An Observational Study of Accretion Flow in the inner Accretion Disks of Dwarf Novae

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Dwarf Novae and Their Outburst Characteristics

- **Non-magnetic Cataclysmic Variables**
  
  WD accretes matter from late-type MS star filling Roche Lobe—forms an accretion disk around the WD reaching all the way to the WD

- **Dwarf Novae**
  
  Matter transferred at continuous or sporadic rates ongoing accretion is interrupted every few weeks to months by intense accretion (outburst) of days to weeks. \( (10^{39}-10^{40} \text{ erg}, \Delta m=2-6) \)

- **Nova-Like variables (anti-dwarf novae VY Scl)**

- **Classical and Recurrent Novae** \( (10^{43}-10^{46} \text{ erg}) \)
- **U Gem Type**
  - $P_{\text{orb}} > 3$ hrs,
  - no superoutburst

- **Z Cam Type**
  - Standstills

- **SU Uma Type**
  - $P_{\text{orb}} < 2$ hrs,
  - Superoutbursts
**X-ray Emission at Quiescence**

- Standard disk theory – Boundary Layer (BL)
  \[ L_{BL} \approx L_{disk} = \frac{GM_{wd}M_{\text{acc}}}{2R_{wd}} = \frac{L_{\text{acc}}}{2} \]
  matter decelerates from Keplerian velocities to the slowly rotating WD---site of rapid variability -- \( L_{BL} \approx L_{x} \quad L_{\text{disk}} \approx L_{\text{opt}} \)

- During Quiescence (low-mass accretion) BL is expected (Narayan&Popham 1993; Popham 1999) to be optically thin and emit mostly in the hard X-rays.

- Narrow emission lines, nearly solar abundances, \( M \sim 10^{-12} - 10^{-10} M_{\text{sun}} / \text{yr} \), possible reflection off of WD – Multi-temperature isobaric cooling flow model plasma emission with \( T_{\text{max}} = 9-55 \text{ keV} \) (see Review by Kuulkers et al. 2006 ; Pandel et al. 2003,2005, Balman et al. 2011)

- Missing BL in the X-rays --> BL emits significant fraction of its luminosity in the EUV/FUV

  BL --> star, temperature very high --> X-rays
  BL --> disk, \( T \sim 60,000 \text{ K} \) --> FUV (e.g., fast rotating hot ring)
Pandel et al. 2005

Balman et al. 2011
**X-ray Emission During DNe Outbursts**


DIM (Disk Instability Model; see Review by Lasota 2001, 2004)

Problems !?

UV delays, (optical rise to UV rise and X-ray suppression)

Decrease of X-ray flux during quiescence to constant level of brightness (as opposed to 1-3 mag expected increase)

Too high mass accretion rates during quiescence
Comparisons with Theoretical Expectations

- WD Irradiation (King 1997)
- Spherical corona (Mahasena & Osaki 1999)
- Hot settling flow (Medvedev & Menou 2002)
- Cool Disk – low viscosity – accumulation- low accretion rate $10^{-13} \, M_\odot/yr$

- Evaporation from cool disk flows via corona onto WD – inherit angular momentum $\rightarrow$ rotating gas cloud at high temperatures close to the W. $T_{\text{cor}} \sim 0.01 \times T_{\text{vir}}$

- Sustain corona via e- conduction heating downwards and heat conduction balancing cooling by radiation

- Frictional Boundary layer (slows down to accrete)

- Thermal Boundary layer below ($T_{\text{cor}} \rightarrow T_{\text{photo}}$)

- Siphon-flow allows higher accretion rates $\rightarrow 10^{-11} \, M_\odot/yr$

- Low accretion rates $\rightarrow \text{larger truncation radii}$

- Typical $\alpha \sim 0.3$ ..... the evaporation maximizes at smaller radii over the disk for high $\alpha$
Accretion Flows-Matter Fluctuations and Broadband Noise

- Variable instant mass accretion rate $\rightarrow$ variable flux from the disk $\rightarrow$ flow propagation

- Low frequency perturbations are generated in the outer disk and propagate to the inner disk and finally to the X-ray emitting region.

- Self-similar variability of accretion rate in the disks $\rightarrow$ flicker noise (Lyubarskii 1997)

- Variations occur at any radii on dynamical or viscous timescales, most variability emerges from the inner regions
PDS (power density) uncorrelated events $\rightarrow$ flat PDS

$$P(f) \propto f^{-1} \left(1 + \left(\frac{f}{f_0}\right)^4\right)^{-1/4}$$

$$\Omega_K(r) = \left(\frac{GM_{wd}}{r^3}\right)^{1/2} = 2\pi f(r)$$

with a break at

$$f_{break} \sim f_{visc} \sim \frac{1}{t_{visc}}$$

$$t_{visc} \approx \frac{R_{disk}^2}{\nu}$$

$$\nu = \alpha \frac{H}{c_s}$$

$$t_{visc} = \alpha^{-1} \left(\frac{H}{R}\right)^{-2} \Omega_K^{-1}$$
Intermediate Polars and Disk Truncation radii

\[ R_{\text{in}} = 1.9 \times 10^9 \text{ cm} \]

\[ f_b = 2.1 \pm 0.1 \times 10^{-2} \text{ Hz} \]

Revnivytev et al. 2011
$f_b = 7 \times 10^{-2} \text{ Hz}$

$R_{in} = 9 \times 10^8 \text{ cm}$

$\text{Opt (SAAO)}$

$\text{X-ray (RXTE), simult.}$

$\text{TV Col}$

$f_b = 5 \times 10^{-2} \text{ Hz}$
Investigating DNe Inner Disk Structure with Broadband Noise

SS Cyg

40 d, 2.4 d

6.6 hrs

~19 keV

$f_b = 0.0056 \pm 0.0014$ Hz

$R_{in} = 4.8 \times 10^9$ cm
\( f_b = 0.0097 \pm 0.0015 \text{ Hz} \)

\( R_{\text{in}} = 3.3 \times 10^9 \text{ cm} \)

\( f_b = 0.022 \pm 0.003 \text{ Hz} \)

\( R_{\text{in}} = 1.9 \times 10^9 \text{ cm} \)

\( f_b = 0.05 \pm 0.02 \text{ Hz} \)

\( R_{\text{in}} = 1.1 \times 10^9 \text{ cm} \)

\( \tau = 175 - 188 \text{ s} \)
VW Hyi
28 d, <1 d, 179 d
107 min
~9 keV

$R_{in} = 8.1 \times 10^9$ cm
$f_b = 0.002 \pm 0.001$ Hz
RU Peg
50 d, 20 d
8.99 hr
~31 keV

τ = 100 - 130 s

Balman et al. 2011
**WW Cet**

45 d

253 min

$\sim$15 keV

$\tau = 130 - 240$ s

$f_b = 0.0018 \pm 0.0009$ Hz

$R_{in} = 9.6 \times 10^9$ cm
T Leo

?? , 420 d

84.7 min

~11 keV

\[ f_b = 0.005 \pm 0.002 \text{ Hz} \]

\[ R_{\text{in}} = 3.7 \times 10^9 \text{ cm} \]

\[ \tau = 65 - 116 \text{ s} \]
Conclusions

- We detect large scale truncation in the Disks of Dwarf Novae (DN) in at least 5-7 systems with radii in a range $R_{tr} \approx 0.5 - 1.5 \times 10^{10} \text{ cm}$. The Magnetic CVs (MCVs) show rather smaller truncation radii $\sim 0.9 - 1.9 \times 10^9 \text{ cm}$.

- We suggest that most these systems (DN) have truncated disks with a coronal flow dominating in the inner disks as in Meyer & Meyer-Hofmeister 1994.

- It is possible that most DN outbursts are outside-in.