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The Extreme Ultraviolet Emission Lines of Some Cataclysmic Variables at Outburst

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Abstract

Using spectral technique, analyses of some astrophysical data from the EUVE satellite in the Extreme Ultraviolet region on accretion disk of some cataclysmic variable were carried out. A number of strong emission lines in 14 CVs were discovered. Most CVs follow a similar trend in the number of ionized elements present in their spectrum while some have very few or no ionized elements in their spectrum. The AM Herculis star, which has the weakest magnetic field of all seven magnetic CVs studied, contain no ionized elements in its EUVE spectroscopy. However, for the rest of the CVs, there is sufficient evidence to conclude that the accretion disks of CVs are highly ionized. This implies also that the accretion disks of other astrophysical objects could be equally highly ionized. This result is in agreement with the suggestion that the most promising candidate for providing the angular momentum transport mechanism during the outburst is magneto hydrodynamics turbulence.

Key Words: Emission lines, accretion disks and Cataclysmic Variables.

1. Introduction

Cataclysmic variables (CVs) are semidetached binaries composed of a mass-losing low-mass main-sequence secondary star, an accreting white dwarf, and an accretion disk. Accretion disks refers to the structure formed when material accreting onto astrophysical objects such as a white dwarf has excess angular momentum resulting in a circulating disks of material supported by internal pressure and heated by turbulent stresses.

The accretion disks, especially in X-ray binaries, are the most efficient machines for extracting gravitational potential energy and converting it into radiation [1]. This property of accretion disks has been suggested as the power source of the central engine in quasars and active galactic nuclei. The disk-like accretion onto a black hole is the most plausible explanation for the strong emission in the ultraviolet (UV), the so-called “big blue bump” [2] and for the X-rays in AGN. Relativistic jets can extract large amounts of energy from central source object [3].

Energy production occurs if the material that produces the energy looses its momentum (thus transporting the energy) outward, and subsequently lowering into the gravitational potential of the central object. In this way the accretion process provides a power source for astrophysical objects. Clearly, an important issue in the theory of accretion disk is understanding the processes that leads to outward angular momentum transport and therefore enable mass accretion to occur. In principle the presence of friction in the form of viscosity allows the exchange of angular momentum between adjacent fluid elements, but this fails to account for the observed accretion rates. If on the other hand, the disk were turbulent, the effective viscosity could be large enough to provide the needed accretion rates. Magneto rotational instability provides a robust and self-consistent mechanism for the production of turbulence and angular momentum in these objects if they are adequately ionized [4].

Spectroscopic study especially in EUV of CVs provides one of the best astrophysical laboratories for study of accretion physics [5]. Emission lines are powerful diagnostics of the physical conditions in all types of objects including these CVs. The emission-line fluxes or relative fluxes can constrain the temperature, ionization state, density, elemental abundance, and geometrical distribution of the gas [6].

2. Observation

Observation of these CVs were carried out via NASA's Extreme Ultraviolet Explorer (EUVE) Satellite, devoted to acquiring astronomical data in the wavelength range 70 to 760 Å. The satellite was launched in June 7, 1992. The detailed description of the science instrumentation is presented by [5] and the references therein. The satellite is devoted to all-sky survey and its primary function is to acquire spectroscopic observation of specific targets for guest investigator sponsored through a NASA Guest Observer Program. For each target observation a Deep Survey image and requested data are obtained. These data are proprietary to the Guest Investigator for a period of six months following the observation, after which they are placed in the EUVE Archive and become publicly available. It is from the EUVE Public Archive that the data used for this work was obtained.

3. Analysis of Data / Results

The spectra of 14 CVs were analyzed using the spectral analysis technique. These CVs have their EUV spectra displayed in the extreme ultraviolet explorer stellar spectral atlas [5].

The Cataclysmic variables cataloged are AM Herculis Stars, Dwarf novae (DNs) and DQ Herculis. The AM Heculis are known to posses a very strong magnetic field (10–230 MG) and DQ Hers primary have moderate fields (1–10 MG) and their secondary stars are believed to be normal main-sequence dwarfs.

In the Her-type CV, accreting material is magnetically funneled directly onto the white dwarf surface in a tightly confined spot of approximately 1000 km, emitting energy in the EUV spectral range [5]. This accretion spot is the major source of EUV photons in AM Her-type stars. The DNs has very low non magnetic fields in their primaries. This is why the accreted material forms a roughly flat disk that may extend all the way to the white dwarf surface. This disk-primary star interface called the boundary layer is thought to be the source of much of the high-energy emission during a dwarf novae outburst.

The results of this work shows that, in the EUV region, iron constitutes the major element in the accretion disks, as can be seen in Tables 1–3.

3.1. Dwarf Novae at outburst

Dwarf novae (DNs) consist of a semidetached binary containing a white dwarf primary and a normal lower main sequence secondary. The secondary loses material via Roche lobe overflow, and this material forms accretion disks around the primary star that can extend all the way to the white dwarf surface (i.e., the boundary layer). They show semi periodic outburst of 2–5 magnitude, that are thought to occur when material stored in the accretion disks is suddenly accreting onto the white dwarf surface owing to angular momentum loss caused by thermally unstable viscous heating [7].

At minimum, light DNs are weak EUV sources. However, when they undergo an outburst, the boundary layer becomes quickly heated to a few hundred thousand Kelvin. Spectroscopic study of this high temperature plasma, in EUV band pass, provides one of the best astrophysical laboratories for study of accretion physics [5].

Three examples of dwarf novae are:

VW Hydri. It is on record that this star shows the softest EUV spectrum of all three DNs observed in outburst to date. Only three ions are present in the spectrum (see Table 1).

Table 1. Dwarf Novas.

CVs → / Ions, with λ in Å ↓	VW Hyi	U Gen	SS Cyg
NeVII 88.08		✓	✓
FeXXI 97.88		✓	-
NeVIII 98.26		-	✓
FeXVIII 103.94		✓	-
FeXX 121.83	✓	✓	-
FeXXII 128.73	✓	-	-
FeXIII 132.84	-	✓	-
NiXII 152.15	✓	-	-
FeXIV 211 .32		-	✓
He II 303.5		-	✓

SS Cygni. This is another DN star with few ionized elements in its spectrum. SS Cygni is the hardest of the three DNs during outburst and show no EUV flux long ward of ∼130 A.

U Germinorum. This DN star contains relative higher ionized elements in its EUV spectrum than the first two earlier mentioned. The total size of the EUV-emitting region during outburst is found to be comparable to that of a white dwarf itself, which indicates that the outburst is mainly confined to the inner disk boundary layer region [8]. Evidence of EUV absorption or scattering is also seen in U Germinorum, attributed to an outer disk bulge at the accretion stream-disk interface.

3.2. AM Herculis Stars

Am Herculis stars are cataclysmic variable in which the accretion stream is magnetically focused onto the white dwarf primary because of large magnetic fields they possess.

The field strengths range ∼10 to 80 MG. The accretion spot, which is the area the accretion stream impacts the white dwarf surface, produces high-energy emission both from a shock slightly above the primary surface and from thermal heating of the surface itself. The accretion sport is found to have a relatively high temperature, about a hundred thousand Kelvin.

Nine examples of AM Herculis stars are:

EF Eridani. This star exhibits a typical AM Herculis-type EUV spectrum. There is a number of ionized elements present in that spectrum of this star (see Table 2).

UZ fornacis. EUV photometry of this star shows that the accretion spot diameter is less than 2000 km. Perhaps this explains why very few ionized elements are present in this star.

VV Puppis. The diameter of the accretion spot is found to be as small as 250–380 km, with an effective temperature of ∼345,000 K. [9] used EUVE photometric data to infer a spot diameter of 350 km and sport height of 50 km above white dwarf surface. VV Puppis equally contains a low number of ionized elements.

Table 2. AM Herculis Stars.

CVs→ Ions with λ in Å. ↓	FFEri	UZ For,	VV pup	Ek Umar	An Uma	V834 Cen,	2RE 1844-741	2REJ1149+288	Am Her
NeVII 88.08	-	-	✓	-	-	-	✓	✓	-
FeXIX 91.02	-	-	-	-	-	-	-	✓	-
FeXVII 93.93	✓	✓	-	-	-	-	✓	✓	-
NeVIII 98.26	✓	-	-	-	-	✓	-	✓	-
FeXIX 101.55	-	-	✓	-	-	-	-	-	-
FeXXI 102.21	-	-	-	-	-	✓	✓	-	-
NeVII 106.14	-	-	-	-	-	✓	✓	✓	-
FeXIX 109.97	-	-	-	-	-	✓	-	✓	-
FeXXI 114 .39	✓	-	-	-	-	-	-	-	-
FeXX 118 .66	✓	-	-	-	-	✓	-	-	-
FeXIX 120.00	-	-	-	✓	-	-	-	-	-
FeXX 121.83	-	-	✓	-	-	-	-	-	-
FeXXII 128 .73	-	-	-	✓	-	-	-	✓	-
FeXXII 132 .84	-	✓	-	✓	✓	-	-	✓	-
FeXXI 135.78	✓	-	-	-	-	-	-	-	-
FeXXI 142.27	-	-	✓	-	-	✓	-	-	-
Ne V 143.07	-	-	-	-	-	-	-	✓	
NI X 145 .06	-	-	-	-	-	-	-	-	-
NiXI 148.21	✓	-	-	-	✓	-	-	✓	-
NiXII 152.15	✓	✓	-	✓	-	✓	✓	✓	-
FeVIII 167.5–169	✓	✓	✓	✓	✓	✓	✓	✓	-
OVI 173 .06	-	-	-	-	-	-	-	✓	-

EK Ursae Majoris and AN Ursae Majoris. It has been observed that these sources were extremely weak EUV sources when observed by EUVE. They might have been in low state at the time. Perhaps this may well explain why there are few ionized species present in their spectrum.

2REJ1149+288. [9] showed that the accretion sport in this AM Her was fairly large, being about 100 km in diameter. This CV contains relatively more ionized elements when compared to others.

V834 Centauri and 2REJ1844-741. Both stars contain a relatively good number of ionized species.

AM Herculis. This star has the weakest magnetic field of any of the earlier mentioned systems, about 11 GM. The EUVE spectroscopy has been discussed by [10]. In the present spectrum no ionized specie is found.

3.3. DQ Herculis Stars

EUVE has observed two DQ her stars. These types of cataclysmic variables are systems in which the white dwarf primary has a magnetic field usually weaker than in an AM Her but still sufficient to cause a disruption of the inner accretion disk. The DQ Her stars have a partial disk and the accreted materials veins down onto the white dwarf in extend areas or arcs.

The following are examples of DQ Herculis Stars.

PQ Geminorum. This DQ Herculis star, with a weak magnetic field, has it's EUVE spectrum showing some highly ionized emission lines consistent with having their origin in a corona- like region of $10^{5.8}$–$10^{6.0}$ K [9]. It was observed that this CV contains the highest number of ionized elements in all the CVs analyzed so far.

EX Hydrae. This is an eclipsing DQ Her-type CV. During the bright portion of the white dwarf spin phase, the EUV spectrum reveals about 20 narrow emission lines (mostly of iron) characteristic of plasma around 10^7 K. Every line identified in the white dwarf bright phase and in their stead appears a few tenuous lines indicative of plasma around 10^6 K.

Table 3. DQ Hers.

CVs → Ions with λ in Å ↓	Ex Hya	PQ. Geminorum
NeVIII 88.08	✓	✓
FeXIX 91.02	✓	✓
FeXVIII 93.93	✓	✓
FeXXI 97.88	✓	✓
NeVIII 98.26	✓	✓
FeXXI 102.21	✓	✓
NeVII 106.14	✓	✓
FeXXII 114.39	✓	✓
FeXX 118 .66	-	✓
FeXX 121.83	-	✓
FeXXII 128.73	-	✓
FeXX/XXII 132.84	-	✓
NeV 143.07	✓	✓
FeXIX 145.06	✓	✓
NiXI 148.37	✓	✓
NiXII 152.15	-	✓
FeVIII 167.5-169	✓	✓
OVI 173.08	✓	✓
FeX 175.28	✓	✓

4. Discussions and Conclusion

In this work, a number of EUV spectral emission lines from the accretion disk of CVs studied were identified. By implication the accretion disks of these CVs were adequately ionized. This implies that the accretion disks of other astrophysical objects could equally be adequately ionized. This result is in agreement with the suggestion that the most promising candidate for providing angular momentum transport mechanism during the outburst is magneto rotational instability.

In Young Stellar Objects (YSO) it is well-believed that the torque exerted upon disks by centrifugal driven winds can not account for both the observed linear momentum and energy transport rates associated with the molecular out flows [11]. The luminosity associated with protostellar objects during the molecular outflows epoch is due to accretion from the disk. This implies that molecular outflows in the form of jets in the young stellar objects are originally powered by the gravitational potential energy liberated by matter accreting from the accretion disk onto a forming star.

The energy source of AGN is from accretion of matter from the accretion disk onto the massive black hole. Tremendous amount of energy is released inform of radiation when a mass m is accreted onto a massive black hole. The initial injection of matter in the AGN jets is powered by the gravitational potential energy released as result of accretion of matter onto the massive black hole.

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