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Linear polarization of monochromatic oscillations in optical spectrum of the intermediate polar PQ Geminorum*

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Abstract. We report the results of optical dynamic spectropolarimetry of the intermediate polar PQ Gem (RE 0751+14), which were obtained with the help of the linear polarization analyzer and the BTA scanner in a high time resolution mode (32 ms) at the 6 m telescope on November 19, 1996. Narrow–band spectral oscillations in the vicinity of the spin period (13.9 min) have been investigated. The dependence of the power of oscillations on the wavelengths (3800–5200 Å, 1 Å/channel) and periods of pulsations in the region 300–2000 s with a mean resolution along the period 10 s has been calculated. Power spectra have revealed strong (amplitude $\approx 20\%$), polarized (dominating in one of the orthogonal polarizations), monochromatic (FWHM in power spectra 2–3 Å) oscillations with periods of 13.3–15.2 min mainly in the profiles of emission lines. The strong dynamic linear polarization (70–80%) with the already detected strong dynamic circular polarization (60–90%) of the monochromatic oscillations make practically impossible any interpretation of the oscillations in the frame of conventional physics.

Key words: stars: individual: PQ Gem= RE 0751+14 – stars: magnetic fields – stars: rotation – stars: oscillations – X-rays: stars

1. Introduction

PQ Geminorum (RE 0751+14) is a member of the intermediate polar subclass of cataclysmic variables discovered in the extreme–ultraviolet (70–200 Å) all–sky survey by the UK Wide Field Camera on the ROSAT satellite (Mason et al. 1992). Intermediate polars (IPs) or DQ Her stars are close binary systems which consist of a magnetic white dwarf accreting matter from a law mass companion star. The principal criterion for membership in this class (IPs) of stars is the presence of a rapid, highly coherent periodicity in a light curve, usually observed at the optical or X–ray wavelengths (Patterson 1994). Photometric observations have detected a 13.9 min period of variation of the light curves (Helditch & Bell 1994; Hellier et al. 1994). Polarimetric observations (Piirola et al. 1993, Potter et al. 1997) have revealed significant the circular and linear polarization modulated with a 13.9 min period in the V to K bands. The periodicity (13.9 min) was attributed to the rotation period of the white dwarf in the system. An ephemeris for this pulsation, which is quasi–sinusoidal in the blue and double–peaked in the red, was presented by Hellier et al. (1994). X–ray and optical timings of the spin period show its increasing on a time–scale of 2.4×10^5 years (Mason 1997). An additional period of 14.5 min in the light curves implies an orbital period of about 5–6 hours. Optical spectral observations have shown a variability of the V/R ratio of emission lines over the spin period (Rosen et al. 1993). The emission lines show complex changes over the spin cycle (Hellier 1997). Our previous spectral and spectropolarimetric (with the circular polarization analyzer) observations of PQ Gem (Somov et al. 1997, 1998) discovered statistically significant (the probability of random signal is as low as 10^{-13}) perturbations of spectral composition of the photoelectron noise in the narrow wavelength passbands (1 Å). Power spectra have revealed strong (amplitude up to 40%), circularly polarized (dominating in one polarization) monochromatic (FWHM in power spectra 2–3 Å) oscillations with periods of 13.3–15.2 min in the vicinity of the spin period of the white dwarf (13.9 min) mainly in the profiles of emission lines with the time of life 3000–5000 s. The wavelengths of the oscillations correspond to the radiation of atoms in strong resonance magnetic fields (quadratic Zeeman effect).

The strong magnetic fields indicate that the sources of radiation causing the oscillations are in the accretion column of the white dwarf. The conclusion was drawn that the physical nature of the sources of the oscillations and their radiation cannot be explained in the frame of a conventional physics. This conclusion makes the monochromatic oscillations in spectra of PQ Gem very interesting for further studies.

The purpose of the paper is to investigate linear polarization characterisics of the monochromatic oscillations in the vicinity of the spin period (13.3–15.2 min) of PQ Gem.

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* Based on observations from Special Astrophysical Observatory of Russian Academy of Sciences, Russia.

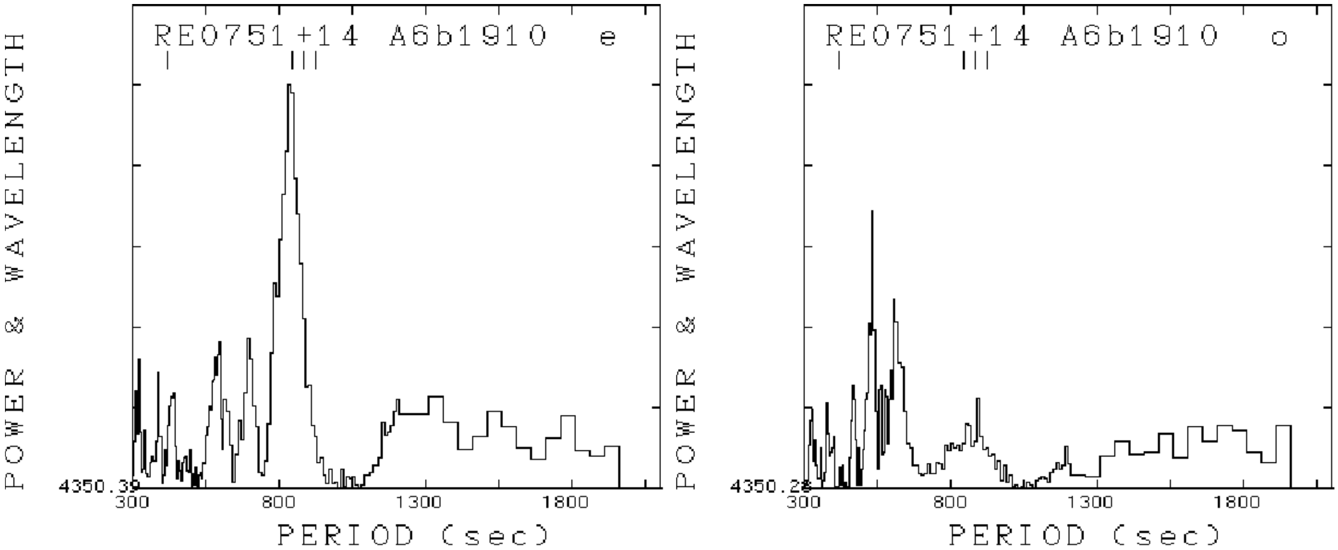

Fig. 1a and b. Monochromatic power spectra in the red wing of the Hγ emission line in the orthohonal polarizations

Table 1. Journal of the observations of PQ Gem

Date	Filename	Start UT time	Exposure (sec.)
11/19/96	a6b19.10	23:25:33	5411
11/20/96	a6b19.11	01:24:16	4470

2. Observations and data reduction

RE 0751+14 was observed at the Special Astrophysical Observatory (Nizhnij Arkhyz, Russia) on November 19 1996. Spectroscopic observations were performed using the SP–124 spectrograph at the Nasmyth secondary focus of the 6 meter Bolshoi Azimutal Telescope, BTA, (Ioannisiani et al. 1982). The spectrograph was equipped with a 1200 lines/mm grating giving a dispersion of 50 Å/mm. A television scanner with two lines of 1024 channels recorded the spectra in two orthogonal linear polarizations simultaneously in a photon–counting mode (Somova et al. 1982; Drabek et al. 1986; Afanasiev et al. 1991).

In this mode of observations the linear polarization analyzer (Najdenov & Panchuk 1996) was installed in front of the slit of the spectrograph and two spectra were recorded. The sky was observed between the exposures. A 2–arcsecond slit was used. The spectra in the wavelength passband ≈ 1000 Å in the range 3900–5200 Å with a dispersion of 1 Å/channel were obtained with a temporal resolution of 32 ms. The spectra were recorded continuously, and between the exposures a He–Ne–Ar lamp was measured for the wavelength calibration. The journal of our observations is presented in Table 1.

The data reduction was performed with the help of a special algorithm. The description and mathematical justification of the algorithm are given in Somov et al., (1998). We present here only a short description of this method. As a result of each exposure, a file with the coordinates (2x1024 channels) and the time of registration (resolution 32 ms) for every photoelectron was written on hard disk in the computer. The range of the investigated periods from 300 s to 2000 s was chosen. The resolution along the period was 5 s in the range from 300 s to 600 s, 10 s in the range 600–1200 s and 50 s in the range 1200–2000 s.

For each period
(300 s, 305 s, ..., 600 s, 610 s, ..., 1200 s, 1250 s, ..., 2000 s)
the spectra with the time of acquisition
(30 s, 30.5 s, ..., 60 s, 61 s, ...,120 s, 125 s, ..., 200 s)
were extracted from the original spectral data (the file with the parameters of photoelectrons) and folded in ten bins. For each bin, each spectrum was divided by the continuous spectrum. Then we calculated the power, amplitude and phase of the oscillations in relative units (the level of continuous spectrum is equal to 1) for each channel (wavelength). The algorithm was realized in the last version of the special programming language SIPRAN (Somov 1986). The integral spectrum was calculated by simple integration of photoelectrons. The wavelength calibration (Kopylov et al. 1986) was made with the help of the He–Ne–Ar lamp. The result of data reduction is the dependence of the power of oscillations on the period (periodogram) and on the wavelength (spectrum), but we will name it a power spectrum

for simplicity. In our case of spectropolarimetric observations two power spectra were calculated, respectively. Observations of standard stars (sun–like star, spectral standard stars without emission lines) and other intermediate polars were used to control the instrumental effects. To distinguish the difference between our method of observations and data reduction and classical methods we use the word “dynamic” for our case.

3. Results and discussion

Significant narrow–band deviations of the linear polarization were not detected in the integral spectra.

Examples of the monochromatic power spectra (the dependence of power of oscillations on period at the selected wave-

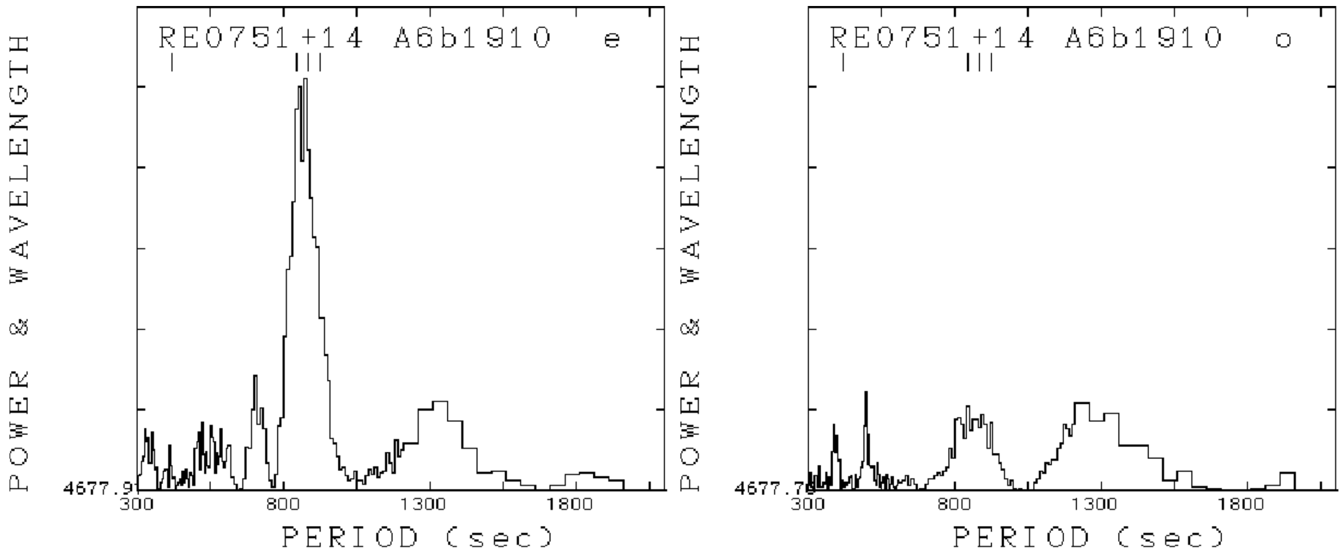

Fig. 2a and b. Monochromatic power spectra in the blue wing of the HeII 4686 Å emission line

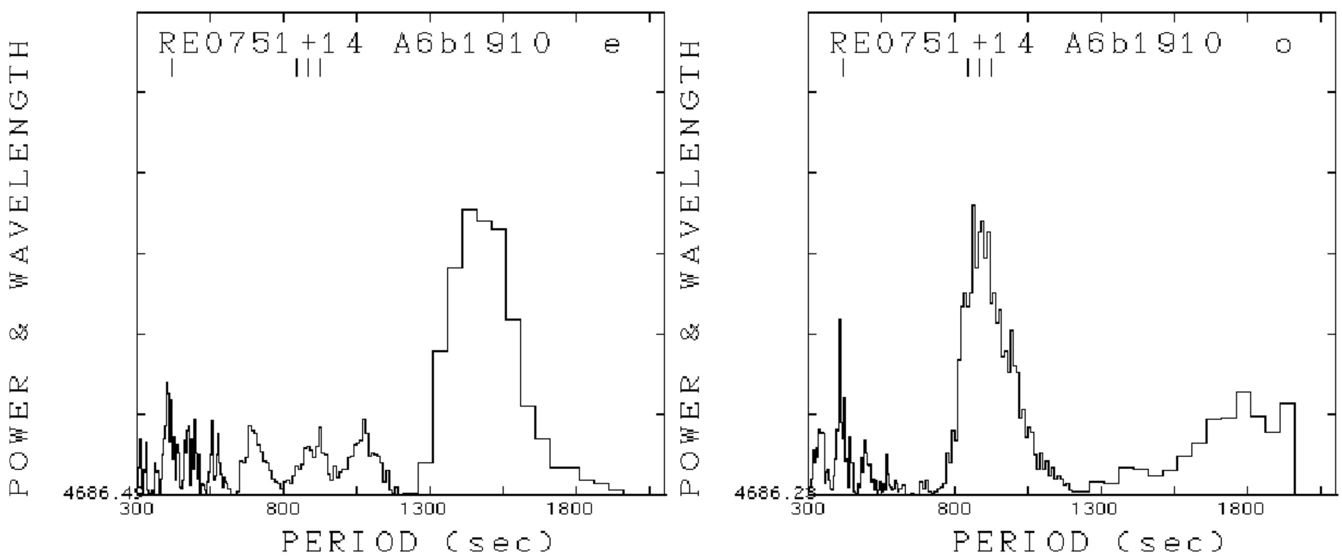

Fig. 3a and b. Monochromatic power spectra near the peak of the HeII 4686 Å emission line

length) from one exposure, but in the red wing of the emission line Hγ at the wavelength 4350 Å in the profile of the HeII 4686 Å emission line at the wavelengths 4678 Å and 4686 Å are demonstrated in Figs. 1a,b, 2a,b, 3a,b. In all Figs. 1–3 the left and right parts correspond to the orthogonal linear polarizations which are designated by "o" and "e", respectively. The scale of power is in arbitrary units but the same for all figures. The marks in the upper part of the figures correspond to the frequencies $2\omega, \omega, \omega - \Omega, \omega - 2\Omega$, where ω and Ω are the spin and orbital frequencies respectively.

To determine the statistical significance of features in power spectra, an individual power spectrum section along wavelength was normalized to the mean standard deviation (σ) from the mean value and multiplied by 2. In this case an individual power spectrum section has as conventional FFT power spectra (Bonnet-Bidaud et al. 1996), from pure statistics, an expected mean value of 2 with the mean standard deviation (σ) of 2 and power values are distributed according to χ^2 distribution with 2 degrees of freedom (see van der Klis 1989). We assumed that the powers of oscillations in the adjacent channells are independent. The observations of standard stars and the cases of the absence of features in power spectra of objects show that this approximation is satisfactory. The oscillations are readily seen to be strongly polarized. We use a formal measure of dynamic linear polrization P_d which will characterize the observed oscillations as

$$P_d = \frac{P_o - P_e}{P_o + P_e} \cdot 100\%, \qquad (1)$$

where P_o and P_e are the powers of the oscillations in the orthogonal polarizations at the same period and at the same wavelength (Somov et al., 1998). This formal measure of polarization for the spin period and for the wavelength 4677.8 Å is equal to

-70% and for the wavelength 4686.4 Å it is equal to 80%. The amplitude of oscillations is $\approx 20\%$ and stastistical significance or the probability of random signal is equal to $\sim 10^{-12}$.

If we compare the results of detection of monochromatic oscillations with the linear (this paper) and circular (Somov et al.,1998) polarization analyzers then the absence of a significant difference becomes evident. Such a behaviour of the oscillations makes it practically impossible to explain radiation of the sources of monochromatic oscillations by the classical electromagnetic waves or photons.

To the already mentioned energetic problem (Somov et al.,1998) in interpretation of the oscillations (absence of significant features in integral spectra at the wavelengths of the monochromatic oscillations) we add the polarization problem or the absence of a significant difference between the linear and circular dynamic polarizations. Both problems or unusual properties of the oscillations are selfconsistent. According to our hypothesis (Somov et al., 1998), the first problem or property means that the source of oscillations is invisible like a black hole or an object with the radiation temperature very close to zero. The second property confirms the first one and means that we cannot consider (as it must be for black holes) classical electromagnetic waves or photons as radiation of the sources of the monochromatic oscillations. We believe that only the invocation of two new physical realities which are electromagnetic waves with the Pointing vector equal to zero as the physical counterpart of waves of probability in quantum mechanics (the hairs) and the black holes can explain these oscillations.

It is interesting to note that monochromatic pulsations were observed in ultraviolet spectra at another telescope (HST) too. Evidence was found for a stronger pulsation (amplitude $\approx 15\%$) within a narrow (0.25 Å) segment of the broad 1242.8 Å Nv component in the ultraviolet spectrum of the Her X–1 system, only at the orbital phase 0.8 (Boroson et al.,1996). We believe that physical nature of the monochromatic ultraviolet oscillations in the pulsar and the monochromatic optical oscillations in the intermediate polar is the same and the ultraviolet oscillations can be considered as an additional indication of existance of strong magnetic fields in the Her X–1 system.

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