Long-term photometric behaviour of symbiotic system AG Dra

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Abstract. The general behaviour of the symbiotic system AG Dra was studied in the context of the long-term photometry and radial velocity analysis. The analysis of new and historical photometric data as well as radial velocities confirmed the continued presence of the second period, found by our previous analysis, which could be due to pulsation of the cool component of the AG Dra binary system. The discussion about very probable resonance of the orbital and pulsation periods as a general cause of the recurrence time of the active stages is also presented.

1. Introduction

AG Dra is a symbiotic binary, containing a fairly cool giant of spectral type K4 III or earlier (Kenyon & Fernandez-Castro, 1987), the luminosity class being rather I b or II according to Zhu *et al*. (1999). The other component is believed to be a hot white dwarf. Parameters for this system were derived by Mikolajewska *et al*. (1995). This object has quiescent and active stages; the latter may be explainable by increased thermonuclear burning of a white dwarf, accreting from the wind of the cool component.

In previous studies a second period in addition to the orbital period of 549.7 days has been found for the symbiotic binary AG Dra. Such a period of about 350 days was indicated in our work using photometry (Friedjung *et al*. 1998, Petrík *et al*. 1998), which is somewhat less than the photometric second period of 378.5 days found by Bastian (1998). Our later study of radial velocities (Gális *et al.* 1999) also indicated a second period of 355.3 days. It was suggested that the second period could arise due to pulsations of the cool giant component of the binary. Moreover it turned out that the epochs of major symbiotic activity started at times when the variations of radial velocity with both periods had simultaneous negative maxima. An explanation was suggested by Gális *et al*. (1999), involving non-radial pulsations of the cool component, leading to higher accretion rates by the white dwarf component at certain times.

Fekel *et al*. (2000) used Fourier transform spectra to measure radial velocities, finding no second period for AG Dra. We re-analysed radial velocity measurements of Fekel *et al.* (2000) to test for the continued presence of the second period Friedjung *et al*. (2003). The Fekel data by themselves marginally suggested the presence of the pulsation period, though they were only obtained over a short time interval at similar phases of that period. The second period was in any case clearly seen when all radial velocities were combined.

At the same time Van Hamme & Wilson (2002) proposed fluorescence model for AG Dra and they confirmed presence of 355-day variations in light as well as radial velocity curves.

Recently the object was photometricaly observed by Skopal *et al.* (2002), Skopal *et al.* (2004) and Leedjärv *et al.* (2004). In the last of mentioned papers is presented study of emission line spectrum of AG Dra.

We have added radial velocity measurements of Iijima & Viotti (2003) to previously studied ones to test for the presence of the second period. The new photoelectric and CCD photometry was used to study the photometric behaviour of AG Dra during 12 years long activity stage.

2. Observations

The new photoelectric and CCD observational material has been obtained at observatories Skalnaté Pleso (SP), Stará Lesná (SL), Valašské Meziříčí (VM), Greve and Vallinfreda, Italy (It). At the observatories SP and SL identical Cassegrain telescopes with a diameter of 60 cm were used. The one-channel photoelectric photometers with digital converters were used, as well as standard UBVR Johnson's filters. The same software (Komžík 1998) has been applied for the reduction of the observations at these observatories. Schmidt-Cassegrain (280/1765) equipped with CCD ST-7 and set of VR filters was used at VM observatory. Since JD 2 450 563 to 2 451 179 was used photographic films as a detector. At Italian observatories were used the 30 cm, F/4.5 telescope at Greve (Firenze), and the 50 cm, F/4.5 telescope at Vallinfreda (Roma). Both telescopes are equipped with an SBIG ST6 CCD detector and set of BVRI filters. The number of observational nights, observational intervals in date as well as in Julian date for particular observatories are listed in Table 1.

Table 1.: The distribution of observations at particular observatories.

Observatory	Interval	Interval in MJD	Number of nights
SP+SL	May 18, 1999 - Dec. 8, 2003	51 317 – 53 900	90
VM	Apr. 24, 1997 – Oct. 5, 2002	50 563 – 53 485	151
It	July 31, 1994 – Jan. 18, 2003	49 565 – 52 653	124

Moreover we used the same data as it has already been analysed and discussed in our previous paper (Gális *et al.* 1999) as well as recently published photoelectric UBVR photometry by Skopal *et al.* (2002), Skopal *et al.* (2004) and Leedjärv *et al.* (2004).

The high dispersion spectroscopic observational material consisting of 120 radial velocity values having relatively a very high precision (0.4 - 0.8) $km.s^{-1}$ discussed in this paper, has been extracted from Mikolajewska *et al.* (1995), Smith *et al.* (1996), Tomov & Tomova (1997), Fekel *et al.* (2000) and Iijima & Viotti (2003). All radial velocity data have been determined using spectral absorption lines formed in the atmosphere of the red giant. The data cover incompletely the time interval from JD 2 446 578.5 to JD 2 451 676.9, but with good over-sampling of individual sets.

Moreover intermediate dispersion spectroscopy of AG Dra was carried out at the Tartu Observatory in Estonia. The data used in this paper cover the interval from September 11, 1997 to October 10, 2004. Altogether 131 spectra of AG Dra were used for period analysis. The spectroscopic material was taken by the 1.5 m telescope equipped with the Cassegrain grating spectrograph. Until March 1999, the spectra were registered by the Spectra Source Instruments CCD camera HPC-1 (Tek 512 x 512 chip, pixel size 24 x 24 μm, Peltier cooled). Since March 1999 the spectra were obtained with the cryogenically (liquid nitrogen) cooled CCD camera Orbis-1 of the same company (Tek 512 x 512 chip, pixel size 24 x 24 μm). The majority of the spectra were recorded in two spectral regions which we call red and blue. Red spectra were taken with dispersion of 28 Å/mm at Hα and they include emission lines of Hα, He I λ 6678 and the Raman scattered O VI line at λ 6825. The blue spectra include at least emission lines of Hβ, He II λ 4686 and He I λ 4713. The linear dispersion of the blue spectra is about 36 Å/mm at Hβ. The typical exposure times were 5 – 15 min for the red spectra and 25 – 35 min for the blue spectra. The spectra were reduced using the software package MIDAS provided by ESO. The wavelength-calibrated spectra were normalized to the continuum and positions, peak intensities and equivalent widths (EW) of the emission lines were measured.

3. Morphology of the light curve between the years 1890 and 1966

First historical photometric observations date to the end of 19th century. Robinson (1969) carried out an analysis of the photographic light curve of the period from 1890 to 1966. During this period the AG Dra system underwent 2 active phases: the first between the years 1931 and 1939, the second between 1949 and 1955. At the end of 1964 and beginning of 1965 a single outburst was observed. It might have been a precursor for another active phase that is not covered by this light curve. In total, we recognize 14 outbursts in this period: seven during the first active phase, six during the second one and the last outburst in 1964 - 1965.

We present results of a re-analysis of these data with contemporary methods. We divided the light curve (Figure 1) into quiescent and active phases and carried out a preliminary period analysis independently for each phase. We utilized the Fourier harmonic analysis and the phase dispersion minimization method. Both approaches gave consistent values of periods. We present the results of this analysis for the given phases in Table 2. We can conclude that the historical light curve shows both of the known periods: $\approx$ 550 days (orbital period) and $\approx$350 days (the period of pulsation of the red giant) (Galis *et al.* 1999).

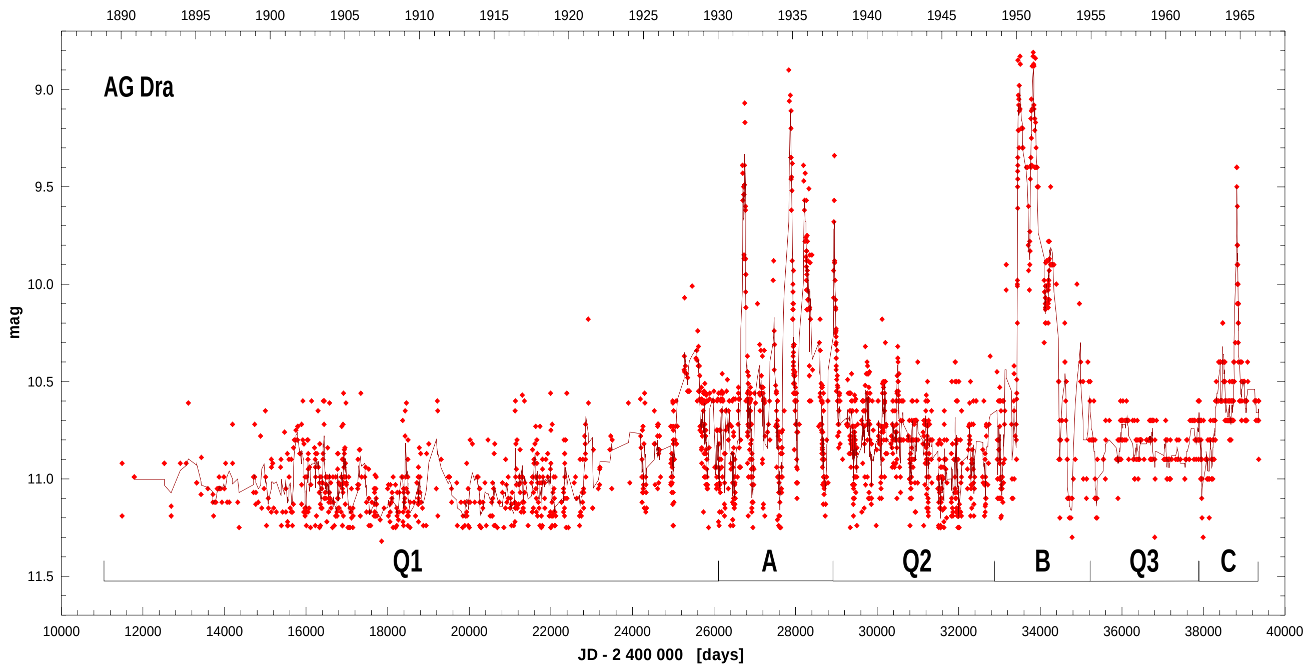

Fig. 1 Historical LC of the symbiotic system AG Dra in V colour. The solid line represents 5 data point averages.

Between the years 1890 and 1927 (stage *Q1*) was AG Dra in a quiescent state with mean magnitude m = 11.02 mag. Small variations of brightness revealed the presence of both mentioned periods. After this at least 37 years lasting quiescence, the system went into an active stage (A). Until year 1938 we can recognize seven major outbursts occurring approximately every 300 - 400 days. The individual outbursts have rather steep rise to maximum and a fast decline. The first peak from the year 1932 has a secondary maximum following the first after $\approx$ 50 days. The system reached maximal brightness of 8.9 mag during the fourth outburst. The following almost 11 years were again quiescent stage with only small semi-regular variations with period $\approx$ 400 days (Luthardt, 1990). These variations might have drowned the two expected periods. An epoch of intense activity was observed between the years 1949 and 1955 (stage *B*). The light curve reveals that the overall morphology of this stage is rather different from that of phase *A*. The peaks have a similarly steep rise to the maximum with the maximal achieved brightness 8.81 mag.

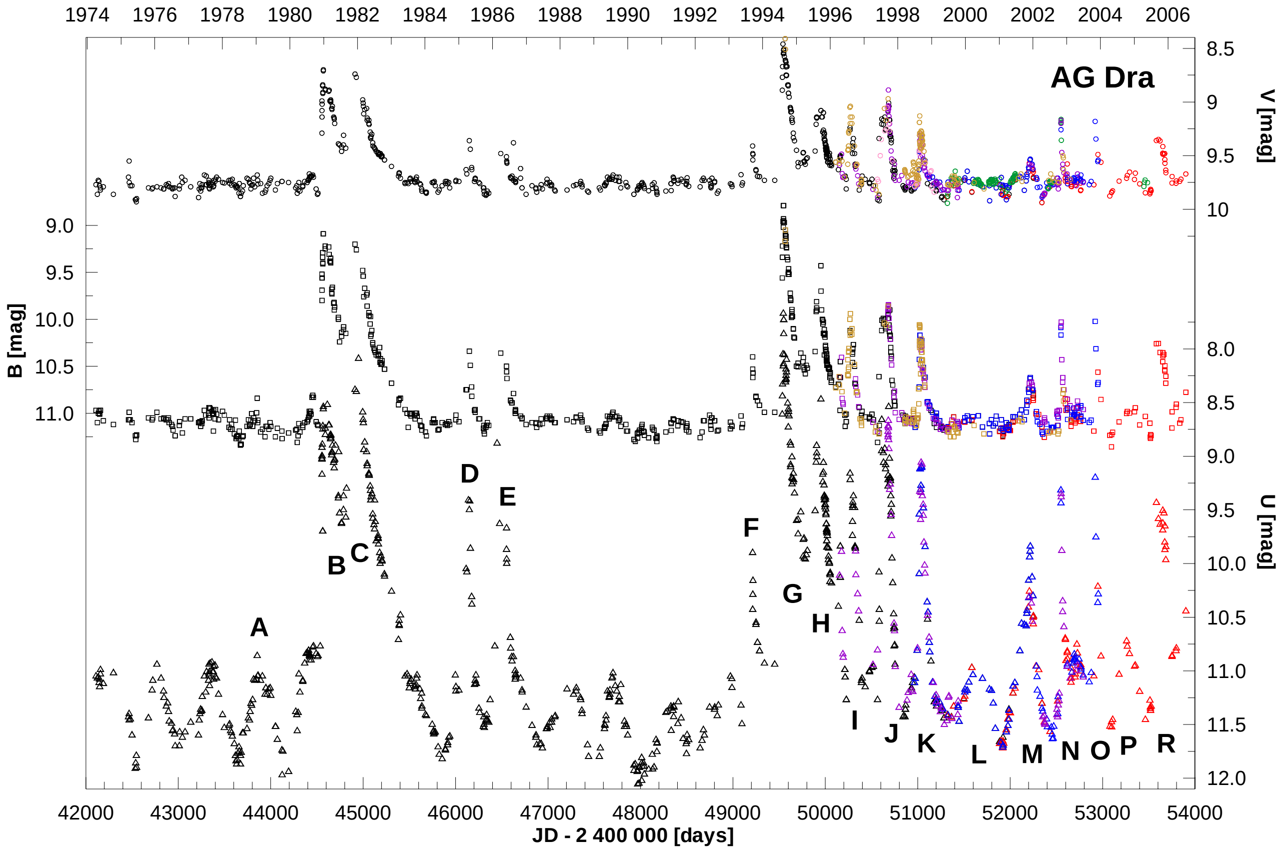

Fig. 2 Historical photoelectric and CCD LCs of the symbiotic system AG Dra in U, B and V colours.

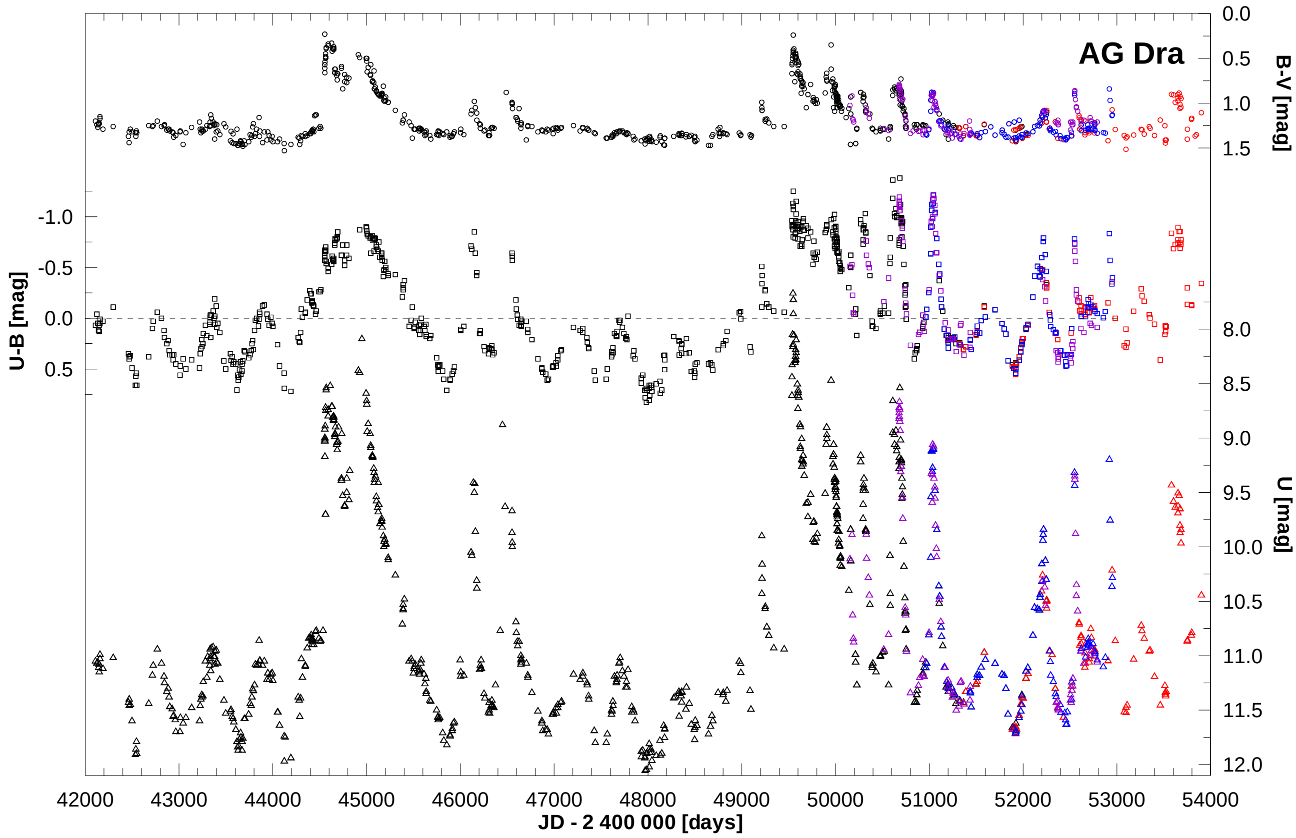

Fig. 3. Indices (U-B) and (B-V) depicted against the light curve in V colour.

The decrease is considerably slower and unlikely to phase *A* the system spends most of this period above 10.5 mag. The maxima follow each other after ≈ 350 days. The second and third outburst might have again secondary maxima approximately 50 days after the primary ones. Stage *Q3* (1955 - 1963) was without significant activity. After year 1963 we can see that the system became disturbed, having a higher mean magnitude than during quiescent stages. It seems that the system undergo the activity since the end of 1964. Period analysis of these last 11 years (stages Q3 and C) confirms the presence of the 350 days period, but the 550 days period is not really observed in this band.

Table 2. Results of the period analysis of historical light curve of AG Dra. T_{start} marks the beginning and T_{end} the end of the given stage. During stages Q1, Q2 and Q3 was the system quiescent whereas stages A, B and C are active.

Stage	T_{start}	T_{end}	Significant periods [days]
Q1	2 411 500	2 42 5000	546.9 ± 3.1, 348.3 ± 1.5
A	2 425 000	2 429 200	375.1 ± 1.3, 530.9 ± 2.7
Q2	2 429 200	2 433 100	399.9 ± 2.7
B	2 433 100	2 435 100	349.4 ±4.8
Q3	2 435 100	2 438 200	374.3 ± 4.0, 509.4 ± 11.1
C	2 438 200	2 439 400	361.0 ± 5.9

4. Analysis of photometric behaviour during activity

Our long-term aim of study of interacting binaries is better understanding of basic physical processes running in internal parts of these binaries. In this paper we try to describe mainly the outburst activity of AG Dra, which has begun in 1994 and continues to present time. For this reason we selected all available photometric data as mentioned above and depicted historical light curves in three colours which homogeneously have covered time interval of three decades since 1974 (see Figure 2). Moreover we constructed the colour indices (U-B) and (B-V) that are depicted against the light curve in V colour in Figure 3. On the historical light curve in Figure 1 we assigned all outburst events and selected maxima by letters in alphabetical order. For each outburst we chose few essential points, which describe truly shape and intensity of individual events. All colour indices are depicted in two-colour diagrams in Figure 4 while only chosen points are connected by lines.

Particular events are distinguished by corresponding letter as well as by colour of line. The numbers close to letters in these diagrams express chronological evolution of particular outbursts. The curve represents relation of intrinsic colour indices $(B\text{-}V)_0$, $(U\text{-}B)_0$ for zero age main sequence stars (Lang, 2002). This approach of outburst activity study allows better understanding of behaviour of individual events. Result of this method is identification of two or three types of outbursts:

The first type are the main outbursts (events B, C and G), in which object blued about 1.2 mag in (U-B) and about 1 mag in (B-V) indices. The paths of these events are arcs, which follow the shape of the relation of intrinsic colour indices for ZAMS stars.

The second type is the most typical outburst (events D, E, F, M, N, O and more intense events I, J and K). The object blues up to 1.2 mag for events D, E, F and up to 1.4 mag for more intense cases in (U-B) index, but only about 0.5 mag in (B-V) index. The path of these events is roughly the straight line.

Event H seems to be intermediate type between both mentioned ones.

Variation *A* is only simple orbital modulation and its path in two-colour diagram is a small loop. The similar behaviour is in L case. The object blued about 0.6 mag in (U-B) and only 0.1 - 0.2 mag in (B-V) indices.

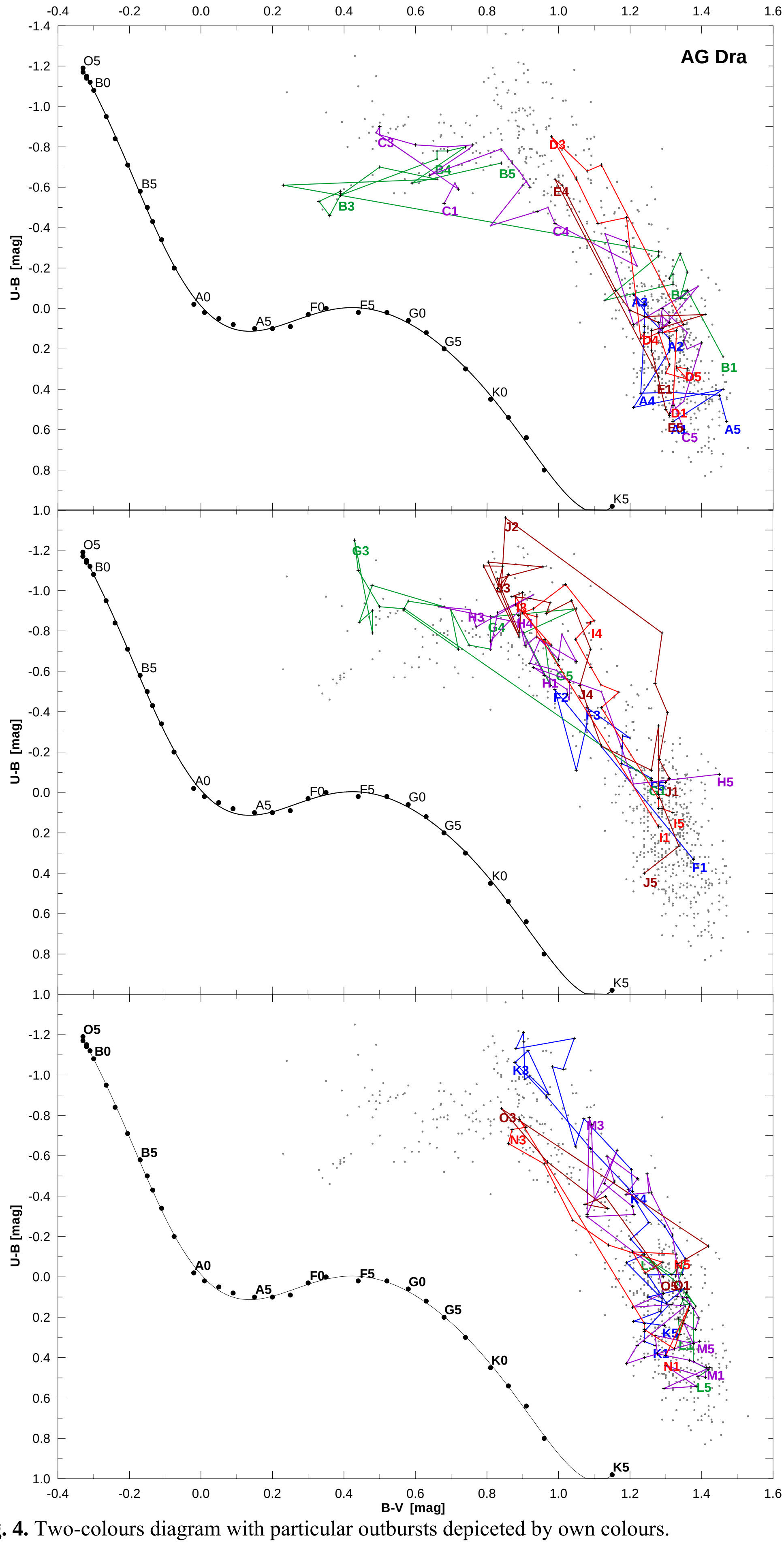

Fig. 4. Two-colours diagram with particular outbursts depicteted by own colours.

5. Analysis of radial velocities

For the period analysis of the radial velocities we used the method of Fourier harmonic analysis (Andronov 1994), which fits the first harmonic term of a trigonometric polynomial to the data. For verification of the results the method of Fourier analysis (Deeming 1975, Kurtz 1985) was used.

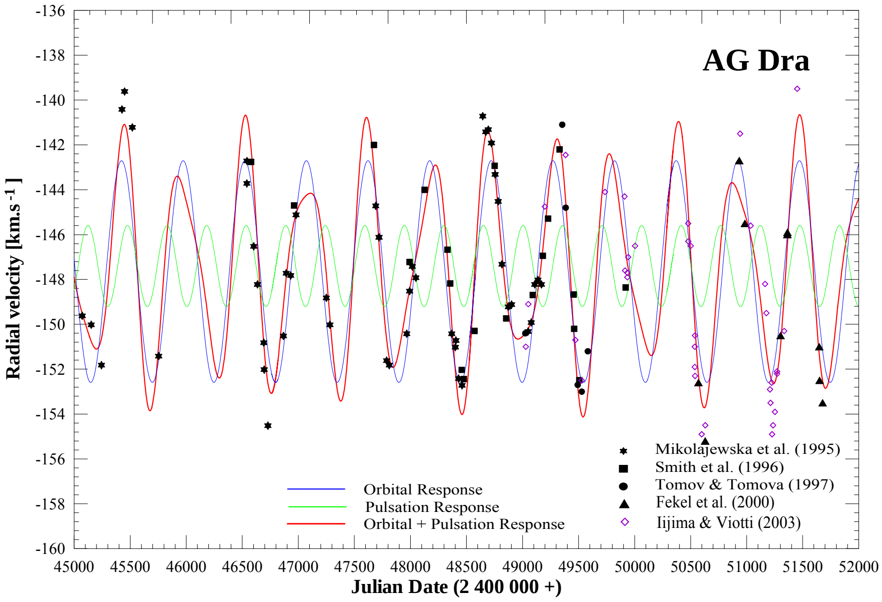

Fig. 5. Radial velocities and synthetic curves for responses presented.

The results of period analysis of AG Dra radial velocities taken from original data of Iijima & Viotti (2003) are two significant periods. Period P_{orb} = (558.2 ± 7.0) days represents the orbital variations of radial velocities and period P_{pul} = (355.2 ± 4.0) days, which in our opinion represents the pulsation of the cool component of AG Dra. This pulsation period is in good agreement with our previous values (Gális *et al.* 1999, Friedjung *et al.* 2003). In view of the last results we have combined the measurements of Iijima & Viotti (2003) with those used by Friedjung *et al.* (2003).

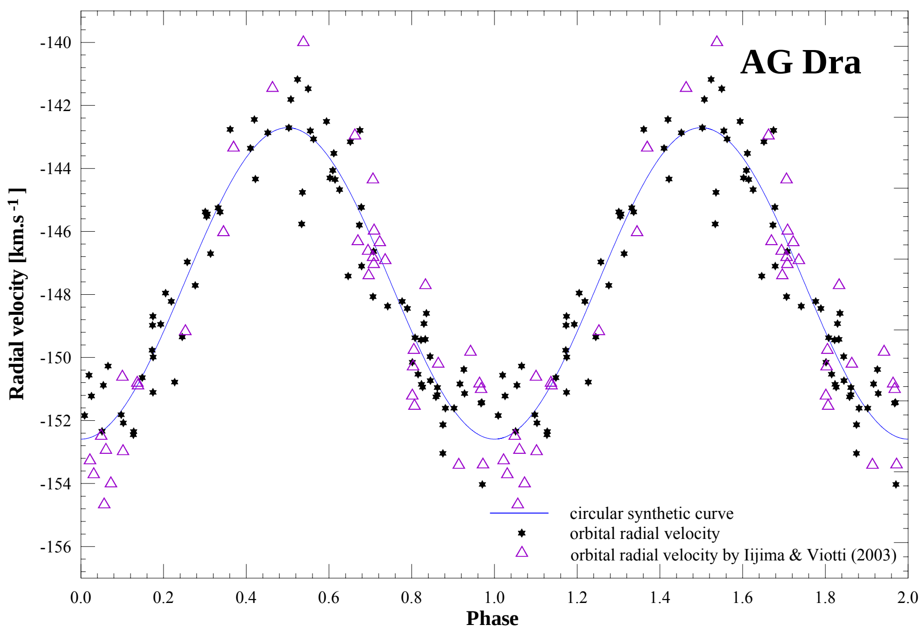

Fig. 6. Phase diagram of orbital radial velocities. Data by Iijima & Viotti (2003) are depicted individually.

Using iteration method we have improved the parameters of orbital motion and pulsation. This period analysis yields the parameters for constructing the synthetic radial velocity curves, which are depicted in Figure 5. The curve of orbital response is described by the following parameters: γ = (-147.6 ± 0.1) km.s^{-1}, K = (4.9 ± 0.2) km.s^{-1}, P = 549.^{d}8 ± 0.^{d}8, JD_{max} = 2 448 996.^{d}4 ± 2.^{d}8 and is depicted by the blue line. The curve of pulsation response is given by the parameters as follows: γ = (-147.4 ± 0.1) km.s^{-1}, K = (1.8 ± 0.2) km.s^{-1}, P = 352.^{d}8 ± 1.^{d}1, JD_{max} = 2 449 181.^{d}0 ± 5.^{d}8 and is depicted by the green line.

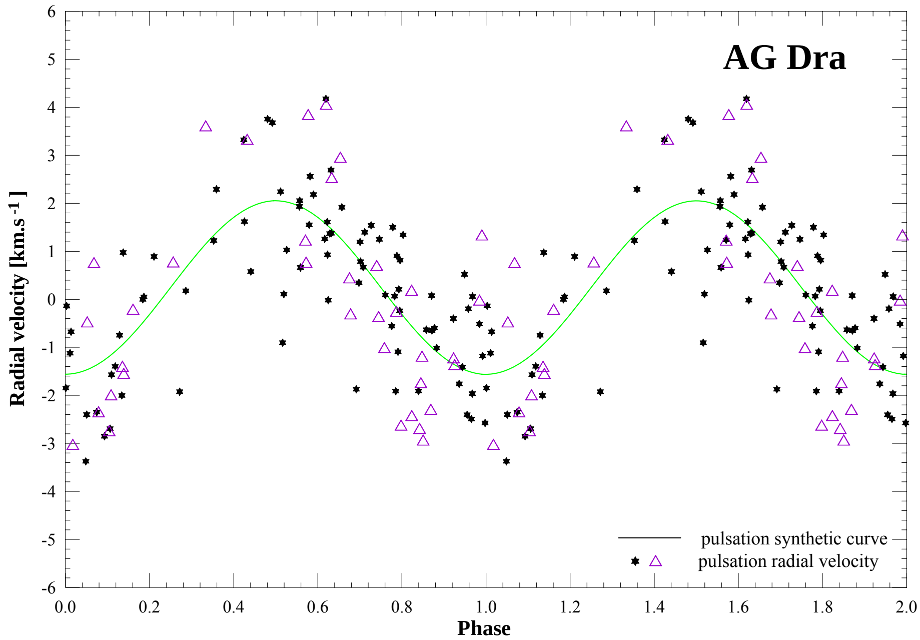

Fig. 7. Phase diagram of pulsation radial velocities and synthetic pulsation curve. Pulsation radial velocities derived from data by Iijima & Viotti (2003) are depicted by triangles.

The complete curve of orbital plus pulsation response is shown by the red line in the same figure. One clearly sees that the complete curve better fits the observational radial velocities than the orbital response alone. The synthetic curve as well as the orbital radial velocities are shown in Figure 6. In Figure 7 the pulsation radial velocities are depicted. The data derived from radial velocities, published by Iijima & Viotti. (2003) are depicted by triangles.

Figure 2 shows the behaviour of radial velocity versus light curves in three colours before and after outburst activity started in 1994.

6. Period analysis of spectroscopic data

For the period analysis of the spectroscopic data taken at the Tartu Observatory we used the methods mentioned in previous chapter. We selected radial velocities of spectral emission lines Hα, Hβ, He I λ 6678 and He II λ 4686 as well as EW for the same lines. The results of the period analysis are listed in Table 3.

Table 3. Results of the period analysis of spectroscopic data of AG Dra.

Line	Periods from Radial velocities [days]	Periods from EW [days]
Hα	568.6 381.5	543.7 382.8
Hβ	575.8 361.9	535.1 382.3
He I λ 6678	429.6 350.6	556.7 372.3
He II λ 4686	549.2 362.9	575.1 374.8

7. Conclusions

The study of two-colour diagram for particular outbursts of AG Dra suggests that in the system there are two or three types of these events. Unfortunately it is not possible to decide if particular events are caused by different physical processes. Nevertheless simultaneous analysis of photometric and spectroscopic observational material gave us the possibility to predict times of outbursts to a certain extent. If the main outbursts are physically connected with 9/14 resonance between orbital and pulsation periods we can expect the main outburst in early 2008.

We re-analysed all available radial velocity measurements of symbiotic binary AG Dra. We can conclude that our analysis of the latest radial velocity measurements is in agreement with our previous results and that the presence of pulsations of the cool component is still plausible explanation. The conclusions are moreover strengthened and theoretical work is required to better understand the exact nature of the second period.
In any case more photometric data and radial velocity measurements will be required to improve the understanding of observed physical processes in the future.

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