Serb. Astron. J. № 194 (2017), 1 - 21
DOI: https://doi.org/10.2298/SAJ1794001M

UDC 524.386 + 524.387
Invited review

LONG PHOTOMETRIC CYCLES IN HOT ALGOLS

R. E. Mennickent

Universidad de Concepción, Departamento de Astronomía, Casilla 160-C, Concepción, Chile
E–mail: *rmennick@udec.cl*

(Received: May 15, 2017; Accepted: May 15, 2017)

SUMMARY: We summarize the development of the field of Double Periodic Variables (DPVs, Mennickent et al. 2003) during the last fourteen years, placing these objects in the context of intermediate-mass close interacting binaries similar to β Persei (Algol) and β Lyrae (Sheliak) which are generally called Algols. DPVs show enigmatic long photometric cycles lasting on average about 33 times the orbital period, and have physical properties resembling, in some aspects, β Lyrae. About 200 of these objects have been found in the Galaxy and the Magellanic Clouds. Light curve models and orbitally resolved spectroscopy indicate that DPVs are semi-detached interacting binaries consisting of a near main-sequence B-type star accreting matter from a cooler giant and surrounded by an optically thick disc. This disc contributes a significant fraction of the system luminosity and its luminosity is larger than expected from the phenomenon of mass accretion alone. In some systems, an optically thin disc component is observed in well developed Balmer emission lines. The optically thick disc shows bright zones up to tens percent hotter than the disc, probably indicating shocks resulting from the gas and disc stream dynamics. We conjecture that a hotspot wind might be one of the channels for a mild systemic mass loss, since evidence for jets, winds or general mass loss has been found in β Lyrae, AU Mon, HD 170582, OGLE 05155332-6925581 and V 393 Sco. Also, theoretical work by Van Rensbergen et al. (2008) and Deschamps et al. (2013) suggests that hotspot could drive mass loss from Algols. We give special consideration to the recently published hypothesis for the long-cycle, consisting of variable mass transfer driven by a magnetic dynamo (Schleicher and Mennickent 2017). The Applegate (1992) mechanism should modify cyclically the equatorial radius of the chromospherically active donor producing cycles of enhanced mass loss through the inner Lagrangian point. Chromospheric emission in V 393 Sco, an optically thicker hotspot in the high-state of HD 170582 and evidence for magnetic fields in many Algols are observational facts supporting this picture. One of the open questions for this scenario is why, among the Algols showing evidence for magnetic fields, the DPV long-cycle is present only under some combinations of stellar parameters, particularly those including the B-type gainers. Other open questions are what are the descendants of these interesting binaries, how much mass contain the discs around the likely rapidly rotating gainers, and the role played by the outflows through the Lagrangian L2 and L3 points reported in a couple of systems.

Key words. binaries: close – Stars: evolution – Stars: mass-loss

1. INTRODUCING ALGOLS

In this section we provide a brief introduction to the class of close binaries named Algols, starting with a review of the importance of binaries in general.

1.1. The importance of binary stars

A large fraction of the stars in the Universe are binaries or members of multiple systems bounded by gravity. The multiplicity frequency of main sequence stars is a steep function of the stellar mass, increasing toward earlier spectral types (Duchêne and Kraus 2013). Binaries are specially useful astronomical tools, since they provide a direct way of weighting the stars, and deriving fundamental parameters like mass and radius (Andersen 1991). The first list of well observed binaries is provided by Popper (1980). Harmanec (1988) collects and analyzes data on absolute dimensions of eclipsing binaries and derives approximation formulae relating the effective temperature with mass, radius and bolometric magnitude. Torres et al. (2010) present and discuss a critical compilation of accurate, fundamental determinations of stellar masses and radii based on data for 95 detached binary systems containing 190 stars. It should be noticed that for eclipsing binaries and multicolor calibrated light curves, it is possible to get relative luminosities and effective temperatures of components and thus good distance estimates, something especially important for binaries in foreign galaxies. Actually, binaries provide valuable tools to study our Universe even beyond the Milky Way (Guinan 2004, Ribas 2004).

Binaries tends to interact at some stages of their lifetime, especially the massive ones. According to Sana et al. (2012), more than 70% of all massive stars will exchange mass with a companion, leading to a binary merger in one-third of the cases. Assuming constant star formation, de Mink et al. (2014) find that $8^{+9}_{-4}\%$ of a sample of early-type stars are the products of a merger resulting from a close binary system. They report that $30^{+10}_{-15}\%$ of massive main-sequence stars are the products of binary interaction. These considerations suggest that the study of binary interaction is relevant to understand the evolutionary paths of massive stars. Actually, binary interaction has been claimed to be relevant even to understand the multiple stellar populations detected in some globular clusters (Jiang et al. 2014, Carraro and Benvenuto 2017). Understanding binary interaction will help us to understand how they arrive to their late evolutionary stages, and in the case of the more massive binaries, how they give rise to the most energetic phenomena in the universe as supernovae, gamma ray bursts or even the merger of binary black holes triggering gravitational waves (Abbott et al. 2016 a,b).

1.2. Some basic theoretical concepts

The basic physical picture for binary interaction and evolution can be described in terms of the Roche model for binary systems (Roche 1873, Kopal 1959). In this model the stars are treated as point masses and an effective potential is defined including the stellar gravitational potentials and the centrifugal potential due to binary motion. A specific equipotential curve defines the Roche lobes or regions of gravitational bounding of each star. When one star evolves until filling this volume, a semi-detached system is formed, and under certain conditions part of its atmosphere starts to be transferred onto the other star through the inner Lagrangian point L1, the common point of both Roche lobes. Depending on the mass ratio and the size of the primary, the gas stream hits directly the gainer or turns around forming an accretion disc (Lubow and Shu 1975); hence two kinds of semi-detached systems can be found, disc and impact systems. The Lubow and Shu (1975) critical radius can be approximated by (Hessman and Hopp 1990):

$$\frac{r_{\rm c}}{a} = 0.0859 q^{-0.426} \qquad \text{for} \;\; 0.05 < q < 1. \qquad (1)$$

where q is the mass ratio M_2/M_1 and the formula is accurate to 1%. This radius is usually taken as the maximum possible radius of the primary allowing disc formation. A particle orbiting at this radius has the same specific angular momentum as a particle released at the inner Lagrangian point L_1, therefore, the radius corresponds to the radial extension of a ring of matter formed by mass loss due to the Roche lobe overflow, just before viscosity starts spreading it into a disc. Therefore, a primary whose radius is larger than the critical radius ($R_1 > r_{\rm c}$) is an impact-system where the gas stream hits the star and disc formation is unlikely. Actually, due to the finite stream size, it is still possible that the outer stream orbits avoid the impact, the respective radius $r_{\rm max}$ is a bit larger than $r_{\rm c}$ and also a function of the mass ratio (Lubow and Shu 1975).

The observational signatures of these semi-detached systems in the high-energy range critically depend on presence of a compact object; cataclysmic variables containing a white dwarf, high-mass X-ray binaries containing a neutron star are some examples of systems emitting strongly in UV and X-rays due to mass accretion in deep gravitational potential wells. However, in this review we consider semidetached binaries of intermediate mass containing no compact object. These binaries emit mostly in optical and infrared wavelengths and besides the spectral contributions of both stars, those of disc and stream must be occasionally included. Even with the main sequence or giant components, the real situation can involve distortion of stars by rapid rotation, which should modify the equipotential surfaces, the irradiation of one star by the other (Claret and Gimenez 1992), the existence of hot regions in the disc due to energy dissipation by dynamical shocks, the existence of disc jets and magnetic spots, among other phenomena (Nazarenko and Glazunova 2006a,b, 2013).

It is interesting that no definitive prescription exists for some kinds of binary interaction in spite of being a critical stage where the future outcome of the binary is defined. Many evolutionary models deal with our ignorance through ad-hoc parameterizations. For instance, the α parameter introduced during common envelope phase (Livio and Soker 1998) represents the amount of energy that is removed from the orbit and is transferred to the circumstellar gas, its value determines how much the orbit of the binary shrinks during dissipation of the common envelope and it is critical to understand the population of cataclysmic variables (Zorotovik et al. 2010). Also, the mass transferred onto the gainer during the stage of Roche overflow is not well constrained since a fraction can be lost into the circumstellar medium through equatorial outflows or disc winds; this uncertainty is represented by the parameter β determining the fraction of transferred mass that is lost from the system (e.g. de Mink et al. 2014). None of these parameters is well constrained and population synthesis models must rest on educated assumptions.

Another uncertainty present in impact systems is the amount of matter the star can accrete from the disc once reached the critical velocity. Petrovic et al. (2005) and de Mink et al. (2009) assume that accretion ceases when the mass-gaining star reaches Keplerian rotation, while Popham and Narayan (1991) argue that a star near critical rotation can sustain accretion due to viscous coupling between the star and the disc.

The above scenarios are illustrated in the Algol-type variables, a class of semi-detached binaries with intermediate mass components, where the less massive star is more evolved that the gainer more massive star, something that can be understood only if the donor was once the more massive star of the system, evolved first, and then lost a fraction of its mass through the Roche lobe overflow onto the gainer. This evolutionary sequence was first explained by Crawford (1955) and later confirmed via evolutionary calculations by Kippenhahn and Weigert (1967) and Eggleton and Kisseleva-Eggleton (2006). The Roche lobe overflow can happen during (Kippenhahn and Weigert 1967): the donor main sequence stage (case-A), during the transition to (or in) the red-giant phase (case-B) or during the supergiant phase (case-C).

1.3. Historical perspective

Goodricke discovered the 2.867 day period in the eclipses of the prototype Algol (β Per) in the year 1783 (Goodricke 1783). However, the star has been know as a variable since ancient times; evidence has been found indicating that the period of Algol was 2.850 days three millennia ago as recorded by ancient Egyptians (Jetsu et al. 2013). Algol is actually a triple-star system: the eclipsing binary pair consisting of a B8V and a K0III star separated by 0.062 astronomical units (AU) from each other, whereas the third star is at an average distance of 2.69 AU from the pair, and the mutual orbital period of the trio is 681 Earth days. The total mass of the system is about 5.7 solar masses (Kolbas et al. 2015 and references therein).

A related system is the widely studied β Lyrae (its arabic name is Sheliak) whose proximity effects are noticed in the rounded shape of the light curve between eclipses, a signature of a gravitationally distorted star. β Lyrae consists of a B8 II star and a more massive primary of probably also B-type. The more massive star is surrounded by an optically thick and geometrically thick disc (Wilson 1974) and a jet has beed detected emerging from the region of interaction between the disc and the gas stream (Harmanec et al. 1996, Ak et al. 2007). The first direct detection of photospheric tidal distortion due to the Roche lobe filling was presented by Zhao et al. (2008) in β Lyrae, based on the CHARA interferometry. These authors also detected the thick disk surrounding the mass gainer at resolved H-band images. The level of activity in β Lyrae is larger than in ordinary Algols, as revealed by variable eclipse shapes, super-orbital photometric cycles and orbital period changes (see below). β Lyr was the second variable star in being discovered, after Algol, and the history of earlier investigations of this fascinating star is skillfully presented by Sahade (1980) and Harmanec (2002).

1.4. Some words about Algols as a classification scheme

The traditional classification of eclipsing binaries in terms of their light curve morphology is EA (flat between eclipses), EB (rounded between eclipses) and EW (no clear distinction when one eclipse ends and the other starts). These systems were also named in terms of famous cases as Algol systems (EA light curve), β Lyrae type systems (EB) and W UMa type systems (EW). Later investigations on the evolution of close binaries yielded to understand β Lyrae as a close binary in a stage of mass transfer and the Roche lobe overflow, while Algol was understood as a system that already underwent a major episode of mass transfer in the past, and now is ongoing very small mass transfer. For this reason it was popular to name Algols also those systems undergoing the Roche lobe overflow. In this scheme β Lyrae is an Algol, although it is not from the point of view of the scheme of light curve classification alone. In this review we consider Algols the whole class of intermediate mass close binary systems independent of their evolutionary stage or light curve morphology, including in this way β Lyrae and Algol itself.

1.5. Variability in Algols

Orbital period changes have been reported in a couple of Algols; they can be interpreted as signature of mass loss as expected from basic laws of energy and angular momentum conservation (Eggleton 2006). However, the orbital period can also vary in a monotonic way in the conservative case due to simple mass transfer among the stars. In the case of β Lyrae, the orbital period of 12.9 days increases at a rate of 19 s/yr (Harmanec and Scholz 1993) and this is usually interpreted as due to the effect of a mass transfer rate of 2.2×10^{-5} M$\odot$/yr (Hubeny and Plavec 1991, Harmanec and Scholz 1993). The orbital period of Algols can also vary cyclically by the light-time effect due to unseen components around the system (e.g. Hoffmann et al. 2006, Soydugan 2008). Another interpretation for these cyclic orbital period changes is magnetic cycles in the cool component producing variations in its quadrupole momentum yielding changes in the angular momentum distribution and therefore in the orbital period (Applegate 1992). From the above, the changes in the orbital period have not an unique interpretation, and must be studied in a case by case basis. In this review we focus on a class of Algols where long super-orbital photometric periods are detected. These long cycles are rare in classical Algols, they usually appear in absence of clear orbital period changes, and might be related to magnetic activity of the donor star as we will show later.

Episodes of systemic mass loss are needed to explain the current population of Algols. For instance, Massevitch and Yungelson (1975) state that it is necessary that in Algols about 40% to 50% of the matter lost by the primary is lost by the system. Sarna (1993) determines that β Per (Algol) loses about 15% of its initial total mass and 30% of its initial total angular momentum during evolution. However, intents to detect where the mass lost by Algols has gone have been unsuccessful (Deschamps et al. 2015).

It is possible that magnetic activity plays a role in the observational signatures of Algols. The relation between Algols and chromospherically active RS CVn binaries was explored by Hall (1989). Indeed, magnetic variability, like those observed in the RS CVn binaries, has been inferred from radio observations (Lefevre et al. 1994 a,b), X-rays (Singh et al. 1995, 1996), Doppler tomography of the Hα line (Richards and Albright 1993, Richards et al. 2012) and starspots (Zhang et al. 2014). Algol itself shows a cycle of 32 years (Soderhjelm 1980) whose connection with magnetic activity has been confirmed by radio observations by Peterson et al. (2010). The possibility of tracing dynamo action in mass-losing stars that are components of Algol-type binaries has been examined by Sarna et al. (1997) and recently explored by Schleicher and Mennickent (2017) in the context of long-cycles of hot Algols, as we will show later in this review. It must be stated that the role played by magnetism in the overall evolution of Algols (and also massive stars) remains to be established.

1.6. Long cycles in Algols

The existence of long cycles is known since a long time ago in a handful of Algols; Gaposchkin (1944) reported a long cycle of 517.6 days in RX Cas, Lorenzi (1980) showed the presence of a 411 day long cycle in AU Mon, Guinan (1989) inferred a 275 day period for β Lyr, Hill et al. (1997) reported a long cycle of 322.24 days for V360 Lac and Koubsky et al. (1998) reported a long cycle of few hundred days in CX Dra. The exact long period for this interesting system is not well determined. From a study of infrared images, Mayer et al. (2016) determined that CX Dra shows an irregular circumstellar environment morphology which might somehow be related to systemic mass loss. More recently, a period of 253.4 days was reported for V 393 Sco (Pilecki and Szczyygiel 2007).

The interpretation of the long cycles has remained controversial. Kalv (1979) interpreted the 516-day periodicity of RX Cas as pulsation of the Roche lobe filling star. Pulsation is also suggested by Guinan (1989) for the B8 II component of β Lyrae although he also mentioned possible changes in the structure of the disc. Peters (1994) suggests that in AU Mon the changes are due to cyclic pulsations of the donor but without any explanation of how this could be possible. Studying β Lyrae, Harmanec et al. (1996) considered the 282 day cycle as a possible beat between the orbital period and the 4.7 day period they detected in spectroscopy. They also noticed the similarity of β Lyrae with V 1343 (SS 433), a massive X-ray binary of orbital period 13.08 days and bipolar jets. Posteriorly, Wilson and van Hamme (1999) concluded that neither apsidal advance nor precession can account for the 282-day light variation in β Lyrae, but they were unable to exclude disc pulsations as the origin. Later, Desmet et al. (2010) study very accurate the CoRoT space photometry, past the Johnson V photoelectric photometry and high-resolution echelle spectra of AU Mon and conclude that the long term photometric variations are due to light attenuation by variable amounts of circumbinary matter. This conclusion is mainly based on the constancy of the light curve shape during the long-cycle.

2. DOUBLE PERIODIC VARIABLES

In year 2003 an announcement of the discovery of a group of stars in the Magellanic Clouds was published, showing two linked periodicities, a short-one lasting a couple of days and a longer one lasting hundreds of days; both periodicities were coupled through the relation $P_l = 35.2 \pm 0.8\ P_o$ (Mennickent et al. 2003). The typical amplitude of the long variability is 0.1-0.2 mag in the I-band and the light curve shape sometimes sinusoidal and sometimes double-hump (e.g. Poleski et al. 2010). The above relation and the existence of two periods have given rise to the name of Double-Periodic Variables (DPVs). An example of the DPV light curve is shown in Fig. 1.

Since the beginning it was clear that these objects were binaries, since the short-term light curves revealed ellipsoidal or eclipsing type variability. Their position in the Hertzsprung Russell diagram was above the main sequence in the $V - I$ color region corresponding to B/A-type stars, actually, they were found during a search of emission line objects of the Be-type. At the beginning their relationship to Algols was not clear and the nature of the long cycles remained unknown. Mennickent et al. (2003) explored hypothesis in terms of disc precession but later observations of V 393 Sco were incompatible with this idea (Mennickent et al. 2012a,b). In year 2005, the first spectra of DPVs in the Magellanic Clouds were published, and the view of low mass ratio binaries containing B-type components was strengthened (Mennickent et al. 2005a). Some Balmer lines in the spectra were filled by emission, pointing to the presence of circumstellar matter.

In the above study, the system OGLE05200407-6936391 presented a remarkable shortening of the long-cycle from 340d to 270d in a couple of cycles. The non-constancy of the long-cycle in many DPVs was confirmed by Mennickent et al. (2005b). In addition, it was clear that the long cycle produces photometric variability of larger amplitude in redder bands (Michalska et al. 2010). The presence of Hα emission in a couple of DPVs was reported by Mennickent et al. (2011) for a sample of 8 DPVs, illustrating their complex nature, and confirming the presence of circumstellar matter in most of these systems.

The connection with β Lyrae was evident with the study of OGLE 05155332-6925581 (Mennickent et al. 2008). This object turned out to be a relatively massive semi-detached binary of orbital period of 7.284297 days resembling β Lyrae in some aspects; a luminous accretion disc surrounds a hidden B-type star. After 12 relatively stable cycles, the system shows a remarkable long period change from 188 to 172 days. This period shortening lasts for at least 10 cycles. Interestingly, the star follows a loop in the color-magnitude diagram during the long cycle, being bluer during the rising phase and redder during decline. This was interpreted by the authors as evidence of mass loss, following a similar phenomenon detected in Be stars by de Wit et al. (2006). Additional evidence for mass loss came from the behavior of discrete absorption components detected in the infrared HI lines; their strength and radial velocities follow a saw-teeth pattern during the orbital cycle consistent with equatorial outflows. Mennickent et al. (2008) proposed cycles of mass loss feeding a circumbinary disc as explanation for the long photometric cycle, the color-magnitude loop and for the orbital behavior of the discrete absorption features detected in infrared H I lines.

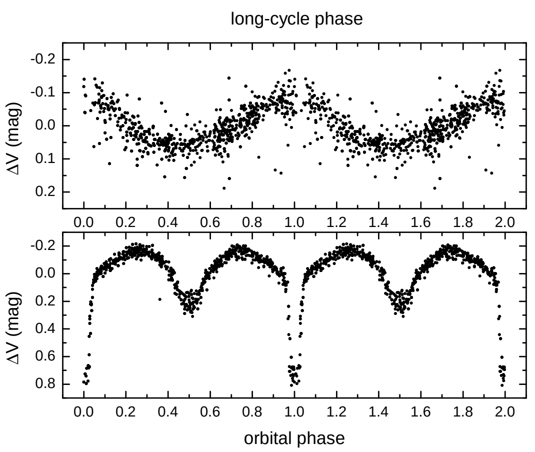

Fig. 1. *Disentangled light curve for V495 Cen, the orbital period is 33.49 days and long period 1283 days (Mennickent and Rosales 2014).*

Further analysis of the system yielded a comparison of the orbital and stellar parameters with those provided by the grid of synthetic binary star models by Van Rensbergen et al. (2008) including epochs of non-conservative mass transfer. The best multi-parametric fit is obtained with a model in a conservative case-B mass-exchange with a relatively large mass transfer rate of $\dot{M} = 3.1 \times 10^{-6}$ M$\odot$/yr (Garrido et al. 2012). However, contrary to the expectation for a conservative high-mass transfer rate system, the orbital period remained relatively stable during 15 years. A complex picture of balanced and opposite effects of mass transfer and mass loss is offered by these authors to account for the absence of orbital period variations. In this picture, outflows through the Lagrangian L2 and L3 points could bring enough angular momentum of the system to keep constant the orbital period.

The definitive connection of DPVs with Algols appeared in 2012 when the first catalogue of Galactic DPVs was released (Mennickent et al. 2012a). Some of them were known Algols: AU Mon, V 393 Sco, LP Ara, DQ Vel, and GK Nor. Among these, only AU Mon was known to show a long periodicity. These objects (except for LP Ara) are still miss-classified as *detached* binaries in the SIMBAD database.

The fact that the long cycles last hundreds of days conspired against an early detection of these Galactic DPVs; only all-sky patrol programs and survey data, especially ASAS, along with scarce long-term monitoring of specific objects, provided the data with enough time coverage to reveal them.

Catalogues of DPVs have been published in the Galaxy (Mennickent et al. 2012a, Mennickent et al. 2016a), the Large Magellanic Clouds (Poleski et al. 2010), the Small Magellanic Cloud (Pawlak et al. 2013) and in the direction of the Galactic Bulge (Soszynski et al. 2016). The current census gives 137 DPVs in the LMC (125 from Poleski et al. 2010 plus 12 found during our own unpublished research), 55 DPVs in the SMC (Mennickent et al. 2003, 2005, Pawlak et al. 2013 and our own unpublished research) and 21 DPVs in the Galaxy (Mennickent et al. 2016a), but see the update at the end of this section. The number of DPVs in the Soszynski et al. catalogue remains to be determined. For comparison, the more recent catalogue of Algols by Budding et al. (2004) lists 411 Algol-type semi-detached binary stars. In the meantime, new samples of similar binaries with long-cycles were released by Desmet et al. (2010) and Harmanec et al. (2015). The above numbers suggest that the DPV phenomenon traces a relatively long-lasting stage in the lifetime of a binary. About 3% of the DPVs have been studied spectroscopically, about 30% of the DPVs are eclipsing.

DPVs have been found in three galaxies, the Magellanic Clouds and the Milky Way; in all cases a relationship:

$$P_{\rm cycle} = f \times P_{\rm orb}, \tag{2}$$

has been found between the long cycle length and the orbital period, with $f \approx 33$ but with single values for the period ratio typically between 27 and 39 (e.g. Mennickent et al. 2016a).

In the past, there was some reluctance in including β Lyrae and RX Cas among DPVs since they showed, contrary to known DPVs, variable orbital light curves and variable orbital periods. TYC 7398-2542-1 (ASAS J182841-3314.6) was also excluded because of showing an Algol-type (EA) light curve typical of a detached system, not as almost all known

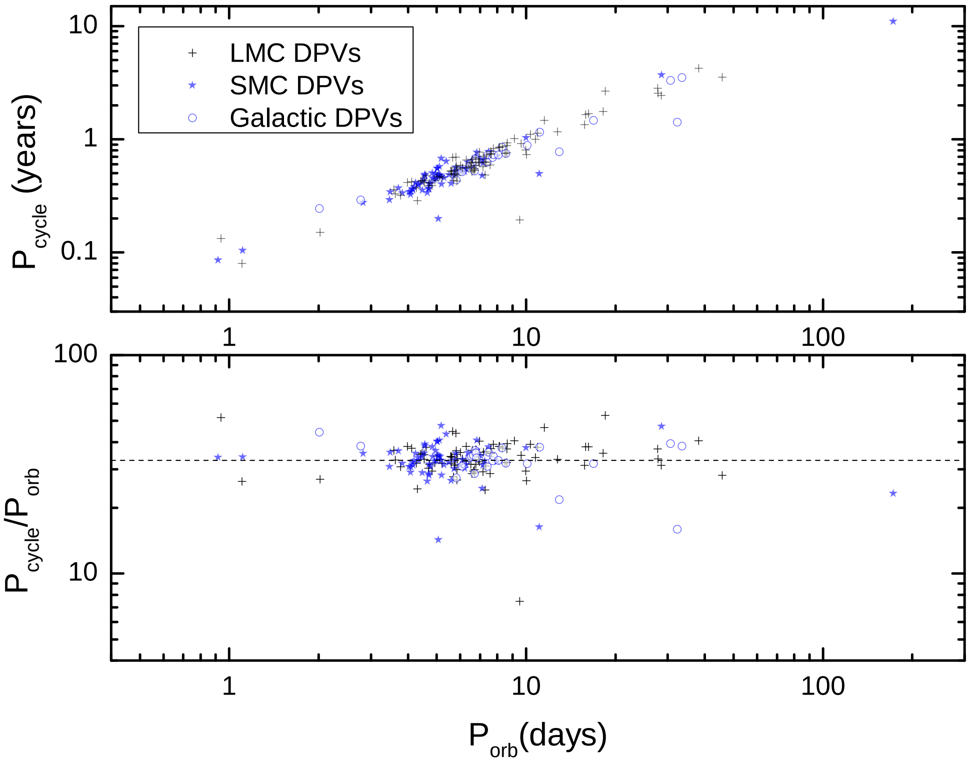

Fig. 2. *Long versus orbital period for Double Periodic Variables. Data are from Poleski et al. (2010), Pawlak et al. (2013), Mennickent et al. (2016a), our own SMC DPV studies (Mennickent and Kolaczkowski, unpublished, 55 objects), and we also have included β Lyrae, RX Cas, TYC 7398-2542-1 and DD CMa. A reference line has been traced at the period ratio P_{cycle}/P_{orb} = 33.*

DPVs (EB-type). However, in this review they are included as possible DPVs, since we don't know a priori if the same mechanism triggering the long DPV cycle operates in them. All DPV periods are shown in Fig. 2. It is interesting that there is a group of systems with orbital period around 1 day, especially considering the relatively small room available for a potential disc; they certainly need more investigation. For Algols TT Hya and SX Cas, presence of a long cycle is unclear, so they were not included in the list of 26 Galactic DPVs presented in Table 1.

3. NOTES ON METHODOLOGY

DPVs have been studied with conventional spectroscopic and photometric techniques often applied to binary stars. In particular, we briefly mention in this section the methodology of spectral disentangling, light curve modeling, Doppler Tomography and χ^2 minimization, the later between multiple observed parameters and those predicted by synthetic evolutionary tracks of binary stars. This section is strongly biased by the experience of the author, while other techniques used in some DPVs by other groups are probably not described in detail.

Spectral disentangling allows separation of spectral components in the binary. This is especially needed due to the multiple-component structure of the DPV spectra where stars, disc, gas stream and wind significantly contribute to the radiative flux.

A method for spectral disentangling is provided by the program KOREL developed by Petr Hadrava at Ondrejov Observatory. It is based on the Fourier Transform; it allows to decouple until 5 different spectral components assuming their constancy in flux contribution during the orbital cycle (Hadrava 1995, 1997). Other method is described by Gonzales and Levato (2006); it consists in translating spectra in the velocity space according to the orbital motion of one of the components, and then sum the resulting spectra removing at first order one component. This procedure is repeated in successive iterative steps until getting a spectrum relatively free of the flux constribution of one of the components. Another method consists in that, after knowing the spectral characteristics of the donor, its orbital motion and their contribution to the total flux, a synthetic spectrum of the same characteristics can be removed from each observed spectrum to get residuals spectra that can be investigated furthermore (e.g. Mennickent et al. 2012b). The advantage of this method is to avoid the assumption of constancy of the fractional light contribution of the donor during the orbital cycle but, on the other hand, it demands adequate a-priori knowledge on the system. Additional disentangling techniques include direct subtraction (Ferluga et al. 1997), tomographic separation (Bagnuolo and Gies, 1991) and wavelength domain (Simon and Sturm, 1994). All these methods can in principle be applied to disentangle DPV

Table 1. The Galactic Double Periodic Variables sorted by increasing orbital period. The published spectral type and extreme visual magnitudes are given. The single-wave (sw), double-wave (dw) or eclipsing (e) character of the orbital light curve is also given. Table adapted from Mennickent et al. (2016a). We include information from The International Variable Star Index (https://www.aavso.org/vsx/). The long periodicity for DD CMa is from Rosales and Mennickent (2017) and data for U Cep from Manzoori (2008). Spectral types indicated with † were estimated based on published temperatures.

Object	Other name	RA (2000)	DEC (2000)	Max V	Min V	P_o (days)	P_l (days)	Type	SpT
DD CMa	TYC 5974-1117-1	07 24 08.65	-19 10 46.5	11.46	12.50	2.008452	89	e	-
U Cep	HD 5679	01 02 18.45	+81 52 32.1	6.75	9.24	2.493087	var	e	B7Ve+G8III-IV
TYC 7398-2542-1	ASAS J182841-3314.6	18 28 41.06	-33 14 34.5	10.68	11.13	2.76903	106	e	-
HD 151582	TYC 7867-2398-1	16 49 54.27	-38 32 40.6	9.43	9.53	5.823	160	sw	B3II/IIIe
DQ Vel	TYC 8175-333-1	09 30 34.22	-50 11 54.1	10.73	11.69	6.0833	189	e	B3V+A1III
BF Cir	HD 132461	15 02 32.02	-64 57 41.9	8.65	9.24	6.4592	219	dw	B5V
GK Nor	TYC 8708-412-1	15 34 50.91	-58 23 59.3	11.13	11.90	6.53971	225	e	-
HD 135938	TYC 8695-2281-1	15 20 08.44	-53 45 46.5	9.13	9.38	6.6477	231	dw	B5/B6IVp
HD 50526	TYC 161-1014-1	06 54 02.03	+06 48 48.8	8.12	8.48	6.7007	192	dw	B9
V1001 Cen	HIP 69978	14 19 09.04	-55 52 56.1	7.20	7.37	6.736	247	dw	B4IV/V+OB:
NSV 16849	HD 256413	06 24 01.82	+19 54 32.3	8.87	9.02	6.775	242	dw	B5III
HD 90834	TYC 8613-1865-1	10 27 41.61	-59 17 04.9	9.08	9.42	6.815	231	dw	B5/B6III/IV(e)
TYC 5985-958-1	GSC 05985-00958	07 44 15.30	-17 58 45.7	10.4	10.75	7.4054	229	dw	-
TYC 8627-1591-1	CPD-58 3114	11 06 29.07	-58 48 18.8	8.77	8.94	7.462	268	dw	B5
V393 Sco	HIP 87191	17 48 47.60	-35 03 25.6	7.39	8.31	7.71259	253	e	B5+A6III†
V761 Mon	HIP 36093	07 26 09.54	-10 32 56.7	8.25	8.45	7.754	268	dw	B5V+A:
CZ Cam	HIP 18593	03 58 43.64	+69 00 59.5	9.37	9.66	8.055	266	dw	B5
TYC 5978-472-1	CPD-21 2186	07 26 41.41	-22 08 53.7	10.20	10.73	8.2958	312	dw	B3V
LP Ara	HD 328568	16 40 01.78	-46 39 34.9	10.00	10.98	8.53295	273	e	B5+A1III†
V360 Lac	HIP 112778	22 50 21.77	+41 57 12.2	5.88	5.99	10.085	322	dw	B3e+F9IV
AU Mon	HIP 33237	06 54 54.71	-01 22 32.8	8.20	9.16	11.11309	421	e	B5e+G
β Lyr	HD 174638	18 50 04.80	+33 21 45.6	3.30	4.35	12.94061713	275	e	B8II-IIIep
HD 170582	TYC 5703-2382-1	18 30 47.53	-14 47 27.8	9.60	9.86	16.871	537	dw	B3.5+A5III†
V4142 Sgr	HD 317151	18 07 44.56	-28 24 04.3	10.85	12.70	30.636	1206	e	A0
RX Cas	HIP 14542	03 07 45.75	+67 34 38.6	8.64	9.49	32.31211	var	e	K1III+A5eIII
V495 Cen	CD-55 4911	13 01 34.81	-56 05 30.9	9.82	10.88	33.4873	1283	e	B4+G0†

spectra, but taking special care of emitting/absorbing structures which might have different visibility at different orbital phases.

The light-curve fitting has been performed using the inverse-problem solving method based on the simplex algorithm, and the model of a binary system with a disc (Djurašević 1992a,b). The Nelder-Mead simplex algorithm (see e.g. Press et al. 1992) has been used with optimizations described by Dennis and Torczon (1991). While the direct problem comprises the calculation of the light curve from model parameters given a priori, the inverse problem is process of finding the set of parameters that will optimally fit the synthetic light curve to the observations. The method has been successfully applied to DPVs and revealed the basic properties of the accretion discs (temperature, radii, vertical extension) and incidentally the presence of bright regions, which are discussed later in this review. Other light-curve fit algorithms applied to Algols with discs are those by Zola (1995) who pointed out the importance of including the disc in the model to avoid spurious contact configurations, and Wilson and Caldwell (1978) who modeled V 356 Sgr.

Doppler tomography was introduced as a tool for the study of accretion discs by Marsh and Horne (1988). This method is now a widespread procedure in the study of emission lines in Algols (Richards 2004, Richards et al. 2012), and provides a quantitative mapping of optically thin line forming regions in the velocity space. The underlying assumptions include an optically thin emitting disc in the binary orbital plane. Even when severe self-absorption and/or intrinsic line broadening are present, the tomograms provide at least a concise and convenient way of displaying phase-resolved line profile measurements. The Doppler reconstructions are computed using the filtered back-projection method (Rosenfeld and Kak 1982), the Maximum Entropy Method (Marsh and Horne 1988, Spruit 1998) or the Total Variation Minimization (Uemura et al. 2015). When interpreting Doppler maps, one should keep in mind the difficulty in representation of optically thick structures and components above or below the orbital plane. Doppler tomography allows the study of the disc emissivity and chromospheric emission sites in Algols and DPVs (Richards et al. 2012, Mennickent et al. 2012b, 2016b). While Doppler tomography is usually sensible to line emission, the light curve model is more sensible to continuum emission and optically thick regions of the disc. This might, in principle, produce differences in the estimated disc size in both methods. A good example of this mismatch is the radius of the disc of AU Mon. While Atwood et al. (2012) determine 23 $R_{\odot}$ with a technique sensible to optically thin line emitting regions, Djurašević et al. (2010) found 13 $R_{\odot}$ with a method sensible to flux emitted in the continuum, i.e. in inner, denser and hotter regions of the disc.

Another method used to reconstruct the image of the disc is eclipse mapping. This technique, developed by Horne (1985), consists in the analysis of multi-wavelength photometry during eclipse to reconstruct the radial brightness distribution of the disc in a close binary, using the maximum entropy approach. The method has been successfully applied to cataclysmic variables (e.g. Baptista 2001) and also to some Algols with discs.

For instance, Pavloski et al. (2006) studied 7-color photometric observations in the Geneva system of the active Algol W Cru, covering several cycles of this long-period (198.5 days) eclipsing binary. They used a modified Rutten's approach to the eclipse-mapping and the optimization of the system's parameters and the recovery of the disk intensity distribution was performed using a genetic algorithm. These authors confirm the presence of a thick disc around the gainer extending 80% of the gainer's critical lobe. The reconstructed image reveal a rather clumpy and nonuniform brightness distribution of the accretion disk rim in this system. According to these authors, this clumpiness accounts for light curve distortions and asymmetries, as well as for secular changes. Afterwards, Mimica and Pavloski (2012), using the same methodology of eclipse mapping, reconstruct the accretion disk image of AU Mon from CoRoT Photometry. They found a clumpy disk structure similar to those detected in W Cru.

In order to study the evolutionary stage of DPVs we have used predicted evolutionary tracks of a sample of binaries by Van Rensbergen et al. (2008) to perform a χ^2 minimization procedure between the observed parameters of a system and those of a grid of models. The best fit is obtained for a system characterized by a given combination of initial masses, radii, temperatures, orbital period and the corresponding set of parameters at the current age. The system age and stellar core metallicities are also provided by this methodology (e.g. Mennickent et al. 2012a). The methodology is limited by the discrete grid of parameters of the synthetic models and also for the ad-hoc prescriptions about mass loss in the same models (Van Rensbergen et al. 2008). In spite of these limitations, the method has provided age and mass transfer rate for β Lyrae consistent with earlier investigations (Mennickent and Djurašević 2013), and for the first time for several systems, all of them were found inside or very close to a burst of the Case-B mass transfer (Mennickent et al. 2016a and references therein).

4. DPV PHYSICAL CHARACTERISTICS

The first comprehensive study of physical data for a sample of DPVs was published by Mennickent et al. (2016a). They find that DPVs are mostly tangential-impact systems, i.e. their primaries have radii barely larger than the critical Lubow-Shu radius. In principle, these systems are expected to show transient discs, but Mennickent et al. (2016a) find that they host stable discs with radii smaller than the tidal radius. We notice here that this last result might be influenced by the method that was used to determine the disc radii in several systems, which is very sensitive to the continuum radiation, i.e. it traces the innermost and hottest regions of the disc. Therefore, the results might indicate that the optically thick disc is confined very inside the tidal radius, whereas optically thin outer regions reaches larger radii. The existence of optically thin disc regions is evident in some systems with well developed double emission lines as AU Mon (e.g. Atwood et al. 2012). In addition, other result of the above paper is that, among tangential-impact systems including DPVs and semi-detached Algols, those systems with primaries with masses between 7 and 10M⊙ (corresponding to B-type spectra types) are always (in the small studied sample) DPVs. This suggests a special role of B-type gainers in the DPV phenomenon. Furthermore, Mennickent et al. (2016a) find that DPVs are in a mass transfer stage, with donor masses usually between 1 and 2 M⊙. The same authors analyze infrared photometry of 2MASS and WISE satellites revealing significant color excesses in many DPVs, which suggests variable amounts of circumstellar matter.

Studies of DPVs suggest that they are found in the Case-B mass transfer, i.e. the donor has almost exhausted hydrogen in its core (Mennickent et al. 2016a). The comparison with synthetic evolutionary tracks for binary stars indicates that DPVs born as close binaries with similar stars of few solar masses and orbital periods of few days, say 2 or 3 days, and then evolve to the stage of longer periods because of mass transfer when the more massive star evolves filling its Roche lobe (Van Rensbergen et al. 2008).

It is instructive to see the positions of the gainer and donor in the luminosity-temperature and luminosity-mass diagrams in comparison with semidetached Algols (Fig. 3). We observe the DPV gainers near the main sequence and closely following the L-M relationship for these stars. However, the donors appear much evolved above the main sequence and detached from the L-M relation for main sequence stars. This is undoubtedly the result of the donor size inflation by nuclear evolution and mass loss onto the gainer, as has been recognized also for semi-detached Algols (circles in Fig. 3, Dervişoğlu et al. 2010). It is also evident that DPV gainers and donors are in the upper range of masses and temperatures of semidetached Algols. We can say that DPVs are found inside the population of hot and massive Algols.

From the DPV light curve analysis it is clear that the accretion disc is optically thick, at least the region closer to the star and to the orbital plane. The stability of this region in most DPVs is remarkable, as revealed by the unperturbed light curve shape during the long cycle, except for β Lyrae and few other highly active systems. Fig. 4 shows diagrams with

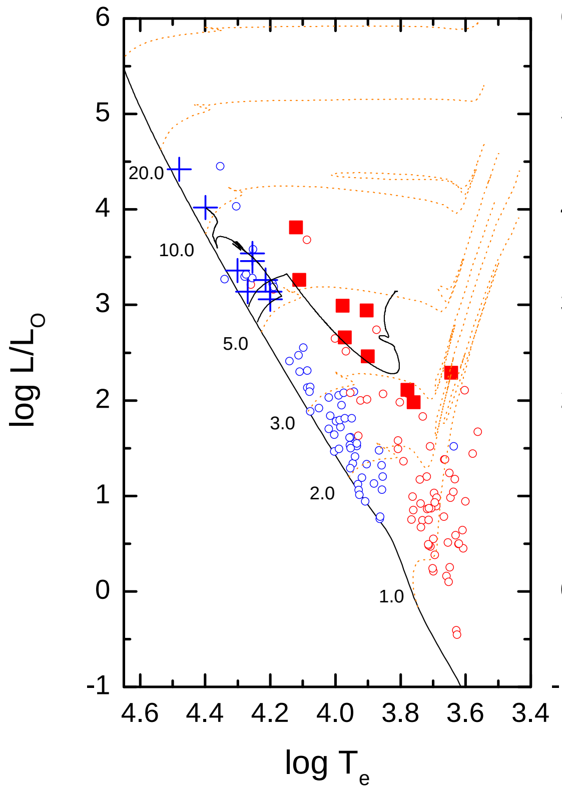

Fig. 3. *Comparison of physical data for semi-detached Algols from Dervişoğlu et al. (2010, primaries blue circles and secondaries red circles) and DPVs (primaries blue crosses and secondaries red squares). The zero-age main sequence for $Z = 0.02$ is plotted with a solid black line and evolutionary tracks for single stars with initial masses (in solar masses) labeled at the track footprints are also shown (Pols et al. 1998). The best evolutionary tracks for the primary and secondary of HD 170582 are also plotted by two solid lines in the left panel (adapted from Mennickent et al. 2016a).*

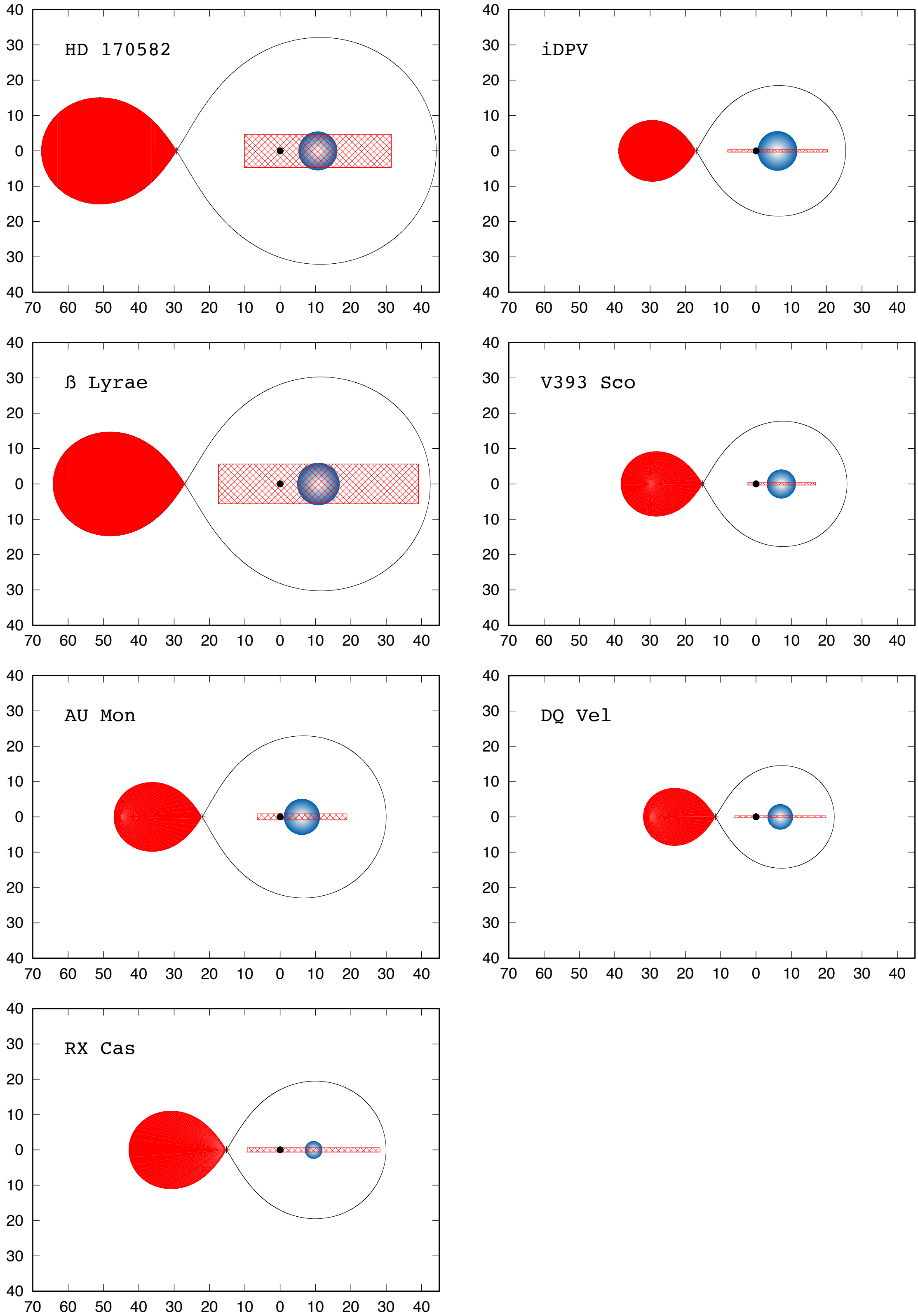

Fig. 4. *Some Double Periodic Variables. The units of the vertical and horizontal axis are solar radii. Disc, Roche lobes and stars are shown with the same scale factor. The center of mass is indicated by a solid circle. Data are taken from Mennickent et al. (2016a, and references therein). Plots courtesy of Mauricio Cabezas.*

the geometry of some DPVs and their discs. The fractional radius of DPV gainers and discs are shown in Fig. 5. This figure illustrates that DPVs are constrained to the mass ratio $M_2/M_1 = 0.15-0.35$ and are mostly "impact-systems", i.e. they are in a region where the stream impact should spin-up the gainer very efficiently.

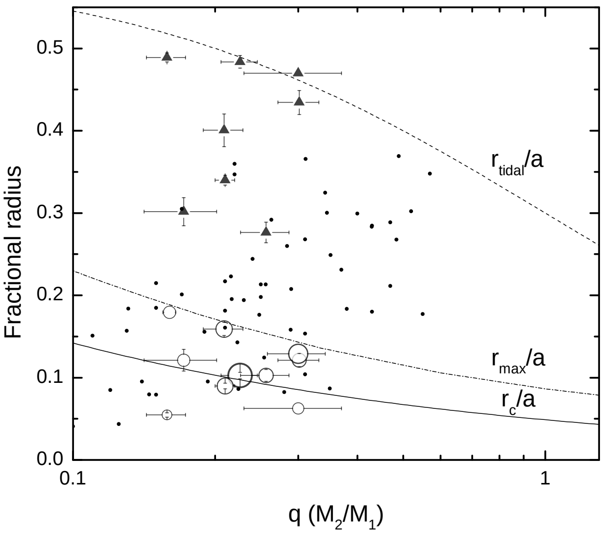

Fig. 5. *The fractional radius for the primary (R1/a; circles) and disc (Rd/a, triangles) of DPVs. Symbol size for stellar radii is proportional to the system total mass. Below the circularization radius shown by the solid black line a disc should be formed and below the dash-point a disc might be formed. The tidal radius indicates the maximum possible disc extension (upper dashed line). Semi-detached Algol primaries from Dervişoğlu et al. (2010) are also shown as black points. Adapted from Mennickent et al. (2016a).*

Table 2. Longitude (λ) and temperature of hotspots, relative to the external-edge disc temperature, in some DPVs. Longitudes are measured from the line joining the star centers counter rotation. References are given in Mennickent et al. (2016a) except for V 495 Cen (one hotspot, Rosales et al. in preparation).

System	λ (°)	$T_{\rm spot}/T_{\rm disc}$	$T_{\rm disc}$ (K)
HD 170582	332 ± 6	1.7 ± 0.1	5700 ± 200
V 393 Sco	324 ± 6	1.2 ± 0.1	8600 ± 600
β Lyr	325 ± 7	1.2 ± 0.1	8200 ± 400
DQ Vel	329 ± 7	1.4 ± 0.1	6580 ± 300
iDPV	324 ± 5	1.1 ± 0.1	12600 ± 600
V 495 Cen	338 ± 9	1.11 ± 0.03	4040 ± 200
HD 170582	141 ± 5	1.4 ± 0.1	5700 ± 200
V 393 Sco	162 ± 9	1.2 ± 0.1	8600 ± 600
β Lyr	107 ± 9	1.1 ± 0.1	8200 ± 400
DQ Vel	143 ± 9	1.4 ± 0.1	6580 ± 300
iDPV	130 ± 13	1.2 ± 0.1	12600 ± 600

5. EVIDENCE OF MASS LOSS AND HOTSPOT WIND

An improvement in the knowledge of the AU Mon system was made by Desmet et al. (2010), who analyzed very accurate CoRoT space photometry, Johnson V photoelectric photometry and high-resolution echelle spectra. They show that the long-term variation must be due to attenuation of the total light by some variable circumbinary material. The fact that the shape of the orbital light curve is the same at high and low state of the long-cycle indicates that the origin of the long-cycle is not inside the stars but comes from circumbinary matter. They find new ephemerides and orbital/system solutions, deriving a mass ratio $M_2/M_1 = 0.17 \pm 0.03$ based on the assumption that the G-type secondary fills its Roche lobe and rotates synchronously. Furthermore, they demonstrate that the Balmer/Helium lines may not be of photospheric origin but be formed in a pseudo-photosphere around the gainer. This research reinforces the idea of variable circumstellar matter as the origin of the long-cycle, as claimed for OGLE 05155332-6925581 by Mennickent et al. (2008).

Later, the system V 393 Sco was studied in detail in a series of papers by Mennickent et al. (2010, 2012a,b). They discuss the evolutionary stage of the system finding the best match with one of the evolutionary models of Van Rensbergen et al. (2008). According to this model, the system is found after an episode of fast mass exchange that transferred 4 M$\odot$ from the donor to the gainer in a period of 400 000 years. Mennickent et al. (2012b) found that the line emission is larger during main eclipse and also during the maximum of the long-cycle. Also, they find chromospheric emission in the lines Mg II 4481 and C I 6588, revealed in Doppler maps. Again in V 393 Sco, as happens in AU Mon, the stability of the orbital light curve suggests that the stellar plus disc configuration remains stable during the long cycle. Therefore, the long cycle should be produced by an additional variable and not-eclipsed emitting structure. The broad emission lines are not compatible with circumbinary disc emission in this case. They conclude explaining the long photometric cycle in terms of variable strength of a bipolar disk wind. We notice that the extra line emission during the maximum of the long-cycle was also observed in DQ Vel (Barría et al. 2014) and AU Mon (Barría and Mennickent 2011). All these findings bring similarities with the case of β Lyrae.

In fact, Harmanec et al. (1996) and Hoffman et al. (1998) independently discovered the presence of bipolar jets in β Lyr from optical interferometry and from spectropolarimetry, respectively. A theoretical justification for the presence of bipolar jets was suggested by Bisikalo et al. (2000), who in their gas dynamical model identified the roots of the jets in the disc/stream interaction region as the zone of larger rate of energy release. Since the collimated character of the jets in β Lyrae has not been proved, we suspect they are of the same nature that the wind detected in V 393 Sco.

The idea of jets or polar winds in Algols is not limited to β Lyrae. Plavec (1992) already suggested that a stellar wind induced by the accretion process might explain the emission observed in ultraviolet lines of Si IV, C IV and N V in some systems, especially those he called W Serpentis stars. Peters and Polidan (2004) interpreted the very little variation in profile, strength, and velocity of the OVI emission line observed in V356 Sgr, TT Hya, and RY Per as evidence of "material that has a substantial flow perpendicular to the orbital plane (perhaps a bipolar jet)". We notice that none of these systems is a DPV. In addition, a recent polarization study of V 356 Sgr by Lomax et al. (2017) reports a large intrinsic polarization signature arising from electron scattering that is not eclipsed.The authors suggest that light scattering in a circumbinary disc or bipolar outflow can be responsible for the constant flux polarization.

The finding of a bipolar wind in V 393 Sco motivated the study of HD 170582, a non-eclipsing DPV seen at intermediate latitudes, where the wind, if present, should show up in spectral signatures. The study by Mennickent et al. (2015) indicates that the system consists of a cool evolved star of $M_2 = 1.9 \pm 0.1$ M$\odot$, $T_2 = 8000 \pm 100$ K and $R_2 = 15.6 \pm 0.2$ R$\odot$ and an early B-type dwarf of $M_1 = 9.0 \pm 0.2$ M$\odot$. The B-type star is surrounded by a geometrically and optically thick disc of radial extension 20.8 $\pm$ 0.3 R$\odot$ contributing about 35% to the system luminosity at the V-band. Two extended regions located at opposite sides of the disc rim, and hotter than the disc by 67% and 46%, fit the light-curve asymmetries. Especially interesting is the double line nature of He I 5875; two absorption components move in antiphase during the orbital cycle; they can be associated with the shock regions revealed by the light curve models constructed by the same authors (Fig. 6). The radial velocity of one of the He I 5875 components closely follows the donor radial velocity, suggesting that the line is formed in a region near the stream-disc interaction region. It is possible that the wind emerging from the hotspot located in the 1st quadrant is the region where this line is produced (Mennickent et al. 2015).

Further analysis of HD 170582 revealed additional details on its interesting nature. The Doppler maps constructed with the Hα emission at high and low state of the long cycle showed interesting changes: increased emission is observed in the hotspot region during the low state (Fig. 7). This finding strengthen the idea that the long cycle represents the variability of a hotspot bipolar wind, as reported for V 393 Sco.

It should be noticed that due to the presence of the disc, the gas stream cannot hit directly the star, but hits the disc at its outer edge, producing a hotspot or hotline, which is revealed in light curve models (Mennickent and Djurašević 2013) and hydrodynamical simulations (Bisikalo et al. 1998, 1999, 2003). The idea of mass loss driven by radiation pressure produced in the hotspot was explored theoretically by Van Rensbergen et al. (2008). This stage occurs when the mass transfer rate exceeds a critical value and the gainer cannot accrete more material, according to these authors.

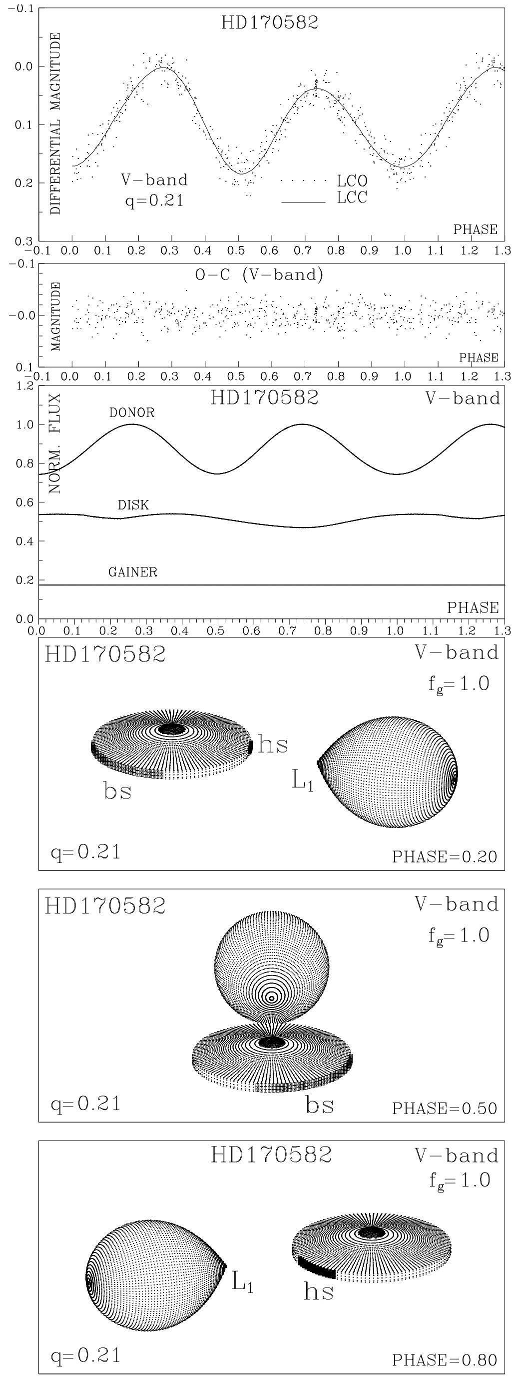

Fig. 6. *Observed (LCO) and synthetic (LCC) light-curves of HD170582 obtained by analyzing V-band photometric observations; final O-C residuals between the observed and optimum synthetic light curves; fluxes of donor, gainer and of the accretion disk, normalized to the donor flux at phase 0.25; the views of the optimal model at orbital phases 0.20, 0.50 and 0.80, obtained with parameters estimated by the light curve analysis. From Mennickent et al. 2015.*

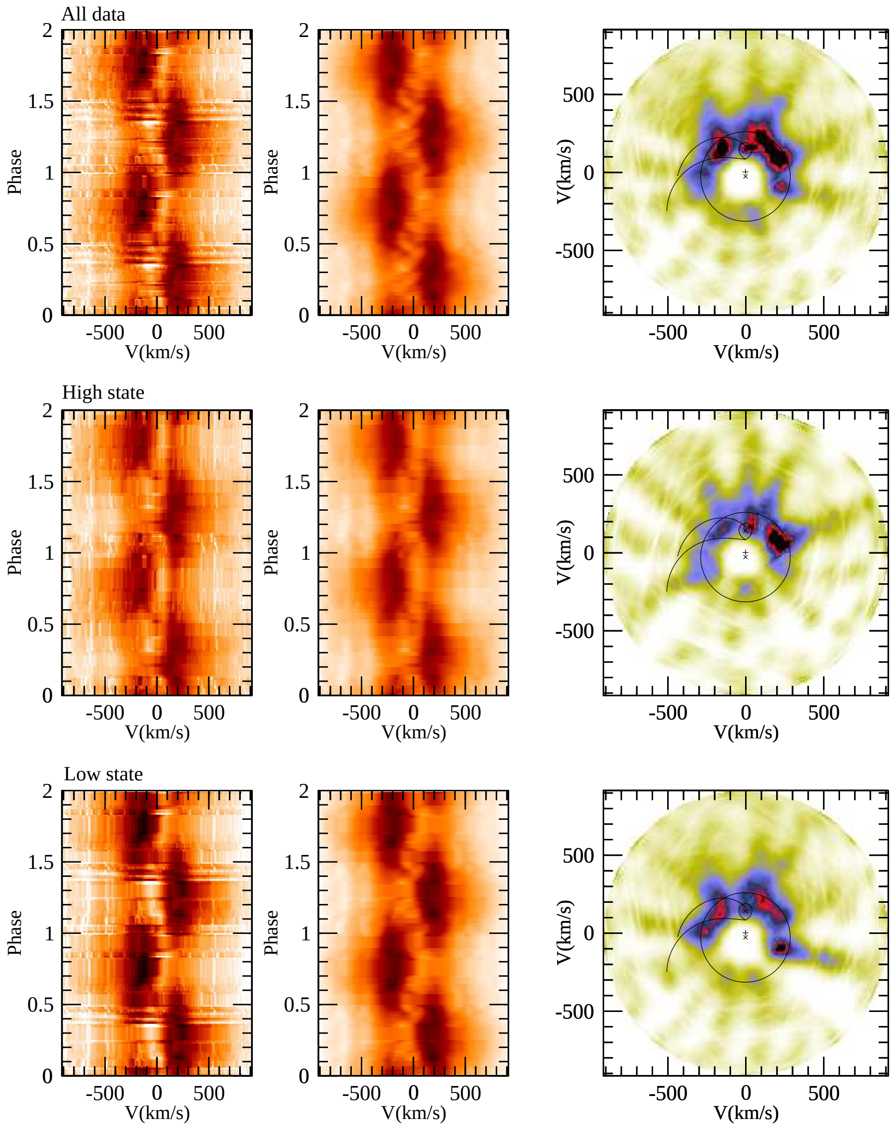

Fig. 7. *Phased time series observed and reconstructed spectra around the Hα line folded with the orbital period of the system and corresponding Doppler maps. Most spectra at the high (low) stage are in 0.7 < Φ_l < 1.0 (0.4 < Φ_l < 0.6). The orbital period of P_{orb} = 16.87 days, the primary mass of M_1 = 9.0 $M_\odot$, inclination angle 67°.4 and the mass ratio of q = 0.21 from Mennickent et al. (2015) are used to overlay positions of the stellar components on the Doppler maps. Φ = 0.0 corresponds to the inferior conjunction of the donor. The loci for the center of mass for both stellar components, the theoretical ballistic gas stream and the Keplerian velocity at the stream are marked on the tomograms. The circle represents the Keplerian velocity of the disc outer radial edge as inferred from the light curve model (Mennickent et al. 2015). The filling of missing phases in the folded spectra is used for best presentation. From Mennickent et al. (2016b.)*

Accretion discs with hotspots have been reported in Algols with long cycles as β Lyrae, AU Mon, DQ Vel, V 393 Sco and HD 170582 but also in classical Algols with discs (Richards 2014, Richards et al. 2012). The evidence comes from disc emissivity maps constructed from light curve models and also from Doppler tomography of emission lines. Bright zones are found at the first and fourth quadrants (Table 2). The first of these regions is usually associated to the site of interaction between the stream and the disc, a region of intense dissipation of kinetic energy. We notice that the first quadrant hotspot is strongly constrained to (average) $\lambda = 327^\circ\!.7 \pm 5^\circ\!.6$ (std). These regions are hotter than the rest of the disc and the temperature could maintain a hotspot wind, as described by Van Rensbergen et al (2008). An indicator of mass loss should be circumstellar matter producing appreciable reddening. Actually, DPVs indeed show reddening in infrared colors, however not so pronounced as in W Serpentids (Mennickent et al. 2016a) or FS CMa stars (Mennickent 2017, in press). As mentioned earlier, evidence for large-scale gas envelopes, relics of violent mass-loss events, have not been detected in Algols (Deschamps et al. 2015).

One of the undetermined parameters is the mass of the disc. Since the spin-up of the gainer is a relatively rapid process (e.g. Dervişoğlu et al. 2010, Packet 1981), and assuming that tidal forces are not so effective to break this rotation, and also considering that the DPV mass loss is a smooth process, we can conjecture that a significant fraction of the transferred mass remains in the disc. This could explain the mentioned lack of nebulosity around these systems (Deschamps et al. 2015). More work is necessary to confirm this suggestion.

Following these ideas, Mennickent et al. (2012a) argue that a significant fraction of the transferred mass has not been accreted by the gainer in V 393 Sco but remains in an optically thick massive (about 2 M⊙) disc-like pseudo-photosphere whose luminosity is not driven by viscosity but probably by reprocessed stellar radiation. Although the mass of the disc has not been confirmed (and it should produce an interesting challenge for the dynamical model of the system), the result regarding the nature of the disk radiation is important since it contradicts earlier assumptions that the disk luminosity of Algols is accretion-driven (Smak 1989, Plavec and Hubeny 1994). This result is later confirmed and generalized to a sample of DPVs by Mennickent et al. (2016a) based on calculations for the disc luminosity arising from light curve models (Fig. 8), and confirmed by theoretical and numerical simulations for Algols with disks by Van Rensbergen and Greve (2016). In other words, accretion is not enough to sustain the observed luminosity of the disks in these systems.

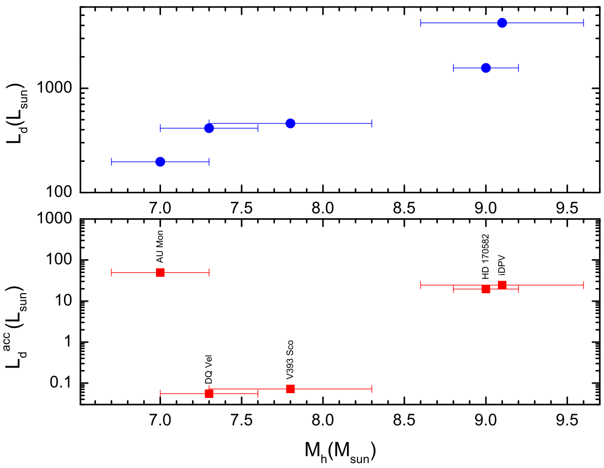

Fig. 8. *The bottom panel shows the accretion luminosity for DPVs, as derived from the mass transfer rate of the best binary model for the present system and stellar parameters. The upper panel shows the disc luminosity inferred from the light curve analysis. iDPV stands for OGLE05155332-6925581. From Mennickent et al. (2015).*

Once the idea of a hotspot wind was settled down, it was necessary to look for a mechanism able to modulate the strength of this wind. This lead us to the study of magnetic dynamos as possible cause for such a variability. But before going to this mechanism, let's put face to face the modulated bipolar wind (e.g. Mennickent et al. 2012b for V 393 Sco) and the occultation by a circumbinary disc (e.g. Desmet et al. 2010 for AU Mon) as competent hypotheses to explain the long cycle.

6. EQUATORIAL OUTFLOWS AND CIRCUMBINARY DISC

In the above Section we have presented a solid evidence for the existence of circumbinary matter in the form of bipolar outflows in some Algols. However, evidence for equatorial outflows has also been reported in the literature. Especially interesting are the reports of material escaping through the Lagrangian L2 and L3 points (see Flora and Hack (1975) for evidence of L2 outflows in β Lyrae and Peters (1989) for evidence of L3 outflows in several systems). These outflows are also expected from numerical simulations (Bisikalo et al. 1998, 1999, 2000, 2003). Mennickent et al. (2010) report ultraviolet and high-resolution infrared spectroscopy of V 393 Sco; they observe lines asymmetries at secondary eclipse during long cycle minimum compatible with large mass loss through the L3 point. According to these authors, the large asymmetries observed in the He I 1083 nm line at orbital phases 0.54 and 0.94 cannot be explained by blends with donor features, but require other explanation, possibly an equatorial outflow (Fig. 9). Since these asymmetries only appear in infrared lines not in super-ionized ultraviolet lines, these authors suggest that the ultraviolet lines form in a wind above the orbital plane, consistent with the bipolar wind scenario discussed in the above section. A similar outflow signature near phase 0.5 was observed in the Si IV line by Peters (1994) in AU Mon.

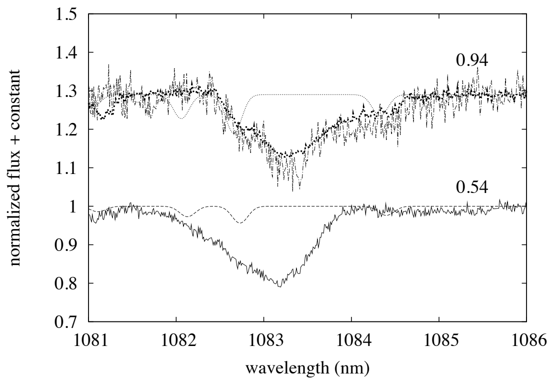

Fig. 9. *The asymmetries observed in the He I 1083 nm line of V 393 Sco at orbital phases 0.54 and 0.94 cannot be explained only by blending with donor features (dashed lines). Mass flows are a possible interpretation. From Mennickent et al. (2010).*

Desmet et al. (2010) propose that a dusty circumbinary disc occults AU Mon during the minimum of the long-cycle and argue that this scenario explains the equal depth of main minima at maximum and minimum of the long-cycle. We notice, however, that it hardly explains the larger Hα emission observed during the maximum of the long-cycle, when the circumbinary disk is expected to disappear (Barría and Mennickent 2011). In general terms, occultation by a circumbinary disc does not explain the deeper primary minima observed during the long cycle minimum in a couple of LMC DPVs by Poleski et al. (2010). These observations are compatible with clearing of the system at minimum, and an extra light during maximum, as should happen with an enhanced bipolar wind at maximum. The large and broad emission lines observed during the secondary eclipse in V 393 Sco were attributed to such a wind (Fig. 10), and it is difficult to image how they could be produced by a circumbinary disc.

We conjecture that equatorial outflows really occur in some systems, but are of second order of importance compared with the outflows related to the hotspot. An artistic view of a Double Periodic Variable is shown in Fig. 11.

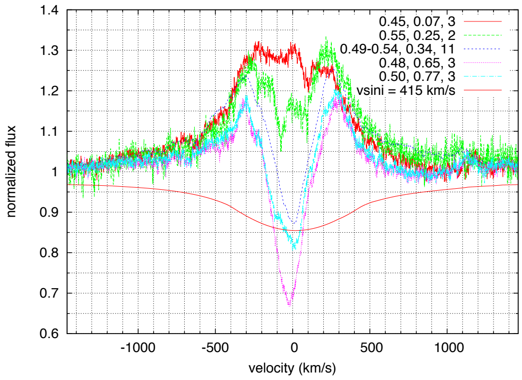

Fig. 10. *Donor-subtracted Hα profiles of V 393 Sco near the secondary eclipse at different long-cycle phases. The labels indicate, from left to right, the orbital phase, long-cycle phase and number of spectra averaged. A synthetic profile of the gainer also is shown. X-axis velocities are with respect to the system centre of mass. From Mennickent et al. (2012b).*

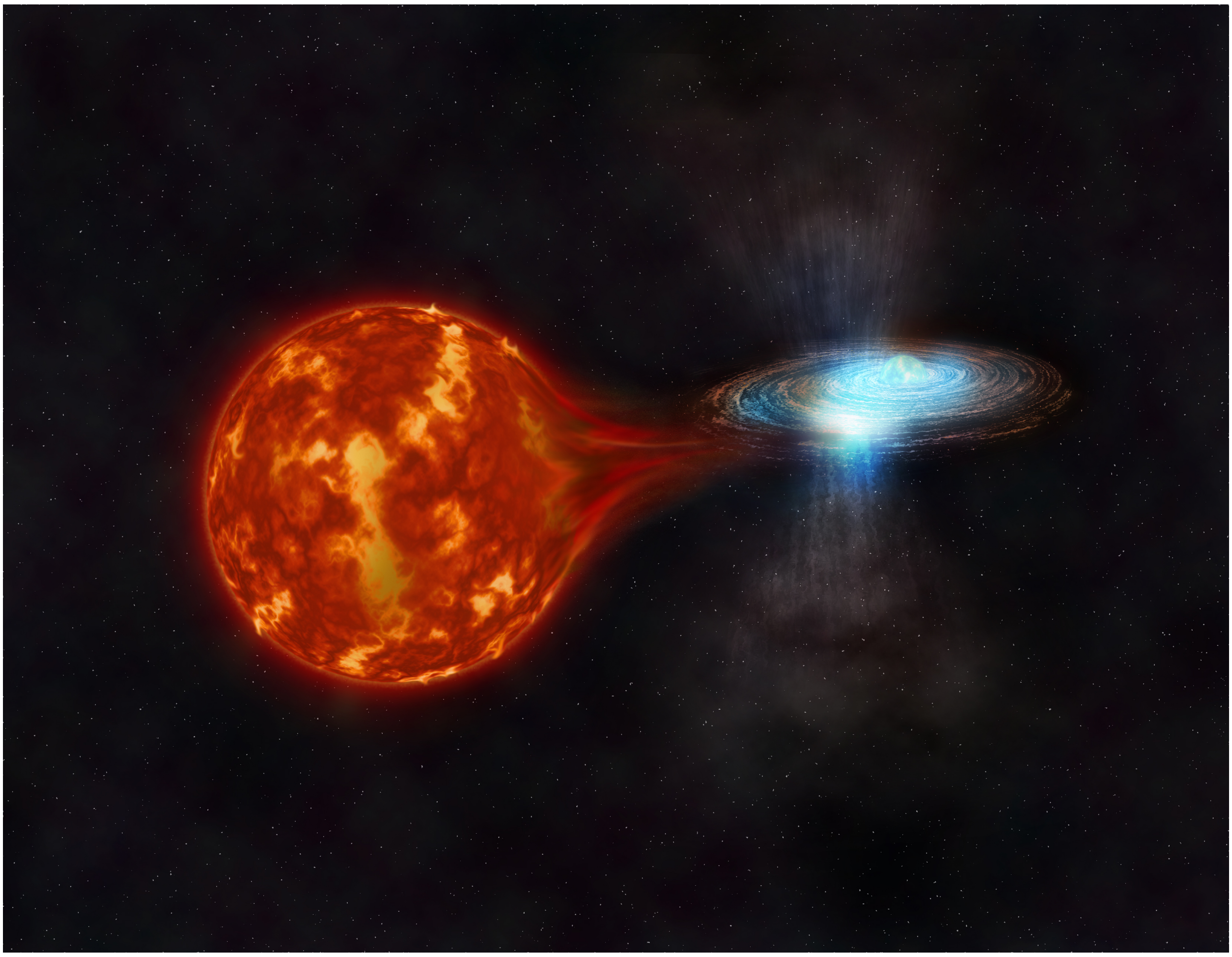

Fig. 11. *Artistic view of a Double Periodic Variable (credits Cristobal Sandoval).*

7. MAGNETIC DYNAMOS IN DPVs

Recently, a model for the DPV long cycle has been proposed by Schleicher and Mennickent (2017) based on Applegate‘s (1992) mechanism. Applegate's mechanism considers torques produced by the star magnetic field into the outer stellar layers, producing a change in the star's oblateness with a consequence on the distribution of its angular momentum. This affects the overall angular momentum of the binary, producing a change in the orbital period of the order of $\Delta P/P \sim 10^{-5}$. Hence, the magnetic cycle in a chromospherically active donor produces structural changes in the star, especially its quadrupole momentum, yielding larger size in the direction of the inner Lagrangian point at some epochs, and eventually producing larger mass transfer rates if the binary is semidetached, and this is possibly observable by changes in the system luminosity. Actually, a potential impact of magnetic activity on mass transfer has already been discussed by Bolton (1989) and Meintjes (2004) for Algol-type binary systems. Indirect evidence for the Applegate mechanism in binary systems includes the fact that orbital period variations only occur in late-type stars, as originally found by Hall (1989) and the relation between activity cycles and O-C modulation periods, as inferred by Lanza and Rodono (2004) and Lanza et al. (2001).

The work presented by Schleicher and Mennickent (2017) is largely inspired in the discovery of a potential relationship between the dynamo number and the rotational velocity of chromospherically active stars. The dynamo number is a parameter central to stellar dynamo theory and it is defined as $D = \alpha\Delta\Omega d^3/\eta^2$, where α is a measure of helicity, $\Delta\Omega$ the large-scale differential rotation, d the characteristic length scale of convection and η the turbulent magnetic diffusivity in the star. In the context of dynamo models, the dynamo cycle $P_{\rm cycle}$ is related to the rotation period $P_{\rm rot}$ via a relation of the form (Soon et al. 1993, Baliunas et al. 1996):

$$P_{\rm cycle} = D^{\alpha} P_{\rm rot}, \qquad (3)$$

with D the dynamo number and α a power-law index, with typical values of α between $\sim \frac{1}{3}$ and $\sim \frac{5}{6}$. Similar phenomenological relations were reported for single stars (e.g. Saar and Brandenburg 1999).

Assuming synchronous rotation of the donor star in a close binary, Schleicher and Mennickent (2017) derive a similar relationship between the dynamo cycle and the orbital period of the binary:

$$P_{\rm cycle} = \eta P_{\rm orb}, \qquad (4)$$

with η a factor involving physical parameter of the donor as luminosity, mass, radius, pressure scale height and mixing length. Then they propose that the long cycle length of DPVs corresponds to a dynamo cycle. Furthermore, they calculate the expected mass transfer rate changes due to stellar quadrupole moment as predicted in Applegate's model, specifically employing the framework outlined by Völschow (2016). This mechanism thus corresponds to a modulation of the mass transfer rate and can give rise to a cyclic variation of the system luminosity. Comparison with observed values of $P_{\rm cycle}/P_{\rm orb}$ gives acceptable results (Fig. 12) and they conclude that a magnetic dynamo in the donor can potentially explain the long-term variability observed in DPVs (Schleicher and Mennickent 2017).

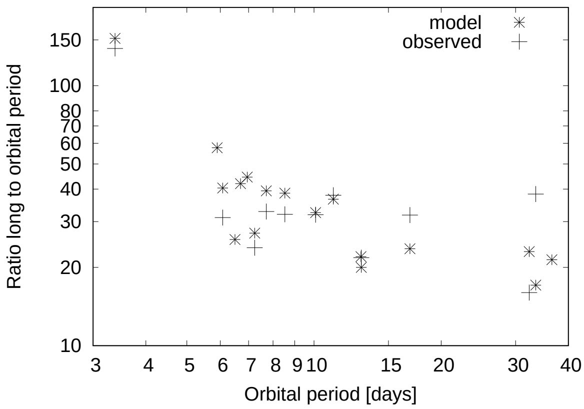

Fig. 12. *Ratio of the long to the orbital period as a function of the orbital period based on observations and the dynamo model. From Schleicher and Mennickent (2017).*

8. POORLY STUDIED PHENOMENA

Here we provide a brief introduction for some interesting and still unexplained phenomena observed in DPVs. Certainly, they deserve further attention, both from the observational as well as theoretical point of view.

8.1. Loop in the color-magnitude (CM) diagram

After disentangling the long and short photometric cycles a loop in the CM diagram is observed during the long cycle of OGLE05155332-692558; the star rises to the maximum through the blue branch and descends to the minimum through the red branch; this was interpreted in terms of mass loss cycles (Mennickent et al. 2008). Extensive and multi-wavelength photometric coverage of several targets is essential to clarify this phenomenon. This CM loop has only been documented in one DPV, but the whole OGLE database might be scanned to study further this phenomenon that mimics the loops observed in the eruptive cycles of some Be stars (de Wit et al. 2006). Color information for the LMC and SMC DPVs can be provided by the MACHO and EROS projects. Multi-band photometric monitoring of bright Galactic DPVs can be done even with small size telescopes.

8.2. Discrete absorption components (DACs)

They were reported in HI infrared lines of OGLE05155332-6925581 following some orbital patterns (Mennickent et al. 2008) and also in some metallic lines of V 393 Sco (Mennickent et al. 2012b). In V 393 Sco a forest of blue-shifted and red-shifted DACs at the O I 7773 and Si II 6347 lines roughly follows the donor RV during the orbital cycle while a few of them remain stationary. DACs sometimes drops 5% below the continuum and are better visible in the first part of the orbital cycle. It is not clear how general this phenomenon is among DPVs neither its origin. High signal to noise spectra sampling the orbital cycle are needed to clarify this phenomenon.

8.3. Chromospheric emission

Chromospheric emission was detected in V 393 Scorpii from Doppler maps of Mg II 4482 and C I 6588 (Mennickent et al. 2012b). Spectra with high signal to noise ratio and good disentangling of additional spectral features (e.g. those of the hot star and the circumprimary disk) are needed to reveal these lines. It is not clear what is the incidence of chromospheric emission in DPVs but seems to be a relatively common phenomenon in Algols (Sarna et al. 1998, Richards et al. 2012). If the hypothesis of magnetic cycles mentioned in Section 7 is true, then we should expect chromospheric emission in many DPVs.

8.4. Weird light curves

OGLE-LMC-DPV-097 shows deeper primary eclipses and the disappearance of secondary eclipses during long cycle minimum (Poleski et al. 2010). OGLE-LMC-DPV-065 shows a decline of the long cycle length from 280 to 215 days in 4200 days (Poleski et al. 2010). As mentioned previously, OGLE05155332-6925581 also shows a remarkable slow shortening of the long cycle from 188 to 172 days lasting about 1800 days, and this shortening occurs after 12 relatively stable oscillations. These still unexplained phenomena are rare in DPVs, but could place constrains on competing models for the long cycle.

8.5. Additional frequencies

The existence of multiple frequencies in the LMC DPVs was reported by Buchler et al. (2009). They re-investigated the MACHO photometry for 30 DPVs selected by Mennickent et al. (2003) and revealed that in 11 of these objects, besides the two most prominent frequencies also a sum of these frequencies $f_1 + f_2$ is significant in the time series analysis. They found a linear relation among the three dominant frequencies. According to these authors, an explanation of this relation requires an interplay between the binary motion and that of a third object. However, spectroscopic monitoring of several DPVs does not reveal a third body (e.g. Desmet et al. 2010, Mennickent et al. 2012a). From 125 LMC DPVs, Poleski et al. (2010) found combination frequencies (not only the most common combination $f_1 + f_2$) in 36 cases (29% of the sample). They also confirmed 5 of the 10 LMC DPVs reported with sum frequencies by Buchler et al. (2009). They note that the detected combination frequency can be sensitive to pre-whitening frequency, period uncertainty and number of harmonics used.

A short periodicity of 5.26 days was also found in the residuals of the V-band light curve of DQ Vel by Barría et al. (2013) who interpreted it as a pulsation of a slowly pulsating B-type (SPB) gainer. Desmet et al. (2010) discovered rapid and periodic light changes visible in the high-quality residual CoRoT light curves of AU Mon, at sub-orbital frequencies of 10.4 and 8.3 c/d. They state that the oscillations are probably due to a non-uniform brightness distribution seated in the accretion disc. Outside the primary minima of the CoRoT light curve, they detected signals in the expected frequency domain of B-stars. According to these authors, both combination frequencies as well as sub-orbital periodicities have an uncertain origin. At present, it is not clear if these frequencies are related to the long-cycle phenomenon or are independent signatures related to other cause.

9. EVOLUTIONARY ASPECTS

If DPVs are near impact systems, the gainer should be rotating near the critical velocity, since this spin-up process seems to occurs rapidly (Dervişoğlu et al. 2010, Packet 1981). If the gainer cannot accrete more material the presence of the disk is explained. The DPV phenomenon, interpreted as cyclic mass loss from the system (Mennickent et al. 2008) is hence consistent with the incapacity of the gainer of accreting more material. Evolutionary tracks for the masses of the donor and gainer and for the orbital period are illustrated in Fig. 13. It is interesting to notice that after the DPV phase the donor will decrease its mass (and luminosity), the orbital period will increase and the system will consist of a rapidly rotating B-type gainer and a low-mass secondary star. Therefore, it is possible that some Be stars have passed through this evolutionary route, accelerating the gainer in a past process of mass transfer. This does not necessarily means that the Be star disc is a remanent of the interacting phase, since formation and ejection of envelopes is usual in Be stars, but the scenario could in principle explain the stellar rapid rotation. Spin-up of gainers in the Roche lobe overflow binaries as origin of Be stars was proposed by Pols et al. (1991) and discussed by Gies (2007). Whereas not all Be stars show signs of binarity until now (Rivinius et al. 2013), more and more Be stars are suspected to be binaries with faint companions (Klement et al. 2017). DPVs might be the progenitors of at least some of the Be stars, but more work is necessary to clarify the true descendants of the DPV phenomenon.

10. FUTURE RESEARCH

A future line of research is to investigate the presence of magnetic fields in DPVs. Under the view of the dynamo model, one should expect modulations in field strength through the cycles, revealed for instance in changes in the strength of chromospherically excited emission lines or in the degree of polarization of the light or in the intensity of chromospheric radio emission. To search for correlations of these parameters with the long cycle is a possible route of future investigation. Some open questions are: if the Applegate mechanism acts in DPVs producing long cycles does it also operate in other Algols, and are there observational manifestations? What are the conditions for the dynamo mechanism to operate? We conjecture that during the mass transfer stage, typically lasting ∼ 10.000 years, changes of donor inner structure are enough to trigger the Applegate dynamo only at certain epochs; this should explain why some semidetached Algols do not show long-cycles. Are there other evolutionary stages where the dynamo and/or the Applegate mechanism are effectively hidden, due to a mass accretion rate that is too small to still observe its modulation? What is the role played by the optically thick disc and the tangential impact condition of the gainer in the DPV phenomenon?

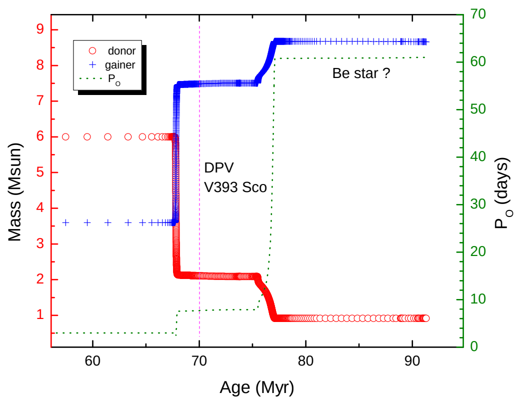

Fig. 13. *Evolutionary tracks for V 393 Scorpii (Mennickent et al. 2012a) resulting of a search in the grid of synthetic models of Van Rensbergen et al. (2008). The vertical dashed line represents the current state of V 393 Scorpii. Episodes of rapid mass transfer are characterized by rapid changes in stellar masses. In the future, V 393 Scorpii might look like a classical Be star, with a hidden low-mass companion. From Mennickent (2012).*

Acknowledgements – My research on DPVs has been possible due to the appreciated contribution of many collaborators during the years, but is not possible to name all of them here. I especially acknowledge Gojko Djurašević for his hospitality in Belgrade and for modeling the DPV light curves. I also thank Zbigniew Kolaczkowski for his hospitality in Wroclaw and valuable help with data reduction and analysis. I thank hospitality and scientific discussions with Pavel Koubsky and Petr Harmanec during my stay in Prague. I also thank Dominik Schleicher for his contribution with theoretical aspects of Double Periodic Variables. Thanks to Gojko Djurašević, Petr Harmanec, Geraldine Peters and Dominik Schleicher for reading a first version of this manuscript and for providing comments that helped to improve this paper. Any remaining error or omission in the text is of my exclusive responsibility. Thanks to Mauricio Cabezas for making Fig. 4 and Cristobal Sandoval for the artistic illustration shown in Fig. 11. I also acknowledge support by the BASAL Centro de Astrofísica y Tecnologías Afines (CATA) PFB–06/2007 and VRID-Enlace 216.016.002-1.0.

REFERENCES

Abbott, B. P., Abbott, R., Abbott, T. D. et al.: 2016a, *Phys. Rev. Lett.*, **116**, 061102.
Abbott, B. P., Abbott, R., Abbott, T. D. et al.: 2016b, *Phys. Rev. Lett.*, **116**, 241103.
Ak, H., Chadima, P., Harmanec, P. et al.: 2007, *Astron. Astrophys.*, **463**, 233.
Andersen, J.: 1991, *Astron. Astrophys. Rev.*, **3**, 91.
Applegate, J. H.: 1992, *Astrophys. J.*, **385**, 621.
Atwood-Stone, C., Miller, B. P., Richards, M. T. et al.: 2012, *Astrophys. J.*, **760**, 134.
Bagnuolo, W. G. Jr. and Gies, D. R.: 1991, *Astrophys. J.*, **376**, 266.
Baliunas, S. L., Nesme-Ribes, E., Sokoloff, D. et al.: 1996, *Astrophys. J.*, **460**, 848.
Baptista, R.: 2001, in "Astrotomography, Indirect Imaging Methods in Observational Astronomy", Edited by H.M.J. Boffin, D. Steeghs and J. Cuypers, *Lecture Notes in Physics*, **573**, 307.
Barría, D. and Mennickent, R. E.: 2011, *ASP Conf. Ser.*, **447**, 263.
Barría, D., Mennickent, R. E., Schmidtobreick, L. et al.: 2013, *Astron. Astrophys.*, **552**, A63.
Barría, D., Mennickent, R. E., Graczyk, D. et al.: 2014, *Astron. Astrophys.*, **567**, A140.
Bisikalo, D. V., Boyarchuk, A. A., Chechetkin, V. M. et al.: 1998, *Mon. Not. R. Astron. Soc.*, **300**, 39.
Bisikalo, D. V., Boyarchuk, A. A., Chechetkin, V. M. et al.: 1999, *Astron. Rep.*, **43**, 797.
Bisikalo, D. V., Harmanec, P., Boyarchuk, A. A. et al.: 2000, *Astron. Astrophys.*, **353**, 1009.
Bisikalo, D. V., Boyarchuk, A. A., Kaigorodov, P. V. et al.: 2003, *Astron. Rep.*, **47**, 809.
Bolton, C. T.: 1989, *Space Sci. Rev.*, **50**, 311.
Buchler, J. R., Wood, P. R. and Wilson, R. E.: 2009, *Astrophys. J.*, **703**, 1565.
Budding, E., Erdem, A. and Çiçek, C. et al.: 2004, *Astron. Astrophys.*, **417**, 263.
Carraro, G. and Benvenuto, O. G.: 2017, *Astrophys. J. Lett.*, in press (arXiv:1705.01776).
Claret, A. and Gimenez, A.: 1992, *Astron. Astrophys.*, **256**, 572.
Crawford, J. A.: 1955, *Astrophys. J.*, **121**, 71.
de Mink, S. E., Pols, O. R., Langer, N. et al.: 2009, *Astron. Astrophys.*, **507**, L1.

de Mink, S. E., Sana, H., Langer, N. et al.: 2014, *Astrophys. J.*, **782**, 7.
de Wit, W. J., Lamers, H. J. G. L. M., Marquette, J. B. et al.: 2006, *Astron. Astrophys.*, **456**, 1027.
Dennis J.E. and Torczon V.: 1991, *SIAM Journal on Optimization*, **1**(4), 448.
Dervişoğlu, A., Tout, C. A. and Ibanoğlu, C.: 2010, *Mon. Not. R. Astron. Soc.*, **406**, 1071.
Deschamps, R., Siess, L., Davis, P. J. et al.: 2013,*Astron. Astrophys.*, **557**, A40.
Deschamps, R., Braun, K., Jorissen, A. et al.: 2015, *Astron. Astrophys.*, **577**, A55.
Desmet, M., Frémat, Y., Baudin, F. et al.: 2010, *Mon. Not. R. Astron. Soc.*, **401**, 418.
Djurašević, G.: 1992a, *Astrophys. Space Sci.*, **196**, 267.
Djurašević, G.: 1992b, *Astrophys. Space Sci.*, **197**, 17.
Djurašević, G., Latković, O., Vince, I. et al.: 2010, *Mon. Not. R. Astron. Soc.*, **409**, 329.
Duchêne, G. and Kraus, A.: 2013, *Annu. Rev. Astron. Astrophys.*, **51**, 269.
Eggleton, P.: 2006, Evolutionary Processes in Binary and Multiple Stars, Cambridge University Press, Cambridge.
Eggleton, P. P. and Kisseleva-Eggleton, L.: 2006, *Astrophys. Space Sci.*, **304**, 75.
Ferluga, S., Floreano, L., Bravar, U. and Bedalo, C.: 1997, *Astron. Astrophys. Suppl.*, **121**, 201.
Flora, U. and Hack, M.: 1975, *Astron. Astrophys. Suppl.*, **19**, 57.
Gaposchkin, S.: 1944, *Astrophys. J.*, **100**, 230.
Garrido, H. E., Mennickent, R. E., Djurašević, G. et al.: 2013, *Mon. Not. R. Astron. Soc.*, **428**, 1594.
Gies, D. R. 2007, *ASP Conf. Ser.*, **367**, 325.
González, J. F. and Levato, H.: 2006, *Astron. Astrophys.*, **448**, 283.
Goodricke, J.: 1783, *Philosophical Transactions of the Royal Society of London*, **73**, 474.
Guinan, E. F.: 1989, *Space Sci. Rev.*, **50**, 35.
Guinan, E. F.: 2004, *New Astron. Rev.*, **48**, 647.
Hadrava, P.: 1995, *Astron. Astrophys. Suppl.*, **114**, 393.
Hadrava, P.: 1997, *Astron. Astrophys. Suppl.*, **122**, 581.
Hall, D. S.: 1989, *Space Sci. Rev.*, **50**, 219.
Harmanec, P.: 1988, *Bulletin of the Astronomical Institutes of Czechoslovakia*, **39**, 329.
Harmanec, P.: 2002, *Astron. Nachr.*, **323**, 87.
Harmanec, P. and Scholz, G.: 1993, *Astron. Astrophys.*, **279**, 131.
Harmanec, P., Morand, F., Bonneau, D. et al.: 1996, *Astron. Astrophys.*, **312**, 879.
Harmanec, P., Koubský, P., Nemravová, J. A. et al.: 2015, *Astron. Astrophys.*, **573**, A107.
Hessman F. V. and Hopp U.: 1990, *Astron. Astrophys.*, **228**, 387.
Hill, G., Harmanec, P., Pavlovski, K. et al.: 1997, *Astron. Astrophys.*, **324**, 965.
Hoffman, D. I., Harrison, T. E., McNamara, B. J. et al.: 2006, *Astron. J.*, **132**, 2260.
Hoffman, J. L., Nordsieck, K. H. and Fox, G. K.: 1998, *Astron. J.*, **115**, 1576.
Horne, K.: 1985, *Mon. Not. R. Astron. Soc.*, **213**, 129.
Hubeny, I. and Plavec, M. J.: 1991, *Astron. J.*, **102**, 1156.
Jetsu, L., Porceddu, S., Lyytinen, J. et al.: 2013, *Astrophys. J.*, **773**, 1.
Jiang, D., Han, Z. and Li, L.: 2014, *Astrophys. J.*, **789**, 88.
Kalv, P.: 1979, *Tartu Astrofuusika Obser. Teated*, **58**, 3.
Kippenhahn, R. and Weigert, A.: 1967, *Zeitschrift fr Astrophysik*, **65**, 251.
Klement, R., Carciofi, A. C., Rivinius, T. et al.: 2017, arXiv:1703.07321.
Koubsky, P., Harmanec, P., Bozic, H. et al.: 1998, *Hvar Obs. Bull.*, **22**, 17.
Kolbas, V., Pavlovski, K., Southworth, J. et al.: 2015, *Mon. Not. R. Astron. Soc.*, **451**, 4150.
Kopal, Z.: 1959, Close Binary Stars, Wiley, New York.
Lanza, A. F. and Rodonò, M.: 2004, *Astron. Nachr.*, **325**, 393.
Lanza, A. F., Rodonò, M., Mazzola, L. et al.: 2001,*Astron. Astrophys.*, **376**, 1011.
Lefèvre, E., Klein, K.-L. and Lestrade, J.-F.: 1994a, *Space Sci. Rev.*, **68**, 293.
Lefèvre, E., Klein, K.-L. and Lestrade, J.-F.: 1994b, *Astron. Astrophys.*, **283**, 483.
Livio, M. and Soker, N.: 1988, *Astrophys. J.*, **329**, 764.
Lomax, J. R., Fullard, A. G., Malatesta, M. A. et al.: 2017, *Mon. Not. R. Astron. Soc.*, **464**, 1936.
Lorenzi, L.: 1980, *Astron. Astrophys.*, **85**, 342.
Lubow S. H. and Shu F. H.: 1975, *Astrophys. J.*, **198**, 383.
Manzoori, D.: 2008, *Astrophys. Space Sci.*, **318**, 57.
Marsh, T. R. and Horne, K.: 1988, *Mon. Not. R. Astron. Soc.*, **235**, 269.
Massevitch, A. and Yungelson, L.: 1975, *Mem. S.A.It.*, **46**, 217.
Mayer, A., Deschamps, R. and Jorissen, A.: 2016, *Astron. Astrophys.*, **587**, A30.
Meintjes, P. J.: 2004, *Mon. Not. R. Astron. Soc.*, **352**, 416.
Mennickent, R.: 2012, *ASP Conf. Ser.*, **464**, 213.
Mennickent, R. E.: 2014, *Publ. Astron. Soc. Pac.*, **126**, 821.
Mennickent, R. E. and Djurašević, G.: 2013, *Mon. Not. R. Astron. Soc.*, **432**, 799.
Mennickent, R. E. and Rosales, J.: 2014, *Inf. Bull. Var. Stars*, **6116**, 1.
Mennickent, R. E., Pietrzyński, G., Diaz, M. et al.: 2003, *Astron. Astrophys.*, **399**, L47.
Mennickent, R. E., Cidale, L., Díaz, M. et al.: 2005a, *Mon. Not. R. Astron. Soc.*, **357**, 1219.
Mennickent, R. E., Assmann, P., Pietrzyński, G. et al.: 2005b, *ASP Conf. Ser.*, **335**, 129.
Mennickent, R. E., Kołaczkowski, Z., Michalska, G. et al.: 2008, *Mon. Not. R. Astron. Soc.*, **389**, 1605.
Mennickent, R. E., Kołaczkowski, Z., Graczyk, D. et al.: 2010, *Mon. Not. R. Astron. Soc.*, **405**, 1947.
Mennickent, R. E., Graczyk, D., Kołaczkowski, Z. et al.: 2011, *IAU Symp.*, **272**, 527.
Mennickent, R. E., Djurašević, G., Kołaczkowski, Z. et al.: 2012a, *Mon. Not. R. Astron. Soc.*, **421**, 862.
Mennickent, R. E., Kołaczkowski, Z., Djurašević, G. et al.: 2012b, *Mon. Not. R. Astron. Soc.*, **427**, 607.

Mennickent, R. E., Djurašević, G., Cabezas, M. et al.: 2015, *Mon. Not. R. Astron. Soc.*, **448**, 1137.
Mennickent, R. E., Otero, S. and Kołaczkowski, Z.: 2016a, *Mon. Not. R. Astron. Soc.*, **455**, 1728.
Mennickent, R. E., Zharikov, S., Cabezas, M. et al.: 2016b, *Mon. Not. R. Astron. Soc.*, **461**, 1674.
Michalska, G., Mennickent, R. E., Kołaczkowski, Z. et al.: 2010, *ASP Conf. Ser.*, **435**, 357.
Mimica, P. and Pavlovski, K.: 2012, *IAU Symp.*, **282**, 63.
Nazarenko, V. V. and Glazunova, L. V.: 2006a, *Astron. Rep.*, **50**, 369.
Nazarenko, V. V. and Glazunova, L. V.: 2006b, *Astron. Rep.*, **50**, 380.
Nazarenko, V. V. and Glazunova, L. V.: 2013, *Astron. Rep.*, **57**, 294.
Packet, W.: 1981, *Astron. Astrophys.*, **102**, 17.
Pavlovski, K., Burki, G. and Mimica, P.: 2006, *Astron. Astrophys.*, **454**, 855.
Pawlak, M., Graczyk, D., Soszyński, I. et al.: 2013, *Acta Astron.*, **63**, 323.
Peters, G. J.: 1989, *Space Sci. Rev.*, **50**, 9.
Peters, G. J.: 1994, *ASP Conf. Ser.*, **56**, 384.
Peters, G. J. and Polidan, R. S.: 2004, *Astron. Nachr.*, **325**, 225.
Peterson, W. M., Mutel, R. L., Güdel, M. et al.: 2010, *Nature*, **463**, 207.
Petrovic, J., Langer, N. and van der Hucht, K. A.: 2005, *Astron. Astrophys.*, **435**, 1013.
Pilecki, B. and Szczygiel, D. M.: 2007, *Inf. Bull. Var. Stars*, **5768**, 1.
Plavec, M. J.: 1992, *ASP Conf. Ser.*, **22**, 47.
Plavec, M. J. and Hubeny, I.: 1994, *ASP Conf. Ser.*, **56**, 87.
Poleski, R., Soszyński, I. and Udalski, A. et al.: 2010, *Acta Astron.*, **60**, 179.
Pols, O. R., Schröder, K.-P., Hurley, J. R. et al.: 1998, *Mon. Not. R. Astron. Soc.*, **298**, 525.
Pols, O. R., Coté, J., Waters, L. B. F. M., et al. 1991,*Astron. Astrophys.*, **241**, 419.
Popper, D.: 1980, *Annu. Rev. Astron. Astrophys.*, **18**, 115.
Popham, R. and Narayan, R.: 1991, *Astrophys. J.*, **370**, 604.
Press, W. H., Teukolsky, S. A., Vetterling, W. T. et al.: 1992, Numerical Recipes in C. The Art of Scientific Computing, Cambridge University Press, Cambridge.
Ribas, I.: 2004, *New Astron. Rev.*, **48**, 731.
Richards, M. T.: 2004, *Astron. Nachr.*, **325**, 229.
Richards, M. T. and Albright, G. E.: 1993, *Astrophys. J. Suppl. Ser.*, **88**, 199.
Richards, M. T., Agafonov, M. I. and Sharova, O. I.: 2012, *Astrophys. J.*, **760**, 8.
Rivinius, T., Carciofi, A. C. and Martayan, C.: 2013, *Astron. Astrophys. Rev.*, **21**, 69.
Roche, M.: 1873, *Mem. Acad. Sci. Montpellier*, **8**, 235.
Rosales, J. and Mennickent, R. E.: 2017, *Inf. Bull. Var. Stars*, **63**, 6207.
Rosenfeld, A. and Kak, A. C.: 1982, Digital Picture Processing - Vol. 1 & 2, Academic Press, New York.
Saar, S. H. and Brandenburg, A.: 1999, *Astrophys. J.*, **524**, 295.
Sabogal, B. E., García-Varela, A. and Mennickent, R. E.: 2014, *Publ. Astron. Soc. Pac.*, **126**, 219.
Sahade, J.: 1980, *Space Sci. Rev.*, **26**, 349.
Sana, H., de Mink, S. E., de Koter, A. et al.: 2012, *Science*, **337**, 444.
Sarna, M. J.: 1993, *Mon. Not. R. Astron. Soc.*, **262**, 534.
Sarna, M. J., Muslimov, A. and Yerli, S. K.: 1997, *Mon. Not. R. Astron. Soc.*, **286**, 209.
Sarna, M. J., Yerli, S. K. and Muslimov, A. G.: 1998, *Mon. Not. R. Astron. Soc.*, **297**, 760.
Schleicher, D. R. G. and Mennickent, R. E.: 2017, arXiv:1703.03876.
Simon, K. P. and Sturm, E.: 1994, *Astron. Astrophys.*, **281**, 286.
Singh, K. P., Drake, S. A. and White, N. E.: 1995, *Astrophys. J.*, **445**, 840.
Singh, K. P., Drake, S. A. and White, N. E.: 1996, *Astron. J.*, **111**, 2415.
Smak, J.: 1989, *Space Sci. Rev.*, **50**, 107.
Soderhjelm, S.: 1980, *Astron. Astrophys.*, **89**, 100.
Soker, N.: 2002, *Mon. Not. R. Astron. Soc.*, **337**, 1038.
Soon, W. H., Baliunas, S. L. and Zhang, Q.: 1993, *Astrophys. J.*, **414**, L33.
Soszyński, I., Pawlak, M., Pietrukowicz, P. et al.: 2016, *Acta Astron.*, **66**, 405.
Soydugan, F.: 2008, *Astron. Nachr.*, **329**, 587.
Spruit, H. C.: 1998, arXiv: astro-ph/9806141.
Torres, G., Andersen, J. and Giménez, A.: 2010, *Astron. Astrophys. Rev.*, **18**, 67.
Uemura, M., Kato, T., Nogami, D. et al.: 2015, *Publ. Astron. Soc. Jpn.*, **67**, 22.
Van Rensbergen, W., De Greve, J. P., De Loore, C. et al.: 2008, *Astron. Astrophys.*, **487**, 1129.
Völschow, M., Schleicher, D. R. G., Perdelwitz, V. et al.: 2016, *Astron. Astrophys.*, **587**, A34.
Van Rensbergen, W. and De Greve, J. P.: 2016, *Astron. Astrophys.*, **592**, A151.
Wilson, R. E.: 1974, *Astrophys. J.*, **189**, 319.
Wilson, R. E. and Caldwell, C. N.: 1978, *Astrophys. J.*, **221**, 917.
Wilson, R. E. and van Hamme, W.: 1999, *Mon. Not. R. Astron. Soc.*, **303**, 736.
Zhang, L.-Y., Yang, Y.-G., Pi, Q.-F. et al.: 2014, *Astron. J.*, **147**, 66.
Zhao, M., Gies, D., Monnier, J. D. et al.: 2008, *Astrophys. J.*, **684**, L95.
Zola, S.: 1995, *Astron. Astrophys.*, **294**, 525.
Zorotovic, M., Schreiber, M. R., Gänsicke, B. T. et al.: 2010, *Astron. Astrophys.*, **520**, A86.

ДУГИ ФОТОМЕТРИЈСКИ ЦИКЛУС У ВРЕЛИМ АЛГОЛИМА

R. E. Mennickent

Universidad de Concepción, Departamento de Astronomía, Casilla 160-C, Concepción, Chile

E–mail: *rmennick@udec.cl*

УДК 524.386 + 524.387

Прегледни рад по позиву

У овом раду сумирамо напредак у области изучавања променљивих звезда са двоструким периодом (двопериодичне променљиве – ДПП, Mennickent et al. 2003) током последњих четрнаест година, и то посматрајући ове објекте у контексту интерагујућих тесних двојних система средње масе, сличних звездама β Persei (Algol) и β Lyrae (Sheliak), генерално названих алголи. ДПП-ови имају енигматски дуг фотометријски циклус који траје у просеку 33 пута дуже од орбиталног периода, и имају физичке карактеристике сличне, у неким аспектима, звездама типа β Lyrae. Око 200 оваквих објеката је пронађено у Галаксији и у Магелановим облацима. Модели криве сјаја и спектроскопска посматрања указују да су ДПП полуконтактни интерагујући двојни системи, који се састоје од звезде спектралнне класе B близу главног низа, која акретује материјал са хладнијег џина и окружена је оптички дебелим диском. Овај диск доприноси значајним делом луминозности система и његова луминозност је већа од очекиване луминозности која потиче само од феномена акреције масе. У неким системима присутан је као компонента оптички танак диск са израженим емисионим линијама Балмерове серије. Оптички дебео диск садржи сјајне зоне до неколико десетина процената врелије од диска, који вероватно указују на ударне таласе који настају услед динамичког кретања гаса у диску или гасне струје. Претпостављамо да ветар из вреле пеге може бити један од канала за благи систематски губитак масе, пошто су нађени докази постојања млазева, ветрова и генералног губитка масе код β Lyrae, AU Mon, HD 170582, OGLE 05155332-6925581 и V 393 Sco. Такође, теоријски радови Van Rensbergen et al. (2008) и Deschamps et al. (2013) сугеришу да вреле пеге могу да покрећу губитак масе са алгола. Посебну пажњу поклањамо недавно објављеној хипотези о настанку дугог циклуса који подразумева постојање променљивог трансфера масе под утицајем магнетног динама (Schleicher and Mennickent 2017). Путем механизма приказаног у раду Applegate (1992) требало би да се циклично мења екваторски радијус хромосферски активног донора, производећи циклусе повећаног губитка масе кроз унутрашњу Лагранжеву тачку. Хромосферска емисија код V 393 Sco, оптички гушћа врела пега у фази појачане активности HD 170582 и докази за присуство магнетног поља код многих алгола су посматрачке чињенице које иду у прилог овој слици. Једно од отворених питања у вези са овим сценаријем је зашто је, међу алголима који показују доказе постојања магнетног поља, дуги период присутан само код одређених комбинација звезданих параметара, посебно оних који укључују акреторе спектралне класе B. Остала отворена питања су које звезде су наследници ових интересантних двојних система, колико масе садржи диск око вероватно брзоротирајућих акретора и улога коју игра губитак материјала кроз Лагранжеве тачке $L2$ и $L3$ који је посматран код неколико система.