Astron. Astrophys. 348, 533–541 (1999)

ASTRONOMY
AND
ASTROPHYSICS

Resonances as the general cause of the outbursts in the symbiotic system AG Draconis

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Received 23 February 1999 / Accepted 22 June 1999

Abstract. The general behaviour of the symbiotic system AG Dra is studied in the context of the long-term photometry monitoring and radial velocity analysis. Period analysis of the data gave two values of periods, $549\overset{\mathrm{d}}{.}73 \pm 1\overset{\mathrm{d}}{.}59$ and $355\overset{\mathrm{d}}{.}27 \pm 1\overset{\mathrm{d}}{.}82$ days for orbital motion and pulsations of cool giant respectively. The new orbital elements have been determined as well as the new orbital and pulsation ephemerides respectively. The ratio of the orbital to the pulsation period is actually very close to 14/9, so resonance might occur. We suggested, that this is the general cause of the recurrence time of the active stages. The pulsations of the cool component are very probably non-radial, so accretion by the white dwarf is particularly high when the material ejected due to the pulsations, is ejected in certain directions with respect to the line joining the two stars. The manifestations of this phenomena are the observed outbursts themselves.

Key words: stars: binaries: symbiotic – stars: individual: AG Dra

1. Introduction

The symbiotic star AG Draconis ($\mathrm{BD} + 67°922$) is a bright binary with an orbital period of $549\overset{\mathrm{d}}{.}73$ days (this paper). The system consists of a cool giant of the spectral type $< \mathrm{K\,III}$ with a mass of $1.5\,\mathrm{M}_\odot$ and the white dwarf with the effective temperature $1.2\mathrm{x}10^5\,\mathrm{K}$ (Kenyon & Fernandez-Castro 1987) which is according to Mikolajewska et al. (1995) embedded in a dense, low metallicity nebula. These authors derived the mass of the white dwarf $\mathrm{M_{wd}} = 0.4\text{–}0.6\,\mathrm{M}_\odot$ and inclination of the system $\mathrm{i} = 30° - 45°$. The light curve (LC) of AG Dra displayed a quiescent stage until 1930. But many outbursts have been observed afterwards (1936, 1951, 1966, 1980 and 1994) with relatively large amplitude mainly in the U colour (4 mags). Some authors tried to explain these outbursts in the framework of the occasional thermonuclear runaways on the white dwarf. Kafatos et al. (1993) noted that the outbursts seem too frequent for classical runaways and suggested accretion events as causes of 2–3 mag eruptions. Leibowitz & Formiggini (1992) found that neither accretion events nor thermonuclear runaways could explain the evolution of the UV continuum with time. They suggested that changes in the structure of the red giant extended atmosphere might produce large eruptions in optical and ultraviolet region without any evolution in the structure of the accretion disc or hot component itself. In recent time the behaviour of the hot component of AG Dra has been studied in the UV band by González-Riestra et al. (1999).

In previous papers (Friedjung et al. 1998, Petrík et al. 1998) we have monitored this system photoelectrically and performed the period analysis separately for its states of quiescence and activity, revealing two sets of periods, with one around 554 days in a good agreement with Meinunger's (Meinunger 1979) orbital period and another set around 350 days, which we have interpreted as the possible period of the cool giant's pulsations. Our discovery of the shorter period connected probably with pulsation of the cool component (Petrík et al. 1998) gave us the idea to look also for these pulsations in radial velocity data. We may also note that Bastian (1998) has found a somewhat longer period of 378.5 days from photometry.

Many authors (Garcia & Kenyon 1988, Mikolajewska et al. 1995, Smith et al. 1996 and Tomov & Tomova 1997) have tried to study the AG Dra system with respect to radial velocity and orbital parameters of a circular orbit of the white dwarf and cool giant components. We used much observational data from these papers for the following analysis.

2. Observations

The photoelectric observational material discussed in this paper was obtained in the framework of the international campaign on symbiotic stars (initiated by Hric and Skopal 1989) and data were published in different papers of this series (see Hric et al. 1996 and references therein). Many photometric observations were adopted from Meinunger (1979), Kaler (1987), Iijima et al. (1987), Petrík & Hric (1994), Montagni et al. (1996), Mikolajewski (1997), Greiner et al. (1997), Tomova & Tomov (1998) and Petrík et al. (1998).

This material has been already discussed in two papers (Friedjung et al. 1998, Petrík et al. 1998). We have continued ob-

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Table 1. Photoelectric observations of AG Draconis

JD_{hel} -2 400 000	U	B	V	Obs
50366.342	10.52	10.94	9.82	SL
50929.514	11.17	11.07	9.82	SL
50931.338	11.15	11.07	9.83	SL
50943.497	11.10	11.06	9.81	SL
50961.417	11.05	11.06	9.81	SL
51105.250	10.51	10.88	9.76	K
51142.656	10.90	10.97	9.78	SL
51178.577	11.28	11.11	9.76	SP
51198.251	11.25	11.03	9.82	SL
51201.345	11.26	11.07	9.83	SL
51202.566	11.32	11.15	9.77	SL
51256.630	11.33	11.14	9.89	SL
51262.563	11.36	11.15	9.88	SL
51283.358	11.43	11.18	9.91	SL

Obs = Observatory: SP - Skalnaté Pleso,
SL - Stará Lesná,
K - Kryonerion

servations and some new UBV data obtained at the Stará Lesná, Skalnaté Pleso and Kryonerion Observatories are collected in Table 1.

73 radial velocity values having a relatively very high precision $(0.4–0.8)\,\mathrm{km\,s^{-1}}$ discussed in this paper, have been extracted from Mikolajewska et al. 1995, Smith et al. 1996 and Tomov & Tomova 1997. 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 JD2446578.500 to JD2449186.761, but with good oversampling of individual sets.

3. The method of analysis and its results

The radial velocity data are taken from three sources; therefore there could be a problem of the zero-point. From a preliminary analysis we concluded that the radial velocities extracted from Smith et al. 1996 and Mikolajewska et al. 1995 are shifted relative to each other by the value $(0.98 \pm 0.48)\,\mathrm{km\,s^{-1}}$. We did not find a reliable offset value with respect to Smith's data, for the data extracted from Tomov & Tomova 1997, because this set is not statistically significant (only 6 useable values). Nevertheless it seems to us looking at the phase diagrams, that there is no shift (or only a very small one) between Smith's and Tomov's data sets. On the basis of these results we have shifted Mikolajewska's data set with respect to the two other sets by adding the value mentioned above. Merged data gave us a more homogeneous set, which we have used in the following analysis process.

We have used for the period analysis of radial velocities 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) have been also used.

The preliminary step of analysis gave us two significant periods. The larger value of $549\overset{\mathrm{d}}{.}4$ is connected with the orbital motion and is in very good agreement with the period of photometric variations during quiet stages. Except for this period we have found a new real shorter one of $351\overset{\mathrm{d}}{.}6$. This result is in good agreement with the value discovered from the photometric data of active stages and as we shall see very probably reflects the pulsations of the cool component. Both these values confirm our previous results obtained in the framework of photometric study (Petrík et al. 1998). In the corresponding periodogram depicted in Fig. 1, part (a) contains two peaks connected with both periods found as well as an alias $(218\overset{\mathrm{d}}{.}1)$ of the longer period. In the next step the orbital response has been removed from the original data. The resulting periodogram shown in Fig. 1, part (b) includes only one peak, corresponding to the shorter period $(355\overset{\mathrm{d}}{.}5)$; the alias has now disappeared.

The previous period analysis gave us parameters for constructing the synthetic radial velocity curves due to the orbital motion as well as to the pulsation from the relation:

$$\mathrm{v_r} = \gamma - \mathrm{K}\cos\left(\frac{2\pi}{\mathrm{P}}\left(\mathrm{JD} - \mathrm{JD_{min}}\right)\right) \qquad (1)$$

The resulting synthetic curves are depicted in Fig. 2. The curve of orbital response $(\gamma = -147.34\,\mathrm{km\,s^{-1}}, \mathrm{K} = 4.96\,\mathrm{km\,s^{-1}}, \mathrm{P} = 549\overset{\mathrm{d}}{.}41, \mathrm{JD_{min}} = 2447892\overset{\mathrm{d}}{.}20)$ is depicted by the dashed line, the curve of the pulsational response $(\gamma = -147.45\,\mathrm{km\,s^{-1}}, \mathrm{K} = 1.67\,\mathrm{km\,s^{-1}}, \mathrm{P} = 355\overset{\mathrm{d}}{.}55, \mathrm{JD_{min}} = 2448132\overset{\mathrm{d}}{.}88)$ by the dotted line and the complete curve of orbital plus pulsational response by the solid line respectively. One clearly sees that the complete curve better fits the observational radial velocities than the orbital response alone.

This is supported by comparison of sums of residual squares (hereafter SRS): SRS (orbital response) = $200.14\,(\mathrm{km\,s^{-1}})^2$, SRS (orbital + pulsation response) = $92.52\,(\mathrm{km\,s^{-1}})^2$.

In the first iteration step we have improved the parameters of orbital motion and pulsation. After removing the pulsation response from the original data the period analysis gave us the following parameters of orbital motion: $\gamma = (-147.39 \pm 0.13)\,\mathrm{km\,s^{-1}}, \mathrm{K} = (4.66 \pm 0.20)\,\mathrm{km\,s^{-1}}, \mathrm{P} = 549\overset{\mathrm{d}}{.}73 \pm 1\overset{\mathrm{d}}{.}59, \mathrm{JD_{min}} = 2447896\overset{\mathrm{d}}{.}71 \pm 3\overset{\mathrm{d}}{.}41$. The SRS of these parameters dropped to the value of $87.21\,(\mathrm{km\,s^{-1}})^2$. After removing the orbital response from original data the period analysis gave us the following parameters of pulsation: $\gamma = (-147.51 \pm 0.16)\,\mathrm{km\,s^{-1}}, \mathrm{K} = (1.75 \pm 0.19)\,\mathrm{km\,s^{-1}}, \mathrm{P} = 355\overset{\mathrm{d}}{.}27 \pm 1\overset{\mathrm{d}}{.}82, \mathrm{JD_{min}} = 2448133\overset{\mathrm{d}}{.}23 \pm 6\overset{\mathrm{d}}{.}97$. The SRS for these parameters improved only a little $86.91\,(\mathrm{km\,s^{-1}})^2$, so the following iteration steps are irrelevant. The corresponding periodograms are depicted in Fig. 3 part (a) for data without the pulsation response and part (b) for data for which the orbital response has been removed.

For better comparison we show in Table 2 the orbital radial velocities (residuals after pulsation response extraction from the original data), the pulsation radial velocities (residuals after orbital response removing from the original data) as well as the original homogenized radial velocities respectively. We may note, that in the homogenized data the intrinsic scatter is still

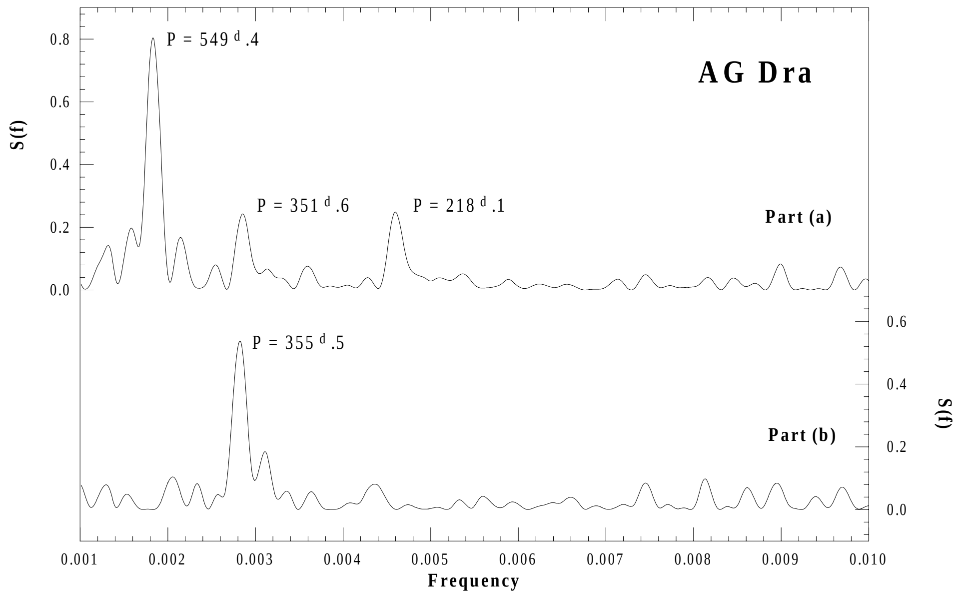

Fig. 1a and b. Periodograms of AG Dra taken from original data - part **a** and from orbital response removed data - part **b**

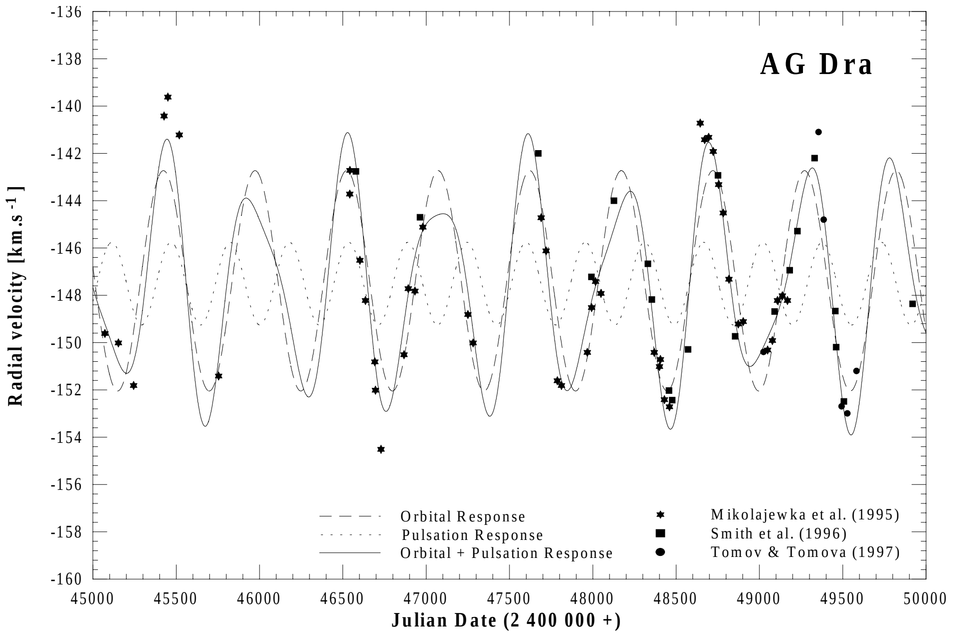

Fig. 2. Radial velocities and synthetic curves for responses presented

present, therefore this scatter remains in the residuals (pulsation as well as orbital) presented in Table 2.

The final solution of orbital elements was obtained by the program based on the simplex method (Kratka 1990), which consists in the optimization method of computation of the spectroscopic orbital elements. We have used as the input parameters the values of orbital response from the first iteration step with the pulsation response removed. The resulting orbital parameters are as follows:

$$\begin{array}{ll} P_{orb} = 549\overset{\rm d}{.}73 & T_0 = 2447622\overset{\rm d}{.}28 \\ e = 0.06 & \gamma = -147.42\,km\,s^{-1} \\ \omega = 359\overset{\circ}{.}8 & K_1 = 4.67\,km\,s^{-1} \\ A_1\,sin\,i = 50.69\,R_\odot & f(M) = 0.00579\,M_\odot \end{array}$$

The SRS for these parameters improved to the value $84.27\,(\mathrm{km\,s^{-1}})^2$, which is the minimal value in our iteration process. It is shown in Fig. 4 that the fit of orbital radial velocities (the second column from Table 2) by an elliptic orbit synthetic curve (solid line) is better in comparison with a circular synthetic curve (dashed line).

In Fig. 5 pulsation radial velocities are depicted (the third column from Table 2) together with a sinusoidal fit - solid line. Very probably the changes of the pulsation radial velocities are more complicated, but a sinusoidal fit is good enough for the scope of this paper. On the basis of these results we are able to compute absolute changes of the radius of the cool giant in the system assuming the pulsations radial. After intregration of the pulsational radial velocities in the interval of one half of the pulsation period, the value of this total radius change is $24.6\,\mathrm{R}_\odot$.

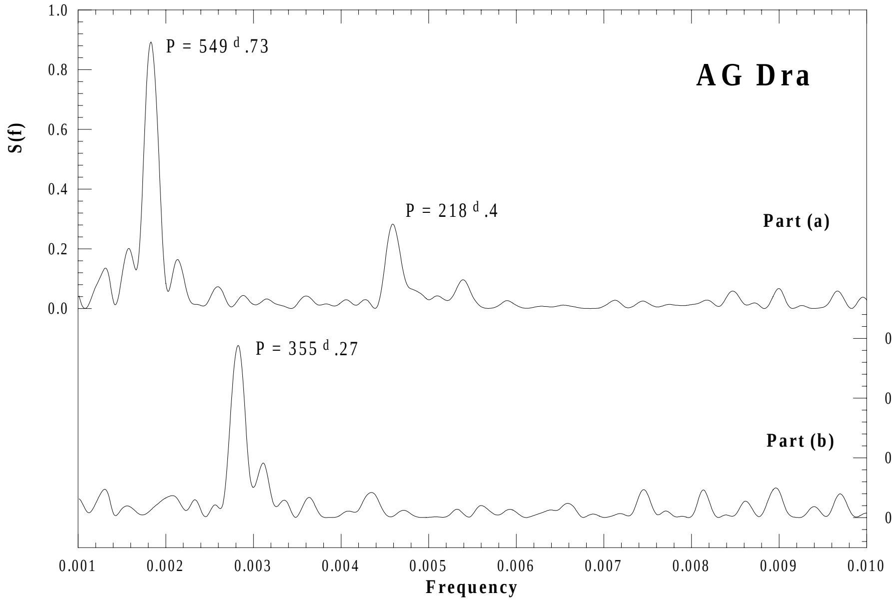

Fig. 3a and b. Periodograms of AG Dra taken from pulsation response removed data - part **a** and from orbital response removed data - part **b**

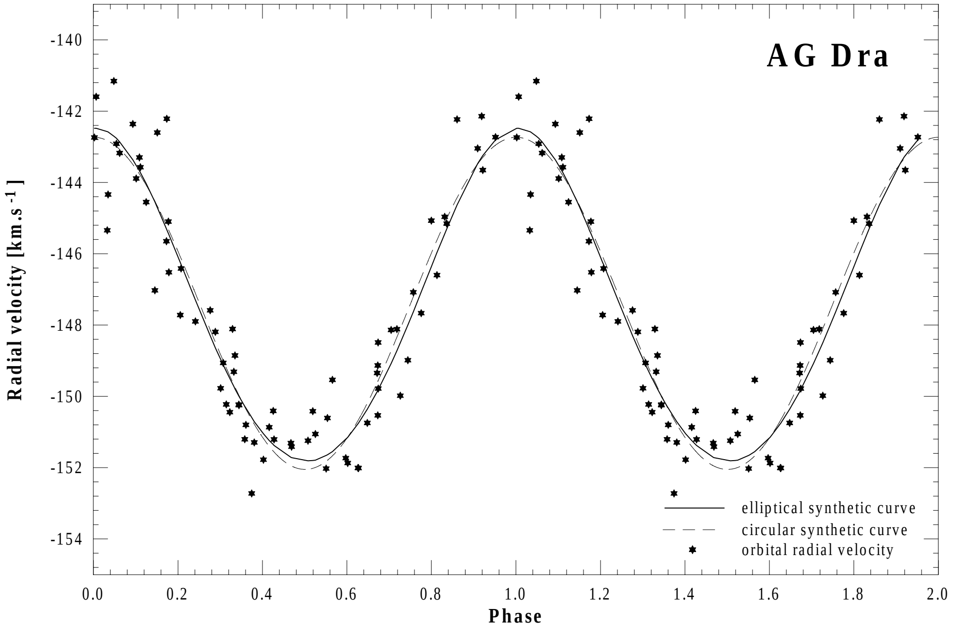

Fig. 4. Phase diagram of orbital radial velocities and comparison of circular and elliptical synthetic curves of AG Dra

All resulting parameters (the first column) are given in Table 3. The second column contains the values of parameters taken by analysis of original (homogenized) radial velocities, the third and fourth column contains the values of parameters taken by analysis of orbital radial velocities for circular as well as elliptical orbit respectively. The last column contains the values of parameters of pulsations. For most of given parameters the standart deviations are presented.

To support the idea of pulsation of the cool component of AG Dra we would like to show that the photometric and radial velocity changes are self consistent.

In Fig. 6 are shown light variations in V during a quiescence stage (JD 2446750 - 2449000) together with pulsation radial velocities as well as the synthetic pulsation curve. Dashed lines represent times of minimal radius of the cool component. One can see that these times correspond very well with maxima of brightness, which is in agreement with the theory of pulsation of cool giants. Two maxima of brightness before and after quiescence do not reflect pulsation variations of the cool component because they are due to another physical mechanism and are connected with post/pre outburst activity of AG Dra. In the next step we have constructed very simple model of the pulsations of the cool component: if we have assumed radial pulsations, a black body energy distribution and radius changes mentioned above, then the temperature change only about 500 K is sufficient to explain the observed 0.2 mag variations in the V colour. We must note that precise theoretical model of the pulsations cannot be settled at present and it is not the main aim of this paper. On the other hand there are a few Miras with late-K spectral types, and there are semi-regular variables in globular clusters

Table 2. Orbital, pulsation and original radial velocities of AG Dra

JD$_{hel}$ -2 400 000	$\mathrm{v_r(orb)}$	$\mathrm{v_r(pul)}$	$\mathrm{v_r}$	Ref.
45071.879	-150.80	0.77	-149.62	Mik
45152.739	-151.24	2.02	-150.02	Mik
45243.617	-150.53	-2.28	-151.82	Mik
45426.899	-141.59	2.31	-140.42	Mik
45449.878	-141.15	3.33	-139.62	Mik
45518.744	-142.21	4.04	-141.22	Mik
45754.023	-151.87	-0.30	-151.42	Mik
46540.861	-145.34	-0.89	-143.72	Mik
46541.874	-144.34	0.13	-142.72	Mik
46578.500	-143.89	0.90	-142.76	Smi
46602.647	-147.03	-1.96	-146.52	Mik
46635.705	-147.72	-2.10	-148.22	Mik
46691.627	-149.06	-1.77	-150.82	Mik
46695.590	-150.22	-2.78	-152.02	Mik
46728.576	-152.72	-3.83	-154.52	Mik
46866.997	-152.01	0.13	-150.52	Mik
46891.947	-149.35	1.86	-147.72	Mik
46931.895	-148.99	-0.28	-147.82	Mik
46962.534	-145.07	1.23	-144.70	Smi
46979.724	-144.97	-0.02	-145.12	Mik
47249.940	-150.44	0.65	-148.82	Mik
47281.800	-151.29	0.80	-150.02	Mik
47673.520	-142.36	1.52	-142.00	Smi
47690.827	-144.55	-0.62	-144.72	Mik
47719.766	-145.10	-0.76	-146.12	Mik
47787.674	-149.78	-2.74	-151.62	Mik
47811.570	-150.25	-1.81	-151.82	Mik
47966.987	-152.01	0.21	-150.42	Mik
47992.576	-148.49	2.30	-147.22	Smi
47992.856	-149.78	0.99	-148.52	Mik
48016.988	-148.12	0.88	-147.42	Mik
48048.812	-147.66	-1.31	-147.92	Mik
48127.382	-142.14	-0.69	-144.00	Smi
48330.701	-148.19	1.86	-146.67	Smi
48354.554	-149.31	1.53	-148.18	Smi
48368.842	-151.21	-0.09	-150.42	Mik
48400.721	-150.87	0.41	-151.02	Mik
48405.846	-150.41	0.84	-150.72	Mik
48429.794	-151.41	-0.45	-152.42	Mik
48457.408	-150.42	-0.02	-152.03	Smi
48460.651	-151.06	-0.73	-152.72	Mik
48476.446	-150.61	-0.66	-152.44	Smi
48571.295	-149.98	-2.23	-150.29	Smi
48645.057	-142.23	3.67	-140.72	Mik
48671.998	-143.04	2.03	-141.42	Mik
48695.033	-142.73	1.62	-141.32	Mik
48722.991	-142.74	0.81	-141.92	Mik
48751.579	-142.91	0.08	-142.93	Smi
48755.843	-143.17	-0.23	-143.32	Mik
48782.815	-143.57	-0.69	-144.52	Mik
48816.750	-145.65	-2.08	-147.32	Mik
48854.401	-147.90	-2.58	-149.74	Smi
48873.622	-147.59	-1.04	-149.22	Mik
48902.578	-148.11	0.51	-149.12	Mik
49024.51	-152.03	1.41	-150.4	Tom
49050.004	-151.73	0.88	-150.32	Mik
49077.976	-150.74	0.24	-149.92	Mik
49091.608	-149.14	0.85	-148.69	Smi
49108.935	-148.14	0.47	-148.22	Mik
49137.858	-147.08	-0.86	-148.02	Mik
49168.761	-146.60	-2.65	-148.22	Mik
49181.386	-145.15	-1.97	-146.94	Smi
49228.389	-143.65	-2.02	-145.29	Smi
49331.235	-143.29	1.59	-142.20	Smi
49354.59	-142.60	3.60	-141.1	Tom
49385.52	-146.41	1.38	-144.8	Tom
49455.644	-148.85	1.11	-148.67	Smi
49460.627	-150.23	-0.19	-150.20	Smi
49492.47	-151.78	-1.49	-152.7	Tom
49506.481	-151.21	-0.91	-152.49	Smi
49528.32	-151.31	-1.04	-153.0	Tom
49582.27	-149.54	0.45	-151.2	Tom
49919.383	-146.52	-2.97	-148.36	Smi

Ref. = References: Mik - Mikolajewska et al. (1995)
Smi - Smith et al. (1996)
Tom - Tomov & Tomova (1997)

with K types - presumably metal deficient stars with very low amplitudes of light variations. Moreover as we will discuss below the pulsations of the coll component of AG Dra may be partly non-radial.

4. Discussion

Let us now try to see what kind of model of AG Dra is compatible with the analysis of the observational facts presented in the previous section as well as with what has been found by other authors.

Fig. 7 presents the historical LC in UBV, as well as the measured radial velocities fitted to the orbital response (dashed line), pulsational response (dotted line) and orbital plus pulsational response (solid line). Comparing the morphology of the LC and the radial velocity behaviour, we see that the stage of activity with the first maximum around at JD2444600 occurred at a time of maximum expansion velocity of the cool component. This stage of activity was preceded by a small drop of brightness in B and V and a standstill in U occurred at the time of minimal calculated radius of the cool stellar component. The next major activity stage culminated at JD2449574, exactly 14 pulsation cycles later. Indeed the start of both these activity stages was also close to the same phase of the orbital cycle (after 9.048 orbital cycles) and they even occurred at the time of the global maximum negative orbital plus pulsational radial velocity. The

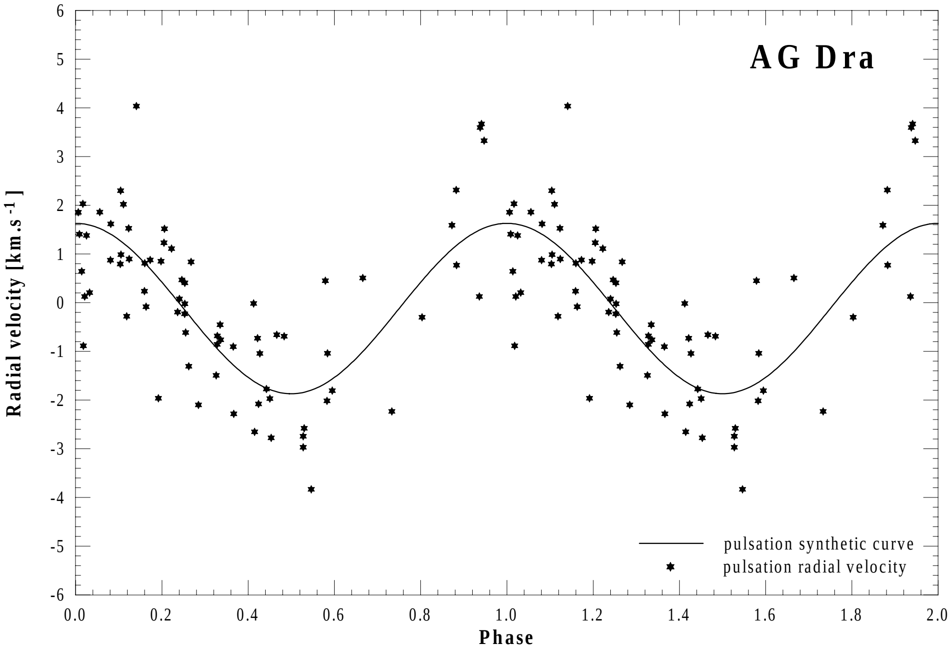

Fig. 5. Phase diagram of pulsation radial velocities and synthetic pulsation curve of AG Dra

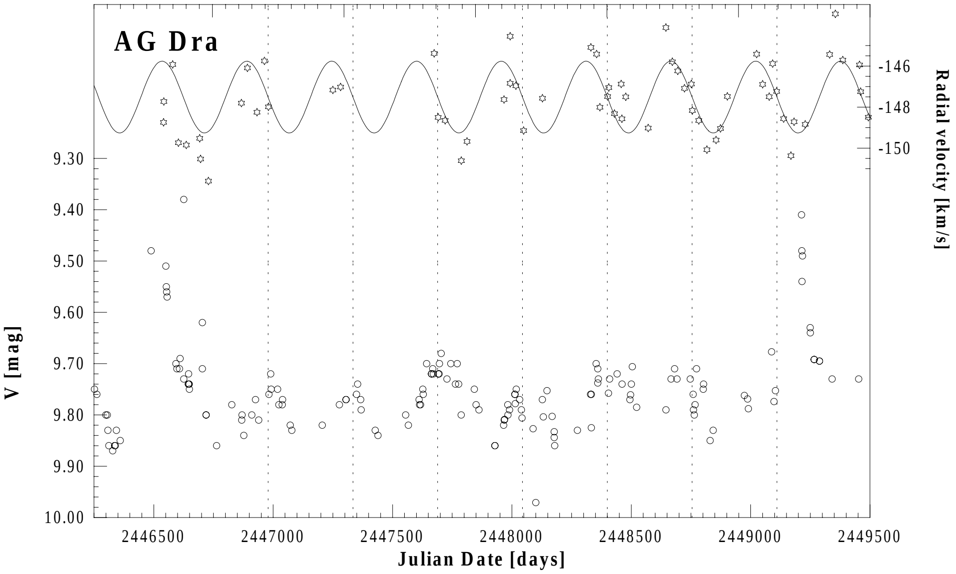

Fig. 6. Light curve in V colour during quiescence and corresponding pulsation radial velocities with synthetic pulsation curve of AG Dra

Table 3. Resulting parameters

Data file	$\mathrm{v_r}$		$\mathrm{v_r(orb)}$		$\mathrm{v_r(orb)}$	$\mathrm{v_r(pul)}$	
N	73		73		73	73	
P [d]	549.41	±2.24	549.73	±1.59	549.73	355.27	±1.82
$\mathrm{T_{min}}$ [JD24..]	47892.20	±4.83	47896.71	±3.41	-	48133.23	±6.97
$\mathrm{T_0}$ [JD24..]	-		-		47622.28	-	
e	0.0		0.0		0.06	-	
$\mathrm{V_0}$ $[\mathrm{km\,s^{-1}}]$	-147.34	±0.20	-147.39	±0.13	-147.42	-147.51	±0.16
ω	-		-		$359.^{\circ}8$	-	
$\mathrm{K_1}$ $[\mathrm{km\,s^{-1}}]$	4.96	±0.30	4.66	±0.20	4.67	1.75	±0.19
$\mathrm{A_1} \sin i\,[\mathrm{R_\odot}]$					50.69	-	
$\mathrm{f(M)}\,[\mathrm{M_\odot}]$					0.00579	-	
SRS $[(\mathrm{km\,s^{-1}})^2]$	200.14		87.21		84.27	86.91	

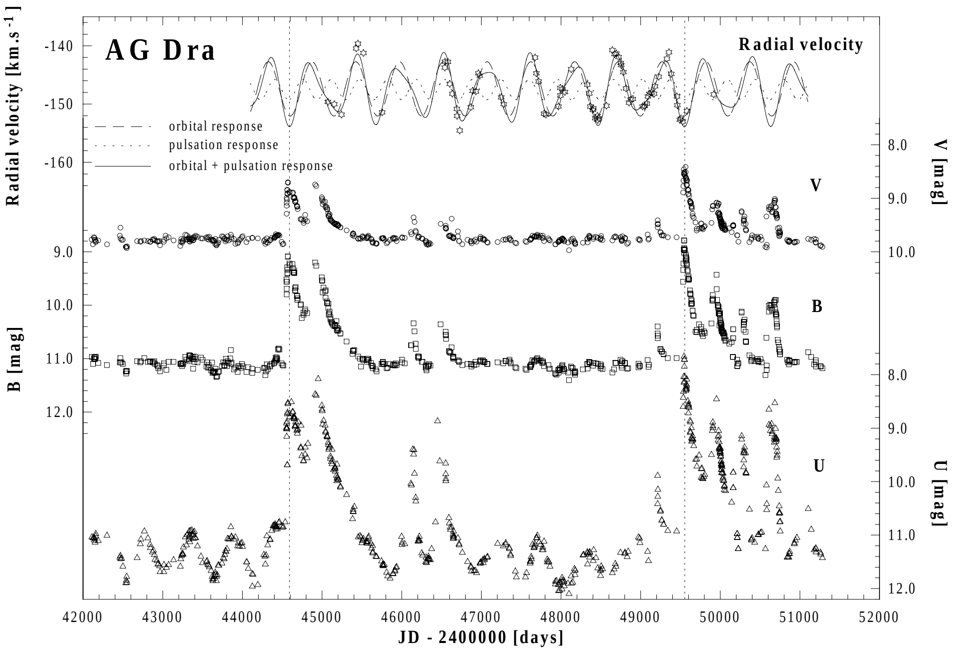

Fig. 7. Historical LCs in U,B,V colours and radial velocities with corresponding synthetic curves for responses presented

weaker stage of activity between them however did not start at such a phase of the pulsation cycle. In spite of this the individual photometric maxima within all these activity stages are separated by a time of the order of the pulsation period.

We note that 14 pulsation cycles are very close (practically exactly within the errors) to 9 orbital cycles. Though the statistical significance of our results are uncertain, a real physical resonance may be present.

The radius and temperature variations of the hot component were studied in X-rays by Greiner et al. (1997) and in the ultraviolet by Leibowitz & Formiggini (1992), by Mikolajeska et al. (1995) and by González-Riestra et al. (1999). Leibowitz & Formiggini (1992) only considered the continuum energy distribution longwards of 110 nm, obtaining lower and for some phases much lower temperatures (90000 down to 25000 K) for the hot component than any of those determined by the authors of the last two papers (never below 90000 K according to Mikolajewska et al. (1995) and in the range 120000 to 80000 K according to González-Riestra et al. (1999)). In those papers He II Zanstra temperatures were considered, which take account of the flux at much shorter wavelengths. The X-ray observations discussed by Greiner et al. (1997), indicate even higher temperatures in quiescence of the order of 175000 K, so it appears that the conclusions of the papers later than 1994 taking account of radiation at shorter wavelengths, are generally much more reliable than those of Leibowitz & Formiggini (1992). The higher X-ray temperatures in quiescence could in addition indicate that all He II continuum photons are not absorbed at such times, making the He II Zanstra temperatures somewhat too low. In any case these results and especially those of Greiner et al. (1997) indicate real radius and temperature changes of the hot component during activity; it does not appear possible to explain the change in X-ray flux by a change in the absorption of circumstellar material. Any model which attempts to explain activity and our new results about activity, must take account of this.

On the basis of our analysis the cool component undergoes pulsations with a period of $355\overset{\mathrm{d}}{.}27$. The wind from the cool component is modulated by these pulsations and creates shells continuously approaching the white dwarf. However the strong radiation pressure from the hot component tends to stop the shells approaching this component, while photoionization creates an ionized gaseous region which has a higher density and line emissivity in regions between both stellar components of the binary system. The existence of these ionized gaseous regions and their variable visibility with orbital phase explains the quiescence photometric variations, while the variations and deviations from axial symmetry of the ionized boundary region produce changes in the phases and shapes of quiescence maxima in the LC especially in the U colour. Depending on the expansion velocity and other physical parameters shock waves are very probably created in this ionized region. One might then expect resonance effects between the pulsational and orbital periods, which in fact have as we have seen, a ratio near to 9/14. It is nevertheless clear that such phenomena cannot explain the changes of the hot component during activity, briefly described above. This means that another explanation of activity is required.

The results of Mikolajewska et al. (1995) and particularly of González-Riestra et al. (1999) indicate that there are at least two types of activity stage. The weaker one observed in the satellite ultraviolet, starting near JD2446000 containing two maxima, called by González-Riestra et al. (1999) “hot bursts”, was not of the same nature as that of the other maxima called by the same authors “cool bursts”. They found that the temperature of the white dwarf *increased* during the hot bursts, while it *decreased* during cool bursts. On the other hand the temperature luminosity plot of Mikolajewska et al. (1995) suggests that all points of the graph lie on a curve having a similar shape to the theoretical curve for a white dwarf, whose outer layers go through different episodes of thermonuclear burning. Hot bursts would then be in such a theoretical framework weaker episodes of increased burning compared with those of cool bursts. In view of our previous considerations it appears that only the activity stages with strong cool bursts, start near times of maximum negative pulsational plus orbital radial velocity.

It appears easiest in view of all that has been said to interpret activity in terms of theories involving different episodes of thermonuclear burning. The white dwarf might be expected to accrete most, near times when the outwards pulsation velocity of the cool component was largest, that is when spectral lines due to it had the largest negative radial velocities. This would cause expansion of the outer layers of a white dwarf undergoing almost stable burning in a time of the order of 100 days (Greiner et al. 1997). The occurrence of major activity stages at the same orbital phase would however require a special additional condition, if this type of theory is considered to be an acceptable explanation. If the orbit were slightly eccentric and the cool component nearly filled its Roche lobe, accretion would be greater at certain orbital phases. In fact the distance of AG Dra and the luminosity and the radius of the cool component with respect to the size of the Roche lobe are uncertain (see Mikolajewska et al. 1995). An alternative possibly more acceptable explanation might be to suppose that the pulsations of the cool component are non-radial. Accretion by the white dwarf might then be particularly high when the material ejected due to the pulsations, is ejected in certain directions with respect to the line joining the two stars. If the ratio of the orbital to the pulsation period is really very close to 14/9, resonance might occur. It may be noted that increased accretion could occur at times close to that of maximum expansion velocity of the cool component, because the velocity of the wind carrying extra material from this component may be much higher than that of a wind from an M giant. The P Cygni profile in NV profiles of IUE spectra obtained during active stages suggests a wind velocity of the order of $170\,{\rm km\,s^{-1}}$; this velocity could be that of the wind from the cool component if it resembled a luminous hybrid giant (Friedjung 1997).Material travelling at such a velocity would take only about 2–3 weeks to travel from the cool component to the hot one. We must note that the significance of the eccentric orbit is however too uncertain at the present stage, for one to determine when activity starts with respect to periastron.

Let it be noted that explanations of the activity stages of symbiotic binaries by variations of the cool component are not new. Luud (1980) considered that a transient accretion disk was formed around a compact white dwarf companion of CH Cygni, when the cool component had large maxima. Friedjung (1982) suggested a slight expansion of the chromosphere of the cool component in active stages of symbiotic stars, also leading to increased accretion. Various possibilities were discussed by Tutukov and Yungelson (1982). Mikolajewska and Kenyon (1992) suggested that activity cycles of AX Per were connected with variations of mass loss due to solar type cycles of the cool component. The detailed discussion of such mechanisms, in situations where unlike in the papers quoted activity is interpreted in terms of different episodes of nuclear burning in outer layers of a white dwarf associated with time variable accretion rates, is however beyond the scope of the present paper (for a brief discussion of this see Sion 1997).

Weaker activity stages with hot bursts might then not require such a high accretion rate. They could in that case start at other times in the orbital cycle, while still being modulated by the pulsational cycle.

Let us finally note that an explanation of the two different periods of AG Dra by a triple star model, probably does not work. Such a system would almost certainly be very unstable, so we feel justified in neglecting that possibility.

5. Conclusions

We can summarize the main results achieved in previous sections as follows:

1. The period of about 350 days found in photometric data in previous published papers is confirmed by analysis of radial velocity data. Now it is seen that the two periods persist in the system simultaneously.
2. We ascribed the period found from radial velocity data ($355\overset{\rm d}{.}27$) to the pulsations of the red giant atmosphere. We can show the pulsation ephemeris for maximum expansion velocity:

$$\begin{array}{lll} {\rm T_{exp}} = & 2448133\overset{\rm d}{.}23 & +\ 355\overset{\rm d}{.}27\,{\rm xE} \\ & \pm 6\overset{\rm d}{.}97 & \quad \pm 1\overset{\rm d}{.}82 \end{array} \qquad (2)$$

3. The orbital period ($549\overset{\rm d}{.}73$) was established more precisely after the process of orbital elements iteration and so we introduce the new orbital ephemeris with the time of photometric minimum taken from very good covered minimum between JD2443397 and JD2443862 in U colour:

$$\begin{array}{lll} {\rm T_{phot.min}} = & 2443629\overset{\rm d}{.}17 & +\ 549\overset{\rm d}{.}73\,{\rm xE} \\ & \pm 2\overset{\rm d}{.}30 & \quad \pm 1\overset{\rm d}{.}59 \end{array} \qquad (3)$$

4. The orbital and pulsation periods were found to be possibly in the resonance 9/14.
5. The times of the start of active stages led us to suggest possible mechanisms for their production.

Acknowledgements. It is a pleasure to express our sincerest thanks to all the observers included in the international campaign as well as to the National Astronomical Observatory of Athens for its hospitality during the stay of two of us (L.H. and R.G.) at the Kryonerion Observatory and to Dr. H.M. Schmid for his valuable comments. This work has been supported through the Slovak Academy of Sciences Grant No. 5016/98, and in part by the Trnava University Grant.

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