The historical light curve of the symbiotic star AG Draconis: intense, magnetically induced cyclic activity

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ABSTRACT

We analyse the historical optical light curve of the symbiotic system AG Draconis, covering the last 120 years. During the first 31 years the brightness of the star has not been varying by more than 0.1 mag. A weak periodic signal with the binary period of the system of $\sim 550$ d can be detected in this section of the light curve, as well as in all other later quiescence sections of it.

Around the year 1922 the quiescence brightness of the star increased by 0.29 mag. Since then the star’s photometric history is marked by a series of brightness fluctuations with an amplitude of 1-2 mag and a typical duration of 100-200 d. The time intervals between outbursts are integral numbers of the period $373.5$ d. The outbursts are grouped in 6 dense clusters, each one lasting some 1500 d, that are well separated from one another along the time axis with a quasi periodicity of 5300 d.

We suggest that the outbursts of the system are triggered by episodes of intense mass outflow from the atmosphere of the cool star onto the environment of the hot component. The $373.5$ d cycle is the length of a ”day” on the surface of the giant that rotates in retrograde direction with a sidereal period of 1160 d. A weak signal with this periodicity is also present in the light curve. The modulation of mass transfer in the system is a combined effect of a dipole magnetic field of the giant star and the tides induced in its atmosphere by its binary companion. The $5300$ d quasi period is that of a solar-like magnetic dynamo process that operates in the outer layers of the giant. The combined effect of the $5300$ d and $373.5$ d cycles induces a second mode of pulsation of the giant star with the period of 350 d.

AG Dra is the 5th symbiotic system that shows in its historical light curve this type of intense magnetic and magnetically induced activity.

Key words: binaries: symbiotic – stars: individual: AG Dra – stars: magnetic fields – stars: rotation.

1 INTRODUCTION

The star AG Draconis is one of the most intensively studied symbiotic systems. Nonetheless, its long term light curve (LC), in quiescence as well as during its outburst episodes, is far from being well understood.

Photometric data of AG Dra, recorded since the year 1890 display several active phases, separated by quiescence periods. In quiescence, a small amplitude modulation is detectable in the B and V band. In the U-band the variation amplitude is larger, $\sim 1$ mag, and shows a periodicity of $554$ d (Meinunger 1979). Three values are given in the literature for the orbital period of the system, as derived from radial velocity data: 554.0 (Mikolajewska et al. 1995), 548.6 (Fekel et al. 2000b), 550.5 (Friedjung et al. 2003).

Many optical eruptions occurred since the first one recorded in the year $\sim 1930$. Iijima (1987) suggested a 15 years periodicity for outburst occurrence.

The presence of more than one periodicity in the LC of AG Dra is claimed by several authors. Bastian (1998) analysing the data base of the Association Francaise des Observateurs d’Etoiles Variables (AFOEV) covering the years from 1973 to 1997, claimed the presence of a $\sim 380$ d period. This periodicity is also detected in the radial-velocity data compiled by Mikolajewska et al. (1995). Petrík et al. (1998)
found $P=552$ d during the quiet state, and $P=350$ d during the activity state. Friedjung et al. (1998) detected three periods, 592 d in U, 356 d in B, and 350 d in V and suggested that the 350 d period could represent the cool giant’s pulsation. Gális et al. (1999) found two periodicities, 549.73 d and 355.27 d in photoelectric and radial velocity data.

In a more recent paper, Friedjung et al. (2003) reaffirmed the presence of a signal with a 357 d period in the radial velocity curve of the star, and suggested again that the origin of this signal is in pulsations of the giant star of the system.

Motivated by the discovery of multiperiodicities in the LC of several symbiotic systems, BF Cyg (Leibowitz & Formiggini 2006), YY Her (Formiggini & Leibowitz 2006), Z And (Leibowitz & Formiggini 2008) and BX Mon (Leibowitz & Formiggini 2011) we have analysed the photometric behavior of AG Dra, with the aim of examining the overall periodic content of the LC of this system.

In Section 2 we present the data sets used, and the method used for constructing a consistent LC along the 120 years of observations. Section 3 describes the time-series analysis and the periods detected. Section 4 discusses the proposed interpretation of the identified periods. In the summary we compare the results presented in this work with our past findings in the light curves of another 4 symbiotic systems, Z And, BF Cyg, YY Her and BX Mon.
2.1 Scaling the data

In order to create one consistent LC we had to find a reliable transformation between the photographic system of the Harvard patrol plates and the eye-visual estimates of the AAVSO data. Unfortunately, there is no overlap in time between these two sets of data. Skopal (2007) estimated that the emission lines contribution to the star brightness in the V band amounts to \(~0.12\) mag. The variability of emission lines in the AG Dra spectrum as well as the beginning of an activity phase of the system (see below), make the task of scaling more complicated.

Consequently, instead of applying the numerical relation between the earlier photographic magnitudes and the B and V magnitudes we adopted an empirical approach, taking advantage of the data collected by many campaigns of photoelectric observations of AG Dra, using them as a bridge between our two major sets. We retrieved all the V and B photoelectric data obtained from the year 1980 up to 2011 (Burch 1980; Meuninger 1981; Iijima 1987; Luthardt 1992; Montagni et al. 1996; Greiner et al. 1997; Gábris et al. 1999; Leedjärv et al. 2004; Hric et al. 1991; Skopal et al. 1992; Hric et al. 1993, 1994e; Skopal et al. 1995; Hric et al. 1996; Skopal 1998; Skopal et al. 2002, 2004, 2007; Munari et al. 2009).

Four segments of quiescence state, which are contemporaneous with AAVSO data points, have been selected in the LC of the photoelectric data, namely 24 40680<JD<24 44200, 24 45613<JD<24 49105, 24 51142<JD<24 52105, 24 54555<JD<24 54892. We evaluated the empirical scale shift between the V photoelectric data and the eye-visual of the AAVSO data, calculating the weighted averages of the data in the four quiescence segments. Using the average (B-V) at quiescence, we transformed the V-scaled AAVSO data to B photoelectric magnitudes. Using the few simultaneous B and \(m_{Bpg}\) data of Greiner et al. (1997), an empirical shift has been established for scaling the B data to the old Harvard photographic system.

With this procedure we transformed the AAVSO set to the scale of the \(m_{Bpg}\) data. We have also calculated anew the empirical shift factor for the Belyakina (1969) data.

Fig. 1 b) shows the final resulting LC transformed to \(m_{Bpg}\) passband. In this presentation we binned the data points into bins of 30 days width. We note, however, that the results of our following analysis are insensitive to any particular reasonable binning, including no binning at all, of this data set.

2.2 The two sections of the Light Curve

Two distinct sections are clearly identified in the LC seen in Fig. 1b. Section A, to the left of the heavy vertical line at JD 24 23300, consists all the measurements performed earlier than that time. Section B are measurements performed later. No outburst has been recorded during the 11800 days covered by Section A.

Section B is characterized by a sequence of major outbursts of the system, of an amplitude of 1 to 2 mag with a typical duration of some 100 days. These are grouped within 6 distinct clusters, well separated along the 32280 day duration of this section. The thin vertical lines in Fig. 1 b) mark the borders between these clusters, to which we refer also as high (H) states of the system, and the in between time intervals, to which we refer as the quiescence (Q) states. The results of our following analysis are insensitive to any reasonable variation in the position of these border lines. The median magnitude of the Q LC of Section B is brighter by 0.29 mag than the median magnitude of Section A. The jump in the quiescence luminosity of the star around the year 1922 is not an artifact, being measured within the single consistent data set of the Harvard plates.

In general we note that all results presented in this paper are independent of the scaling procedure presented in sec. 2.1, because Section A consists entirely of data of the Harvard plates system and Section B is mostly the AAVSO data set. We obtained almost the same results as for section B if we analyse only the AAVSO data.

2.3 The U light curve

We have also analyzed a third data set of photoelectrical photometry measurements in the Johnson U band. The sources are: Meuninger 1981; Taranova & Yudin 1982; Iijima 1987; Martel & Gravina 1985; Hric et al. 1991; Luthardt 1992; Skopal et al. 1992; Hric et al. 1993, 1994; Skopal et al. 1995; Montagni et al. 1996; Greiner et al. 1997; Skopal 1998; Gábris et al. 1999; Skopal et al. 2002, 2004, 2007; Munari et al. 2009. Fig. 1 c) presents the U LC of the system. It covers the last two clusters of outburst events seen in the photographic light curve shown in Figs 1 a) and b). The structure of the two events is very similar in the 2 photometric bands. Here again we refer to Quiescence (Q) states and High (H) states of the system as in Fig. 1 b).

3 TIME-SERIES ANALYSIS

3.1 Section A and the quiescence states

Section A of the LC covers a time interval of 11800 d during which the system was in a quiescence state, with no interruption by any outburst. The PS of this LC (Scargle 1982), shown in Fig. 2 a), has its highest peak at the period 546.5 d. This peak is higher than 6 times the standard deviation of the noise in the PS, but its false alarm probability (Scargle 1982) is not small. We consider it significant in view of the fact that a similar peak is present also in the PS of the independent Q LC of section B, displayed in Fig. 2 c), at a frequency corresponding to 548 d. In the PS of the quiescence states of the U LC shown in Fig. 4 a), a similar peak, at a frequency corresponding to 547 d is present, where it has a clear high statistical significance (see section 3.3). Finally, the frequency of this peak coincides well within its uncertainty interval with the well known binary period of the system.

A second feature in the PS of section A is a broad peak around the period of 350 d. Although by itself it is not statistically significant within this PS, we draw attention to it, in view of its appearance in another independent LC, that of the PS of section B shown in Fig. 2 b), especially in the PS of the H states shown in Fig. 2 d). It is also clearly present in the PS of the H states in the U LC shown in Fig. 4 b) (see section 3.3). It also coincides with a periodicity that was
identified in the radial velocity curve of the AG Dra system (Galis et al. 1999, Friedjung et al. 2003). The uncertainty in the value of this period is quite large, as apparent in the large width of the feature in the PS, due to interference with the 365 d periodicity in the timing of the observations. We refer to this period as $P_p = 350$ d.

### 3.2 Section B and the major six outbursts

Fig. 2 b) displays the PS of section B of the LC in the period range 250-30000 days. The major peak is around the frequency corresponding to the period 5300 d. Its false alarm probability (Scargle 1982) is less than 5 percent. The second highest peak corresponds to its 2nd harmonic. The inset shows twice the cycle of the B LC folded onto this periodicity. As apparent in the inset, as well as in Fig.s 1 a) and b), the $\sim 5300$ d cycle is a quasi periodicity in the occurrence of the 6 clusters of outbursts along the last 88 years in the history of the star, referred to above.

The third highest peak in Fig. 2 b) corresponds to the period 373.4 d. The next highest peak to its left is an alias of it. It disappears from the PS when a "clean" routine is applied on the data. The 373 peak is even more pronounced in the PS of H states shown in Fig. 2 d). The broad feature to the right of the 373 peak corresponds to the $P_p = 350$ d periodicity mentioned above.

#### 3.2.1 Statistical Tests and Simulation

As a test of the statistical significance of the $P_p \sim 5300$ d period, we have developed, following Broadbent (1955, 1956, and references therein), a period search routine that finds the periodicity, or "quantum", in the language of Broadbent, that fits best a set of given numbers. The time points among which we looked for a "quantum" are the highest points in the 6 clusters of the H state of the system. We performed this search on various different binning of the LC and the "quantum" found is $\sim 5300$ d, with a dispersion of the observed high points around the predicted times for a strict periodicity is some 450 days, or 0.085 in the phase space.

The 373 d periodicity in section B of the LC is clearly far from being harmonic. Its Fourier signal is therefore rather weak. We therefore applied on the same data the "quantum" search routine, which is especially suitable for finding a cyclic feature in a time series, regardless of the detailed structure of the time dependent parameter of the series. Here the set of numbers for which a "quantum" is looked for is the times of the highest points of the individual outbursts of the system that rise higher than $2.5\sigma$ of the magnitude population. This test enables also an evaluation of the statistical significance of the 373 d period.

We find a best-fitted period ("quantum") of $P_a = 373.5$ d. The dispersion is $S=49.34$, which is 0.132 in phase. The time of the 1st peak is JD=2425249.03.

The high statistical significance of the 373 d period is confirmed by the value of the statistic $\sqrt{N(1/3 - S^2)} = 1.87 > 1$. Here $N=35$ is the number of elements in the series of times of maximum brightness in individual outbursts of the star. As shown by Broadbent (1956) this inequality is indicating a very small false alarm probability for the 373 d period.

As an additional check, we have also conducted a "bootstrap" (Monte-Carlo) test of the robustness of the 373 d pe-
3.2.2 The ∼350 d and the 1160 d periods

In Figs 2 b) and d) one can identify a small peak that corresponds to the period 358 d that is also seen in Fig. 2 a), the PS of section A. We identify it with the period $P_v = 350$ d periodicity, already mentioned above. This peak is also clearly seen in Fig. 4 b), the PS of the entire independent data set of the U LC of the system (see section 3.3). The large variability in the peak position of this feature in the different PSAs is due to interference with the nearby annual 365 d periodicity inherent in long term ground based observations.

Another small peak is marked in Fig. 2 b) and d), corresponding to the period $P_v = 1160$ d. It is not statistically significant within the PS of section B. However, its conspicuous appearance in the PS of the independent data set of the U LC (Fig. 4 b) implies with a high statistical probability, that it does represent a true periodicity of the AG Dra system.

Application of a "clean" PS routine on the section A and section B data sets shows that within the signal to noise level of the data, it is rather unlikely that any additional periodicity is hidden in the data, in particular any periodicity that might explain the residual variability that still remains in the LC after removing from it all the periods listed in Table 1 below. This was also confirmed by numerical tests that we performed, showing that adding one or a few periods, beyond those listed in Table 1 does not change the quality of the curve fitting in any significant way.

3.3 The photoelectric U light curve

Fig. 1 c) presents the LC of the system as measured photoelectrically in the Johnson U band, extracted as described in section 2.3. It covers the last two clusters of outburst events seen in the visual light curve and shown in Figs 1a) and b), and having a very similar structure. Here again we refer to quiescence (Q) and the outburst-high (H) states.

Fig. 4 a) displays the PS of the U Q LC, and Fig. 4 b) that of its H section. The dominant peak corresponds to the period 547 d. The two satellites of the main peak are aliases of the 547 periodicity. The inset in Fig. 4 a) presents twice the LC folded onto this periodicity. The other high peak in Fig. 4 b), corresponding to the period 1357 d, results from the interference of the 550 periodicity, the 5300 d periodic gaps in the partial Q LC, and the 365 d annual cycle: $F(1357) = F(365) - [F(5300) + F(550)]$. Here $F(P) = 1/P$.

Fig. 4 b) is the PS of the U-H LC. Here, in addition to the low frequency peaks due to the window function of the broken LC, the dominant peaks correspond to the periods 373.6 and 1130.4 d. The inset displays twice the H LC in the U filter, folded onto the 373.5 d periodicity.

3.4 The periodic content of the LC

Table 1 presents a summary of our findings concerning the periodic content in the long term LCs of AG Dra. There are 5 distinct periodicities that seem to dominate the temporal behavior of the continuum emission of the system. They are the quasi period 5300, and the periods 1160, 550, 373.5 and 350 days. The table presents our adopted value for each of these periods, and our estimated uncertainty in each one of them. Our error estimates are based mainly on the dispersions of the peak frequencies of the corresponding features in the different power spectra, and in the published literature. The last 5 columns in the table indicates at which particular LC each period is present and the numerical value it takes in each of the corresponding PS.

We note that all the variations that we are discussing in this paper can hardly be attributed to variation in emission lines. As noted already in section 2, Skopal (2007) estimated that the emission lines contribution to the star brightness in the V band amounts to ∼0.12 mag, while the main variations that are of our concern here are of the order of 1 mag. Furthermore, as Table 1 shows, all the periods discussed here appear to modulate the brightness of the system in 2 and even 3 different photometric broad passbands.

Table 1 presents also 2 numerical relations among the 5 periods of the system, which we shall discuss in the following sections.
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4 DISCUSSION

4.1 The binary period

Spectroscopic observations in AG Dra have established its binary orbital period between 548.5 d and 554.0 (Mikolajewska et al. 1995; Fekel et al. 2000b). This periodicity has been also clearly identified in photometric measurements in the U photometric band (Meinunger 1979).

As described in section 3.1 this photometric period is present also at the two additional independent LCs of section A and of the quiescence states of section B. It is not detected during the high state events. It is also present in the U Q LC (see Fig 4 a).

For period between 550.5 and 552.5 d, the phasing of the 3 independent photometric LCs presented in this work agree with each other to within less than 0.09 in phase space.

We have also considered the radial velocity curve of the system, as presented by Mikolajewska et al. (1995), Fekel et al. (2000b). The phase of maximum positive radial velocity for periods in the above period range is lagging by 0.25 to 0.3 in its value behind a weighted mean phase of minimum light of the corresponding 3 photometric LCs. Specifically, for $P=552.5$ the phase difference is precisely 0.25. This is very much consistent with the "reflection" model that has been proposed as an interpretation of the U binary LC (Kenyon 1986, Formiggini & Leibowitz 1990, Skopal 2001).

4.2 The other periodicities

As shown in Fig 2 b) and Table 1, section B LC is characterized by 4 periodicities. One is $P_{\text{m}}\sim$5300 d, which is the characteristic quasi-periodicity in the occurrence of the 6 H states discussed in section 3.2. The other three, $P_{\text{r}}=373.5$ d, $P_{\text{p}}=350$ d and $P_{\text{z}}\sim1160$ d seem to be the periods of three other cyclical processes that operate in the AG Dra stellar system, preserving their value as well as their phase throughout the time of the observations.

4.2.1 The rotation period of the giant

We suggest that the period $P_{\text{r}}\sim1160$ d is the sidereal rotation period of the cool component of the AG Dra binary system. This is different from estimation of the rotation period of the giant given by Zamanov et al. (2007). We note however that this estimate is based on a few assumptions and measured quantities that are far from being well established. They rely on the assumption that the axis of the giant rotation is normal to the binary plane, and they use an estimate of the radius of this star that is much in dispute in the literature (Mikolajewska et al. 1995, Zhu et al. 1999, Greiner et al. 1997, Huang, Friedjung & Zhou 1994).

Also, the uncertainty in the basic observational parameter of the projected equatorial radial velocity of the giant $v_{r}$ sin $i$ itself is quite large (Fekel, Hinkle & Joyce 2004). According to Mikolajewska et al. (1995), strictly from observations, only an upper limit of the inclination angle of the orbital plane $i(\text{B})<70^\circ$ may be inferred. Also Kenyon & Garcia (1986) analysing the parameters of T CrB system, caution that $v_{r}$ sin $i$ is not necessarily a true measure of the star rotation in such composite systems.

Some indirect evidence that 1160 d is the rotation period of the cool giant comes from the fact that it is absent from the LC of the system in the quiescence states, in the visual as well as in the U photometric bands (sections 3.1 and 3.3). We shall argue below, that the quiescence of the system are time intervals during which the magnetic activity in the outer layers of the giant is dormant. At this times the giant surface brightness is relatively uniform, with too few spots to enable identification of rotation by photometry. High states of the systems are times of highly intensive magnetic activity, accompanied, as in the sun, by appearance of dark spots on the surface of the star. These are the features that enable photometric monitoring of the giant rotation.

Our suggestion that $P_{\text{r}}\sim1160$ d is the giant rotation period makes AG Dra an exception in the claimed general trend of synchronization of the star rotation with the binary orbital revolution, in symbiotic systems with orbital periods <1200 d, (Zahn 1977, Zamanov 2011). However, in the calculations of Zahn (1977) it is assumed specifically that the amplitude of the tidal oscillations of the giant are small enough to justify linear treatment of the problem. In AG Dra, the oscillations need not be small due to the thick stellar wind of this star (Skopal 2001). Also the giant pulsations with the $P_{\text{p}}=350$ d periodicity introduces a mechanical and hydro and thermo-dynamical elements into the physical processes that are so far unaccounted for by present day theory (see also Olgilvie & Lesur 2012).

The rotation of the giant of AG Dra is not very unique in not being synchronized with the orbital revolution also on a purely observational basis. There are in fact some other symbiotic systems that are far from synchronization (see, for example Figure 1 in Zamanov 2011, Cikala et al. 2011).

Table 1. Peaks in the PSa

| Name | Period (d) | Error | Measured period in individual LCs |
|------|------------|-------|----------------------------------|
| $P_\text{m}$ | 5300 | quasi-p | 5373 | 5310 |
| $P_\text{r}$ | 1160 | ±40 | 1135 | 1130 |
| $P_\text{b}$ | 550 | ±4 | 546.5 | 548 | 545 | 547 |
| $P_\text{a}$ | 373.5 | ±1 | 373.7 | 373.6 |
| $P_\text{p}$ | 350 | ±10 | 352 | 358 | 344 |
4.2.2 The 350 d period

As already noted in section 3.5, Friedjung et al. (2003) established a periodicity of \( \sim 350 \) d in the radial velocity of the system which they have attributed to pulsations of the giant star. In this work we discovered the same period in the LC of the system. Fekel et al. (2000b) have objected to this interpretation on the ground that the amplitude of the radial velocity oscillation with this period in AG Dra is much larger than those measured in pulsations of other single K giants with similar long periods.

We shall return to this point at the end of section 4.3.

4.2.3 The 373 d periodicity

A major hint toward understanding the nature of the \( P_a=373.5 \) d periodicity can be found in the numerical relation that exists among this period and the other 2 coherent periods of the system, namely: \( F_{P_a}=F_{P_r}+F_{P_b} \) (Table 1). Here \( F=1/P \), is the frequency corresponding to the period \( P \). This is an expression of the fact that the period \( P_a \) in the occurrence of the major outbursts of the system is a beat of the binary period \( P_b \) and the giant rotation period \( P_r \).

A similar case of the presence of a beat of the binary and the giant rotation periods has been recently found by us in the LC of another symbiotic system BX Mon (Leibowitz & Formiggini 2011). We propose that the interpretation that was given to the presence of the three periods in the LC of BX Mon is applicable also in the case of AG Dra.

If the giant star is rotating with the period \( P_r \) in the retrograde sense with respect to the binary revolution, the period \( P_a \) is the length of a "day" for an observer on its surface, whose sun is the hot component. Fekel, Hinkle & Joyce (2004) estimated that the radius of the Roche lobe of the giant is 141 R\( \odot \). If the radius of the giant is indeed 70 R\( \odot \) or more, as suggested by Greiner et al. (1997) and certainly if it is a supergiant, as suggested by Huang, Friedjung & Zhou (1994), its surface layers are quite deformed by the tidal force exerted by its companion. In particular, its deformation can be described to first approximation as a bulge in its atmosphere that circulates around the surface of star with its synodic diurnal period, namely with the period \( P_a \) (Lecar, Wheeler & McKee 1976).

4.3 The proposed scenario

We suggest that the giant star in the AG Dra system possesses a magnetic field, and that the axis of its dipole moment is inclined with respect to the rotation axis. Around the magnetic poles, due to the intensity and direction of the magnetic field lines, the hydrostatical equilibrium in the atmospheric layers is reached with material that is less bound by gravity than in areas where the magnetic field is weaker. Whenever the tidal bulge is crossing the area around one of the poles, equilibrium is broken and the giant is shedding hydrogen rich material onto the Roche lobe of the hot component. A large amount of gravitational energy is being released in this process, some of it is translated into the form of outbursts in visible light. The amount of material that is being poured onto the hot component in each one of such an accretion event would depend on the intensity of the magnetic field at the time of the bulge sweeping, as well as on hydro and thermo-dynamical parameters that characterize the bulge in the giant atmosphere at that time. In particular, it will depend, for example, on the phase of the giant peculiar pulsation period \( P_a \) at the time of the mass transfer. In events of large mass transfer, hydrogen rich material may also reach the surface of the white dwarf of the system, igniting or intensifying nuclear reaction on its surface. Such events may be responsible for the particularly large outbursts of the system.

This process has been termed "combination nova" by Sokoloski et al. (2006), who studied it in details in their thorough analysis of photometric and a great deal of spectroscopic data, covering two outbursts of the symbiotic star Z And. Recently a great deal of spectroscopic data has been accumulated about AG Dra, in the optical as well in the UV and the x-ray regions of the spectrum (e.g. Shore et al. 2010). These provide a promising raw material for similar studies in AG Dra which may either confirm or perhaps refute the qualitative model that we are suggesting in this paper.

As an example, we examined the peculiar phenomenon discovered by Shore et al. (2010) that was termed by them the "bifurcation" of the O VI Raman line in the bottom right frame of their figure 2. We found that the six points that are responsible for this effect, are measurements that were performed within less than .1 in phase according to the ephemeris of \( P_a=373.5 \) (see section 3.2.1). In fact, Shore et al. already pointed out that these points are associated with an outburst of the system. In view of our proposed cycle it will be interesting to check out whether or not this effect appears cyclically in the spectrum with the period of 373.5 d.

Also the classification of the outbursts of AG Dra into hot and cool types (González-Riestra et al. 1999) may be related to the difference that Sokoloski et al. (2006) have found...
between "combination nova" and disk instability outbursts in the LC of Z And.

According to our suggested scenario, the quasi-periodicity of \(\sim 5300\) d in the occurrence of the outburst events, is the period of a solar-like magnetic cycle that operates in the outer layers of the giant star. The quasi-periodicity of this cycle around 5300 is not unlike the well known quasi-periodicity of the solar magnetic cycle which has the mean period of 4000 d (11 years) but with individual cycles that vary between 3000 and 5000 d (Babcock 1961; Mursula & Ulrich 1998; Fligge, Solanki & Beer 1999).

The mass transfer episodes from the giant with the \(P_a\) periodicity are most intensive when the intensity of the dipole magnetic field around the pole of the giant is highest. Hence the 5300 d quasi-periodicity in the occurrence of the 6 clusters of outbursts in the history of the star.

The 373.5 d periodicity is a product of the parameters, the masses of the components, the radius of the giant, the inter-binary distance and the angle between the rotation and the magnetic axes of the giant. All these are independent of the internal magnetic dynamo process in the giant, hence the independence of the 373.5 d periodicity from the 5300 d one.

According to this scenario, the brightening of the system by 0.29 mag around JD 24 23300 is also related to the commencement of the operation of the magnetic dynamo solar-like cycle in the outer layers of the giant, through some process that is yet unknown.

Mikolajewska et al. (1995) also suggested that the outbursts of AG Dra are powered mainly by nuclear runaway on the surface of the white dwarf (WD) of the system. These authors, however, were concerned about the fact that a continuous process of accretion of matter from the giant wind onto the WD may not be enough to fuel the eruptions of the system at the rate at which they are observed.

Our suggested scenario is very much in line with Mikolajewska et al. idea. It adds a natural explanation for the cyclic nature of the outbursts. It also reveals the power source that is required in order to maintain the long term energy budget of the proposed process. Wind accretion from the giant is indeed not enough. The outbursts are fueled mostly by the flow of large amount of giant material through the \(L1\) point of the system, at epochs of intense magnetic activity in the giant’s outer layers.

Finally we note that the exceptionally large radial velocity amplitude of the pulsation of the K giant of AG Dra (Fekel et al. 2000b) may be well understood in view of the relation \(F(373)+F(5300)=F(350)\) (see Table 1). What gives the oscillations of the K giant of AG Dra their exceptionally large amplitude is the combined effect of the 5300 quasi periodicity of the magnetic dynamo operating within the giant, and the 373.5 period of its tidal oscillations. These two cycles beat with each other, augmenting in the giant its pulsations mode of the 350 d periodicity.

### Table 2

| Z And | Ref. | BF Cyg | Ref. | YY Her | Ref. | BX Mon | Ref. | AG Dra | Ref. |
|-------|------|--------|------|--------|------|--------|------|--------|------|
| Giant Sp. Type | M4 III | 1 | M5 III | 1 | M4 III | 1 | M5 III | 1 | K2 II | 3 |
| Binary period (d) | 759.0 | 5 | 757.3 | 6 | 593.2 | 7 | 1256 | 4 | 548.65 | 5 |
| Giant Spin period (d) | 482* | 8 | 798.8 | 6 | 551.4 | 7 | 656 | 9 | 1160 | 10 |
| Tidal wave period (d) | 1317 | 8 | 14580 | 6 | 7825 | 7 | 1373 | 9 | 373.5 | 10 |
| Solar-type period (d) | 7550 | 8 | 5375 | 6 | 4650 | 7 | 7370 | 9 | 5300 | 10 |

*) This is a slightly preferred number among four possible values.

1) Mürset & Schmid (1999), 2) Mürset et al. (1991), 3) Zhu et al. (1999), 4) Fekel et al. (2000a), 5) Fekel et al. (2000b), 6) Leibowitz & Formiggini (2006), 7) Formiggini & Leibowitz (2006), 8) Leibowitz & Formiggini (2008), 9) Leibowitz & Formiggini (2011), 10) This paper.

### 4.4 Comparison between BX Mon and AG Dra

It is interesting to compare our findings in the LC of AG Dra with those found by us in the LC of BX Mon (Leibowitz & Formiggini 2011). That star exhibits in its long term LC a series of outbursts that take place with a periodicity of 1373 d which, as in AG Dra, is the beat of the binary and the giant rotation periods of that system. As in section A of the LC of AG Dra, in BX Mon there is also a long time interval during which the 1373 d periodicity in the occurrence of outbursts disappeared from the LC. But unlike the case in AG Dra, in BX Mon at that time, the 1373 period is being replaced by \(P=1263\) d, the binary period of the system. This difference between the two symbiotics finds a natural explanation within the framework of the scenario that we are suggesting.

The disappearance of the spin-orbit beat period from the LC in both cases could be due to a long minimum phase in the operation of the magnetic dynamo cycle within the giant star, reminiscence of the well known Maunder minimum (Eddy 1976) in the history of the solar magnetic dynamo. At that minimum the dipole magnetic field of the giant is lowest. Hence the 5300 d periodicity in the occurrence of the outburst may be well understood in view of the relation \(F(373)+F(5300)=F(350)\) (see Table 1). What gives the oscillations of the K giant of AG Dra their exceptionally large amplitude is the combined effect of the 5300 quasi periodicity of the magnetic dynamo operating within the giant, and the 373.5 period of its tidal oscillations. These two cycles beat with each other, augmenting in the giant its pulsations mode of the 350 d periodicity.
5 SUMMARY AND THE GENERALITY OF THE PHENOMENON

AG Dra is the 5th symbiotic system in the historical LC of which we have discovered similar patterns of temporal behavior. Here and in the other cases we interpret the findings as tracks of strong periodic activity, driven and modulated by three clocks in the system, the binary revolution, the giant rotation and a quasi-periodic, solar-like magnetic dynamo cycle in the outer layers of the giant star. Table 2 presents the periodicities and quasi-periods that we have uncovered in the LCs of these 5 symbiotics. The similarities in the corresponding periods seem to be quite remarkable.

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