A SEARCH FOR RAPID VARIABILITY OF RADIAL VELOCITY AND EFFECTIVE MAGNETIC FIELD OF THE RAPIDLY OSCILLATING AP STAR GAMMA EQUILEI

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ABSTRACT. Eleven high-dispersion Zeeman spectrograms of a rapidly oscillating Ap star gamma Equilei are analyzed in the search for radial velocity and effective magnetic field (B_e) oscillations related to the photometric period of 12.5 mins. While no oscillations of radial velocities correlated with the photometric period were detected, a variability of B_e with the period 12.5 mins cannot be excluded. Spectrograms on a time-base comparable with the Kurtz´s (1983) photometry are needed for finding the evidence of the expected radial velocity and magnetic field oscillations.

ПОИСК БЫСТРОЙ ПЕРЕМЕННОСТИ ЛУЧЕВОЙ СКОРОСТИ И ЭФФЕКТИВНОГО МАГНИТНОГО ПОЛЯ БЫСТРО ОСЦИЛЛИРУЮЩЕЙ АР ЗВЕЗДЫ ГАММА МАЛОГО КОНЯ. Исследована переменность лучевой скорости и эффективного магнитного поля в отношении к периоду фотометрических осцилляций I2.5 мин быстро осциллирующей Ар звезды гамма Малого коня. Одиннадцать высокодисперсионных земановских спектрограмм получилось с высоким временным разрешением. Изменения магнитного поля с периодом около I2.5 мин неисключаются, изменений лучевой скорости с этим периодом нет. Намечается, что для наблюдений этого типа продолжительность сравнимая с продолжительностю фотометрии Куртца необходима.

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HĽADANIE RÝCHLEJ PREMENNOSTI RADIÁLNEJ RÝCHLOSTI A EFEKTÍVNEHO MAGNETICKÉHO POĽA RÝCHLO OSCILUJÚCEJ AP HVIEZDY GAMA EQUILEI: Oscilácie radiálnej rýchlosti a efektívneho magnetického poľa s 12.5 min fotometrickou periódou sa hľadali v 11 vysokodisperzných spektrogramoch rýchlo oscilujúcej Ap hviezdy gama Equilei. Premennosť B_e s periódou okolo 12.5 min sa nedá vylúčiť, zmeny radiálnej rýchlosti s touto periódou sa nenašli. Na dôkaz existencie takýchto zmien by boli potrebné spektroskopické pozorovania za obdobie dĺžkou porovnateľné s fotometriou, ktorú urobil Kurtz (1983).

1. INTRODUCTION

Currently, the group of cool rapidly oscillating Ap stars (roAp) comprises twelve stars of spectral types A7 - F2. While their photometric characteristics are well known - the oscillation periods spread from 4 to 15 mins with amplitudes of $\lesssim 0.01$ mag - the variability of radial velocity and magnetic field on the same time scales have not yet been studied intensively. The amplitude of radial velocity variations based on the non-radially oscillating oblique rotator model can amount to 5 km s^{-1} (Baade, Weiss, 1987). However, Matthews et al. (1988), in up-to-date the only confirmed case HR 1217, measured the amplitude of the radial velocity variations of 400 m s^{-1} with the photometric 6.13 mins period of the star.

In this contribution we deal with the analysis of the radial velocities and effective magnetic field of the roAp star gamma Equ (HR 8097, HD 201 601, V = 4.6, F0p). Its photometric period is 12.5 mins (Kurtz, 1983). The star is known as a slow magnetic variable of $B_e \approx +0.05$ T when discovered by Babcock (1954), $B_e \approx 0$ T in early seventies (Bonsack, Pilachovski, 1974) and $B_e \approx -0.08$ T in 1978 (Scholz, 1979). Bychkov (1987) examined the radial velocities of this star on 19 spectrograms taken at the 6-m BTA telescope of dispersion 0.9 nm mm^{-1}. The length of the exposure time was 1 min in steps of 3 - 5 mins. He arrived to the following conclusions: 1) during the observations the radial velocity changed up to 2.8 km s^{-1} on a scale of 12 - 14 mins, 2) the periodic variability of RV´s on scales 5 - 35 mins is absent. Evaluating another set of observations, Bychkov (1988) concluded that: 1) the radial velocity probably varies on time scales of 5 - 7 mins 2) the lines of certain elements display variations of the amplitude 5 - 6 km s^{-1} with double of the photometric period, 3) on the whole, 47 estimations of radial velocities from spectra obtained in 4 sets do not allow to draw a definite conclusion about radial velocity oscillations.

This suggests considerable inconclusiveness of the results.

2. OBSERVATIONS, REDUCTION AND RESULTS

Improvements of the instrumentation of the 6-m BTA telescope of the

Special Astrophysical Observatory (SAO) of the Academy of Sciences of the USSR were carried out during 1987. This enabled to obtain Zeeman spectrograms of gama Equ with high dispersion and time resolution of minutes. On September 20, 1987 eleven 0.9 nm mm^{-1} spectrograms were obtained with the II - nd camera of the basic spectrograph of BTA. The spectral interval was 380 - 495 nm, the height of the spectrum in every polarization 0.25 mm. The Kodak IIa-O emulsion sensibilized in hydrogen atmosphere was preflashed prior to every exposure. A stellar spectrum exposure lasted 90 s, the mid-of-the-exposures followed after 170 - 190 s, see Table 1.

TABLE 1

List of Zeeman spectra taken on September 20, 1987.

Sp. No.	Time	Time
	h m s	h
1436	16 23 45	16.3958
1437	16 26 45	16.4458
1438	16 29 45	16.4958
1439	16 32 35	16.5431
1440	16 35 45	16.5958
1441	16 38 45	16.6451
1442	16 41 35	16.6931
1443	16 44 35	16.7431
1444	16 47 45	16.7958
1445	16 50 35	16.8431
1446	16 53 25	16.8903

Length of exposure 90 s; Dispersion 0.9 nm mm^{-1}; Wavelengths 380 - 495 nm

The spectrograms were measured by means of TV - Abbe laser-interferometer comparator at Astronomical Institute of the Slovak Academy of Sciences at Tatranská Lomnica. A polynomial regression of 7 to 9-th degree (Belas,1985) was fitted to 43 - 54 Fe + Ar comparison lines. The standard deviation of the approximation amounts to 1.1 - 1.7 pm. The average values from both polarizations were taken as the final wavelengths.

In the papers of Bychkov (1987, 1988) the accuracy of the measurements was limited by technical possibilities of the oscilloscopic comparator at the Special Astrophysical Observatory. Thus he was able to measure only about 160 stellar lines. The higher parameters of the TV - comparator enabled us to find and measure the weakest stellar lines. On each spectrogram we were able to measure 370 - 633 stellar lines. This spread is mainly due to a subjective estimation of the weakest lines and to a selection of measurable blends. The lines common on different spectrograms were searched by coincidence in the interval ± 25 pm. There were 160 stellar lines on all 11 spectrograms. 231 common lines were measured on at least 10 spectrograms. In summary, there were 403 lines measured commonly on at least 5 spectrograms. The lines found on less than 5 spectrograms were not accepted. The standard error of the value of radial velocity derived from one spectrogram lies between 0.2 - 0.4 km s^{-1}. The mean heliocentric radial velocity from 11 spectrograms is RV = - 16.4 km s^{-1} with the standard deviation $\delta = \pm 0.6$ and the standard error $\sigma = \pm 0.2$ km s^{-1}. Table 2 summarizes results in a form of differences relative to the mean, $\Delta RV = RV(i) - \overline{RV}$, $i = 1,\ldots 11$. It is remarkable that the two successively taken spectrograms, namely Nos. 1440 and 1441, give opposite extreme values + 1.18 and - 1.04 km s^{-1} respectively. Both the values exceed the limits of $3\sigma = \pm 0.6$ km s^{-1}. This pattern could arise due to systematic errors between individual spectrograms. Therefore we checked a possible correlation between ΔRV-s and the "a_0" - coefficients of the polynomial regression of individual dispersion curves. No correlation was found, for the extreme ΔRV-s the corresponding coefficients are close to the average. Similarly, one of the values of B_e, namely the one from spectrum No. 1442, exceeds the mean of magnetic field by more than $3\sigma = \pm 0.021$ T. As the B_e values are calculated from the line splitting, we checked the "a_1" coefficients (dispersion) of the polynomial regression. Again, no correlation between the extreme value of B_e and a_1 has been seen.

TABLE 2

Sp. No.	ΔRV	ΔRV revised km s^{-1}	B_e	B_e revised T
1436	+ 0.49	+ 0.32	- 0.0895	- 0.1023
1437	+ 0.41	+ 0.70	- 0.0930	- 0.0902
1438	+ 0.35	+ 0.43	- 0.0762	- 0.0484
1439	+ 0.02	+ 0.02	- 0.0694	- 0.0748
1440	+ 1.18	+ 1.50	- 0.0916	- 0.0806
1441	- 1.04	- 1.29	- 0.0657	- 0.0845
1442	+ 0.31	+ 0.12	- 0.0112	- 0.0407
1443	- 0.22	- 0.39	- 0.0786	- 0.1069
1444	- 0.86	- 0.86	- 0.0948	- 0.0589
1445	- 0.02	+ 0.05	- 0.0874	- 0.0740
1446	- 0.77	- 0.61	- 0.0874	- 0.0616

RV(helc) = - 16.4, $\delta = \pm 0.6$, $\sigma = \pm 0.2$ km s^{-1}; $B_e = - 0.0768 \pm 0.0072$ T

The RV and B_e data were subjected to a frequency analysis in a frequency interval 0 - 20 h^{-1}. The methods used were the Fourier transform according to Deeming (1975) and Kurtz (1985) and the phase dispersion minimization according to Stellingwerff (1978) and Nemec and Nemec (1985). Both these methods gave always the same results for every data sets used. Two frequencies, (8.0 ± 1.0) h^{-1} and (12.0 ± 1.0) h^{-1} were indicated in the radial velocity data. The photometric frequency 4.8219 h^{-1} (12.5 min) discovered by Kurtz (1983) lies outside the error interval of those two frequencies.

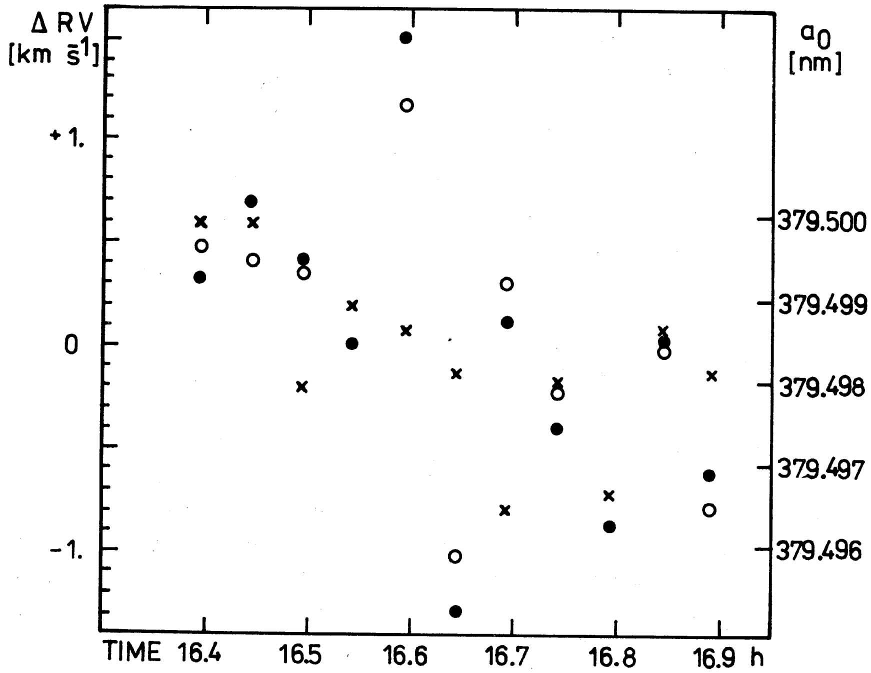

Figure 1. The course of the relative radial velocities. Open circles: values from 403 lines; full circles: revised values from 88 lines; crosses: the "a_0" coefficients of the polynomial regressions.

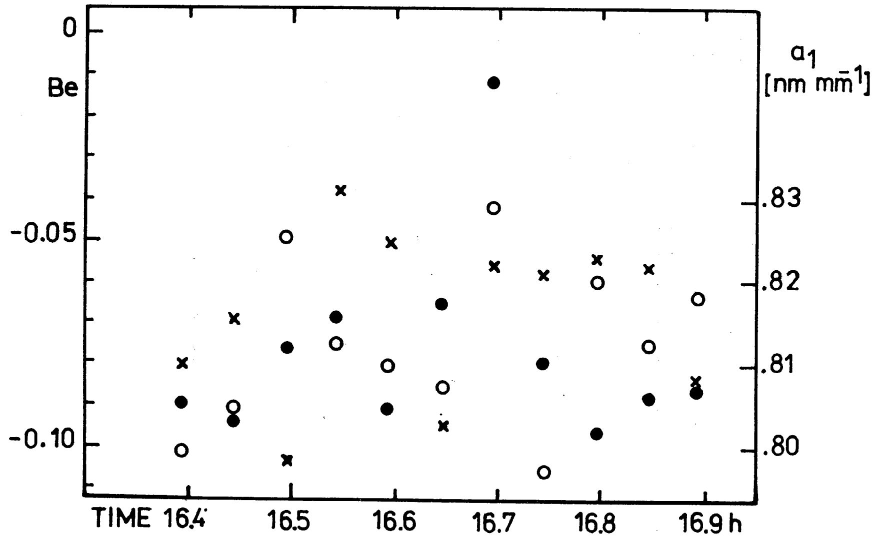

Figure 2. The course of the effective surface magnetic field. The meaning of the symbols as in the Fig. 1.

TABLE 3

Frequencies derived from different data sets

Data set	f_1	f_2
	h^{-1}	
ΔRV	8.0	12.0
ΔRV revised	8.0	12.0
B_e	2.4	5.4
B_e revised	5.4	10.0

Photometric frequency = 4.8219 h^{-1}, Kurtz (1983)

Although the randomization test indicates both corresponding periods as statistically significant, the extreme ΔRV-s in the phase diagrams occur in close phases to other values which in amplitude lie outside of error bars. Consequently, their significance should be considered as formal only, since if the phase diagram reflected an intrinsic variability, the accuracy of RV´s would have to be overestimated and this is an inconsistency. Moreover, there is no known suggestion how could these two periods be related with the photometric one, manifestation of which is searched for.

The frequency analysis of B_e data resulted in two quite different frequencies, (2.4 ± 1.0) and (5.4 ± 1.0) h^{-1}. The first value almost exactly corresponds with the half of the photometric frequency, the second one´s error interval comprises the photometric frequency. Thus, these variations of B_e might reflect some relation to the photometric oscillations. But the diversity of the results from RV and B_e casts in some extent doubts on our material. Therefore we reanalyzed the initial data. The original idea was to measure as many as possible lines to decrease internal errors of resulting values of RV and B_e. Thus, many blends and possibly missidentified weakest lines could have got into our final collection. Therefore we thoroughly

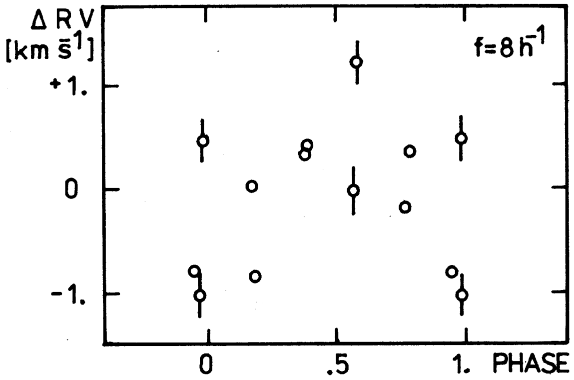

Figure 3. The phase diagram of the relative radial velocity values in the period of 7.5 mins (f = 8 h^{-1}).

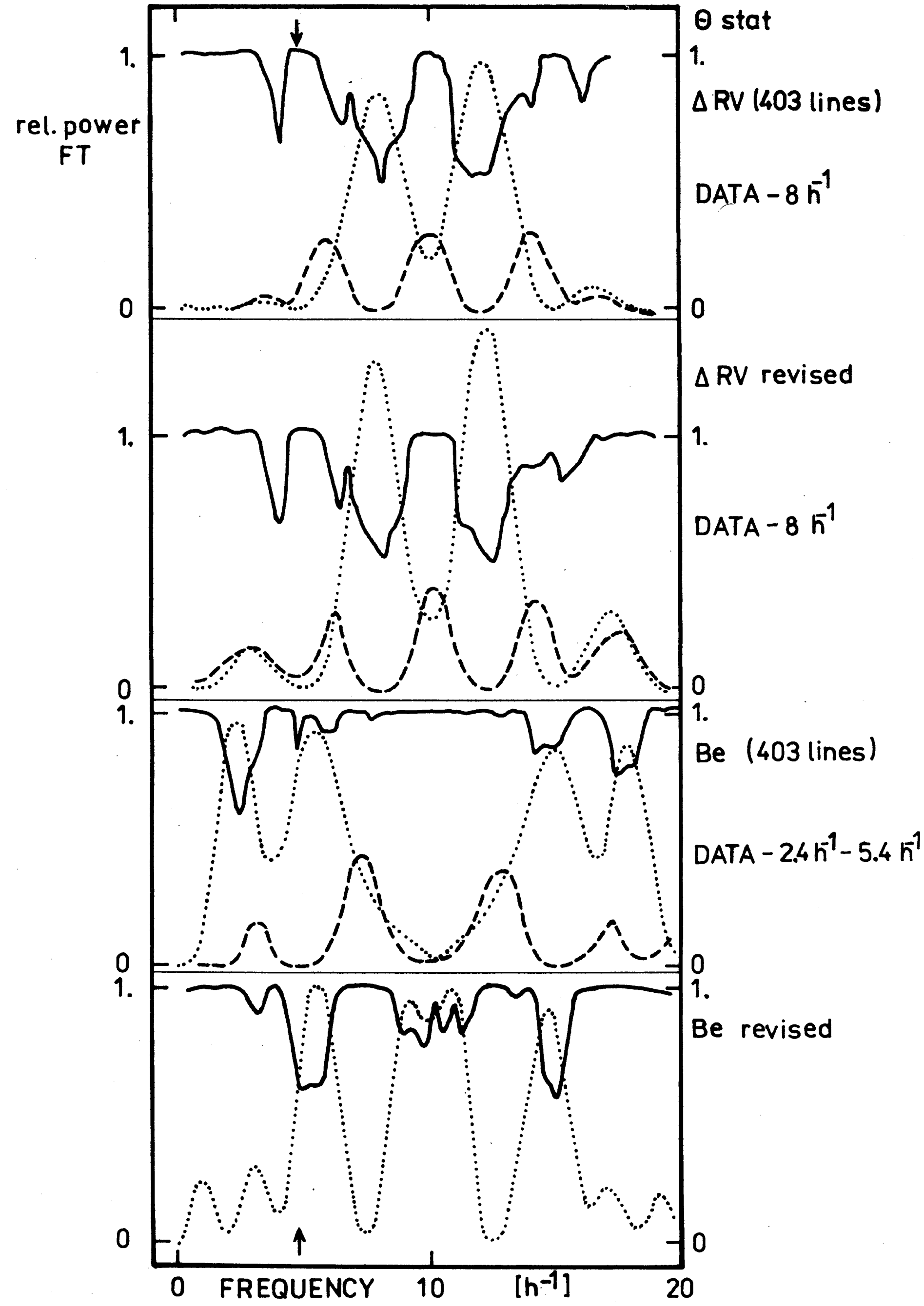

Figure 4.The result of the frequency analyses of the individual data sets.The abscissa is the frequency in h^{-1}, the ordinate is the relative power for the Fourier transform (FT) and the Θ - statistics for the phase dispersion minimization method (PDM). Dotted line: the power spectrum (PS) after the FT, full line: the Θ- statistics after the PDM, dashed line: the PS after removing the frequency labelled from the data.

re-checked all those 403 lines by means of two intensity tracings. One of them was performed using a high microdensitometer slit recording both the polarizations in one trace, the second was only record of one polarization. This enabled us to differentiate between blends and splits. The final list included 88 lines, 74 of them occur on all 11 spectrograms, 14 remaining lines occur at least on 10 spectrograms.

New frequency analysis left the results from RV unchanged. As for magnetic field, the value of 5.4 h^{-1} kept apparent, the half-frequency, 2.4 h^{-1} was not indicated and new one, (10.0 ± 1.0) h^{-1} appeared. Inside the last value error interval lies the double of the photometric frequency 9.6 h^{-1}. However, neither by careful selection of the stellar lines we succeeded to bring the results from the radial velocities and the magnetic field measurements into agreement. The results of our frequency analyses are displayed on Figure 4. Arrows indicate the photometric frequency.

Even when the instrumental and processing errors have been estimated to be $\approx$0.5 km s^{-1} in total, their verification through a comparative study on an RV-standard star material obtained with the same instrumentation would be desirable.

3. CONCLUSIONS

Although there are some indications of variability of B_e related to the photometric oscillation, our data do not allow to deduce any conclusive results. This mainly stems from the fact that our spectroscopic material covers no more than two photometric periods. The accuracy attainable might be sufficient unless some instrumental effects do not occur during observations. But sufficiently long time-base is of importance. For example, consider the photometric material obtained by Kurtz (1983). In the longest runs the night´s standard errors were 2.2 - 5.4 mmag. The semiamplitude of the discovered 12.5 mins oscillations was 0.8 - 1.4 mmag. If one took any segment of duration 0.5 h from his photometry, the analysis would certainly result in a similarly puzzling pattern as our spectroscopy does. Moreover, a dependence between amplitudes of photometric and radial velocity or magnetic field oscillations can play a serious role. Matthews et al. (1988) observed an roAp star HR 1217 simultaneuously photometrically and spectroscopically. When the photometric amplitude was 1.8 mmag (compare with 1.3 mmag in B found by Kurtz (1983) in gamma Equ !), no radial velocity changes larger than 130 m s^{-1} were seen as well as no periodicity. The following night, the photometric amplitude was 6.8 mmag and clear periodic variations of amplitude 400 m s^{-1} appeared. Our conclusion is that spectroscopic observations on a time-base comparable with the Kurtz´s (1983) photometry would be desirable to detect a microvariability of radial velocities and effective surface magnetic field of roAp star gamma Equilei. A classical spectroscopy would certainly overwhelm a man´s ability. Other, more effective techniques are needed to continue this program.

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