THE AM CVN SYSTEMS - THE FINAL STAGE OF BINARY WHITE DWARF EVOLUTION

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ABSTRACT. The last decade has shown a surge in research on the Interacting Binary White Dwarf s (IBWDs), or Helium CVs, also called AM CVn systems. We have witnessed long photometric campaigns, time resolved spectroscopy, UV and X-ray observations, and modelling of disc structure, disc atmosphere and their evolution. Recently several new members of the AM CVn family have been added, and a new subclass - double degenerate polars has been identified. A review of the research on AM CVn systems during the last decade is given, and some problems to be solved in the future are presented.

Key words: Stars: binary: cataclysmic; interacting; helium cataclysmic; stars: individual: AM CVn, HP Lib, V803 Cen, CR Boo, CP Eri, GP Com, CE 315, RX J1914+24

1. Introduction

The AM CVn objects are helium-rich analogues to the ER UMa cataclysmic variables - they have short orbital periods and a low mass secondary, transferring mass through the L1 point between the stars.

They evolve through common envelope phases to a close binary system, where the secondary appears as a low mass stellar core, either degenerate or semi-degenerate. Because of the close orbits, angular momentum is lost by gravitational radiation, and the orbits shrink until mass transfer takes place and the orbits again increase. During the common envelope phase the outer hydrogen atmosphere is lost, and we get systems with almost pure helium - at least in the outer parts.

Observations show that the AM CVn stars have orbital periods between 9 and 65 minutes, and that their orbits are increasing while the mass transfer rate is decreasing (Patterson et al. 2001). For the objects with periods more than 15 minutes the mass is transferred through an accretion disc which is made of almost pure helium. For periods between 15 and 30 minutes the discs show signs of non-circularity and thermal and tidal instabilities. Recently the first magnetic AM CVn object type polar, RX J1914+24 has been discovered (Cropper et al. 1998), with an orbital period of only 9.5 min. This is an exciting discovery, and more possible polars are under investigation.

In the following we will give a review of the status of the research on the AM CVn objects, basically after 1994, when an extensive review was given by Warner (1995). We will start with a presentation of new research related to old and new members of the AM CVn family, and then discuss models for their evolution and challenges for future research.

2. The Family Members

Photometry shows that they have nova or dwarf nova like variability. Two of the objects (AM CVn and HP Lib) are stuck in a high, superoutburst state. For the objects with discs the light curve is modulated by a fundamental period, interpreted as the superhump period, and the FT of the light curve shows a series of harmonics, which are related to structures in the disc (Solheim & Provencal 1998)

Warner (1995) argued that the two members AM CVn and HP Lib are equivalent to H-rich nova-like variables with high mass transfer rate $\dot{M}$, which leads to a stable high state disc, and V803 Cen, CR Boo and CP Eri are the helium analogues of the VY Scl stars, moving from high to low states as a result of variations in $\dot{M}(2)$, and that GP Com is probably a SU UMa analogue, spending long time in the low state with very infrequent superoutbursts. Skillman et al. (1997) argued that CR Boo is a " helium Z Cam star " (standstill slightly below maximum light) and a "helium ER UMa star" (very frequent short maxima) as well as a "helium SU UMa star" (superoutbursts punctuated by common superhumps). The same nomenclature may be used for V803 Cen and CP Eri.

Some of the AM CVn stars: AM CVn, CR Boo and GP Com are weak, soft X-ray emitters (Ulla 1995). The X-rays come from the accretor or the inner part of the accretion disc and is evidence for non-magnetic behaviour (Teeseling et al. 1996). A reanalysis of the ROSAT Position Sensitive Proportional Counter (PSPC) data for AM CVn gave as a best fit a black-body source of temperature $\sim 3 \times 10^6$K from a hot boundary layer between the disc and the white dwarf

Table 1: Basic data for for AM CVn family members.

Object	V	P_{orb}	P_{sh}	q
RX J1914+24	>19.7	569		
AM CVn	13.7-14.2	1029	1051	.084
HP Lib	13.7	1103	1119	.060
CR Boo	13.0-18.0	1471	1488	.037
V803 Cen	13.2-17.4	1611	1618	.014
CP Eri	16.5-19.7	1701	1716	.029
KL Dra	16.8-20	unknown		
GP Com	15.7-16.0	2790		.02
CE 315	17.5	3906		.022

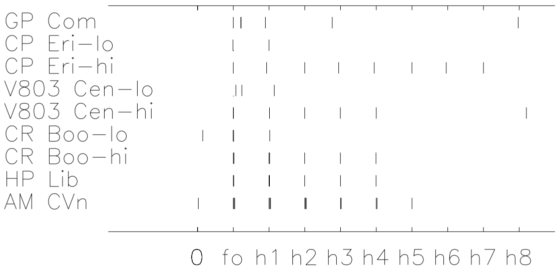

Figure 1: Modulation frequencies observed for AM CVn objects. Frequencies detected are shown relative to a fundamental frequency f_0 which is the superhump frequency if that is detected, otherwise the orbital frequency. Thicker bars tell that closely spaced signals in frequency exists.

(Kellogg et al. 2000). GP Com also shows X -ray modulations both in flux and hardness ratio with its orbital period (Teeseling & Verbunt 1994), which may be explained by modulations of the accretion stream on to the accreting object.

Table 1 gives some basic data for the AM CVn family. In this table P_{orb} is the orbital period, P_{sh} is the superhump period, and $q = M(2)/M(1)$ which is determined by the formulae (1) in Warner (1995) , except for GP Com and CE 315 where q is determined by spectroscopy. References for each object are given in the subsections below. Data for orbital and superhump periods are mostly from Patterson (2001) and Patterson et al. (2001).

Figure 1 shows the modulation frequencies observed for the AM CVn systems. f_0 is the fundamental frequency, which for the disc-objects is the superhump frequency, and hn is the harmonics of number n.

2.1. The Novalike: AM CVn And HP Lib

For AM CVn there has long been a controversy on what is the orbital period and what is the superhump period. Based on WET observations in 1990, Provencal et al. (1995) and Solheim et al. (1998), concluded that the period 1051 s was stable over time and should therefore be the orbital period, even if the period itself was not detected in the FT of the light curve, while the low amplitude 1029 s peak was the superhump period, classifying AM CVn as a negative superhumper.

Harvey et al. (1998) proposed P=1029 s as the orbital period. Skillman et al. (1999) observed the star for 670 hr over 227 nights in the period 1992-1999, and concluded that P=1029 s is the orbital period and P=1051 s is the superhump period, with 5 harmonics and sidebands representing periods of ***apsidal advance*** Ω and ***nodal regression*** N of 13.36 and 16.69 hr, respectively.

The controversy is finally put to rest with the detection of a clear S-wave in spectra folded on the 1029 s period, and at the same time Doppler tomography showing a prominent hot spot superimposed on a weak disc emission when folded on this period (Nelemans et al. 2001a).

So far secondary objects in any AM CVn system have not been observed in their spectra. The reason for this is that they are sub-luminous, and do not show up as infrared objects as normal CV secondaries do. The short orbital periods bring them close to the hot disc and the hot primary, and their atmospheres are irradiated and heated up to the same temperature as the outer part of the disc (Nymark 1997). Figure 2 shows how the secondary and the disc spectrum adds up in the AM CVn case.

For the second nova like, HP Lib, a 70 hr photometric campaign revealed the 4 harmonics of the fundamental periods, and its similarity with AM CVn (Aminzade et al. 1999). A more substantial campaign covering 720 hr over 185 nights, reported by Patterson et al. (2001) shows that the main photometric signal varies between 1118.89 and 1119.14 s on a time scale of a few years, and displays a waveform characteristics of superhumps. After subtracting the main signal they found a weak residual signal at 1102.70 s, which they interpreted as the underlying orbital period of the binary. The full amplitude of this variation is just 5 mma, which makes it the weakest orbital signal yet found in a CV. The star showed remarkable constancy in magnitude and superhump behaviour, and displayed sidebands giving a precession period of Ω =21 hr. It has much more power in the fundamental period and much less power in the harmonics than AM CVn. This may be related to their different angles of inclination and different dis c structures.

2.2. The Dwarf Novae

Six of the AM CVn systems are helium dwarf novae

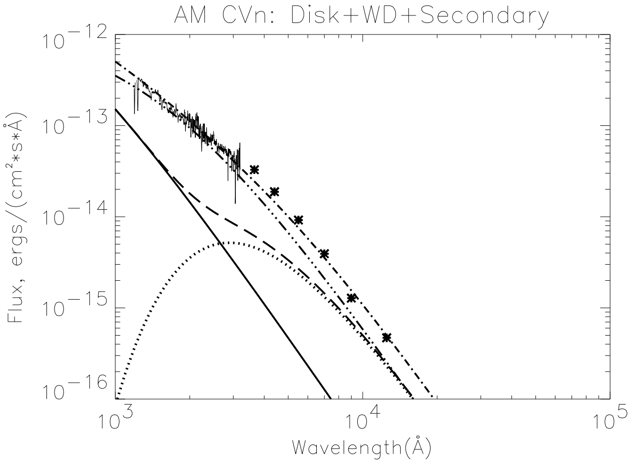

Figure 2: A combined model spectrum (dash-dot) consisting of a blackbody disc model(dash-trippel dots), an irradiated secondary star (dots) and a hot accreting white dwarf (solid line), that fits the observed IUE spectrum plus photometric points for AM CVn. The model parameters are $M_1 = 1.1M_{\odot}, \dot{M} = 3 \times 10^{-9}M_{\odot}/\text{yr}$, $R_{in} = 1.4R_1, R_{out} = 15R_1, i = 45°, d =$ 288 pc, T_{eff} =10 000K for the secondary star and for the central star $T_{eff} = 1.0 \times 10^5$ K (Nasser et al. 2001).

analogues. 4 of these have frequent dvarf nova outburst and two are SU UMa analogues, spending a long time in the low state with very infrequent superoutbursts. Due to the rapid variability – the changes can be of the order 0.1 mag/hr – stable light curves over long periods of time are difficult to obtain, and spectra change continuously.

2.1.1 Dwarf Novae: CR Boo, V803 Cen CP Eri

An intensive photometric campaign for CR Boo in 1996 (Patterson et al. 1997) confirmed the orbital period of 1471 s which was found in the first WET campaign (Provencal et al. 1997). This signal kept its phase and amplitude despite erratic variations of the total brightness. In addition Patterson et al. (1997) proved that the signal with period 1486 – 1494 s is the superhump period, which at the end of an outburst stabilised itself at P=1487.29 s. They also found that CR Boo for two weeks went into a qua si periodic *cycling stage* with P∼19 hr between the high and low states. From the beat between the superhump period and the orbital period an eccentric precession of the accretion disc with period P∼36 hr can be calculated. This was also observed as a skewness variation in absorption lines (Patterson et al. 1997).

Photometry of V803 Cen in the period 1992-1999 (Patterson et al. 2000) showed a strong periodic signal at P=1618 s with harmonics, which resembles the superhumps associated with the other AM CVn objects. However, it is unusual because it appears to endure through all brightness states, even down to V=17. The system also shows some times a periodic signal at P=1612 s which by Patterson (2001) is interpreted as the orbital period. The star is occasionally stuck in a cycling stage with a quasi period of P∼ 22 hr in the magnitude range 13.4–14.5 and shows in addition a period of ∼ 5 days between outbursts from the lowest state at V=17.2 (Patterson et al. 2000).

Spectroscopy is done of CP Eri in its low state by Groot et al. (2001). They found a spectrum dominated by He I emission lines, as observed for GP Com and CE 315. All clearly identified lines were double-peaked, which is an indication of lines formed in a rotating accretion disc. One marked difference was observed with respect to GP Com and CE 315: No central low radial velocity amplitude peak was seen in the He I line profiles, and the presence of Si II lines points to a progenitor with solar metallicity (Marsh et al. 1991). They conclude that CP Eri has lower than solar metallicity but is certainly not as metal poor as GP Com and CE 315.

The helium accretor GP Com has been studied by Marsh (1999) and he confirms the S-curve with period 46.52 min and the absence of hydrogen and the presence of strong helium and nitrogen emission lines. This is consistent with seeing material from the core of a star that has undergone hydrogen burning and CNO-cycle processing of most of the carbon and oxygen into nitrogen. Mash (1999) also found erratically variability in the emission lines. The He II line at 4686 Å changed most, which is consistent with X-ray driven photoionization. The flaring part of the line profiles are broader than the average, as expected if they originate in the inner, unstable, 1/4 of the disc. Marsh (1999) also detected a small radial velocity variation with a semi-amplitude of ∼10 km s^{-1} in the sharp component in the centre of the emission lines, which indicates that it comes from the accreting star. He found q of the order 0.02, as expected on evolutionary grounds.

2.1.2 New Members: KL Dra and CE 315.

KL Dra was first identified as a supernova (SN 1998di), but a spectrum showing shallow He I absorption features at zero relative velocity, made an identification as an AM CVn object of the dwarf nova type in outburst more likely (Jha et al. 1998). The magnitude at discovery was 16.8. Because of its variability we expect an orbital period between 20 and 40 minutes.

A new member of the family, CE 315 – much like GP Com – was discovered during a spectroscopic follow up of proper-motion stars in the Calán-ESO Catalog (Ruiz et al. 2001). The object was found to have a spectrum consisting of a blue continuum with strong emission lines of He I and He II, with a handful of faint lines of nitrogen. The He lines exhibit triple peaked profiles with remarkably broad widths of ~ 2000 km s^{-1} . Ruiz et al. (2001) find an orbital period of 65.1 min and a mass ratio q=0.022. The line profiles consists of a double peaked profile from the disc, and a central, occasionally quite strong peak, which may originate from the accreting object.

2.3. New Class Of Members: AM CVn Polars

The X-ray object RX J1914+24 was identified as a polar with a degenerate secondary object by Cropper et al. (1998) on the basis of ROSAT observations with the PSPC and the High Resolution Imager (HRI). The object has an X-ray light curve with a single strong modulation at 569 s, which is interpreted as the orbital period of a syncronized binary system. I-band observations with the Nordic Optical Telescope (NOT) show the same period but with maximum out of phase with the X-ray peak flux (Ramsay et al. 2000). The I-band flux must be from the face of the donor star irradiated by the X-ray flux from the accreting region of the primary star. Since only one period is observed, a disc is not present, and the short period makes a double degenerate system the only possibility. In order to become a stable syncronized system the acccretion torque must be balanced by a MHD torque from a magnetic field of the order a few MG (Ramsay et al. 2000).

This polar may be the first example of an electric powered star. Because of the short orbital period and large mass of the primary, huge electric currents are driven between the stars, and the energy of these currents is liberated at the magnetic poles of the magnetic white dwarf and X-rays are generated. Much of the observed flux may come from this energy source (Wu et al. 2001).

Another source RX J0806+1527 has similar X-ray characteristics, showing a single period ~ 321 s pulsation. It has B=20.5 with no red counterpart (Israel et al. 1999), and may be another member of the polar branch of the AM CVn family.

3. Disc Atmosphere And Structure

A remarkable paper on the spectral properties of AM CVn was published by Voikhanskaya (1982). She observed in the prime focus of the six-meter telescope in 1978 and 1980 and noted many details in the spectrum which have much later been confirmed. In addition to the broad He I lines, she identified an emission feature at λ4640 Å as the C III–NIII blend, which is also observed in many X-ray sources, and also the faint He II emission at λ4686 Å. She also noted emission peaks inside the He I absorption lines which moved with time, and that the absorption line edges also moved with time. Recently it is found that the emission peak variability shows an S-wave with period 1029 s identified as the orbital period (Nelemans et al. 2001a), and the movement of the absorption line edges has revealed the 13.4 hr precession period of the disc (Patterson et al. 1993).

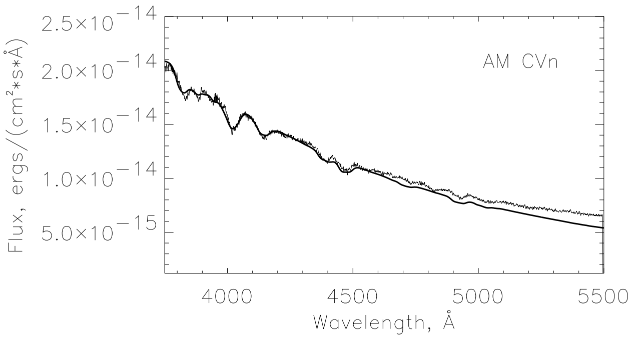

Figure 3: Observed AM CVn spectrum (thin line) fitted with NLTE a pure helium disc atmosphere model (thick line) with the following parameters: $M(1) = 1.1M_{\odot}, \dot{M} = 3 \times 10^{-9}, M_{\odot}/yr, R_{in} = 1.4R_1, R_{out} = 15R_1, i = 45°$ and $d = 288$pc. R_1 is the radius of the central star. The excess flux beyond 5000Å may be a sign of the donor star (Nasser et al. 2001).

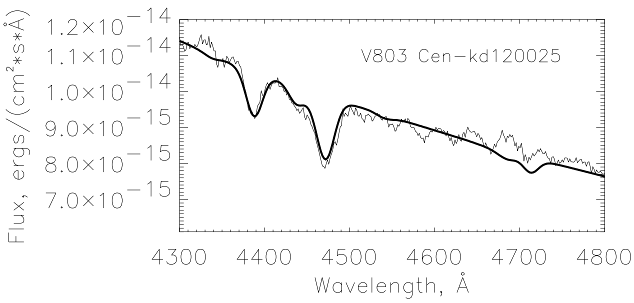

Figure 4: Observed V803 Cen (thin line) fitted with a pure helium NLTE disc atmosphere model (thick line) with the following parameters: $M(1) = 1.2M_{\odot}, \dot{M} = 3 \times 10^{-9} M_{\odot}/yr, R_{in} = 1.4R_1, R_{out} = 15R_1, i = 5°$ and $d = 380$ pc. (Nasser 2001).

3.1. Disc Atmosphere Models

The main contribution to the flux observed in the optical region for the AM CVn objects is from the disc (Figure 2). Disc spectra can be calculated for geometrical thin discs and depend on the following parameters: The mass of the accreting star: $M(1)$, the mass transfer rate: $\dot{M}$, and the inner and outer radii of the disc: R_{in} and R_{out}, and the disc inclination: i. In addition the abundance, in particular the H/He ratio is important.

El-Khoury and Wickramasinghe (2000) has calculated syntetic disc spectra for a range of parameters and fitted them to observed spectra of AM CVn and CR Boo. They use a χ^2 minimisation technique to determine the best fit in a grid of acceptable models, but reduce their number of free parameters by keeping the disc size between the Roche Lobe radius R_{L1} and the maximum radius for the last stable orbit in the restricted three body problem R_{st}. Their best fits for AM CVn and CR Boo are given in table 2. In addition they find upper values for the hydrogen to helium number density ratios to be 10^{-2} to 10^{-3}, which they claim is consistent with a helium-degenerate donor surrounded by a helium-rich envelope. The mass transfer rates determined place the objects in the region of a thermally-stable disc for AM CVn and thermally unstable for CR Boo.

Another approach has been taken by Nasser et al. (2001) who used the TLUSDISK code to calculate NLTE accretion disc models. NLTE models give differences in line equivalent widths between 10 and 40 per cent for certain temperatures or mass transfer rates, and may be a better approximation than the LTE models.

We observed 4 of the AM CVn systems with the NOT during 3 observing seasons, and determined the best set of parameters that fitted the observed spectra. Figures 3 and 4 give examples of the best fits for two of the objects: AM CVn itself and V803 Cen. For this model fitting procedure the inner and outer radius of the disc and the mass of the accretor is determined from photometry, and only allowed to vary within the uncertainty limits. The parameters determined from the spectra are given in table 2 and sho wn in Figure 5. In none of the spectra the H_γ is detected, and the model calculations show that this gives us an upper limit of the number density of H/He of 10^{-5}. For all the observed objects the mass transfer rate is so high that it indicates a stable disc, which is not obviously true for the dwarf nova like objects CR Boo and V803 Cen. This discrepancy may be due to the observations done only in the outburst state, and that the objects on the average have lower mass transfer rates.

3.2 Disc Structure

The AM CVn systems have all a mass ratio, $q < 0.1$. Simulations have shown (Whitehurst 1988) that discs with such small mass ratios will develop assymetries due to tidal stress produced by parametric resonance between particle orbits and an orbiting secondary star with a 1:3 period ratio. The initially circular disc is deformed into a slowly precessing disc. Hirose and Osaki (1990) found a similar result and in addition noted that the difference between the superhump period and the orbital period is a fu nction of the mass ratio: q. Using this relation, and a mass-radius relationship for the secondary, which radius is determined from the Roche Lobe size at a given period, the mass of the primary object can be determined (Warner 1995).

For the AM CVn stars 3-D SPH models of helium accretion discs with small q values have been calculated by Wood and Simpson (1995), and they have also computed the energy production time series that display remarkable similarities with the observed light curves (Simpson & Wood 1998). These calculations show that the disc during one orbital revolution changes its shape from circular to elliptical, and that the stress in the disc when it is non-circular produces more energy, which leads to a pulse profile which can be compared with the observed profiles from the light curves. The pulse will change with time, giving a more triangular shape of *young* pulses from a newly formed disc, than for the more pulses from more mature (*old* discs which are confined to a smaller part of the period.

From the SPH calculations it is also found that spiral shocks appear near the outer edges of the discs, and that the appearances of spiral shocks will have a noticeable effect on the light curve, producing the higher harmonics in the FT of the light curve ((Simpson et al. 1998). They also show that the amplitudes of the harmonics are very sensitive to the angle of inclination, and that the time series amplitude spectra for inclination angles $i < 45°$ are dominated by the superhump frequency, but t hat linear combinations of the superhump and orbital frequencies appear at higher inclinations.

3.2.1 Discoseismology

A special feature of the photometric light curves of the AM CVn stars with discs is the appearance of harmonics in the times series amplitude spectra as shown in Figure 1. The number of harmonics and their relative amplitude is obviously a function of properties of the disc. For AM CVn itself 13 modulation frequencies were detected in the WET campaign in 1990 (Solheim et al. 1998). These frequencies are all related to 3 independent frequencies: ω, Ω,and N with harmonics of the orbital fre quency ω and sums and differences of the type $n\omega - m\Omega$, where $m = 1, ..., n$ are a manifestation of the positive superhump, and this $\pm N$ demonstrate the negative superhump (Skillman et al. 1999).

Simulations as described in the section above (Simpson et al. 1998), show that the synthetic light curve produced also show harmonics, in particular for high values of inclination, and we expect that the relative amplitudes of the harmonics may be related to the visibility of the spiral shocks that appear in the discs (Solheim & Provencal 1998). The relation between the harmonics and disc structure may be a way to investigate discs, we may call it *discoseismology*, and should be explored in more det ail (Solheim 1999).

Table 2: Parameters determined from disc spectra.

Object	$M(1)/M_\odot$	$\log(\dot{M}(M_\odot/\mathrm{yr})$	i	B
AM CVn[1]	0.84	-8.8	45°	
AM CVn[2]	1.1	-8.5	45°	
HP Lib[2]	1.1	-8.4	28°	
CR Boo[1]	0.94	-8.9	44°	
CR Boo[2]	1.0	-8.4 to -8.2	30°	14.7-13.9
V803 Cen[2]	1.2	-8.5 to -8.3	5°	14.8-14.3

Notes: 1. El-Khory & Wickramasinghe 2000; 2. Nasser 2001

Figure 1 shows that there is a difference in the pattern of the harmonics when objects go from the high state to the low state. This must reflect changes in the structure or size of discs. Discoseismological studies of AM CVn dwarf nova type objects which go from high to low states and back may reveal how disc structures evolve through an outburst.

4. Evolution – From Common Envelope to Helium CV

One model for formation of AM CVn systems (Tutukov & Yungelson 1996) is the formation of close white dwarfs during two phases of common envelope evolution in which a substantial mass is lost from the system. The initial mass of the primary is between 1.5 and 6 $M_\odot$. The emission of gravitational waves will subsequently bring the two white dwarfs in a semi-detached phase and mass transfer will start. The Tutukov & Yungelson (1996) evolution calculations predict that at the time of the start of stable mass transfer the secondary white dwarfs must have masses between ~ 0.3 and $\sim 0.13 M_\odot$ and the mass function for the accretors peaks at 0.65-0.75$M_\odot$, which is $0.05 M_\odot$ higher than the normal WD mass distribution peak.. They claim that a non-degenerate secondary is not possible, but allow for a larger radius for the secondary than a zero temperature white dwarf has.

An alternative route of evolution is that the donor star is replaced by a helium star that becomes semi-degenerate and dim during the mass transfer (Iben & Tutukov 1991). A population synthesis (Nelemans et al. 2001b) has compared the two models for AM CVn stars evolution. They find that for the first route possibly no accretion disc forms at the onset of the mass transfer. The stability and the rate of mass transfer then depend on the tidal coupling between the accretor and the orbital motion. If this co upling is not efficient most systems merge, and the formation rate of AM CVn stars becomes very low. In this case the magnetic coupled systems are almost the only ones to survive. RX J1914+25 may be such a system. In the second channel of formation – from a helium star that stops burning – the formation of AM CVn stars may be prevented by explosive burning of the helium layer which may cause detonation of the CO white dwarf accreator and the disruption of the system.

Nelemans et al.(2001b) combine their population synthesis results into two models, one *efficient*, in which the stability of mass transfer is not affected by the absence of an accretion disc and explosive helium burning happens when 0.3 $M_\odot$ has accumulated, and one *inefficient* model in which the the absence of an accretion disc is very important and the explosive helium burning disruption starts already when 0.15 $M_\odot$ has accumulated. In the inefficient model only one in 30 pote ntial AM CVn systems evolve from double white dwarfs. In the efficient route both progenitor families produce a comparable number of observable system.

4.1 Comparison Of Two Routes Of Evolution

It is now possible to test the evolutionary scenarios in a more direct way, by comparing the calculated relations between orbital periods and mass transfer rates for the two routes of evolution with the mass transfer rates determined from spectra (Tables 1, 2). The result is shown in Figure 5 where we have drawn the evolutionary relations for degenerate and semi-degenerate secondaries and show the mass transfer rates calculated from our spectra as diamonds with error bars. The error bars also include s ystematic errors in determining the rate, and are quite long for the dwarf nova objects since they are observed only in a high state. The figure also include the results of El-Khory & Wickramasinsinghe (2000) for the two objects AM CVn and CR Boo. In the figure we have also drawn the the border line between stable and unstable discs according to the thermal-tidal instability calculated by Tsugawa & Osaki (1997). The conclusion is that all the 4 objects with discs have mass transfer rates far too high to have degenerate secondaries. The only evolutionary route for these is the helium secondary that becomes semi-degenerate.

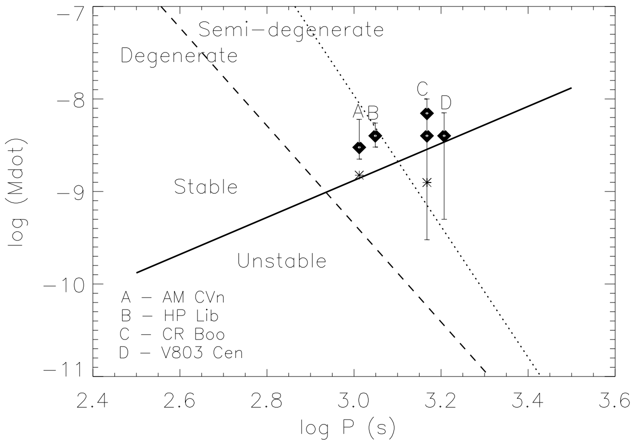

Figure 5: The mass transfer rate versus period for the AM CVn objects as calculated by Nasser et al (2001) and Nasser (20001) are shown as diamonds with error bars representing the systematic errors due to the observations done at a particular phase. Also the results of El-Khory & Wickramasinghe (2000) are included as stars. The solid line is the border between the thermally stable (upper part) and unstable discs (lower part) (Tsugawa & Osaki 1997). The dashed line is the evolution calculated for systems with a white dwarf secondary and the dotted line is the evolution of systems with a semi-degenerate pure helium atmosphere secondary with a C-O core (Nelemans et al. 2001b).

4.2. Future Evolution

Some time in the future the accretion will cease, and the stars will again come closer by loss of angular momentum by Gravitational Radiation. A new period of low mass transfer may take place. Finally the degeneracy of the secondary will be completely lifted, and no material can be transferred. The end product can be a helium type white dwarf (DB) with a small object, maybe planet or brown dwarf, in orbit. A search for such objects has started, but no convincing example has been found yet.

The accreting object may have undergone several helium flashes, and this may make the stellar interior different from normal stars. We may also also find signs of magnetic field and circumbinary matter for some of the objects (Solheim & Sion 1994).

5. Conclusions

The smallness of these systems, and the closeness of the secondary, makes these systems laboratories for exciting physics. In the future we expect Gravitational Radiation to be detected from a large no of AM CVn systems by space borne devices. Hydrodynamic simulation of the particle flow through the discs and to the accreting object may also be done. One day we may also discover a pulsating accreting AM Cvn object, and get a possibility to test directly how the accretion can change the structure of a star.

The metallicity variations observed in the emission line objects CP Eri (low state) , GP Com and CE 315 opens the possibility of constraining the evolutionary history of these system from the chemical composition of the transferred material. One remaining question is if some AM CVn systems have already evolved into DBs. This is related to the age of the Universe - at least the age of the nearby population in our galaxy.

Acknowledgements. This research is supported by a grant from the Norwegian Research Council. Observations are made with the Nordic Optical Telescope, operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatory del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. The data presented here have been obtained using ALFOSC, owned by the Instituto de Astrofisica de Andalucia (IAAA) and operated at the Nordic Optical Telescope under agreement between IAA and the NBIfa of the Astronomical Observatory of Copenhagen.

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