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Cataclysmic Variables: A Review

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Abstract In this paper I review cataclysmic variables (CVs) discussing several hot points about the renewing interest of today astrophysics about these sources. Because of limited length of the paper and my knowledge, this review does not pretend to be complete. However, I would like to demonstrate that the improvement on knowledge of the physics of our Universe is strictly related also with the multifrequency behaviour of CVs, which apparently in the recent past lost to have a leading position in modern astrophysics.

Key words: Multifrequency Astrophysics — Cataclysmic variables — X-ray binary systems — high energy astrophysics

1 PREAMBLE

With the advent of space experiments it was demonstrated that cosmic sources emit energy practically across all the electromagnetic spectrum via different physical processes. Several physical quantities give witness to these processes which usually are not stationary; those physical observable quantities are then generally variable. Therefore *simultaneous multifrequency observations* are strictly necessary in order to understand the actual behaviour of cosmic sources.

Space experiments have opened practically all the electromagnetic windows on the Universe. A discussion of the most important results coming from multifrequency *photonic astrophysics* experiments will provide new inputs for the advance of the knowledge of the physics — very often in its more extreme conditions — of our Universe (e.g. Giovannelli & Sabau-Graziati 2004).

When the first theories about accretion discs around compact stars started to be developed around the 1960s, the class of the so-called Cataclysmic Variables (CVs) started to have a leading position in astrophysics. They constituted the perfect laboratories for testing those theories. When the UV window to the universe was opened at the end of 1970s with the advent of the historical IUE (International Ultraviolet Explorer), CVs became really one of the most interesting class of objects of the whole astrophysics. Previously, essentially two schools of thought born in Cambridge (UK) and in Warsaw (Poland) in order to tackle with the difficult subject of the mass exchange in close binary systems (e.g. Smak 1962, 1972, 1981; Paczynski 1965, 1977; Bath 1969, 1975, 1976, 1978, 1980, 1984 and the references therein; Bath et al. 1974; Mantle & Bath 1983). However, a fundamental paper about accretion discs appeared at the beginning of 1970s (Shakura & Sunyaev 1973). This paper marked substantially the development of theories about accretion discs around compact objects in binary systems, until present times. Pringle (1981) reviewed accretion discs in astrophysics.

New generation satellites, with high energy astrophysical experiments on board, opened e new panorama about the X-ray and γ-ray sky starting to favour the study of X-ray binary systems containing neutron stars or black holes, very useful also as probes for active galactic nuclei (AGNs). Then, being CVs not so high energetic emitters, they wrongly lost enough of their importance for the new field of high energy astrophysics.

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The news from INTEGRAL have recently renewed the interest of high energy astrophysicists for CVs, and subsequently involving once more the low–energy astrophysical community.

2 HISTORICAL BACKGROUND AND CLASSIFICATION

In the 1950s it was recognized that the various phenomena displayed by the CVs are all the consequence of accretion of matter onto a white dwarf from a low mass donor star (e.g., Warner 1976, 1995). CVs are binary systems in which the primary component is a white dwarf ($M_{\rm wd} \sim 1\,M_\odot$) and the secondary is a late type Main Sequence star ($M_{\rm s} \leq 1\,M_\odot$) (e.g., Smak 1985a).

More than 600 CVs are known, most of them discovered through optical observations, and some, especially those in which the magnetic field of the white dwarf is strong, discovered through X-ray observations, but with the detectors of the second and further generations, since CVs are in general not very bright in X-ray energy range. Those with known or suspected orbital period are listed by Ritter & Kolb (1998).

The first CV detected in the X-ray range, with rocket experiments, was the dwarf nova SS Cyg (Rappaport et al. 1974; Heise et al. 1978). The UHURU satellite detected two CVs, which were not recognized as such. Warner (1976) proposed the identification of 4U 1249–28 with EX Hya, and the variable AM Her, which on further optical studies was recognized as a CV (Forman et al. 1978). The magnetic field in these two systems is strong ($\approx 10^7$–10^8 G). A few dozen CVs were detected in X-rays with HEAO-1 satellite, with EXOSAT, and with the Einstein satellite (e.g., reviews of Cordova & Mason 1983; Cordova 1995). Later Verbunt et al. (1997) recognized 91 CVs from a sample of 162 systems with known or suspected binary periods by using data of the ROSAT XRT-PSPC All Sky Survey.

Historically, because CVs were observed photometrically and without seeming to follow any regular pattern, they were given the term *cataclysmic* (from the Greek word kataklysmos = flood, storm; Hack & la Dous 1993). As collecting of observational data progressed it became apparent that these objects were regular binary systems which for some reason changed in brightness; some of them also regularly (Recurrent Novae and Dwarf Novae) while some others only once (Classical Novae). Therefore the classification of CVs was based on the optical outburst properties, by which one may distinguish four groups of CVs: (i) classical novae; (ii) recurrent novae; (iii) dwarf novae; (iv) nova-like objects (e.g., Giovannelli & Martinez-Pais 1991 and references therein; Ritter 1992). This classification, however, is neither self-consistent nor adequate and it is much better to consider primarily the observed accretion behaviour (Smak 1985b). One obvious advantage of such an approach is connected with the time scales of various accretion phenomena, which are sufficiently short to avoid any major observational bias: the mass accretion rates in CVs usually range from 10^{-11} to $10^{-8}\,M_\odot$ yr^{-1} (Patterson 1984); the time scales are from tens of seconds (oscillations in dwarf novae at outbursts) to years (super-outbursts of SU UMa stars or long term variations in VY Scl stars).

Depending on the magnetic field intensity at the white dwarf, the accretion of matter from the secondary star onto the primary can occur either via an accretion disc (in the so-called Non-Magnetic CVs: NMCVs) or a channelling through the magnetic poles (in the case of Polars: PCVs) or in an intermediate way (in the case of Intermediate Polars: IPCVs).

CVs in a time scale of order between weeks and years flare up almost periodically, about few magnitudes in optical wavelengths; the duration of the outbursts is much shorter than the recurrence time. Figure 1 (left panel) shows typical light curves for classical novae and dwarf novae of the U Gem, Z Cam, and SU UMa types (Ritter 1992).

The recurrence time-scale of outbursts in dwarf novae is correlated with their amplitude and the outburst duration is depending on the orbital period (Figure 1 right upper and lower panel, respectively) (Warner 1987).

In PCVs the white dwarf magnetic field is strong enough to make the Alfvén radius greater than the circularization radius, so no accretion disc is formed and the accretion structure is fully governed by the magnetic field, which canalize the accreting matter across the field lines. Owing to the intense magnetic field (~ 10–200 MG), the white dwarf rotation is synchronized with the binary orbital period (a few hours).

IPCV white dwarfs have moderate magnetic fields (order of a few MG); the Alfvén radius is smaller than the circularization radius but it is greater than the white dwarf radius. Therefore an accretion disc is formed in these systems but being disrupted at its inner region. In IPCVs matter follows again the magnetic

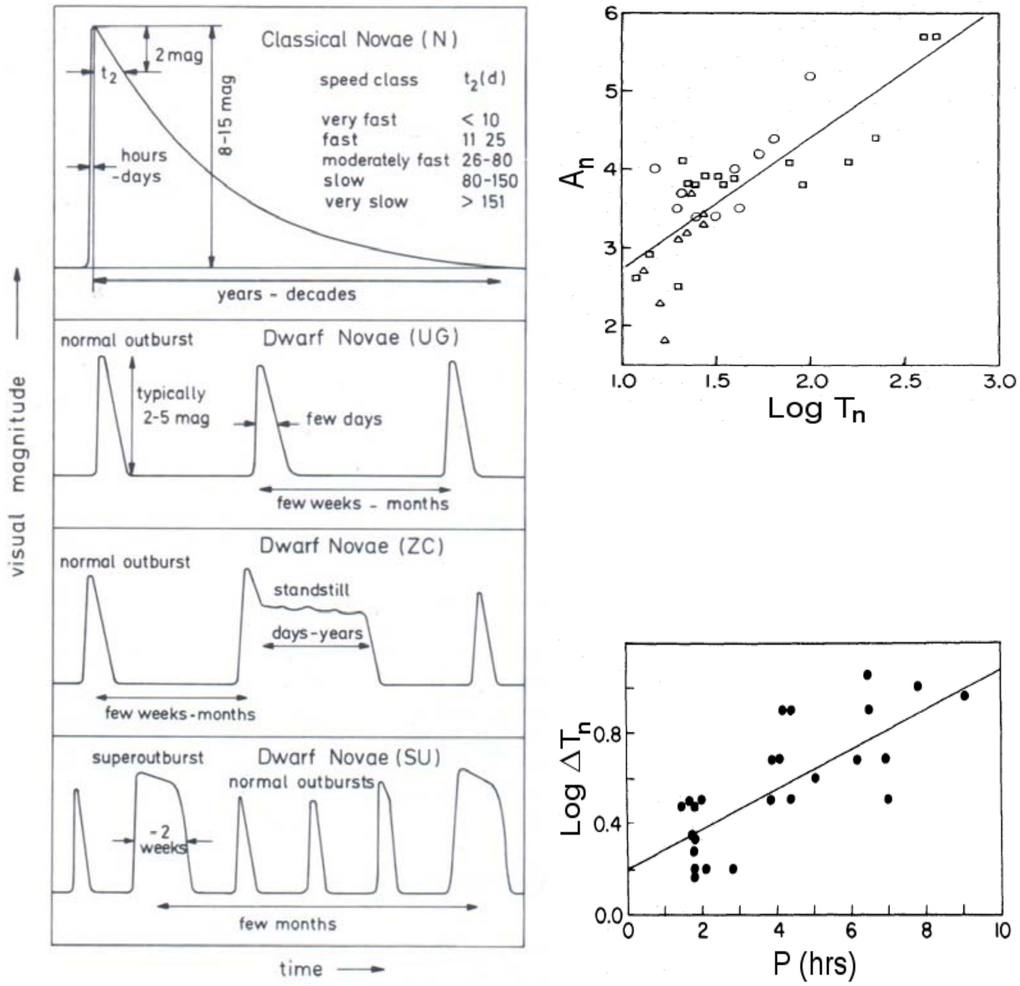

Fig. 1 Left panel: main characteristics of the visual light curves of classical novae (top panel) and of dwarf novae of the U Gem, Z Cam, and SU UMa types (lower three panels) (Ritter 1992). Right panel: (up) recurrence time-scale T_n vs. amplitude A_n of dwarf nova outburst measured from minimum luminosity (Kukarkin-Parenago relationship); (down) correlation between outburst duration ΔT_n and orbital period for dwarf novae (Warner 1987).

field lines but just inside the Alfvén radius. The rotating white dwarf is asynchronous with the binary orbital period ($P_{\rm spin} \ll P_{\rm orb}$).

The last group defined by the accretion structure criterion, NMCVs, includes those systems whose white dwarf magnetic fields are not relevant in governing the accretion structure. In these systems the accretion disc extends down to the white dwarf surface and a boundary layer is formed. This family shows a great diversity of observational behaviour; for this reason the historical criterion of classification is, in this case, more appropriate for distinguishing their sub-classes. However, it is simply an attempt of classification for lack of a more general physical classification (e.g., Giovannelli 1991 and references therein).

As recalled by Giovannelli & Sabau-Graziati (1999), it is evident that the properties of an outburst in CVs depend crucially on the accretion rate, the mass of the white dwarf, and the chemical composition of its hydrogen rich envelope in which the thermonuclear runaway occurs. And the accretion process onto the white dwarf is strongly influenced by its magnetic field intensity. Indeed, the three kind of CVs (non-magnetic, polars, and intermediate polars) obey to relationships between the orbital period of the system and the spin period of the white dwarf (Warner & Wickramasinghe 1991), where the magnetic field intensity plays a fundamental role. Figure 2 shows such a relationship, where the so-called *period gap* between $\sim 2-3$ h is marked. The orbital evolution of CVs, and hence the mass-transfer rate ($\dot{M}$) from the secondary to the white dwarf is driven by magnetic braking of the secondary for long-period systems ($P_{\rm orb} > 3$ hr) and gravitational radiation for short-period systems ($P_{\rm orb} < 2$ hr).

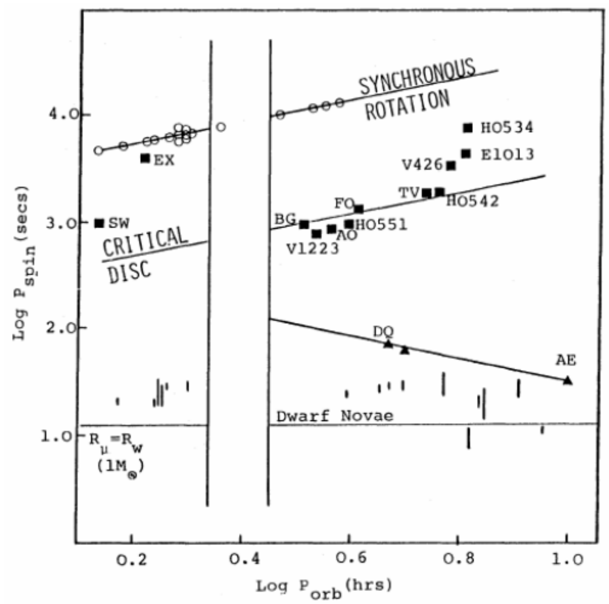

Fig. 2 Relationship between orbital period and spin period of CVs (Warner & Wickramasinghe 1991).

However, such a gap — which was believed true for long time — is now partially filled by the SW Sex systems (e.g. Rodriguez Gil 2003). The apparent *period gap* was due to a smaller number of systems having orbital periods in such an interval, which were escaping from the observations. Figure 3 shows the number of CVs versus orbital period. The positions of polars, intermediate polars and SW Sex systems are marked, as well as the *period gap*.

Therefore the investigation on the magnetic field intensities in white dwarfs is crucial in understanding the evolution of CVs systems. Then, our suggestion is in favor of studying CVs considering them as grav-imagnetic rotators, avoiding in such a way any *a priori* classification. The fundamental parameters to be searched are the magnetic moment, the mass accretion rate and the orbital parameters of the systems. In this way it will be possible to fulfill the plane $\log P_{\rm spin}$–$\log P_{\rm orb}$, where a priori there are not restricted ranges of magnetic moment $|\,\boldsymbol{\mu}\,|$, or special correlations between $P_{\rm spin}$ and $P_{\rm orb}$ and $|\,\boldsymbol{\mu}\,|$. The distribution of objects in that diagram is owed to the interaction of braking torques and accretion torques, with the superposition of the observed or implied variations of the accretion rate on long time scale ($> 10^{\,2}$ yr), acting on a continuum of magnetic moments. In this way each system is completely described by those physical parameters.

The field strength distribution of MCVs differs from that of single white dwarfs, although both cluster around 30 MG. The distribution of isolated white dwarfs extend on a wide range of magnetic field strength ($\sim 10^5$–10^9 G), whilst in accreting white dwarfs of CVs, as far as is presently known, there is a lack of systems at both high and low field strengths. However, the apparent absence of low field MCVs might be explained by the IPs, which generally have unknown field strengths, and the lack of high field systems is still not understood (e.g., Beuermann 1998). Wynn (2000) discusses the problem of accretion flows in MCVs. On the base of the ratio $P_{\rm spin}/P_{\rm orb}$ he divides the MCVs in three classes: class 1, class 2 and class 3 if such a ratio is $\ll 0.1$, ~ 0.1, and $\gg 0.1$, respectively. For the systems in class 1 the disc equilibrium condition is clearly satisfied. Those in class 2 are very unlikely to possess accretion discs. The systems in class 3 are EX Hya-like systems which lie below the *period gap* and cannot possibly contain accretion discs. These are

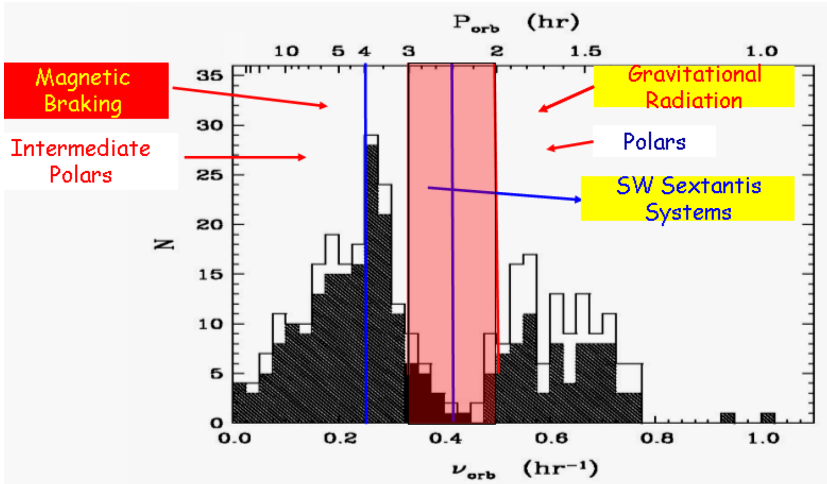

Fig. 3 Number of CVs versus orbital period. Positions of polar, intermediate polars and SW Sex systems are indicated as well as the main physical processes experienced by them (Rodriguez Gil 2003).

EX Hya, HT Cam, RXJ1039.7–0507, and V1025 Cen. These all have $P_{\mathrm{spin}}/P_{\mathrm{orb}} > 0.1$ and $P_{\mathrm{orb}} < 2$ hr. DD Cir and V795 Her lie within the *period gap* with $P_{\mathrm{spin}}/P_{\mathrm{orb}} \sim 0.1$ and may be included in the class 2 (Norton, Somerscales & Wynn 2004, and the references therein). Wynn (2000) crudely classifies the MCVs according to the magnetic moment and orbital period. EX Hya systems have magnetic moment similar to IPs above the *period gap* and comparable to the weakest field AM Her-like systems. This indicates that MCVs above the *period gap* will evolve to long spin periods below it. Norton, Wynn & Somerscales (2004) investigate the rotational equilibria of MCVs. They predict that IPCVs with $\mu \geq 5 \times 10^{33}$ G cm^3 and $P_{\mathrm{orb}} > 3$ hr will evolve into PCVs, while those with $\mu \leq 5 \times 10^{33}$ G cm^3 and $P_{\mathrm{orb}} > 3$ hr will either evolve into low field strength polars that are presumably unobservable, and possibly EUV emitters, or into PCVs when their fields, buried by high accretion rate, revive when the mass accretion rate reduces.

Our opinion is that a more appropriate investigation of the class of the so-called IPCVs is necessary. Indeed, such systems could show surprises if deeply studied, as for instance occurred for SS Cyg. This system, usually considered a NMCV because of a classification once made by Bath & van Paradijs (1983), whilst since 1984 it has been claimed as an IPCV by Giovannelli et al. (1985) and later confirmed several times (e.g., Giovannelli & Martinez-Pais 1991; Giovannelli 1996; Giovannelli & Sabau-Graziati 1999, Gaudenzi et al. 2002). As explained by them, the behaviour of SS Cyg are sometimes close to those of a NMCV and sometimes to those of a PCV, being its magnetic field of $\sim 10^6$ G (Fabbiano et al. 1981). This would teach a lesson: it is mandatory to observe CVs for long time in order to follow at least a whole period of the binary system between two successive outbursts. This is, of course, possible only for systems like dwarf novae where the almost periodical outbursts occur in time scales of weeks-months.

However, we can say that CVs form a broad stellar family of highly variable and dynamical members. When it comes to explaining particulars about, e.g., the detailed interaction between the transferred matter and the white dwarf's atmosphere; irregularities within regular photometric behaviour; turbulent transport in the disc; or the final fate of these objects, more is missing than what is known, rendering their study ever more challenging. At least, because CVs are natural multi–wavelength laboratories offering us the possibility of studying in detail the behaviour of plasma and radiation under extreme physical conditions. The understanding of stellar evolution, electromagnetism and polarization, mass and radiation transfer or 3-D geometrical effects, in a broad spectral range from hard X-rays to radio, is mandatory for improving the knowledge of the nature of CVs.

Variability, from milliseconds to hundreds of years, follows from different physical processes taking place in these systems and can be studied by means of several astronomical techniques. As our skills in developing further these techniques grow our understanding of the CVs insights also grows; and the more we learn about CVs the further techniques and theory develop. On the other hand, it is well known that conclusions obtained in the field of CVs have been extrapolated, upwards or downwards in scale, to other fields such as AGNs or LMXRBs, and vice versa. From such exchanges of information and results astrophysical research in general always benefits. Rapid oscillations in CVs are particularly interesting. As reviewed by Warner (2004), the rich phenomenology of dwarf nova oscillations (DNOs) and quasi–periodic oscillations (QPOs) observed in CVs favour the interpretation that these rapid brightness modulations (3 to 11 000 s timescales) are magnetic in nature–magnetically channelled accretion from the inner accretion disc for DNOs and possible magnetically excited travelling waves in the disc for QPOs. There is increasing evidence for the magnetic aspects, which extend to lower fields the well–known properties of strong field (PCVs) and intermediate strength field (IPCVs) CVs. The result is that almost all CVs show the presence of magnetic fields on their white dwarf primaries, although for many the intrinsic field may be locally enhanced by the accretion process itself. There are many behaviors that parallel the QPOs seen in X-ray binaries, with high– and low–frequency X–ray QPOs resembling, respectively, the DNOs and QPOs in CVs. Other recent papers about rapid oscillations in CVs are those by Warner & Woudt (2005) and Pretorius, Warner & Woudt (2006).

The current estimate of the space density of CVs is of $\sim 3 \times 10^{-6}$ pc^{-3} (Warner 2001). This may be a significant underestimate of CVs space density, as discussed by Patterson (1984). Although densities from the most comprehensive optical Palomar–Green survey raises the estimate at $(3-6) \times 10^{-6}$ pc^{-3}, X-ray All-Sky surveys give densities of $\sim 1 \times 10^{-5}$ pc^{-3} for detected systems of low $\dot{M}$ in hard X-rays (Patterson 1998). Then from observational point of view, it is necessary an intensive search for the faint CVs predicted by population synthesis with orbital periods at $\sim 80-100$ min that have passed through the *orbital period minimum* at $\sim$ 78 min and have increasing orbital periods. This research must be done among the low $\dot{M}$ systems detected by X-ray surveys. Thanks to its high sensitivity, INTEGRAL is very useful for this purpose. Up to now, it discovered several new faint CVs, with P$_{\rm orb} > 3$ hr, and only one with $P_{\rm orb} < 3$ hr (e.g. Simon et al. 2006; Hudec et al. 2008). High speed photometry of faint CVs have shown that: i) 1 of 10, TV Crv has $P_{\rm orb} = 1.509$ hr (Woudt & Warner 2003); ii) 5 of 13 have $P_{\rm orb} < 2$ hr (Woudt Warner & Pretorius 2004); iii) 1 (CAL 86) of 12 has $P_{\rm orb} = 1.587$ hr (Woudt, Warner & Spark 2005); iv) 3 of 11 have $P_{\rm orb} > 3$ hr (Witham et al. 2007).

For reviews about CVs see the fundamental papers by Robinson (1976), Patterson (1984, 1994), Hack & la Dous (1993), and the books of Warner (1995) and Hellier (2001).

3 MULTIFREQUENCY EMISSIONS

In CVs there are two stellar components that are responsible for minor but significant fractions of the total emission:

i) the secondary stars are cool main sequence stars with spectral type ranging from G8 to M6, corresponding to temperatures from 5 000 to 3 000 K. So they contribute substantially to the integrated radiation only in the red and IR regions;

ii) the primary stars: the temperatures of white dwarfs are known only in few cases: when they belong to high inclination systems, or when they accrete matter with a very low mass transfer rate. However, the white dwarf temperatures range between 10 000 and 50 000 K (Sion 1986, 1991). Recently, Urban & Edward (2006) found that the WDs in CVs above the period gap are hotter and more accretion heated ($\overline{T}_{\rm eff} = 25\,793$ K) than those below the gap ($\overline{T}_{\rm eff} = 18\,368$ K).

Therefore white dwarfs are expected to radiate essentially in the UV, but they can be visible also in the optical range if they are not too hot. However, in CVs the geometrical dimensions of the white dwarfs are negligible with respect to those of the accretion discs; the consequence is that their emission can usually be compared with the background. The white dwarf is visible during the quiescent state of a low mass transfer system and manifests itself with the presence of the broad red wing of the L_α absorption line in the IUE spectrum, such as WZ Sge (Sion, Leckemby & Szkody 1990) and reviewed by Szkody (1998).

Two other components responsible for the most conspicuous emission in CVs are: iii) the accretion disc; and iv) the boundary layer. Figure 4 schematically shows a NMCV with all components responsible for the energy emission.

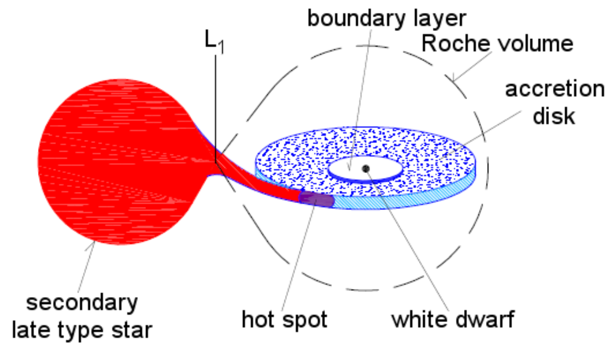

Fig. 4 Sketch of a NMCV with all components responsible for the energy emission.

iii) The accretion disc: it does not have a homogeneous temperature, but spans a large range. Since the temperature distribution in discs is poorly known, in order to obtain a rough evaluation of their contribution to the total emission it is necessary to evaluate the contributions at different frequencies of a synthetic disc constituted of black bodies at different temperatures, the temperature distribution being that of a stationary accretion disc (e.g., la Dous 1994). It then appears evident that the contribution of such an accretion disc is important in the whole range between EUV and IR, depending on the choice of the disc parameters. Furthermore, the UV radiation can be supplied from a zone in the vicinity of the white dwarf (some ten stellar radii), which could contain any optically thick material left there.

In a first approximation, in order to fit the observed flux distribution it is possible to assume that only the accretion disc contributes to the radiation, and that at each distance from the white dwarf it radiates like a black body with a radial temperature derived for a stationary accretion disc. For the theory of accretion discs see the book of Warner (1995) and references therein. With these assumptions la Dous (1989) computed the contribution function of a black body disc for a $1\,M_\odot$ white dwarf and accretion rate of $10^{-9}\,M_\odot$ yr^{-1}. She divided the disc into annuli and computed the intensity emitted by each annulus, weighting with the area of the annulus. The UV radiation is dominated entirely by radiation from the central disc. The central and middle disc contribute to the optical. The IR radiation comes from the middle and outer disc. The contribution of the accretion disc to the total emission of a CV is shown in Figure 6.

However, the argument of accretion discs deserves an important comment. It appeared evident that the viscosity of matter inside the accretion discs plays a fundamental role in the description of physical processes occurring there. In spite of numerous attempts in determining such a viscosity, the physical nature of that still remains largely indeterminate. The best training for study the viscosity is a subclass of CVs, namely dwarf novae showing quasi-periodic outbursts which occur on a time scale from weeks to months (or even years) and are due to non-stationary accretion.

Meyer & Meyer-Hofmeister (1981, 1982, 1983) firstly discussed the physical mechanism responsible for dwarf nova outbursts which is connected with the thermal instability of the disc which occurs in the temperature range corresponding to the ionization of hydrogen. Soon after Smak (1984a,b) extended the study of such a mechanism. The details are summarized by Smak (2002) as follows.

Integrations of the disc's vertical structure equations produce the surface density *versus* effective temperature ($\Sigma - T_e$) relation which has a characteristic S-shape (Fig. 5). Under thermal equilibrium conditions the flux radiated from the surface of the disc $F_r = \sigma {T_e}^4$ is equal to that dissipated inside by the viscosity $F_\nu \sim \Sigma\bar{\nu}$, where $\Sigma\bar{\nu}$ is the viscosity integral. Note that the local accretion rate $\dot{M}_{\rm accr}$ is also proportional to F_ν or $\Sigma\bar{\nu}$. Therefore the $\Sigma - T_e$ relation represents a more general relationship: $\Sigma\bar{\nu} \sim \dot{M}_{\rm accr} \sim \sigma {T_e}^4 = f(\Sigma)$.

The middle branch (BC) of the $\Sigma - T_e$ relation is thermally unstable. Consequently for the mass-transfer/accretion rates corresponding to this branch stationary accretion is impossible and it is replaced with a limit cycle behavior, alternating between the two stable branches (see Fig. 5). On branch AB (corresponding to quiescence) the *local* accretion rate ($\dot{M}_{\rm accr}$) is lower than the rate at which the material is

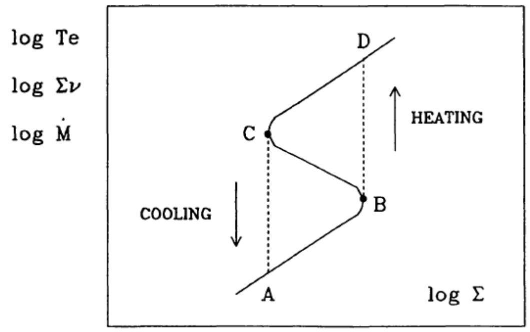

Fig. 5 The $\Sigma - T_e$ relation and the resulting limit cycle mechanism for the dwarf nova behavior (Smak 2002).

supplied from the outside ($\dot{M}_{\rm tr}$) and, consequently, the surface density increases. When the critical density is reached (and exceeded) at point B, the thermal instability develops, resulting in a rapid transition to branch CD (corresponding to the outburst maximum). There the situation is reversed: with $\dot{M}_{\rm accr} > \dot{M}_{\rm tr}$ the surface density decreases until critical point C is reached, where the thermal instability develops again, resulting in a transition to the lower branch.

It is important to point out that the shapes of dwarf nova light curves, which depend on a number of relevant parameters, depend also on viscosity. In particular, the characteristic time-scales observed during outbursts depend on the viscous time-scale. This provides an important and almost unique opportunity of obtaining some constraints on viscosity or – within the α disc approach (Shakura & Sunyaev 1973) – of an empirical determination of α.

For a more complete and detailed discussion of dwarf novae and models of their outbursts – see reviews by Cannizzo (1993), Osaki (1996), and Lasota (2001).

iv) The boundary layer: a very important zone for the emission is that of the transition between the accretion disc and the white dwarf surface, namely the boundary layer. It is possible that all, or at least a significant fraction, of the kinetic energy of the material contained in the accretion disc must be radiated away within the geometrically very small boundary layer in order to have the possibility of the material accreting onto the white dwarf's surface. Then, whatever the situation, one can assume the presence of a strong X-ray source at the boundary layer, which will be visible also in the EUV and short-wavelength UV according to the choice of disposable theoretical parameters.

Most of the radiation then comes from the accretion disc and boundary layer, which contribute roughly 50% each. From the accretion disc the radiation is essentially emitted in the optical and UV, whilst from the boundary layer — optically thick (which occurs at high accretion rates) — the radiation is emitted in the soft X-ray range; when the accretion is at low rates the boundary layer is optically thin and appears as a hard thermal bremsstrahlung source.

These predictions have been tested experimentally, comparing the observations of CVs in optical, UV and soft X-ray ranges. The most promising technique has been used by Wood et al. (1989) and Horne (1994); this consists in observing eclipses at different frequencies in order to derive spectra at different radii of the disc surface. These experimental spectra are compared with those theoretically computed, by using models for deriving the physical parameters such as temperature, mass transfer rate, etc.. Alternatively, the image reconstruction is used to find the best map fitting the data best. The results from the high inclination dwarf novae Z Cha and OY Car have shown that the 'steady state accretion disc model' is correct during outburst, but not during quiescence, when the accretion disc becomes optically thin.

The picture of the boundary layer, coming from the X-ray, optical, and UV data, appears rather confusing, and in any case the emission from the boundary layer is much lower than predicted ($\leq 1/4$ of the disc's luminosity) (e.g., Mauche et al. 1991; Belloni et al. 1991). The explanation for the low emission from the boundary layer could be a fast rotational velocity of the white dwarf, close to the break up velocity; but this has been experimentally contradicted by the detection of the SiIV line from the photosphere of U Gem, which is consistent with a low rotational velocity (Sion et al. 1994).

The ionization state of the winds from dwarf novae at outburst and in nova-like systems at high accretion rates can provide constraints on the boundary layer temperatures (Drew 1990), but developed models (Vitello & Shlosman 1993; Shlosman & Vitello 1993) using such a constraints (i.e. temperature of boundary layer less than 100 000 K) present many other difficulties not yet completely explained, such as a disc/wind asymmetry, as measured by Woods et al. (1992) with the IUE in low inclination systems. Probably, considering the presence of the white dwarf's magnetic field, the picture could be clarified. Indeed, the phase-dependent profiles imply an asymmetry which extends all the way to the inner disc. As shown by Shlosman, Vitello & Mauche (1996), the data are most consistent with an extensive moderately collimated rotating wind that originates from the surface of the accretion disc. A kinematic model and a rotating biconical disc wind (Knigge et al. 1997) contain a high density transition region which can explain the FeII curtain which is evident in high resolution HST spectra of high inclination systems such as OY Car (Horne et al. 1994).

Two more components of CVs as minor contributors to the total emission are: v) the gas stream; and vi) the hot spot.

v) The gas stream: it is definitively optically thin and cool and contains rather little material; so, probably, its contribution to the total emission of CVs is negligible at all frequencies as source of continuum, while it could contribute to the formation of lines in the red and IR regions;

vi) The hot spot: its structure and radiation characteristics are still an open problem; it is visible in many systems in optical photometry (less in the IR and never in the UV) as a periodically recurring hump in the orbital light curve. Its temperature must be $\leq 10\,000$ K;

Finally, some observations of individual systems show the presence of a:

vii) hot corona or chromosphere: i.e., a shell of optically thin and rather hot gas, below and above the accretion disc. X-ray and UV line radiation are tentatively attributed to it, whilst it probably does not contribute to the UV, optical or IR continuum emission.

No radio emission from CVs has been measured. Only upper limits for individual systems of order of a few mJy are available (e.g ≤ 10 mJy in SS Cyg — Cordova, Mason & Hjellming 1983).

Figure 6 shows the contribution functions of the most important components of a cataclysmic system, previously discussed, as computed by Pringle & Wade (1985).

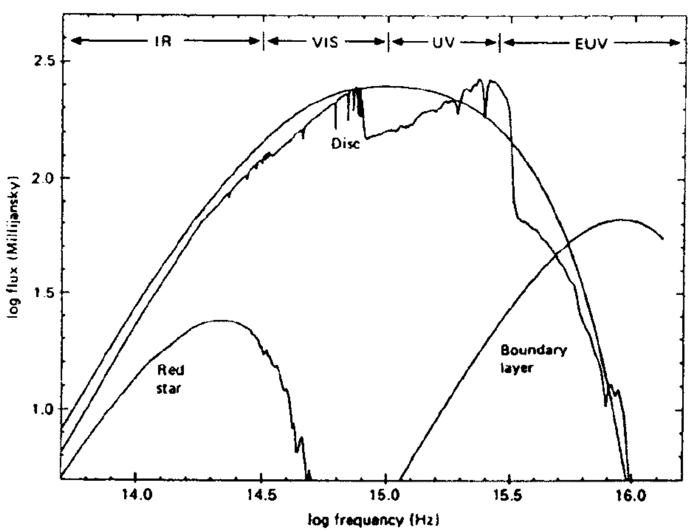

Fig. 6 Contribution functions of the most important components of a cataclysmic system from IR to EUV (Pringle & Wade 1985).

In the case of magnetic CVs, the accretion of matter onto the white dwarf is driven by the force lines of the magnetic field, as sketched in Figure 7 for IPCvs (left panel) and PCVs (right panel). In the case of IPCVs the magnetic field intensity forbids the accretion disc to lick the proximity of white dwarf' surface, and then the boundary layer does not form. Then, an accretion ring is formed and the matter falls onto white dwarf' magnetic poles. Inner and outer radii of such an accretion ring depend on the morphological and physical parameters of the system. In the case of PCVs, the magnetic field is so intense to prevent even the formation of a thin accretion ring: the matter accretes onto magnetic poles of the white dwarf. The cool supersonic accretion flow produces a shock in the accretion column originating high energy radiation such as hard X-rays, and then the hot subsonic setting flow generates soft X-rays and UV radiation at the white dwarf' photosphere.

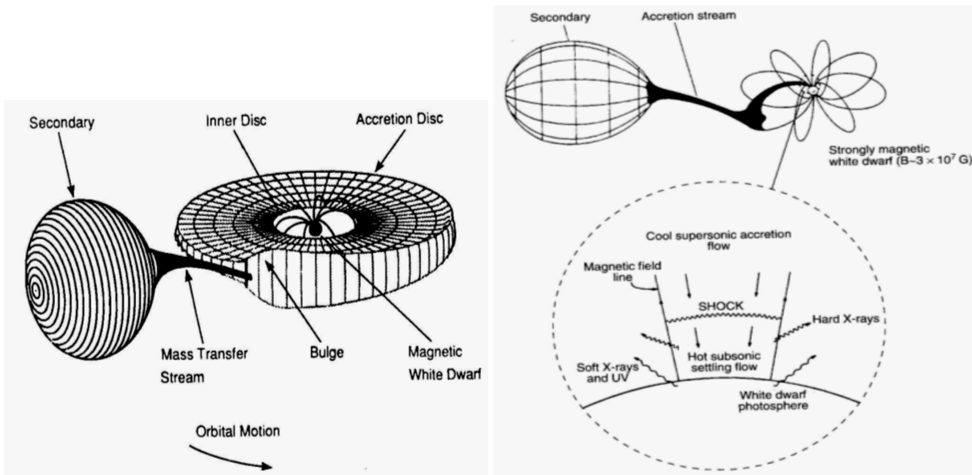

Fig. 7 Sketch of magnetic CVs. Left panel: Intermediate polar; right panel: polar (Charles & Seward 1995).

During quiescence dwarf novae emit essentially hard X-rays (~ 0.1–4.5 keV) and the flux distribution is rather well approximated by a thermal bremsstrahlung with $KT_{\rm brems} \approx 10$ keV (Cordova & Mason 1983). A direct correlation between the hard X-ray/optical fluxes ratio and H$_\beta$ equivalent width has been found by Patterson & Raymond (1985b), as shown in the left panel of Figure 8.

During outburst dwarf novae emit soft X-rays (0.18–0.5 keV) with an increase of the flux of the order of 100 or more, although most of the radiation is hidden in the EUV range (Cordova & Mason 1984). The soft X-ray spectra can be fitted either with black bodies at $KT_{\rm bb} \approx 25$–30 eV or, alternatively, with bremsstrahlung spectra at $KT_{\rm brems} \approx 30$–40 eV.

The most important features, shown in the right panel of Figure 8, are the anti-correlation between the hard and soft X-ray emissions during the outburst cycle and the correlation between soft X-ray and optical emissions, as measured for SS Cyg (Watson, King & Heise 1985), or — what is the same — anti-correlation between the hard X-ray and optical emission (Ricketts, King & Raine 1979).

What does that mean? The UV flux and the bulk of optical flux in dwarf novae and nova-like stars originate in the accretion disc. The IR flux observed during quiescence and possibly some of the optical flux come from the secondary late-type star. The rise to an outburst either occurs simultaneously at all wavelengths when it is slow, or progressively starts later with decreasing wavelengths when it is fast, since ever more central hotter parts of the disc become involved. Indeed, several dwarf novae have been observed in the UV and optical during the rise to maximum outburst brightness and their behaviour are quite similar: the UV rise lags the optical rise by up to a day (e.g., VW Hyi: Hassall et al. 1983; CN Ori and RX And: Cordova, Ladd & Mason 1986; WX Hyi: Hassall, Pringle & Verbunt 1985). With respect to the optical

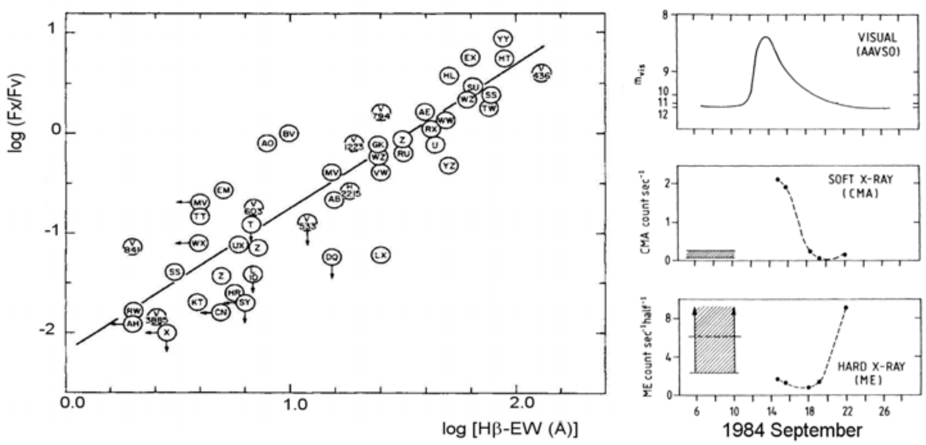

Fig. 8 Left panel: X-ray/optical flux ratio vs H_β-equivalent width in CVs (Patterson & Raymond 1985a). Right panel: the anti-correlation between hard and soft X-ray intensities, which is correlated with the optical luminosity of SS Cygni (Watson, King & Heise 1985).

band, this lag is similar also in the EUV region covered by the Voyager (50–1200 Å) for SS Cyg (Polidan & Holberg 1984) and VW Hyi (Polidan & Holberg 1987).

This fact strongly supports the origin of the outburst being in the cooler outer part of the disc rather than in the hotter parts near the white dwarf; therefore mini-nova models for the outbursts are probably excluded (Cordova & Howarth 1987). The two models for triggering the outbursts, compatible with the lag observations, are then:

- an instability in the secondary star which allows the transfer of more mass to the disc;
- a thermal instability in the outer disc, which results in material stored there being suddenly transported through the disc. During the decline, the whole disc cools simultaneously. The contribution to the total emission from the boundary layer between the disc and the white dwarf surface is in UV and X-ray ranges: the boundary layer is optically thin during quiescence and then emits hard X-rays, but it is optically thick during outburst and then emits soft X-rays since the radiation is thermalized before escape (la Dous 1993).

From the EUVE (Extreme Ultraviolet Explorer) Craig et al. (1997) have shown the EUV spectra of three NPCVs in outburst, namely VW Hyi, U Gem and SS Cyg. VW Hyi shows the softest EUV spectrum peaked at ~ 250 Å. However, its boundary layer/disc luminosity ratio — $L_{\rm bl}/L_{\rm disc} \sim 0.2$ (Mauche et al. 1991) — is in contrast with the boundary layer models. In U Gem the total size of the EUV emitting region is comparable to that of the white dwarf itself, which indicates that the outburst in mainly confined to the inner disc/boundary layer region (Long et al. 1996). Its $L_{\rm bl}/L_{\rm disc} \sim 1$. SS Cyg is the hardest of the three EUV NMCVs. Its EUV spectrum is rather complex and changed by a factor 100 during the outburst with an almost constant spectral energy distribution. Quasi-coherent oscillations ($\sim 7-9$ s) have been detected in the EUV emission (Mauche 1996). SS Cyg shows no EUV emission longward ~ 130 Å. Mauche, Raymond & Mattei (1995) found that for SS Cyg the relation $L_{\rm bl}/L_{\rm disc} \sim 1$, valid for the boundary layer models is strongly violated, being this ratio $L_{\rm bl}/L_{\rm disc} \sim 0.07$. And this is one more proof that SS Cyg is not a NMCV — as already remarked — as claimed by Giovannelli's group.

IUE satellite deserves special comments since it was fundamental in improving the knowledge of CVs. In particular it was possible to obtain significant contributions on:

i) knowledge of disc accreting and magnetic CVs, as extensively discussed by Cordova (1995), and references therein.

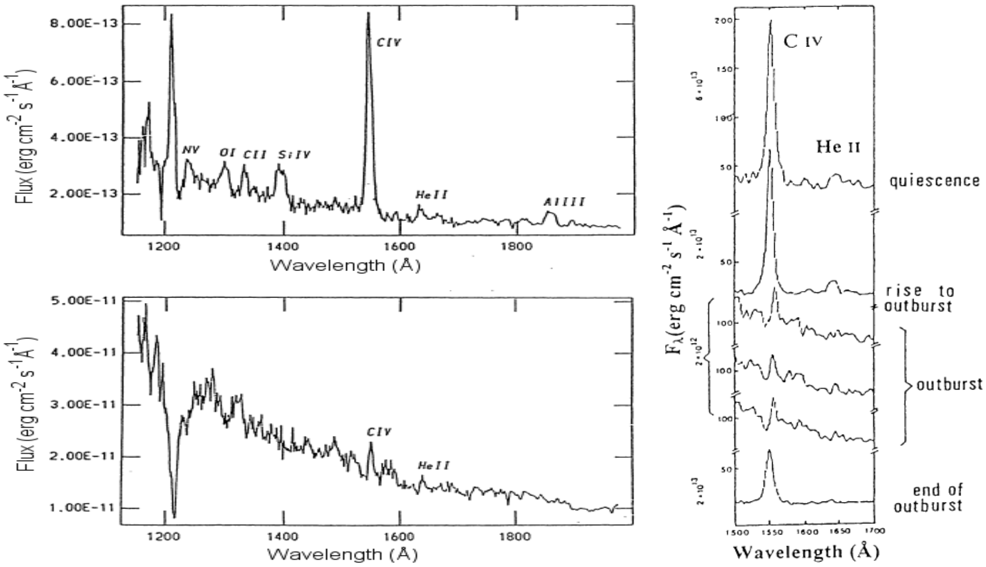

Fig. 9 Left panel: UV spectrum of SSCyg in quiescence (upper) and in outburst (lower) (Gaudenzi et al. 2002). Right panel: Evolution of the UV spectrum of SS Cyg – around CIV – from quiescence to outburst and back (Giovannelli et al. 1990).

Figure 9 (left panel) shows typical UV spectra of SS Cyg in quiescence (up) and in outburst (down). As to the spectral features of the UV emission, the behaviour of the spectral index, α, being the flux F$_\lambda \propto \lambda^\alpha$, along the outburst cycle, may be described as follows: at quiescence, the values of the spectral index are $\alpha = -4.0$ for $\lambda \leq 1450$ Å and $\alpha = -1.2$ $\lambda \geq 1450$ Å; at outburst such values are $\alpha = -0.5$ for the far-UV (500 Å$\leq \lambda \leq 1200$ Å), $\alpha = -2.7$ for $\lambda \leq 1760$ Å, $\alpha = -1.6$ for 1760 Å$\leq \lambda \leq 2200$ Å, and $\alpha = -3.2$ for $\lambda \geq 2200$ Å. The emitted EUV flux is much smaller than the soft X-ray flux, and shows variability (Giovannelli & Martinez-Pais 1991 and the references therein). It appears evident that the simple steady accretion disc model does not work.

Urban & Edward (2006) present a synthetic spectral analysis of nearly the entire IUE archive of spectra of dwarf novae (DNe) in or near their quiescence. The sample consisting of 30 DNe above the period gap and 23 DNe below the gap. The average WD temperature for the systems below and above the period gap is $\overline{T}_{\rm eff} = 18\,368$ K, $\overline{T}_{\rm eff} = 25\,793$ K, respectively.

Hamilton et al. (2007) present a synthetic spectral analysis of nearly the entire IUE archive of spectra of dwarf novae in or near outburst. They present newly estimated accretion rates and discuss the implications of their study for disc accretion physics and CV evolution.

Also the optical spectra of dwarf novae contain many emission lines, such as Balmer and He lines, often showing doublings. Figure 10 shows, as example, optical spectra of SS Cyg in outburst and during decline (left and right upper panels, respectively) (Martinez-Pais et al. 1996), and in quiescence (lower left panel) (Giovannelli et al. 1990). The lower right panel shows a sketch of how doubled emission lines from accretion disc form (e.g. Charles & Seward 1995).

Assuming that the matter in the disc is rotating with a Keplerian velocity distribution we can derive the geometrical parameters of the disc from the line profiles. With almost complete independence of the radial distribution of the emitting material, one half of the velocity separation of the peaks gives, to within an uncertainty of 15%, the projected rotational velocity ($v_{\rm obs} = v_{\rm d} \sin i$) (where i is the orbital inclination angle) of the outer edge of the annular zone within the disc where the given emission line is formed (Smak 1969, 1981; Huang 1972). For $v_{\rm d}$ we use:

$$v_{\rm d}^2 = GM_{\rm wd}/R_{\rm d}\,, \tag{1}$$

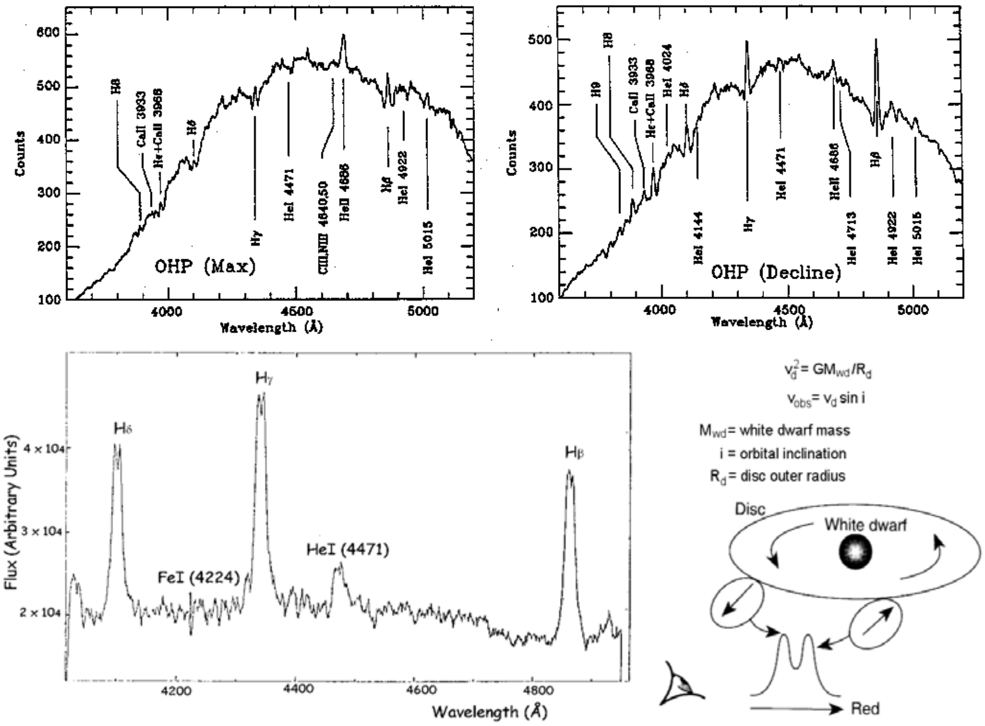

Fig. 10 Optical spectra of SS Cyg: upper panel) in outburst (left) and decline (right) (Martinez-Pais et al. 1996); lower left panel) in quiescence (Giovannelli et al. 1990). Lower right panel) sketch of how doubling emission lines from accretion disc form (e.g. Charles & Seward 1995).

where $M_{\rm wd}$ is the mass of the white dwarf and $R_{\rm d}$ is the outer radius of the disc. From the doubling of H_ϵ, whose equivalent width is orbitally modulated, Giovannelli et al. (1983) derived the outer radius of the accretion disc of SS Cyg ($R_{\rm d} = 2.86 \times 10^{10}$ cm), and then the orbital parameters of the whole system by using physical constraints coming from different sets of multifrequency measurements. The half-widths of the emission lines at the continuum level give information about the rotational velocity of the innermost part of the disc. A roughly evaluation of the inner radius from H_β gives $R_{\rm in} \leq 3.8 \times 10^9$ cm (Giovannelli et al. 1983). Later such orbital parameters have been confirmed by classical radial velocity measurements, and the accretion disc size was confirmed by the doubling of the Balmer H_β, H_γ, and H_δ emission lines (Martinez-Pais et al. 1994).

With the same simple calculation, it is possible to determine the inner radius of the accretion disc by using the doubling observed in the emission lines produced in the inner part of the disc, such as for instance CII (1335 Å). Gaudenzi et al. (2002) from this line derived the inner radius of the accretion disc of SS Cyg ($R_{\rm d} = 1.1 \times 10^9$ cm — in agreement with the former upper limit derived from H_β), being the radius of the white dwarf $R_{\rm wd} = 5.1 \times 10^8$ cm.

SS Cyg represents one of the few cases in which the radii of the accretion disc were determined. However, this simple experimental methodology is crucial in deriving such parameters, which are fundamental for the comprehension of dwarf nova outburst mechanisms. Indeed, following Smak (2002), characteristic time-scales observed during dwarf nova outbursts depend on the viscous time-scale, defined by the parameter α on the hot branch of the $\Sigma - T_e$ relation. This provides an important opportunity of an empirical determination of $\alpha_{\rm hot}$ from the widths (or durations) of outbursts, the rates of decline following outburst maximum, and the UV delays observed during rise, and their correlations with the orbital period.

It is instructive to begin with the following analytical considerations (for details see Smak 1999). The characteristic, effective time scales observed during outbursts, can be related to the travel time of the accretion wave. Using the α-disc approximation we can obtain for the travel time between $R_{\rm d}$ and the inner radius $R_{\rm in}$

$$\Delta t \; (R_{\rm d}, R_{\rm in}) \; \sim \; \alpha^{-0.7} \; \dot{M}^{-0.37} \; M_1{}^{-0.46} \; (R_{\rm d}{}^{1.33} - R_{\rm in}{}^{1.33}) \; . \tag{2}$$

Assuming that $R_{\rm d}$ is the tidal radius $R_{\rm tid}$, which can be expressed as a certain fraction of the effective radius of the Roche lobe around the primary component and using Kepler Law we can replace $R_{\rm d}$ with $P_{\rm orb}$ to obtain the dependence of the characteristic time scales on the orbital period and the viscosity parameter $\alpha = \alpha_{\rm hot}$:

$$\Delta t \; \sim \; \alpha^{-0.7} \; P_{\rm orb}{}^{0.74} \; . \tag{3}$$

This shows that correlations of the observed time scales with the orbital period simply reflect their dependence on the radius of the disc. It is therefore crucially important to make sure that the assumptions and procedures used in model calculations do indeed result in correct values of the disc radii.

Orbital modulations of the equivalent widths of emission lines and continuum have been detected in many systems in different wavelength regions. One of the most studied is SS Cyg for which during quiescence, the UV continuum flux shows modulations with the orbital period. Such modulations depend at least on the type of the preceding outburst (long or short) and on the time elapsed since the end of the outburst (Giovannelli et al. 1985; Gaudenzi et al. 1986; Lombardi, Gaudenzi & Giovannelli 1987). The UV spectral lines show resonance emission lines from highly ionized elements: CIII (1176 Å), NIV (1240 Å), OI (1304 Å), CII (1335 Å), SiIV (1393–1402 Å), CIV (1548–1551 Å), MgII (2796–2803 Å). Fainter lines such as HeII (1640 Å) and AlIII (1860 Å) also appear. The fluxes of these lines show orbital modulation of the same kind of the continuum (see left panel of Fig. 11).

Also in optical wavelengths the continuum shows orbital modulations. For instance in the case of SS Cyg, orbital modulations with amplitudes of order a few tenths of magnitude were detected in quiescence and during the decline from an outburst (Giovannelli & Martinez-Pais 1991 and the references therein). Right panel of Figure 11 shows orbital modulations of the equivalent widths of Balmer and HeI lines (Martinez-Pais et al. 1994).

ii) nature of the high velocity winds. During outburst the spectral emission features disappear or go into absorption, some of them showing P Cygni profile (e.g. CIV), which clearly indicate the presence of high velocity wind from the system. Figure 9 (right panel) shows the evolution of the UV spectrum of SS Cyg – around CIV – from quiescence to outburst and back (Giovannelli et al. 1990).

However, the ionization structure, mass loss, and geometry of the wind are still uncertain, as well as the relationship between the changes in the X-ray emission and the appearance and evolution of short period oscillations.

iii) boundary layer emission. Multifrequency observations show that X-ray luminosity at all outburst phases is much lower (about at least a factor 10) than the UV/optical luminosity from the disc, as expected from the models (e.g., Mauche 1998). This simply means that the boundary layer models are not correct.

iv) underlying white dwarf and its photosphere. IUE provided the first evidence that the white dwarf is heated by the dwarf nova outburst and subsequently cooled. A list of nine such systems has been reported by Szkody (1998). These measurements are very difficult because of the long quiescence–outburst–quiescence cycles (from weeks to years). The short outburst period dwarf nova VW Hyi cooled to 18 000 K (from 20 500 K) in the 14 days before the next outburst began (Verbunt et al. 1987).

Time resolved spectroscopy with IUE and optical telescopes of CVs in quiescence provided measurements on the temperature of the white dwarf and its mass and rotational velocity. With higher time and spectral resolutions of HST, estimates of CV masses and associated core compositions were discussed by Sion (1999) in the context of thermonuclear runaway theory. Such a theory was corroborated by the analysis of VW Hyi quiescent spectra which have shown the first evidence of a thermonuclear runaway on the white dwarf (Sion et al. 1997). This means that they found the first direct spectroscopic link between a dwarf nova and a classical nova by using the white dwarf surface chemical abundance.

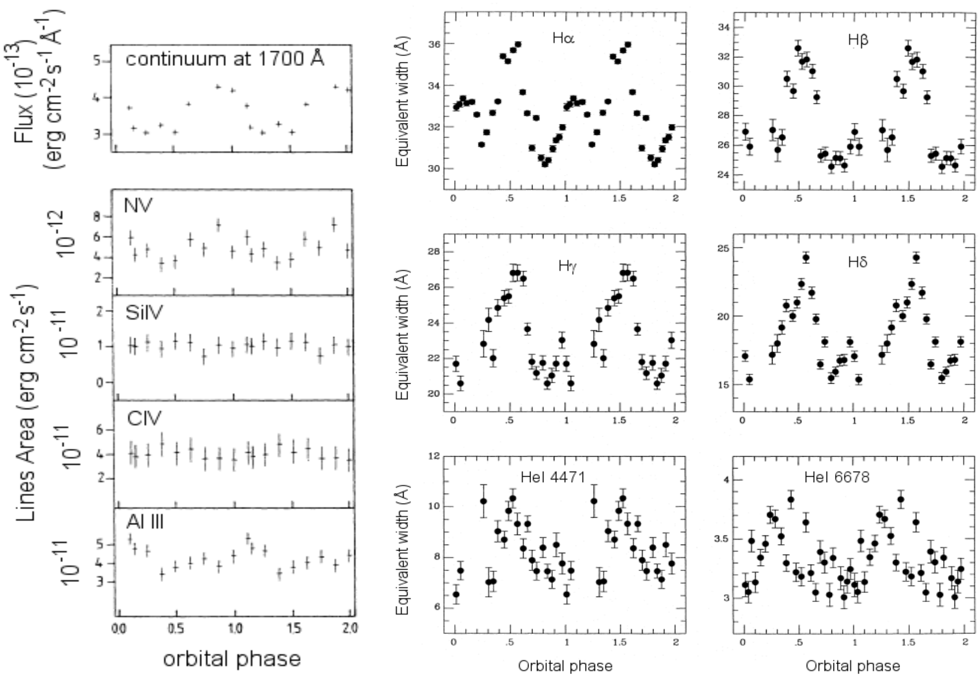

Fig. 11 Left panel: orbital modulations of the continuum (top) and several emission lines total area (bottom) of UV emissions from SS Cyg in quiescence after a long outburst (Gaudenzi et al. 1986). Right panel: orbital modulations of the equivalent widths of Balmer and HeI lines of SS Cyg in quiescence (Martinez-Pais et al. 1994).

These observations are important for the relationship between dwarf novae and other types of CVs, and also for understanding the influence of outbursts on the boundary layer emission.

Verbunt (1987) presented and discussed on the UV observations of CVs by using the IUE archive. He presented a comparative study of the UV properties of CVs, determined the reddening of 51 systems from the 2200 Å feature. He noted that the spectral flux distribution of CVs does not depend on system type, orbital period, or (for dwarf novae) average length of interval between outburst maxima; it does not depend strongly on inclination. The exception is formed by the DQ Her systems — excellently reviewed by Patterson (1994) — which may have relatively low fluxes at short wavelengths as compared to other systems. All systems for which observations are available show variability on a time scale of hours. In two nova-like variables in a low state and in five dwarf novae in quiescence there is evidence that most of the ultraviolet flux at short wavelengths is owed to the white dwarf. He calculated disc model spectra in order to show that the slope of the spectrum depends strongly on the white dwarf mass. Hence, determinations of the mass transfer rate from the spectral slope are subject to large errors in cases where the white dwarf mass is not known.

Paerels et al. (1996) presented high resolution spectroscopy of the stellar photospheric spectrum of the white dwarf in AM Her in the 75–120 Å band, obtained with the Short Wavelength Spectrometer on the EUVE satellite. They detected ionization edges and absorption lines from highly ionized neon (NeVI, NeVIII). Surprisingly they did not detect absorption at the OVI 2s and 2p edges, which are expected to be the strongest spectral features in this band in an atmosphere of solar composition at the density and temperature expected from the accretion region in this object. There was evidence for limb brightening of the spectrum in egress from eclipse, indicating the presence of a temperature inversion in the X-ray/EUV photosphere. These results are in agreement with the classical model for the soft X-ray/EUV emission from AM Her, namely hard X-ray irradiation of the atmosphere by the accretion shock.

v) magnetic field of the white dwarf. Indirect evaluations of magnetic field intensities in CV white dwarfs have been obtained through multifrequency observations (e.g., Fabbiano et al. 1981). My feeling is that the problem of magnetic fields in white dwarfs has been underestimated in the studies of CVs. Too many simplified models of disc accreting and magnetic CVs have been developed under the hypothesis that CVs can be sharply divided into three classes: Polar, IP, Non-Magnetic. Magnetic fields are smoothly varying in their intensities from one class to another, probably giving rise to misunderstandings in classifying CVs in the three classes mentioned, which probably contain systems which evolve from one class to another. Indeed, the discovery in some IPs of a circularly polarized optical emission suggests that these intermediate polars will evolve into polar systems (e.g., Mouchet, Bonnet-Bidaud & de Martino et al. 1998). Some evidence of the continuity between the IPCVs and PCVs is coming from the detection of the SW Sex systems. They have orbital periods just inside the so-called *period gap*, which separates the two classes of IPCVs and PCVs (see Fig. 3) (e.g. Rodriguez Gil 2003 and references therein).

Looking at the homogeneous set of data coming from the IUE for PCVs and IPCVs, it has been possible to obtain important information on common properties and peculiarities of these binaries (de Martino 1999 and references therein), which render the two classes rather similar in some of their UV behaviour. MCVs are relatively bright UV sources ($L_{\rm UV} \sim 2 \times 10^{30}$–$3 \times 10^{32}$ erg s^{-1}). Their IUE spectra show a blue continuum with strong resonance lines of NV (1240 Å), SiIV (1397 Å), CIV (1549 Å) as well as of HeII (1640 Å) in emission. The UV line luminosity is $\sim 2\% - 10\%$ of the continuum (Bonnet-Bidaud & Mouchet 1988; de Martino 1995a,b). The UV line luminosities are comparable in both classes (PVCs and IPCVs), whilst the continuum luminosity in PCVs is $\sim 10\%$ that in IPCVs (Mouchet, Bonnet-Bidaud & de Martino 1998). This means that the accretion rate is higher in IPCVs (10^{16}–10^{17} g s^{-1} than in PCVs because of the presence of an accretion annulus (it is a disc with an internal radius much greater than in the case of NMCVs), which is responsible of a brighter UV continuum in IPCVs. Weak emission lines of HeII (2307, 2386, and 2733 Å), MgII (2800 Å) and AlIII (1857 Å) are also present in the spectra of both classes. An observational difference between PCVs and IPCVs is the presence of very weak emission lines of lower ionization states in polars, which are not in IPCVs. Line flux ratios of NV/CIV and NV/SiIV also indicate a higher ionization efficiency in IPCVs, being $L_{\rm SiIV} < L_{\rm NV} < L_{\rm CIV}$, whilst in PCVs $L_{\rm SiIV} > L_{\rm NV} < L_{\rm CIV}$ (de Martino 1999). The effect of increasing ionization efficiency is the tendency to suppress SiIV and to increase NV and CIV. The higher ionization efficiency in IPCVs could be owed to an efficient absorption of the soft X-ray emission (de Martino 1995b). These differences re-enforce the hypothesis that the two classes are evolutionary related (e.g., Mouchet, Bonnet-Bidaud & de Martino 1998; de Martino 1998).

The UV continuum properties can be inferred by colour–colour diagrams. Contrary to NMCVs, MCVs show a less steep UV energy distribution, since PCVs do not possess accretion disc and IPCVs have an accretion annulus (or truncated disc). Differences are also encountered in the two classes of MCVs and IPCVs.

Figure 12 shows the far UV vs near UV colour–colour diagram for MCVs (de Martino 1999). Such a diagram was constructed measuring broad band continua in the IUE short wavelength range (1420–1520 Å and 1730–1830 Å) and in the long wavelength range (2500–2600 Å and 2850–2900 Å). Colours of black-body and white dwarf distributions with different temperatures as well as power laws, $F_\lambda \propto \lambda^{-\alpha}$ are reported for comparison. In both classes the far UV and near UV colours cluster around the power law region with spectral index between 0 and 3. Typically PCVs have steeper far UV continua than in the near UV. Also their spectral shapes are steeper than those of IPCVs (de Martino 1995a). The Rayleigh–Jeans tail of the hot soft X-ray/EUV reprocessed component searched for long time (e.g. Tanzi et al. 1980) has not been observed in the time averaged spectra. Clearly the UV continua cannot be simply described by a single component but possess different contributions, as discussed by de Martino (1999) and already noted in the past, since 1984, by Giovannelli et al. (1985).

Araujo-Betancor et al. (2005) obtained Hubble Space Telescope (HST) STIS data for a total of 11 PCVs as part of a program aimed at compiling a homogeneous database of high–quality FUV spectra for a large number of CVs. Comparing the WD temperatures of PCVs with those of NMCVs, they find that at any given orbital period the WDs in PCVs are colder than those in NMCVs. The temperatures of PCVs below the period gap are consistent with gravitational radiation as the only active angular momentum loss mechanism. The differences in WD effective temperatures between PCVs and NMCVs are significantly

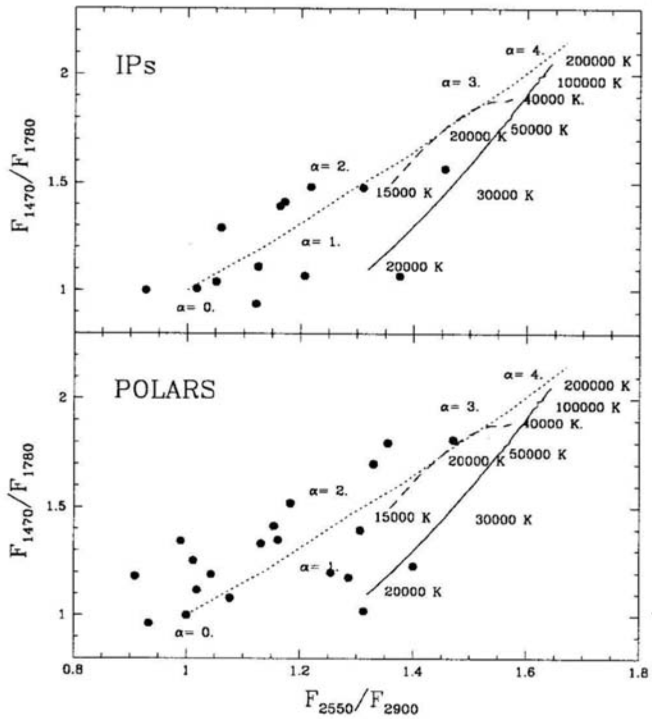

Fig. 12 Far UV vs. Near UV colour–colour diagrams for IPVCs (top) and PCVs (bottom). Power laws, $F_\lambda \propto \lambda^{-\alpha}$, (dotted lines), white dwarf (dashed lines), and black body (solid lines) distributions are reported too (de Martino 1999).

larger above the period gap, suggesting that magnetic braking in PCVs might be reduced by the strong field of the primary. They derive a lower limit on the space density of PCVs of 1.3×10^{-6} pc^{-3}.

4 RENEWED INTEREST FOR CATACLYSMIC VARIABLES

Acceleration of particles by the rotating magnetic field of the WD in intermediate polars in the propeller regime- AE Aqr - detected by ground-based Cherenkov telescopes in the TeV passband (e.g. Meintjes et al. 1992), and TeV emission from the polar AM Her detected by ground-based Cherenkov telescopes (Bhat et al. 1991) were the main reasons of renewed interest for CVs in the high energy astrophysicists community.

INTEGRAL observatory, until the beginning of 2007, had observed over 70 percent of the sky, with a total exposure time of 40 million seconds. Bird et al. (2007) published the third Integral catalogue of gamma-ray sources. It contains a total of 421 gamma-ray objects. Most have been identified as either binary stars in our Galaxy containing exotic objects such as black holes and neutron stars, or active galaxies, far away in space. But a puzzling quarter of sources remain unidentified so far. They could be either star systems enshrouded in dust and gas, or CVs. Integral observes in the gamma-ray band so it can see through the intervening material. It has demonstrated that it can discover sources obscured at other wavelengths. One surprise has been the efficiency with which Integral has detected just one minor subclass CVs, the so-called IPCVs. Initially astronomers were not sure that CVs would emit gamma rays. Indeed, Integral has already shown that only about one percent of them do. This fact overbearingly renewed the interest for CVs, apparently fallen into disgrace in favour of binary systems containing either neutron stars or black holes.

5 SOME AS YET OPEN QUESTIONS

Several fundamental questions concerning CVs still remain waiting for a proper answer. I will present briefly only some of them here.

One of them is the lack of a coherent classification, especially for NLs. On the other hand, in gross features and in most respects, DN and NLs, as well as quiescent novae, are almost indistinguishable, although, in addition to their different outbursts' behaviour, there appear to be some further minor differences which are not yet understood (see Hack & la Dous 1993). The question arises of whether the outburst behaviour, the current basis of almost all classification is really a suitable criterion for sorting CVs in physically related groups. There are also too many exceptions, either systems that do not fit in any particular group or that can be included in several of them, to be able to render the observational behaviour, at least as it is used at the present, suitable.

Could CVs be considered simply gravimagnetic rotators? This should be the most suitable approach for studying them from a physical point of view.

Studies of rotational equilibria of MCVs predict that IPCVs will evolve either into PCVs or into low field strength polars — presumably unobservable, and possibly EUV emitters — depending on their magnetic moments and orbital periods. Indeed, there are systems, like EX Hya-type, having magnetic moment similar to IPCVs above the *period gap* and comparable to the weakest field AM Her-like systems.

Moreover, the detection of several SW Sex systems having orbital periods inside the so-called *period gap* opens a new interesting problem about the continuity in the evolution of CVs.

Ultra-short period CVs (i.e. AM CVn systems) are still waiting for a general model. They are probably binary systems of two white dwarfs, but even this is still controversial.

Despite all the work developed during the last decades, the problem of modelling accretion discs in CVs is by no means closed, especially in quiescence. Closely related is the problem of the cause of outbursts. We really do not know which of the present two families of models (Disc Instability Models or Secondary Instability Models) is responsible for the CVs outburst phenomenon, or in which system is each model valid, although Martinez-Pais et al. (1996) gave a contribution in solving this problem at least in the case of SS Cygni; they found some evidence for an increase of the mass transfer rate from the secondary star as the mechanism responsible for symmetric outbursts. Something similar can be said about the super-outburst phenomenon in SU UMa systems.

Gaudenzi et al. (1990), analysing IUE spectra of SS Cygni, discussed about the outburst production as due to the destruction of the accretion disc. The matter, passing through the boundary layer, slowly accretes onto the white dwarf. Long and short outbursts correspond to total or partial destruction of the disc, respectively.

Alternatively, could nuclear burning be responsible of the production of outbursts in CVs? Indeed, nuclear burning onto white dwarf' surface was proposed by Mitrofanov (1978, 1980) as a mechanism suitable to generate X-rays in CVs. In spite of this shrewd suggestion, the community of theoreticians did not consider such a mechanism — certainly possible — worthy of taking up a part of their time. However, I believe that this alternative solution in explaining the generation of outbursts in CVs would deserve theoretician community's care. For instance, the white dwarf surface interested in the accretion in the system SS Cygni has been evaluated as 24% of the total (Gaudenzi et al. 2002). There, nuclear burning could occur.

Accretional heating by periodic DN events increases substantially the surface temperature of the white dwarf in CVs (Godon & Sion 2002). Then, the envelope thermal structure resulting from compression and irradiation should be a crucial component in understanding the envelope structure of a pre–nova white dwarf.

Another problem still open is connected with the classification of CVs in three kinds, namely NMCVs, PCVs and IPCVs. This is, in my opinion, another convenient classification, although artificial, probably not necessary if CVs are studied as gravimagnetic rotators. In this way a smooth evolution of the systems could be responsible of the variations of the gravimagnetic parameters.

Are the IPCVs and PCVs smoothly connected via the SW Sex-like systems placed just in between? SW Sex systems have indeed orbital periods belong to the so-called *period gap*, and then their presence there sure cancel that gap.

Could some systems behave in different ways depending on their instantaneous physical conditions? For this reason they could apparently behave sometimes as PCVs and sometimes as NPCVs.

An example very clear is that of SS Cygni, usually classified as a non-magnetic dwarf nova. Several proofs have been shown and discussed many times by Giovannelli's group in order to demonstrate the Intermediate Polar nature of it (e.g., Giovannelli 1996, and references therein; Giovannelli & Sabau-Graziati 1998); indeed, SS Cygni shows characteristics of a NMCV, as well as those of IP and sometimes even those of polars, although its position in the $\log P_{\rm spin}$–$\log P_{\rm orb}$ plane is very close to the line where IPs lie.

6 CONCLUSIONS

At the end of this review it appears evident that the most suitable approach for studying CVs from a physical point of view is to consider them as gravimagnetic rotators.

The detection of several SW Sex systems having orbital periods inside the so-called *period gap* opens a new interesting problem about the continuity in the evolution of CVs. Are the IPCVs and PCVs smoothly connected via the SW Sex-like systems placed just in between?

In order to understand fully the emission properties and evolution of CVs, the mass–transfer process needs to be clearly understood, especially magnetic mass transfer, as well as the properties of magnetic viscosity in the accretion discs around compact objects. Consequently, the investigation on the magnetic field intensities in white dwarfs appears crucial in understanding the evolution of CVs systems, by which it is possible to generate classical novae (e.g., Isern et al. 1997) and type-Ia supernovae (e.g., Isern et al. 1993).

In those catastrophic processes the production of light and heavy elements, and then the knowledge of their abundances provides strong direct inputs for cosmological models and cosmic ray generation problems.

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