第 12 卷 第 3 期
1994 年 9 月

天 文 学 进 展
PROGRESS IN ASTRONOMY

Vol.12, No.3
Sep., 1994

激变变星的多波段研究 (II)

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摘 要

本文继续介绍激变变星在紫外、极端紫外 (EUV) 、以及 X 射线波段的辐射特征。我们仍然从观测现象和理论解释两方面来介绍。激变变星在这些波段有很强的辐射，因而有丰富的观测现象，这对于我们更好的认识这类吸积系统有重要意义。

Multi-waveband Studies of Cataclysmic Variables(II)

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Abstract

Radiation features of Cataclysmic Variables are introduced further in ultraviolet, extreme-ultraviolet (EUV) and X-ray bands, both in observational phenomena and in theoretical explanation. There is a strong radiation for Cataclysmic Variables in these bands, and the abandunt observational phenomena will thus enhance our understanding about this kind of accretion system.

1 Ultraviolet radiation of CVs

The observation of ultraviolet radiation of CVs mainly comes from IUE (International Ultraviolet Explorer) satellite. Numerous ultraviolet spectra have been accumulated since IUE satellite was launched. At the Chinese IUE Archive Data Center in University of Science and Technology of China in Hefei, there are about two thousand low dispersion spectra taken before the end of 1987. Because the radiation of CVs at UV band is very strong, the observation through this window provide us with important

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information about CVs, especially about the accretion disk.

1. 1 IUE spectra of CVs

The UV spectra of CVs are very similar to their optical spectra. From equation (2) in the previous paper, the maximum temperature of accretion disk, $T_{\max} = 0.488T_*$, is generally about 10^4 - 10^5K. Typical effective temperature of CV's inner disk is always above 10^4K, and its radiation mainly concentrates in the UV band. Theoretical spectrum of the disk is close to a power law distribution of $\lambda^{-2.33}$, while observation data indicate that α is between 1 - 3 for most of CVs[1]. For a CV in outburst, its spectrum is close to a disbribution of 2.33, which is a typical disk spectrum. For a low luminosity CV, there is a relatively flat continuum distribution ($\alpha < 2$). Statistical analysis shows that magnetic CVs, including DQ Her stars and AM Her stars, have a redder spectrum than other CVs at high luminosity[2,3]. The possible reason is that its inner disk is destroyed by magnetic field. For a CV at low luminosity, its UV radiation comes not only from the disk but from the white dwarf (WD) . From our analysis[4], the relative ratio of its radiation depends on its inclination and period. WD radiation is dominant in CVs with a large inclination and a short period, otherwise, UV radiation mainly comes from the accretion disk. The contribution from WDs in an outburst state is negligible. This difference is produced because the accretion rate is very low at quiescent state, so that the contribution from WDs is comparable with those from disks. Several SU UMa stars such as VW Hyi have a deep descend at its continuum shorter than 1400Å, which comes from the absorption of the WD's atmosphere (Lyman α absorption[3,4,5]).

In the UV spectra of CVs, highly ionized resonance lines such as CIV1549, SiIV1400 and NV1240 are clearly visible. Dwarf novae in quiescence and magnetic CVs show an emission spectrum; DNe in outburst and non-magnetic CVs show an absorption spectra or a PCyg profile, except for the clipse systems, which present a pure emission spectrum even in an eruptive state. In the case of Mg II 2800, only the emission lines are observed. Statistical studies show that the equivalent width of resonance lines has some correlation with the inclination and the orbital period[2,4].

1. 2 Model spectra

In most cases, CVs' UV radiation comes from accretion disk. Therefore in the model of the UV radiation, the accretion disk is mainly concerned. The temperature distribution of the disk is given by equation (2), it's the base of all the radiation model. The most common radiation models are blackbody model, stellar atmosphere model and radiation transfer models. The former two kinds of models are very simple ones. The disk is divided into several concentric rings and the temperature of each ring is given by equation (2). Then each ring is calculated using blackbody or stellar atmosphere formula (for example the stellar atmosphere spectra of Kurucz[6]). Finally all the rings are sum up. Detailed description of these two models can be found in reference[7]. These two models can not give a satisfactory description about the observed spectrum. The former one misses the Balmer jump, while the later one gives a too large Balmer jump. If both the optical and UV bands are considered, these two models can not fit them well simultaneously[7]. The radiation transfer model is similar to the former two models, except that it calculates the spectrum with the radiation transfer equation [8,9,10]. The detailed description is not given here.

Because the radiation of CVs does not completely come from the disk, sometimes the contribution from other parts such as WDs, hot spots and secondary stars should be considered, especially when multiwavelength flux distribution is fited or when CVs are at low luminosity state. Figure 1[11] includes four well fited cases, the fit covers three bands of infrared, optic and ultraviolet radiations.

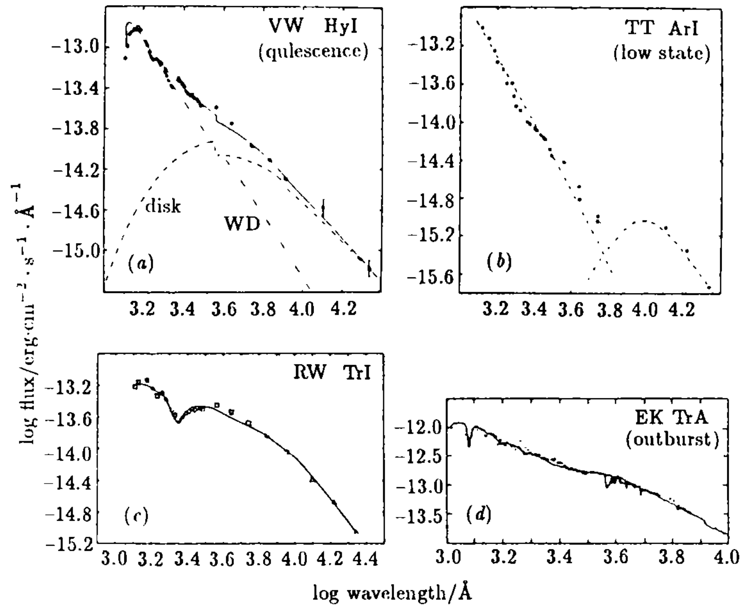

Fig.1 Fitting of CV's continuum from ultraviolet to infrared band[11]. (a) Spectrum of VW Hyi at quiescent state, using a steady disk model of $\dot{M} = 10^{-11}M_{\odot} \cdot \mathrm{yr}^{-1}$ and a WD with T=20 000K and log g=9. (b) Spectrum of TT Ari at low luminosity state, fitting with a WD of 50000K and a M2 - M3 red dwarf. (c) Spectrum of RW Tri, using a steady blackbody disk model of $T_* = 9 \times 10^4$K, $R_{\mathrm{out}}/R_{\mathrm{in}} = 50$, and with a extinction correction of $E(B-V) = 0.25$. (d) Spectrum of EK Tra at eruptive state, using a combination of Kurucz's stellar atmosphere model with T_{eff} between 6000 - 60000K and a recombination spectrum of 10000K.

Through the fitting of CV's spectra, the knowledge about the accretion rate can be obtained. Using the disk model of Williams *et al.*[12], Szkody found that the accretion rate is, $\dot{M} \sim 10^{-7} - 10^{-8} M_\odot \cdot \mathrm{yr}^{-1}$, for NLs and DNe in outburst; but $\dot{M} \sim 10^{-10} - 10^{-9} M_\odot \cdot \mathrm{yr}^{-1}$, for DNe in quiescence[13]. Since the result of the fitting depends on the model, different models may give out different results. Here is an extreme example. For RW Tri, Wade[6] gave $\dot{M} = 10^{-10.8} M_\odot \cdot \mathrm{yr}^{-1}$ with stellar atmosphere model; Cordora and Mason[14] got $\dot{M} \doteq 10^{-9.8} M_\odot \cdot \mathrm{yr}^{-1}$ using a blackbody disk model to fit the flux distribution from ultraviolet to infrared band; Frank and King[15] obtained $\dot{M} = 10^{-9.6\pm0.4} M_\odot \cdot \mathrm{yr}^{-1}$ from a blackbody model fitting the V and R light curves of RW TRi; Horne and Stiening[16] got $\dot{M} = 10^{-7.8\pm0.4} M_\odot \cdot \mathrm{yr}^{-1}$ using the method of simulating the luminosity distribution of the disk surface.

In comparison with the continuum, the understanding about the origin region of emission lines is much more limited. Jameson *et al.*[17] have suggested that highly ionized resonance lines come from the disk corona which is produced by photoionization, while Mg II and Lyα mainly come from an optically thin disk, which is produced by free collision ionization. Observations of UX UMa and RW Tri show that the intensity of emission lines does not decrease during the WD's eclipse[18], which indicates that they are produced at places far beyond the WD, for example in the stellar wind or disk wind. But the dependence of the spectra's equivalent widths on the orbital inclination seems to be in contradiction with this suggestion[2]. Further research is needed. For AM Her stars without disks, the emission lines mainly come from accretion stream and from the intensity of spectral lines, the electron density is estimated to be 10^{13} - $10^{14}\mathrm{cm}^{-3}$; if the emission is caused by the photoionization of soft X-rays, its temperature should be $1 - 2 \times 10^4$K from the continuum [19], while a temperature of 10^5K was obatined according to the intensity ratio of emission lines[20]. In the high resolution spectra of AM Her, a multi-component structure was found in the emission lines: a broad base component, a relatively narrow peak component, and a very narrow peak component in some phase. All these components have obvious variation in the radial velocity and equivalent width within an orbital period[21,19,22]. It is generally suggested that these components come from different parts of the accretion stream. The broad component comes from accretion region near the WD, and it has the largest radial velocity, including stream velocity and orbital velocity. The peak component comes from accretion stream at outer region, and the stream velocity is rather small, and the contribution mainly comes from ortibal velocity. The most narrow component may come from the heated side of secondary star, so only the orbital velocity serves.

1. 3 UV delay

UV delay is an important discovery by IUE satellite. When the DN transfers from quiescence to outburst, its UV radiation is increased about a half day later than its optical radiation, such as that of VW Hyi[24] (fingure 2). Some other DNe with UV delays are WX Hyi[25], RX And[26] and SU UMa [3]. Observations show that the more the optical flux increases, the longer the UV delay lasts. UV delay provides us with a clue to understand the physics of the outbursts of DNe.

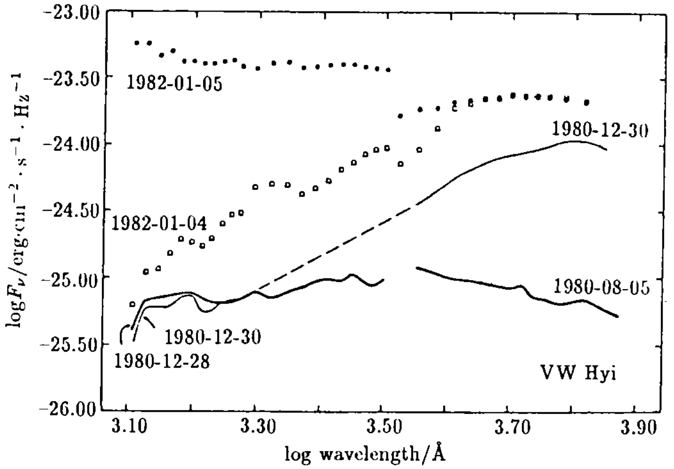

Fig.2 The UV delay of VW Hyi. Thick lines represent spectra taken at quiescence. In December 30, 1980 and January 4, 1982 flux distribution are at rise state, clearly showing the UV delay. Black dots represent the outburst spectra[24].

Currently there are two theoretical models about the outburst of CV[27]. One is Disk Instability Model (DIM). The outburst of CV is the eruption of the disk caused by the variation of the disk's viscosity. According to the curve of “ S ” shape on $\log T_{\rm e}$ – $\log\sum$ map, DIM assumes that the material flow from the secondary star is stable. At first the disk has a very small viscous coefficient, and the matter accreted on the WD are less than the matter comes from the secondary star, then the matter accumulates in the disk, and the surface density of the disk, $\sum$, is increased, so is the effective temperature $T_{\rm e}$, when $\sum$ surpasses a certain critical value, viscous coefficient increases rapidly with the ionization of H and He, and causes the outburst. For the detailed description about DIM, please refer to [28, 29, 30]. The other model is Matter Transfer Instability Model (MTIM). Because of the instability of ionization at the outer region of the secondary star, the matter transfer rate is also instable. Its sudden increase causes the outburst of CVs[27,31].

The radiation flux of optical band mainly comes from the outer region of accretion disk, while the ultraviolet radiation mainly comes from the inner disk. UV delay means that the eruption should begin first at outer disk, then spreads to the inner region. MTIM can well explain this phenomenon. If the timescale of the increase of matter transfer rate $\dot{M}_{\rm tr}$ is very shorter than the viscous timescale (The instability propagates in the disk with viscous timescale $\tau_{\rm vis} \sim \frac{R}{v_{\rm r}} \sim \frac{R^2}{v}$), the outer disk accretion rate increases first and propagate inward, and that causes UV delay. UV delay makes a challenge to DIM. According to DIM, only DNe with large $\dot{M}_{\rm tr}$, have the most probability to begin the outburst from outer disk, and SU UMa with shorter period is most likely to begin outburst from inner disk[32]. Moveover, to the fast outburst the heat discontinuity wave causing the eruption propagates throughout the disk rapidly, so the UV and optical fluxes should increase simultaneously, but to the slow outburst, there should be a visible delay between UV and optical flux increase, which is just opposite to the observation. To solve such difficulty, Meyer[33] suggested that the hot halo around WDs can "evaporate" out the whole inner disk of DNe, so that the quiescent disk lacks the part of inner disk, just like a ring. During the eruption, it begins from the "ring", and then expands inward to WDs, therefore results in a UV delay. In brief, used as a criterion, UV delay obviously surports MTIM.

1. 4 CV wind

In the IUE spectra of CVs with disks, if in a high luminosity state, its CIV line and NV line appear to be P Cyg profile , and this P Cyg profile only exists in low inclination system. This phenomenon indicates that there is a high speed material flow perpendicular to the disk surface, like the stellar wind of early type stars, which is called CV wind. Its limiting velocity (which is determined by the blue end of the observed absorption lines) is very high, from 3000 $\rm km{\cdot}s^{-1}$ up to 5000$\rm km \cdot s^{-1}$, close to the escape speed of WD, and this means that the wind may comes from the center of the disk[34].

The mechanism of this wind is not clear yet. It may be similar to that of early type stars, and results from the radiation pressure of UV photons at inner disk. Because the UV photons come from the accretion of WD, then the matter loss rate $\dot{M}_{\rm w}$[35] can be obtained.

$$\dot{M}_{\rm w} v_{\rm w} \le \frac{L}{c} \simeq \frac{GM\dot{M}}{R_{\rm wd}c} \simeq \frac{v_{\rm esc}^2}{c}\dot{M} \Longrightarrow \frac{\dot{M}_{\rm w}}{\dot{M}} \le \frac{v_{\rm esc}^2}{v_{\rm w}c} \simeq 0.01.$$

From the above relation, the matter of loss is only about 1% of WD's accretion mass, i.e. 10^{-11}–$10^{-10} M_\odot \cdot {\rm yr}^{-2}$. If $\dot{M}_{\rm w}$ is larger, some other driving mechanisms such as magnetic driving may exist. Some evidence of the existence of wind in DQ Her star[37] indicates that the hydromagnetic effect exists at least in magnetic CVs.

The P Cyg profile of YZ Cnc and IR Gem is observed to change obviously with orbital phase[35,38]. It means that the wind may blow out of a tapered tube inclining to the axis of rotation[38].

A number of theoretical calculations have been made for the P Cyg profile of CVs in an attempt to estimate the size and shape of emission and acceleration regions, the line optical depth, the ionization coefficient and the matter loss rate $\dot{M}_{\rm w}$. Early work based on stellar wind model of early O,B stars[34], got $\dot{M}_{\rm w} \sim 10^{-11} M_\odot \cdot {\rm yr}^{-1}$, and the size of emission region, about $10R_{\rm wd}$. But more exact calculation based on disk model indicates [39,40] that the temperature of emission region is too low for collision excitation, and the spectral lines can only come from resonance scattering, which requires a too high $\dot{M}_{\rm w}$. Another problem is that if ionizing radiation comes from boundary layer, then the calculated ionization level is too low. One possible explanation is that there is a strong shock wave heating in the wind [40,41].

2 EUV radiation of CV

FUV (912 – 1200Å) and EUV(100 – 912Å) are important bands of CV's radiation. The peak radiation corresponding to the highest temperature of accretion disk ($\sim 6 \times 10^4$)K falls at these bands, and the flux distribution is proportional to $\lambda^{-2.33}$, so in the short wavelength band radiates a large part of the accretion energy. And the typical temperature of WD is also about 2.5×10^4K. As to the CVs in high luminosity, a large amount of energy released by accretion matter can make the temperature of WDs as high as 10^5K. The boundary layer also releases nearly about a half accretion energy. For an optical thick boundary layer (BL), its effective temperature is above 10^5K. All these radiations concentrate in the band of EUV. Can they be observed?

Table 1 lists parameters of 5 CVs observed by Voyager[42]. These results show that there is no radiation detected from all the 5 CVs at the band 600 – 700 Å. This is because the interstellar extinction of H and He in this band is very severe. But for the VW Hyi with the minimum column density, the calculated flux is one or two orders of magnitude larger than the observed limit value even with the correction of interstellar extinction[43]. If VW Hyi is not a special case but a general one of all CVs, the present theory is not a complete one. One possible reason is the line blocking by the disk atmosphere and the CV wind.

Tabel 1. EUV Observations of CVs[42]

Source	Type	Distance pc	$N_{\rm HI}$ cm^{-2}	925–1075Åflux ergs·cm^{-2}· s^{-1}·Å^{-1}	600–700Åflux ergs.cm^{-2}· s^{-1}· Å^{-1}
SS Cyg	UG	95	3.5×10^{19}	2.7×10^{-11}(outburst)	$< 5 \times 10^{-14}$
VW Hyi	SU	65	6.0×10^{17}	3.8×10^{-12}(outburst)	$< 3 \times 10^{-13}$
				2.4×10^{-11}(superoutburst)	$< 1 \times 10^{-13}$
V3885 Sgr	UX	130	5.6×10^{19}	7.0×10^{-12}	$< 5 \times 10^{-14}$
RW Sex	UX	150	8.9×10^{19}	4.1×10^{-12}	$< 2 \times 10^{-13}$
IX Vel	UX	140	2.0×10^{19}	1.2×10^{-11}	$< 3 \times 10^{-13}$

For the magnetic CVs, their EUV radiation comes from the blackbody radiation of WDs which are heated by the accreted matter. The observation shows that in the DQ

Her system with a weak magnetic field, there is no EUV radiation detected, but in AM Her star, there is a strong EUV radiation. The CV's radiation mechanism of EUV is the same one as that of soft X-ray, which is described in the next section.

3 X-ray radiation of CV

The X-ray observations of CVs mainly come from HEAO-1, Einstain Observatory (HEAO-B), EXOSAT, Ginga and ROSAT satellite. These observations show that CVs have a strong radiation in both soft and hard X-ray bands. X ray observational features are introduced in two aspects, the energetic distribution and light variation. Theoretical explanation is also included.

3. 1 Observational properties

The most obvious feature of DN's X-ray radiation is that in quiescence, there is a strong hard X-ray (HXR) radiation, but the soft X-ray's (SXR) can hardly be detected, and the ratio of HXR to optical flux $F_{\rm HXR}/F_{\rm V} \sim 1$; in outburst, the X-ray radiation of CVs mainly concentrates in SXR band. In U Gem, SXR radiation increases about 100 times in outburst than in quiescence. Though HXR can still be detected in U Gem, it is far from the main radiation band. Observations from Einstain Observatory show $F_{\rm HXR}/F_{\rm V} \sim 0.06$[44,45,46]. Another results show that the HXR radiation of both SS Cyg and U Gem increases at the beginning of outburst, and then the HXR radiation decreases in the former one, while the later one remains the same magnitude until the end of the outburst [44]. Observations from EXOSAT show that the SXR radiation of VW Hyi increases 2.5 days later than its optical radiation in superoutburst [46,47], just like the UV delay of DNe.

Like the optical radiation, the X-ray radiation of DNe also has light variation. SS Cyg and U Gem have quasi-periodic pulse of 9s and 25s respectively[44]. EXOSAT also found VW Hyi has a very accurate SXR pulse of 14.07s at superoutburst state[48]. But there is no such light variation observed in HXR. And U Gem has a light variation of SXR in the timescale of several hours, which may be a kind of modulation by orbital movement.

In DQ Her stars with a weak magnetic field, a strong HXR is observed, but SXR can hardly be detected, and there is an obvious periodic pulse in X-ray radiation, the period of which (from tens of seconds to tens of minutes) is shorter than the orbital one. The suggested reason is the modulation of the rotation of the WDs. Besides the pulse, many sources have modulation by orbital movement. The most typical example is EX Hya. Part of its X-ray radiation is eclipsed with the eclipse of optical radiation, its eclipse depth is the function of 67 min rotation phase of the WD; and so the emission region of X-ray is suggested reasonably at the region near the WD, and its size is twice that of the

WD [49]. Observation also shows that the higher the energy is observed (i.e. the harder the X-ray), the less modulation of the rotation of the WD will be[49].

AM Her stars have the most abundant features of CV's X-ray radiation. The strong magnetic field of WDs makes their rotation and revolution couple, and present strong radiation in HXR and SXR. HEAO-1 satellite has made an HXR observation of AM Her[50] and EF Eri[51] in a relatively large extent of energy (2 – 150keV), and found thermal bremsstrahlung spectrum corresponding to 30keV and 20 keV respectively. And the observation of SXR with a high resolution shows that the SXR spectrum of AM Her and QQ Vul can be fitted with blackbody spectrum of 20 – 55eV and 18 – 29eV respectively[52,53]. Observation of V834 Cen by EXOSAT indicates that its HXR radiation is similar to a thermal bremsstrahlung of $kT > 1$keV, and its SXR is most approximate to a blackbody radiation of kT=14 - 15eV[54].

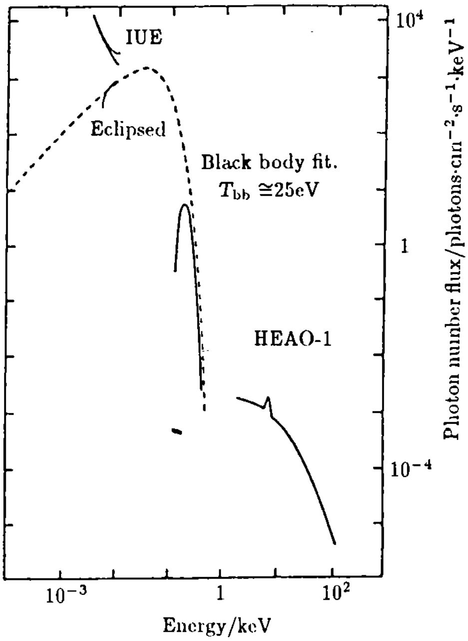

Fig.3 Continuum distribution of AM Her, from UV to X-ray band. The excess of SXR flux can be seen obviously.

In the X-ray observation of AM Her stars, there is a problem of "Soft X-rays" which has long been argued. Early observations by HEAO-1 found that the intensity of SXR was nearly 50 times larger than that of HXR in AM Her [50,55], which contradicted with $L_{\rm HXR} \sim L_{\rm SXR}$ predicted by theory, while observations from Einstein Observatory didn't exhibite such prominent results. The fitting to AM Her and VV Pup shows that $L_{\rm HXR}/L_{\rm SXR} \sim 1$, though there is a large uncertainty in it[56]. But results from EXOSAT make the arguement rise again. Observations showed, $L_{\rm SXR}/L_{\rm HXR} \sim 10$ in AM Her[57] and $L_{\rm SXR}/L_{\rm HXR} \sim 4.5$ in QQ Vul [53]. The most recent research confirmed that there is indeed an excess of SXR flux[58].Results from observations of AM Her are given in fig.3. The excess of SXR can be obviously seen.

The strong magnetic field of AM Her star makes the accretion matter move along the magnetic field lines to the nearby region of magnetic poles. The geometric configuration of the system can influence the light variation of X-rays. For the AM Her star with two magnetic poles appearing alternately at the line of sight (bipolar AM Her stars), X-rays can only be seen in a certain phase, as shown in figure 4[48]. For the AM Her system with only one pole facing the Earth (mono-polar AM Her stars), its HXR has a sine variation, while the variation of its SXR is rather complicated, as shown in figure 5[48]. In the case of AN UMa, there are two peaks; one is rather broad, about half an period, the other is rather narrow, with two narrow eclipse inside. Meanwhile the SXR light curve of AM Her stars has a variation of long timescale (months, years). For instance, comparing the observations of QQ Vul from EXOSAT at 1985 and 1983, there is a complete reverse in its phase[59]. Such a phenomenon also exists in the light curve of HXR and SXR in AM Her and V834 Cen[54,57].

Another kind of light variation of AM Her's X-ray radiation is the short timescale variation. There are two kind of short variation in optical band; one is in seconds, and the other is from tens of seconds to minutes. For the X-ray radiation, the variation in seconds can not be detected yet, but the relatively long quasi-periodic variation or flickering can be observed in many systems. For example, the SXR from AM Her has a quasi-periodic flickering of 37s[55], and similar flickerings in several minutes have been observed in EF Eri[60], BL Hyi[61] and QQ Vul[59].

3. 2 Theoretical explanation

The tremendous energy in CV's X-ray radiation (10^{32} -10^{34}erg·s^{-1}) can only comes from the release of gravitational energy by accretion matter. And the universal existence of short timescale variations, orbit and spin modulations indicate that the emission region of X-rays is at the neighbourhood of WDs.

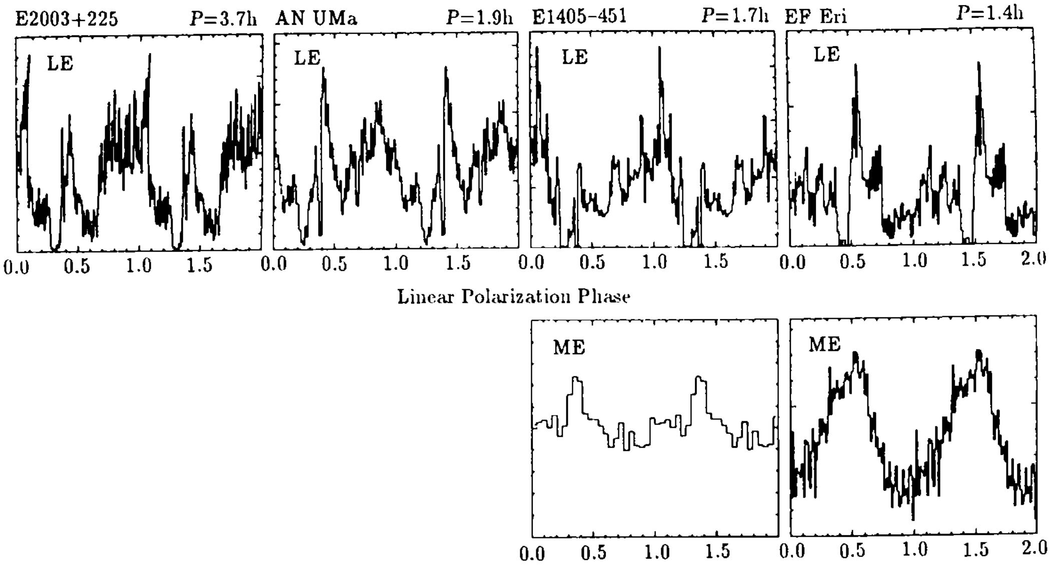

Fig.4 X-ray light curve of bipolar AM Her stars. X coordinate axis represents linear polarization phase, Y coordinate axis represents relative X ray flux. LE corresponds to SXR, ME to HXR[48].

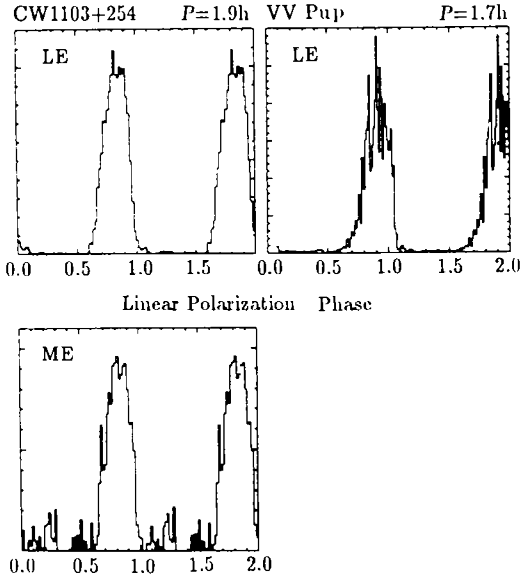

Fig.5 X-ray light curve of mono-polar AM Her stars[48].

For the weak magnetic system such as DN, the inner edge of accretion disk is in contact with the surface of WD, and forms boundary layer (BL), where the kinetic energy released by accretion matter contains almost half of the accretion energy. And it is the main energy source of X-ray radiation for this kind of CVs. The energy releasing way may be turbulent viscous dissipation[62] or strong shock wave[63]. No matter which way it is, if the accretion rate is low enough ($\leq 10^{16}\text{g}\cdot\text{s}^{-1}$), the small matter density makes the BL optically thin, and the timescale of cooling through particles' f-f emission is longer than that of adiabatic expanding. The matter is heated to 10^7 – 10^8K because the cooling rate is low, and at the same time it expands adiabatically, forming a halo. And the halo radiates HXR through thermal bremsstrahlung. So it is mainly HXR that was observed in quiescence. On the other hand, if accretion rate is large ($\geq 10^{17}\text{g}\cdot\text{s}^{-1}$), the BL becomes optically thick, and the energy is radiated in a more effective way of blackbody radiation. The effective temperature is between 10^5 and 10^6 K, so radiation mainly concentrates in SXR and EUV bands[64], which is the case observed in outburst. The X-ray delay may be similar to the UV delay, may be both because of the evaporation of inner disk. Because the radiation region of SXR (BL) is at the edge of WDs, the orbital modulation and short timescale variation can be understood. While the radiation region of HXR is very large, thus there is no such variation observed.

In the magnetic CVs, accretion energy is released by column accretion at the neighbourhood of WDs. Figure 6 is the illustration of column accretion. The falling matter forms a strong shock wave at certain altitude, and the speed of falling matter reduces about one third after it passes through the shock wave, but its temperature and density are increased. Passed the shock wave, the gas temperature is $T_s = 3.7 \times 10^8 M_{wd}(R/10^9\text{cm})^{-1}\text{K}$, and therefore the heating region between the shock wave and the surface of the WD (i.e. the accretion region) radiates HXR through thermal bresstrahlung. If the radiation is isotropic, nearly half of the HXR will be absorbed or reflected by the WD, and radiates out in the way of blackbody to produce SXR. This process is called re-habitation model. At the same time, the electron in this region will move along the magnetic field lines to produce cyclotron radiation, and its energy falls at ultraviolet and optical bands. Among these cooling mechanisms, the one which is dominant depends on the magnetic field strength and accretion rate per unit area in accretion region. Generally speaking, thermal bremsstrahlung is dominant in the case of high accretion rate and weak magnetic field, and cyclotron radiation holds the opposite condition[65].

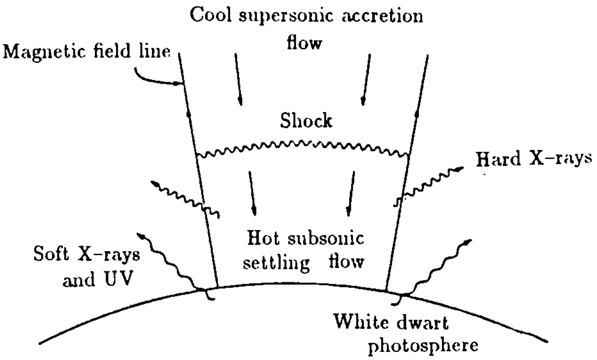

Fig.6 Illustration of column accretion.

DQ Her stars have a relatively large accretion rate and weak magnetic field, and therefore they have a strong HXR. While AM Her stars have a relatively weak HXR. The above mentioned model is fitted better for the observed X-ray spectrum, but faces some difficulties in the explanation of SXR radiation. First, the SXR of the DQ Her star can not be detected. King and Lasota[66] suggested that its relatively weak magnetic field causes the accretion area to be very large, its ratio to the surface area of the WD, $f > 0.1$, so the effective temperature of the WD is relatively low, makes the radiation fall at EUV band, which is easily absorbed by the interstellar medium. However, the equivalent column density estimated from theory is $N_H \sim 10^{23}\text{cm}^{-2}$. In a typical distance of 100 pc, the from interstellar extinction can not contribute all the absorption. Another possible absorption is produced by the accreted matter itself.

It is very difficult for the re-habitation model to explain the excess of SXR for AM

Her star. From the model, it should be $L_{\mathrm{HXR}} \sim L_{\mathrm{SXR}}$, but from observations, L_{SXR}, is several times up to one hundred times larger than L_{HXR}. Many models are established to solve such a problem. There are mainly five kinds: (1) SXR is produced by nuclear burning[67]; (2) the energy is transfered to WD through nonthermal electron conduction instead of shock wave[68]; (3) the reverse scattering of HXR by accretion column[69]; (4) the high density filament in the accretion stream penetrates directly upon the surface of WDs[70]; (5) HXR is absorbed by trench wall which is produced by the ram pressure of accretion matter in the photosphere of WDs[71]. Further research shows that steady nuclear burning produces too low a luminosity to increase SXR flux[72]. The false of the second theory lies in the wrong energy deposition timescale[73]. Only the last three models can bear careful examination, and the research on the fourth model is the most active one. This model is also called bombardment model, which suggests that owning to the effect of magnetic field and tidal force, the accretion matter becomes instable and forms dense "blobs", and they hit WD directly without being heated in the shock wave and the accretion regions, and release their kinetic energy beneath the surface of the WD, and cause the SXR excess in the radiation of WD[73,28].

Because the X-ray radiation of magnetic CVs is produced at a certain region in the WD (polar cap region), therefore it is easily modulated by the rotation of WD, such as the pulse of DQ Her and light variation of bipolar AM Her stars. For mono-polar AM Her stars, their light variation is rather complicated, and its eclipse is probably caused by the absorption of accretion stream[74]. In order to explain the phase reverse of SXR, Heise *et al.*[59] suggested that SXR may comes from the other polar cap, i.e., one polar cap region radiates HXR and SXR, and the other polar cap radiates only SXR.

4 Conclusion

The studies of CVs not only help us understand the physics in them, but also further help us understand a more general astrophysical phenomenon — accretion. The concepts of accretion and accretion disk have been applied to many fields of astrophysics. They are not only applied to CVs, but also to X-ray binary stars, symbiotic stars, protostars, T Tau stars, energetic γ–ray sources, AGNs, QSOs and giant radio galaxies, etc.. They have been developed into a relatively systematic astrophysical theory. The abundant observing phenomena of CVs make them the best lab to study accretion processes, and it's the very reason for the CVs to be so attractive to astronomers.

The observations of each band of CVs are introduced in the previous sections. Each component has its special radiation window. The secondary star mainly radiates infrared photon, the primary star mainly contributes UV and EUV; the radiation of accretion disks covers bands from infrared to ultraviolet; accretion streams and hot spots are radiation sources of optical light; the boundary layer radiates EUV and SXR, and HXR comes from the halo and the accretion column. Each CV has its special observational phenomenon, such as UV delays and winds from DNe, superoutbursts and superhumps of SU UMa stars, polarizations and pulses of magnetic CVs, SXR excesses of AM Her stars etc.. Meanwhile, all the CVs have common observational features, such as the similar energy distribution and light variation. Most observational phenomena have almost reasonable theoretical explanation.

Similar to the case in other fields, what we know about CVs is far less than what we do not know. For example, the radio observation of CVs has just begun. The explanation about the outburst of CVs and emission lines and some other observational features are not very satisfactory. To enrich our understanding needs not only the development in theory but providing abundant observations. Therefore multiwavelength studies of CVs are very important. Currently, some simultaneous multiwavelength studies of one source has just been published. The most noticeable case is the studies of VW Hyi. There are 5 papers on MNRAS, Vol 225, 1987, studying its multiwavelength radiation. Another similar example is the studies of V834 Cen[54].

To find more and more new CVs and new phenomena about CVs is the main task for the future multiwavelength studies of CVs. And thus observational data with higher space and time resolution is needed. Hubble telescope, ROSAT satellite and other aerocraft will bring a new era to the multiwavelength studies of CVs in nineties.

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