to continuous spectra and the normalization to the continuum were done within the echelle package of IRAF. All calculations to determine the basic stellar parameters and the abundance patterns are based on the Abundance Analysis Procedure AAP (Gelbmann 1995).

### 3. Fine Analyses

An abundance analysis was carried out for the three roAp stars HD 166473, HD 203932 (Gelbmann et al. 1997), and HD 217522. Abundance analyses of three further roAp stars have been carried out by the Vienna working group with the same spectrum synthesis tool:  $\alpha$  Cir (Kupka et al. 1996),  $\gamma$  Equ (Ryabchikova et al. 1997), and HD 24712 (Ryabchikova et al. 1997a).

To identify the abundance peculiarities of the group of roAp stars, their abundance spectra were compared to four normal B stars (Adelman 1986) and 15 early A type stars (Hill 1995). In addition, abundance analyses of two  $\lambda$  Bootis stars with effective temperatures comparable to the roAp stars have been carried out within the Vienna working group with the same spectrum synthesis toolkit (Heiter 1996).

### 4. Results

The effective temperature range of all six roAp stars spectroscopically investigated so far varies from  $T_{\text{eff}} = 6750$  K to 8000 K, corresponding to spectral types from F2 to A4. The surface gravities range from  $\log g = 4.2$  to 4.4 which is consistent with  $\log g$  values for A4 to F2 main sequence stars in a theoretical HR-diagram ( $\log g = 4.3$ , Gray 1992). Although the accuracy of the determination of  $\log g$  is rather poor, it is evident that roAp stars are positioned on or close to the ZAMS, they do not seem to be considerably evolved. The close proximity of the roAp stars to the ZAMS indicates that chemical peculiarities have developed on relatively short time scales. Table 1 summarizes the fundamental atmospheric parameters of all six roAp stars discussed within this study.

Although the abundance of atmosphere models for the syntheses are solar scaled within a wide range of different scaling factors, all roAp stars spectroscopically investigated as yet show similar abundance patterns:

The overabundance of rare earth elements and some other heavy elements are comparable to other cool Ap stars. The elements C, N, and O are less abundant than the scaled solar abundances, their overall abundances relative to the Sun vary from  $[\text{CNO}] = -0.8$  to  $-0.2$  with the mean at  $-0.5$ . Most iron peak elements are more abundant than iron, which is the main contributor to opacity in the atmosphere. For all iron peak elements the total abundances vary from  $[\text{I.P.}] = -0.8$  to  $+0.7$  with the mean at  $+0.2$ , while the Co abundances vary from

**Table 1.** The atmospheric parameters of all roAp stars analyzed so far;  $[M/H]$  is the total metallicity of all iron peak elements. The stars are sorted in order of increasing temperature.

Star	Name	$T_{\text{eff}}$ [K]	$\log g$	$[M/H]$	$v_{\text{micro}}$ [km s <sup>-1</sup> ]	$v \cdot \sin i$ [km s <sup>-1</sup> ]
HD 217522	BP Gru	6750	4.3	-1.36	1.0	12.0
HD 24712	DO Eri	7250	4.3	-0.34	1.0	7.0
HD 203932	BI Mic	7450	4.3	+0.03	<0.6	12.5
HD 201601	$\gamma$ Equ	7750	4.2	+0.06	1.0	<4.5
HD 128898	$\alpha$ Cir	7900	4.2	0.00	1.5	12.5
HD 166473	V694 CrA	8000	4.4	+0.67	1.0	18.0

$[\text{Co}] = +1.0$  to  $+2.0$  with the mean at  $+1.6$ . As the abundances of the iron peak elements increase, the abundances of the heavy elements increase as well. Among normal A-type stars this tendency of the heavy elements to be overabundant has been noted before by Lemke (1990). The total abundances of all rare earth elements vary from  $[\text{REE}] = +1.3$  to  $+3.4$  with the mean at  $+2.7$ ! Table 2 lists all abundances of the six roAp stars in order of increasing temperatures.

## 5. Conclusions

This study shows that roAp stars have similar abundances for up to 38 elements identified in the sample. These abundances are being used to compute stellar atmosphere models based on individual opacities. Within the significantly smaller number of analyzed elements in the literature, a comparison to non-roAp stars do not reveal large abundance differences. The derived fundamental stellar parameters and abundances allow to locate the stars in the HR-diagram and provide important boundary values for pulsation models. Stellar structure and evolutionary parameters can be derived from such models.

A comparison of the iron peak abundances in the six roAp stars shows an unexpected relation between effective temperature and metallicity. Fig. 1 shows this tendency for the total metallicity of all iron peak elements  $[M/H]$  versus the spectroscopically derived effective temperature  $T_{\text{eff}}$ . However, since all stellar parameters – including also effective temperature – are determined mainly with iron lines, it is not clear whether this tendency is astrophysically significant or an artifact due to the applied analyzing algorithm. The derived stellar parameters and abundances are resulting from optimization routines. Inadequate model atmospheres, limited signal-to-noise ratio of the spectra, errors in atomic parameters and problems in defining the continuum can result in fairly large errors. Therefore, the correlation between metallicity and effective temperature has to be further investigated.

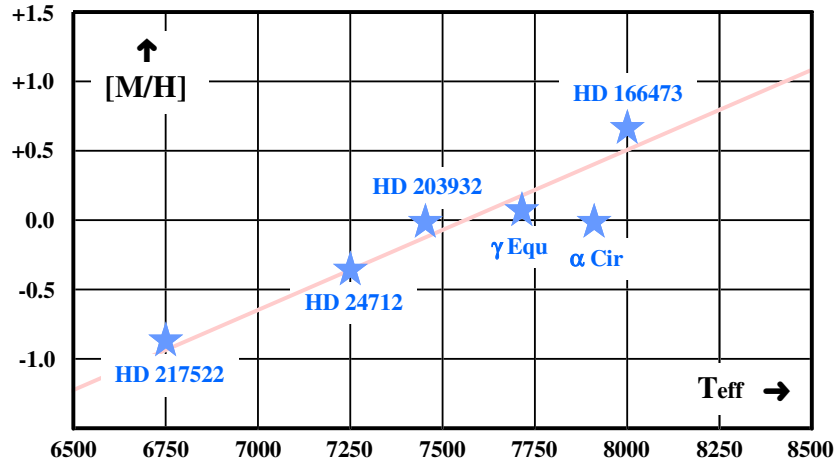
**Table 2.** Abundances of elements normalized to the total number of atoms for all six roAp stars and for the Sun (Anders & Grevesse 1989).

Element	HD217522	HD 24712	HD203932	$\gamma$ Equ	$\alpha$ Cir	HD166473	Sun
Li	-	-	-	-	-	-	-10,88
C	-3,79	-	-4,09	-3,66	-4,00	-3,24	-3,48
N	-	-	-4,40	-	-4,40	-4,75	-3,99
O	-4,70	-	-3,73	-	-3,80	-3,92	-3,11
Na	-7,48	-	-5,72	-5,27	-5,90	-6,17	-5,71
Mg	-4,82	-5,08	-4,23	-4,35	-4,46	-4,39	-4,46
Al	-5,47	-5,53	-5,34	-4,93	-	-4,89	-5,57
Si	-4,23	-4,70	-4,39	-4,42	-4,20	-3,88	-4,49
P	-	-4,43	-	-	-	-4,13	-6,59
S	-	-	-5,05	-4,74	-	-3,95	-4,83
Cl	-	-	-6,54	-	-	-5,26	-6,54
Ar	-	-	-	-	-	<-4,22	-5,48
K	-	-	-6,81	-	-	-6,06	-6,92
Ca	-6,30	-5,26	-5,17	-5,72	-5,15	-4,89	-5,68
Sc	-	-	-9,77	-9,45	-9,80	-6,93	-8,94
Ti	-7,08	-7,22	-7,01	-6,98	-6,87	-6,27	-7,05
V	-6,46	-	-7,49	-7,10	-7,65	-6,34	-8,04
Cr	-6,55	-5,66	-5,64	-5,55	-5,55	-5,10	-6,37
Mn	-6,37	-6,89	-6,39	-5,74	-6,00	-5,42	-6,65
Fe	-5,48	-4,89	-4,42	-4,35	-4,50	-3,75	-4,37
Co	-5,67	-5,75	-5,97	-6,08	-5,50	-5,08	-7,12
Ni	-5,99	-6,26	-5,88	-5,78	-6,15	-5,28	-5,79
Cu	-7,61	-	-7,89	-	-	-6,51	-7,83
Zn	-	-	-7,88	-	-	-	-7,44
Ga	-6,81	-	-	-	-	-	-9,16
Rb	-	-	-	-	-	<-7,06	-9,44
Sr	-6,65	-8,20	-7,38	-7,14	-7,25	-6,78	-9,14
Y	-9,23	-8,05	-8,29	-8,23	-8,50	-7,66	-9,80
Zr	-8,49	-	-9,27	-8,68	-9,00	-7,45	-9,44
Ba	-8,79	-9,05	-9,33	-9,06	-10,30	-	-9,91
La	-8,16	-9,08	-10,10	-9,59	-10,32	-7,11	-10,82
Ce	-8,11	-9,04	-9,27	-9,20	-9,40	-7,73	-10,49
Pr	-9,12	-9,88	-10,09	-9,98	-10,40	-8,51	-11,33
Nd	-8,63	-8,89	-9,50	-9,17	-9,30	-7,32	-10,54
Sm	-8,31	-9,46	-10,06	-9,53	-9,50	-7,46	-11,04
Eu	-8,55	-9,25	-9,15	-10,24	-9,40	-7,51	-11,53
Gd	-7,74	-8,91	-9,90	-9,35	-9,45	-7,46	-10,92
Dy	-8,37	-9,16	-	-9,14	-10,00	-8,26	-10,94
Er	-8,55	-9,66	-9,73	-10,04	-	-8,40	-11,11
Tm	-	-	-	-	-	-	-12,04
Yb	-9,55	-	-	-	-	-8,66	-10,96
Lu	-9,27	-	-10,40	-	-	-8,71	-11,28
Hf	-	-	-	-	-	-	-11,16
Th	-	-	-10,85	-	-	-8,89	-11,92

Beside this possible relation, no outstanding differences between pulsating and non-pulsating Ap stars could be detected.

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**Figure 1.** Relation between effective temperature and total metallicity of all iron peak elements.

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