Radial Velocity Pulsations in the Atmosphere of HD 24712

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We present results of the analysis of spectroscopic time-series observations of the roAp star HD 24712 obtained at the phase of magnetic maximum. Observations were carried out on November 6, 2003 with the SOFIN high resolution échelle spectrograph at the 2.56m Nordic Optical Telescope, La Palma, Spain. 53 spectra with the resolution $R = 80000$, $S/N = 80$ and time resolution 105 s (50 s of exposure + 55 s overhead) in the 5000–6800 Å region were analysed for radial velocity (RV) pulsations. More than 100 unblended spectral lines were measured. As in previous investigations of roAp stars we found that only lines of the rare-earth elements (REE) show RV pulsational variations. Spectral lines of iron-peak elements, $H\beta$ core, strong Y II and Ba II lines are not variable above the errors of RV measurements (15–30 m s^{-1} for strong lines). Pulsation period derived from the REE lines (Pr III, Nd II, Nd III, Eu II, Tb III) coincides with one of the 7 photometric periods, $P = 6.20$ min. RV pulsations in HD 24712 are characterised by gradual phase shifts between RV curves of different REE. The same pulsations of HD 24712 were observed in 2001, giving a strong evidence for stability of the pulsational mechanism in this star. NLTE calculations of Nd line depth formation in stratified atmosphere of HD 24712 allowed to study pulsational phase distribution with optical depths, providing strong evidence for running wave , propagating with nearly constant RV amplitude.

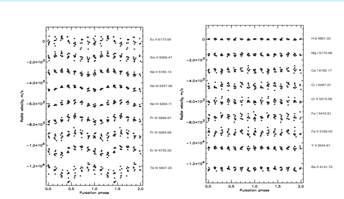
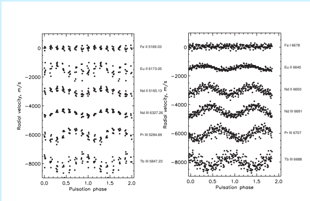


Figure 1: Pulsating (left) and nonpulsating (right) lines.
The subsequent measurements show that as in other roAp stars maximal RV amplitudes have lines of rare-earth elements in the first and the second ionisation stages. RV amplitudes for strong lines of Mg, Si, Ca, Cr, Fe, Co, Y, Ba, H β core do not exceed the error of our measurements (15–30 m s^{-1}). Pulsating lines were searched first by calculating the power spectrum image separately for each wavelength pixel.

Figure 2: 2001(right) and 2003 (left) observation sets.
Pulsation curves for the lines of the same REE ions do not significantly differ in phase, but phase shifts occur between the pulsating curves of the different REE elements. Our preveous study (Sachkov et all., IAU 193) with others lines of the same elements shows the similar pulsational behaviour, although the star was pulsating with slightly different period, P=6.13 min., which coincides again with another of the photometric periods.



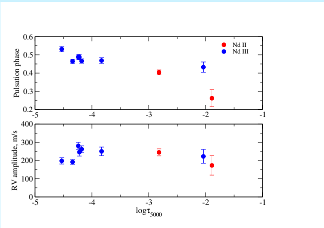
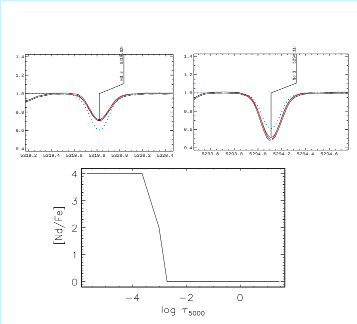


Figure 3: NLTE analysis for HD 24712 (*see L. Mashonkina, T. Ryabchikova, A. Ryabtsev, FT3, this conference*). On figures (right top) we show as examples Nd II 5319.820 and Nd III 5294.110 spectral lines: observations (black), LTE-calculation (blue) and NLTE-calculation (red).
NLTE analysis of Nd lines shows that Nd is concentrated above $log\tau \approx -3$. This distribution describes well the observed line profiles. Depth formation of a few spectral lines was calculated for stratified model. Phase of pulsation maximum increses with optical depth, supporting a hypothesis of running wave in the atmosphere. Clearly, NLTE calculations of the other REE, in particular Pr II and Tb III are needed for better understanding of the pulsation phenomenon in stellar atmospheres.



Line	Period,min	Probability of Period	Amplitude, m	Phasemax	r	EqW
4570.65	6.12(0.01)	1.0000	344(30)	0.425(0.014)	0.675	56
4642.99	6.20(0.04)	0.8993	176(37)	0.343(0.034)	0.778	50
4651.62	6.20(0.01)	1.0000	255(19)	0.422(0.012)	0.531	94
4734.76	6.14(0.04)	0.9922	170(32)	0.449(0.031)	0.733	65
4740.67	6.24(0.05)	0.8212	320(79)	0.402(0.040)	0.898	21
4759.54	6.17(0.02)	0.9999	200(19)	0.435(0.016)	0.584	97
5064.05	6.17(0.04)	0.9998	247(52)	0.382(0.034)	0.838	30
5083.85	6.13(0.04)	0.9967	323(58)	0.446(0.030)	0.847	35
5852.44	6.18(0.02)	1.0000	238(28)	0.339(0.018)	0.760	69
6012.30	6.17(0.03)	0.9993	194(29)	0.387(0.024)	0.799	49
6014.56	6.22(0.02)	0.9999	258(29)	0.431(0.018)	0.769	52
6148.86	3.69(0.03)	0.3565	81(44)	0.362(0.087)	0.882	30
6524.48	6.22(0.02)	0.9999	308(37)	0.363(0.019)	0.850	38
7873.68	6.19(0.02)	0.9955	283(27)	0.425(0.015)	0.779	76
8454.68	6.20(0.02)	0.9052	260(25)	0.492(0.016)	0.776	87

Table: Unidentified pulsating lines in HD 24712.
In roAp stars only lines of the rare-earth elements (REE) show RV pulsational variations (up to 1 km s^{-1} and even more). Such unique pulsational behaviour can serve to identify unknown lines in roAp stars spectra. In the table (left) we represent pulsational data for unidentified lines in HD 24712. Unpublished Mrs. Crosswhite's lists of Nd III lines (both classified and unclassified) contain 4570.65, 4651.62, 4734.76, 4740.67, 4759.54, 5083.85 lines. Our study give a strong support for identification of these lines as Nd III (marked by red). Pulsational amplitudes and phase shifts of 6014.56, 7873.68 and 8454.68 allow to propose these lines as Nd III lines, too.

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