HELIUM CATACLYSMIC VARIABLES

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Abstract: The so-called AM CVn systems, or Interacting Binary DB White Dwarf stars, have grown from four members in 1992 to twelve in 2003; five out of the eight new discoveries were found during the 21st century. Also, the observational properties of these systems show nowadays a widespread and unexpected range of characteristics, which seems to confirm the existence of "subclasses" within the group. Four objects at least show X-ray emission. For two objects at least, H seems to have been detected in their optical spectra. A brief review of the recent findings for this peculiar group among the Cataclysmic Variables is here presented.

1 Introduction

A Cataclysmic Variable (CV) is, by its usual definition, a close interacting binary system where a solar-type secondary star overflows its Roche Lobe and donates matter, mostly hydrogen from its atmosphere, in a stable manner onto a White Dwarf (WD) primary accretor, within orbital time spans in the range of hours. Excellent reviews on the topic can be found in, e.g., [1], [2], [3], [4].

Helium Cataclysmic Variables (He CVs), also referred to as AM CVn systems ([5], [6]) or Interacting Binary DB White Dwarf stars (IBDBWDs: [7], [8], [9]), constitute a subclass of the CVs where the secondary star is a Helium-rich WD (i.e., of DB type), donating matter onto the primary object, which is also a DB WD. Two main characteristics distinguish them from the bulk of the H-rich CVs: their composition (with spectra entirely depleted from H and dominated by He lines) and their ultra-short orbital periods (on the order of minutes). See for example [10], [5], [9], [11], for a revision of their properties.

Until 1992 only four AM CVn objects were known (AM CVn, V803 Cen, CR Boo and GP Com), despite the prototype, AM CVn itself, had been discovered as a variable object by [12] and classified as an IBDBWD system by [13]. A review of their characteristics published to that date can be found in [9]. Tables listing the twelve AM CVn systems known to date, together with a summary of some of their properties, can be found in, e.g., [14].

In the next sections, some of the main recent findings for the objects will be summarized, together with a discussion of their implications in the context of the Cataclysmic Variables.

2 The objects

There are at present twelve AM CVn systems identified and catalogued as such, namely AM CVn, HP Lib, GP Com, CE 315, V803 Cen, CR Boo, CP Eri, KL Dra, 2003aw, V407 Vul, ES Cet and RX J0806.3+1527 (RX J0806, hereafter), which, according to [14] could be grouped into three classes: the "high state" objects AM CVn and HP Lib, with orbital periods shorter than 1200 seconds, a high mass transfer accretion rate and a thick disk, showing absorption He lines in their optical spectra; the "low state" objects GP Com and CE 315, with orbital periods larger than 2500 seconds, a low mass transfer accretion rate and a thin disk, showing emission lines; and those objects in an "unstable (or cyclic) state", with periods ranging from about 1200 to 2500 seconds and showing both He emission (when in low state) and absorption (when in high state) lines. These would be V803 Cen, CR Boo, CP Eri, KL Dra and 2003aw.

It is worth noting that already in 1992 V803 Cen and CR Boo were considered "intermediate" objects between AM CVn (assumed in a permanent high state) and GP Com (in a permanent low state), according to the variations of their observed magnitudes: V $\sim$ 14 for AM CVn, V $\sim$ 16 for GP Com, and V between $\sim$13 and 18 for V803 Cen and CR Boo ([9]). So, we see that nowadays more systems have been found to fit within the three classes.

On the other hand, V407 Vul and RX J0806 are found to display X-ray emission ([15], [16]) while [17] suspected ES Cet to be a soft X-ray source. The three systems have been proposed to host magnetic primaries ([18], [17]). They display periods ranging from 321.5 to 620.26 seconds; periods that would place them inside the "high state" regime of the AM CVn systems as previously defined. However, while V407 Vul does not display emission lines and only a dubious Mg I absorption line was detected in its optical spectrum ([19]), ES Cet and RX J0806 only display emission lines of He ([17], [20]), a characteristic of the "low state" objects. Besides, [21], [22] claim the detection of Balmer lines in the optical spectra of ES Cet and RX J0806, respectively, disregarding therefore their classification as AM CVn systems. All these peculiarities render the three objects as most peculiar and worth studying ones.

In what follows, a brief summary of characteristics and findings –which does not mean to be complete, will be included for each of the twelve AM CVn systems.

2.1 "High state" objects:

AM CVn: Until 1999 two main photometric periods, $\sim$1051 and $\sim$1028 seconds, coexisted for the prototype of the IBDBWD stars group, when [23] confirmed that the orbital period was 1028.73 seconds, a value also later on confirmed by [24]. [25] and [26] supported the interpretation of 1051 seconds as the "superhump" period for the system. These two findings were crucial for a significant advance in the understanding of the binary nature of AM CVn, which, for several authors had not even been proven beyond doubt before (see, e.g., [9]).

To date, after several disk models have been proposed for the system (e.g., [5], [27], [28], [29], [25], [24]), an accretion rate of 10^{14} kg/s, a precession period of 13.38 hours and an inclination of about $\sim 15°–45°$, are suggested. Also, the masses for the primary and secondary components would be, respectively, 0.84 and 0.07 $M_\odot$, yielding a mass ratio (q) of 0.087 ([25]). Instead, [30] reports values of 0.5 $M_\odot$ and 0.22 for the primary mass and q, respectively.

HP Lib : EC15330-1403, also known as HP Lib ([31]), was discovered as an AM CVn system by [32]. The object did not display magnitude variations within several days, staying around a magnitude of V=13.6. A value of 1102.7 seconds was assigned to its orbital period ([31]). Only HeI absorption lines were found in its optical spectrum, with no traces of H. The system is though to remain in a permanent high state, as AM CVn itself, and a period of 1119 seconds ([32]) has been identified as the the superhump period of the object ([31]).

2.2 "Low state" objects:

GP Com: When only five AM CVn systems were known, around 1993, GP Com was suggested to be the most different object among them, based on its observational characteristics ([33], [34], [35]). A most intriguing feature was a variable "central spike" displayed by its tripple-peaked emission lines of He, of unknown origin. Nowadays, it seems well established that GP Com is an AM CVn system, with an orbital period of 2794 seconds, a mass ratio on the order of 0.02 and a primary mass around 1 $M_\odot$ ([36]). [37] reported that observed flares in its light curve are generated at the inner disk , which is thin, in a permanent (quiescent) low state and with a low mass transfer rate ([27], [25]). As a major discovery for GP Com, the origin of its "central spike" is found to be very close to the accreating primary WD, and it is due to Stark effect ([37]). X-ray emission has been reported for the system ([38], [39], [40], [35], [41]).

CE 315: It was discovered spectroscopically by [42], who reported the presence of HeI and HeII lines and no traces of H, and classified it as an AM CVn system. The optical spectrum of the target was found to resemble very closely that of GP Com, with tripple-peaked emission lines –as stated, its most peculiar and unique feature among the AM CVn's, with the central spike variable. The orbital period reported by the authors, of 3906 seconds, is the largest one found to date for an AM CVn system. They also suggested values of 0.77 and 0.017 $M_\odot$ for the masses of the primary and secondary component, respectively, and a mass ratio q of 0.022. [43] detected the existence of CNO material in CE 315, according to their spectroscopical analises, a characteristic also shared by GP Com ([44]).

2.3 "Cyclic state" objects:

V803 Cen: Like several other AM CVn systems, V803 Cen has a thermally unstable disk ([27], [45]), where a variable mass transfer rate makes the system oscillate among a high (V $\sim$ 13), a low (V $\sim$ 17) and a "cyclical" (V $\sim$ 13.5 - 14.5 for more than 50% of the time) states ([46]). Its optical spectrum shows HeI lines ([47], [48]), both in emission (when at low state) and in absorption (when at high state).

[46] have suggested that the system undergoes normal outbursts, like the Dwarf Novae ([45]), a possibility already pointed out by [49]. A period of 1618 seconds displayed by the object was suggested by the authors to be attributable to its superhumps; a possibility confirmed by [45] who reported values of 1614.5 and 1618.1 seconds for its superhump period and "late" superhumps, repectively. [45] also reported a value of 1594 seconds for the orbital period of V803 Cen, although no conclussively results exist for that issue so far.

[50] reported a low X-ray count rate detection for the system, compatible with a 10 keV bremsstrahlung source.

CR Boo: PG1346+082, also known as CR Boo, shares many observational properties with V803 Cen. In this case, several precession periods for its small disk ([27], [51]) have been suggested: 1.18 days by [52]; 36 hours by [51]; and 32 hours by [25]. Superhumps have been observed when in high state with a superhump period of 1487.29 seconds, while its orbital period seems to be established around 1471 seconds ([51]). [52] also compared de object with a Dwarf Nova and provided the following values for its q and secondary mass: 0.057 and 0.057 $M_\odot$, respectively. [25] gave a value of 43.8° for the disk inclination angle and values of 0.05 and 0.05 $M_\odot$ for q and the secondary mass, respectively. Meanwhile, [27] assigned to the secondary mass a value of 0.14 $M_\odot$.

CP Eri: [53] classified CP Eri as an IBDBWD star, of similar characteristics to those of V803 Cen and CR Boo. They found a period of 1724 seconds, no H in its optical spectrum, and a transition between emission and absorption of its He lines from low (at a V magnitude of $\sim$ 19.7) to high (V magnitude of $\sim$ 16.5; see [53] for details), respectively, of its thermally unstable disk ([25], [27]). A clear orbital nature for that dominant period has not been established yet, as far as we can tell. [54] reported double-peaked lines of He I in emission, similar to those found for GP Com and CE 315, together with emission lines of Si II. The authors also reported a primary mass of at least 0.27 $M_\odot$ and an inclination angle for the disk in the range 33°–80°.

KL Dra: KL Dra ([55]) was discovered as an apparent supernova (SN 1998d,I) by [56]. [57] reported He I spectral absorption lines, on a blue continuum, for its optical spectrum, which was found to resemble that of CR Boo at maximum, by the same authors. Magnitude variations between V=16.8 and V=20, together with transitions between a high and a low states, were reported by [58]. The same authors confirmed KL Dra as a new member of the AM CVn family, with similar characteristics to those of CR Boo, V803 Cen and CP Eri. A light curve, also closely resembling that of CR Boo, was obtained by [58], who reported as well the existence of superhumps for the system when in high state, with a period of 1530 seconds. Besides, they provided a value of 1500 seconds for its suspected orbital period, and values of 0.075 and 0.76 $M_\odot$ for q and the primary mass, respectively.

2003aw: This system was discovered by [59] as a suspected supernova, and studied spectroscopically by [60] who found it to display a blue continuum with emission lines of He, with resemblances to KL Dra. The same authors reported the presence of Ca II, H and K in absorption. [61] estudied its light curve and found its behaviour very similar to that of CR Boo and V803 Cen. Its visual magnitude was found to vary between V=16.5 and V=20.3 and to display cyclic brightness changes. The authors suggested an IBDBWD model for the system, which displays faint eclipses ([62]) and superhumps when at high state. A superhump period of 2041.5 seconds has been determined by [61], who also suggested an orbital period in the range 1200-2500 seconds.

2.4 "Magnetic" objects:

RX J1914.4+2456: This object, also known as V407 Vul, was reported by [63] as a soft X-ray ROSAT object ([64]), with an optical magnitude V=19.7. A preliminary classification as Intermediate Polar was assigned to the object by [15].

A value of 569.38 seconds was meassured for its orbital period by [65] who, based on the accumulated evidence, concluded that V407 Vul is the first He double-degenerate Polar; this is, the first AM CVn system where the presence of a magnetic field of a few MG was propossed to exist. Related to this, [66] also reported variations in the X-rays light curve of the object, similar to those found for other Polars. However, they did not detect neither emission lines nor polarization, as expected for a true Polar, which therefore casted some doubts on its classification as such.

While [14] indicated that the 569 seconds value did not conclussively correspond to the object's orbital period, [22] stated that the absence of emission lines reported by [19], both in the optical and in the IR, could be due to a high mass accretion rate together with a low (0°) inclination for the orbital plane. This inclination result contradicts the one previously reported by [65], of 90°.

To date, the classification of V407 Vul according to its magnetic nature seems far from being well established. Besides a Polar ([65]) and an Intermediate Polar ([15] or [68]), [69] and [19] suggested it to be an "Electrical Powered" system, while [70] propossed a double-degenerate Algol as an alternative possibility.

ES Cet: KUV 01584-0939, also known as ES Cet o Cet3 ([71]), was discovered by [72] as an UV object of the Kiso survey [72]. [21] reported the detection of strong HeII lines in emission. [14] signed the presence of double emission lines, as meassured by [73]. [17] reported emission lines of CIV, together with values of 0.094 for the mass ratio, 0.7 $M_{\odot}$ for the primary mass, a visual magnitude of V=16.9 and a period of 620.26 seconds. These authors also suggested that the system must be a high luminosity soft X-rays source, and perhaps a Polar; they found it similar to V407 Vul, and suggested it as a potential source of strong gravitational radiation. A mass transfer rate value of 10^{-8} $M_{\odot}$ /yr was also proposed for the system by [17] who speculated with the possible existence of permanent superhumps, although a superhump period has not been detected yet.

RX J0806.3+1527: [74] discovered this object as a ROSAT source and they suggested to catalogue it as an Intermediate Polar (see also [75], who reported a V magnitude of 21.1 for the system). [18] compared this system, for their similarities, to V407 Vul and they suggested to catalogue it as a "Electric Star" –i.e., in disagreement with the IBDBWD model proposed by [67]. [75] reported a period of 321.5 seconds and [67] confirmed its orbital nature. [75] also reported soft X-rays for the object, based on which a neutron star hipothesis ([67]) for its nature was discarded. [20] reported the detection of emission lines of He, as found for other AM CVn systems, and suggested a classification for RX J0806 as an IBDBWD system (see also [67]). However, [22] discarded such a model, based on the detection of H lines in the optical spectrum of the object. [20] detected C and N for the system, while [18] found C and Ne. [20] provided values between 0.2 and 0.5, and 0.12 $M_{\odot}$, respectively, for the primary and secondary masses.

3 Summary and discussion

To date, twelve AM CVn, or Interacting Binary DB White Dwarf (IBDBWD), systems are known. The AM CVn systems share, as a main distinguishing characteristic among the Cataclysmic Variables, a remarkable absence of H in their optical spectra. Also, their ultrashort orbital periods (in the range 321-3906 seconds) render them unique and support the model most widely accepted, of a two He (i.e., DB-type) WD binary system, for their natures. Here, a secondary DB WD would transfer He from its atmosphere onto the primary WD, also of DB type (see, e.g., [14]). The presence of H detected in the spectra of three of the new objects (i.e., ES Cet, RX J0806 and 2003aw) seems to cast however some doubts on their classification as AM CVn systems.

Far from sharing homogeneous appearances and behaviours, at least three subgroups seem to coexist in the class, according to their observed photometric properties: AM CVn itself, the prototype, and HP Lib display absoption lines of He and are thought to remain in a so-called permanent "high state" of mass transfer; GP Com and CE 315, in a permanent "low state", display emission lines of He, double and triple-peaked; and V803 Cen, CR Boo, CP Eri, KL Dra and 2003aw form the so-called "cyclic state" objects with transitions between low –typically V$\sim$20– and high –typically V$\sim$13– states, over time spans ranging from days to months.

Besides, three more systems, V407 Vul, ES Cet and RX J0806, have been proposed to contain magnetic accreators, in what whould constitute the first examples of double-degenerate Polars known (see, e.g., [65]). However, this classification is not exent from controversy as alternative possibilities (such a double-degenerate Algo model, for example) have also been suggested ([70]).

The existence of superhumps in many of the systems, together with several accretion disk models –containing or not tidal and/or ellipticity effects– considered (see, e.g., [25], [27]), open broad possibilities of study for the properties of the, most likely, unstable mass transfer processes at place in the systems.

Although the number of AM CVn systems known has grown from 4 objects in 1992 [9] to 12 in 2003 ([14]), [24] have estimated that the total number of objects in our Galaxy would be of approximately 10^7, so that realistic possibilities exist of enlarging considerably the amount of new AM CVn detections ([14]). Since the exact role played by the AM CVn systems as end points of cataclysmic binary evolution has not been defintively established yet, an exhaustive study of the observational properties of those eventual detections in the context of the already known AM CVn binaries, would be of crucial interest to the further understanding of this class.

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NOTE ADDED IN PROOF: A new AM CVn candidate, SDSS J1240-01, has been reported by [76].