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

Şölen Balman

Middle East Technical University, Ankara, Turkey

Mikhail Revnivtsev

Russian Space Science Institute, Moscow, Russia

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**

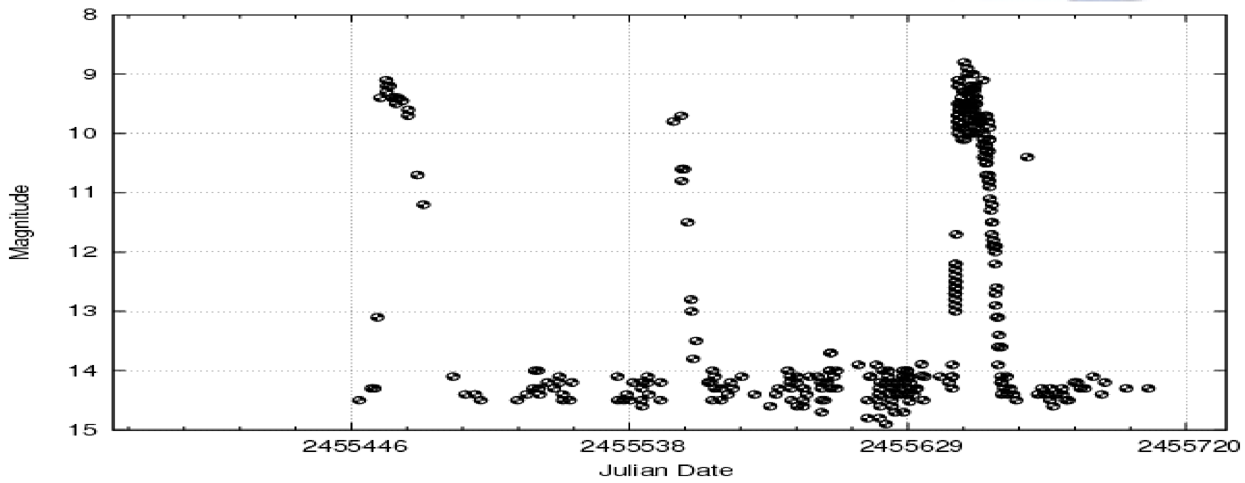
Matter transfered at continuous or sporadic rates ongoing accretion is interrupted every few weeks to months by intense accretion (outburst) of days to weeks. (10^{39}-10^{40} erg, $\Delta m=2$-6)

- **Nova-Like variables (anti-dwarf novae VY Scl)**
- **Classical and Recurrent Novae** (10^{43}-10^{46} erg)

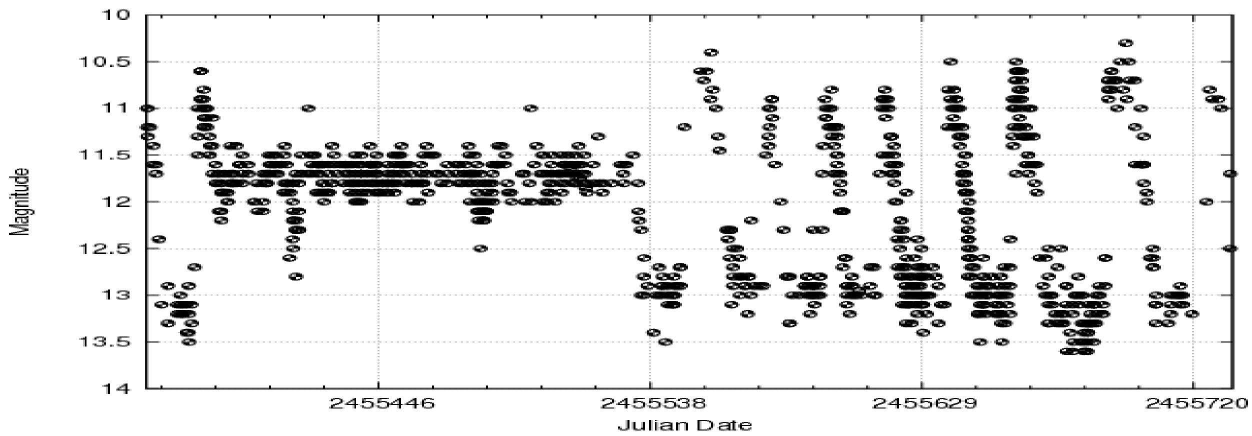
- **U Gem Type**

$P_{orb} > 3$ hrs,

no superoutburst



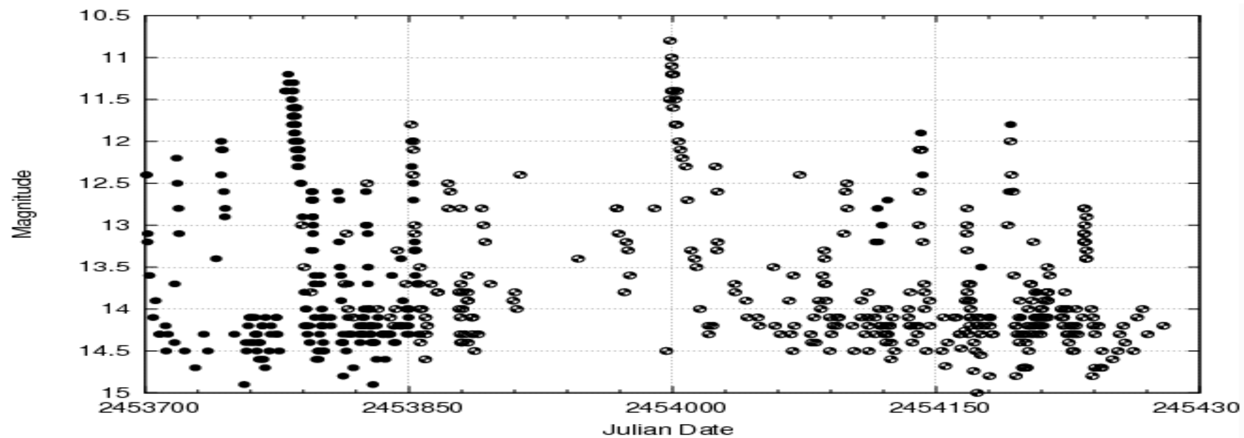
- **Z Cam Type Standstills**



- **SU Uma Type**

$P_{orb} < 2$ hrs,

Superoutbursts



X-ray Emission at Quiescence

- Standard disk theory – Boundary Layer (BL)

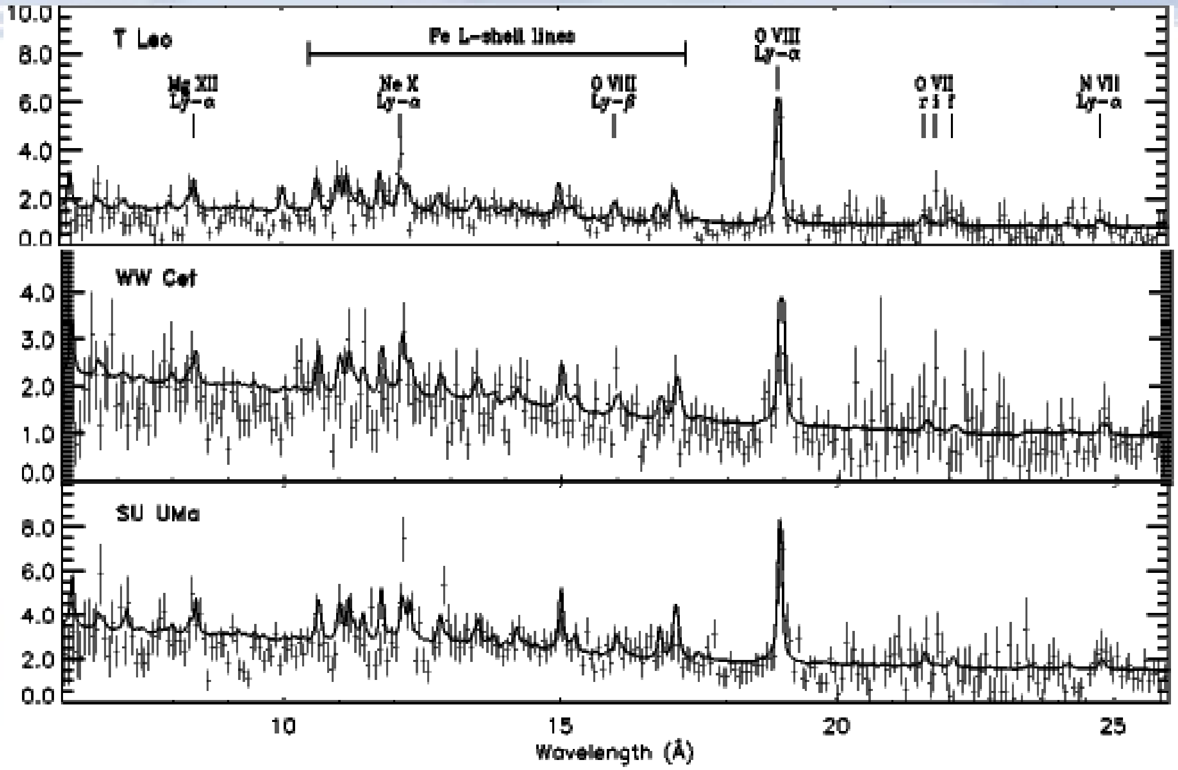
  $L_{BL} \approx L_{disk} = GM_{wd}M_{acc} / 2R_{wd} = L_{acc}/2$
  matter decelerates from Keplerian velocities to the solwly rotating WD--- site of rapid variability -- $L_{BL} \approx L_x$ $L_{disk} \approx L_{opt}$

- 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.

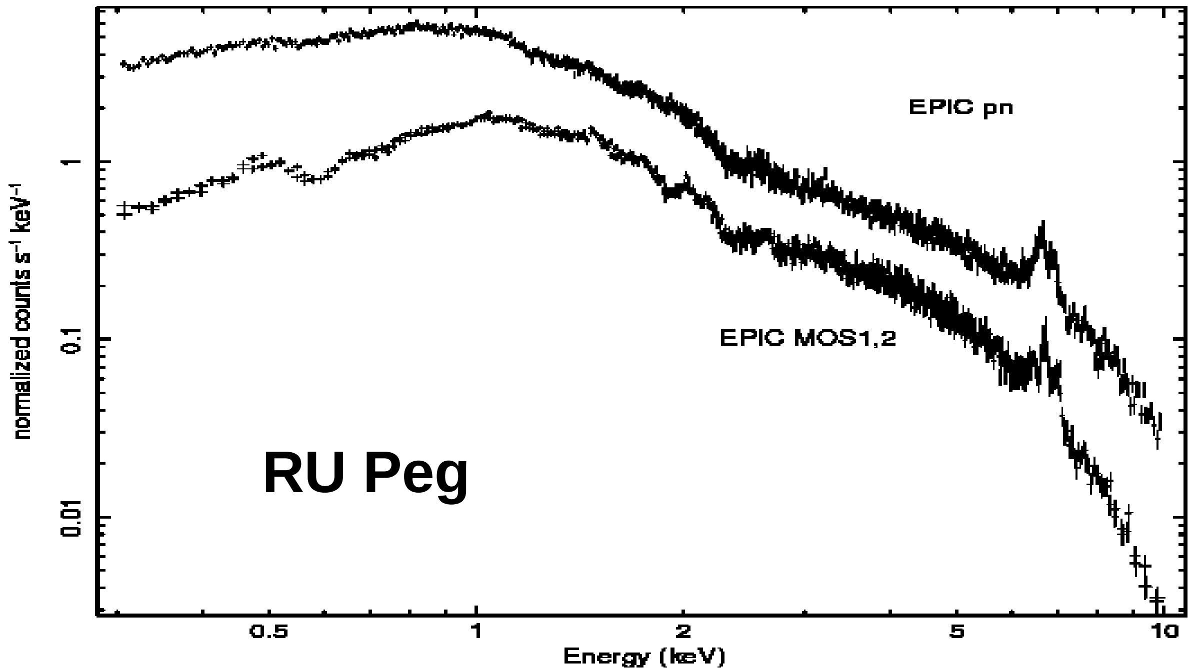
- Narrow emission lines, nearly solar abundances, M~ 10^{-12}-10^{-10} M_{sun} /yr, possible reflection off of WD – Multi-temperature isobaric cooling flow model plasma emission with T_{max} = 9-55 keV (see Review by Kuulkers et al. 2006 ; Pandel et al. 2003,2005, Balman et al. 2011)

- 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~60,000 K --> FUV (e.g., fast rotating hot ring)



Pandel et al. 2005



Balman et al. 2011

X-ray Emission During DNe Outbursts

→ optically thick BL with 10^5-10^6 K (Warner 1995; Godon et al. 1995, Popham&Narayan 1995) emitting in the soft X-ray to FUV band.

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

TTIM and EMTM (Tidal Thermal Instability, Osaki 1996

And Enhanced Mass Transfer , Hameury et al. 2000)

Problems !?

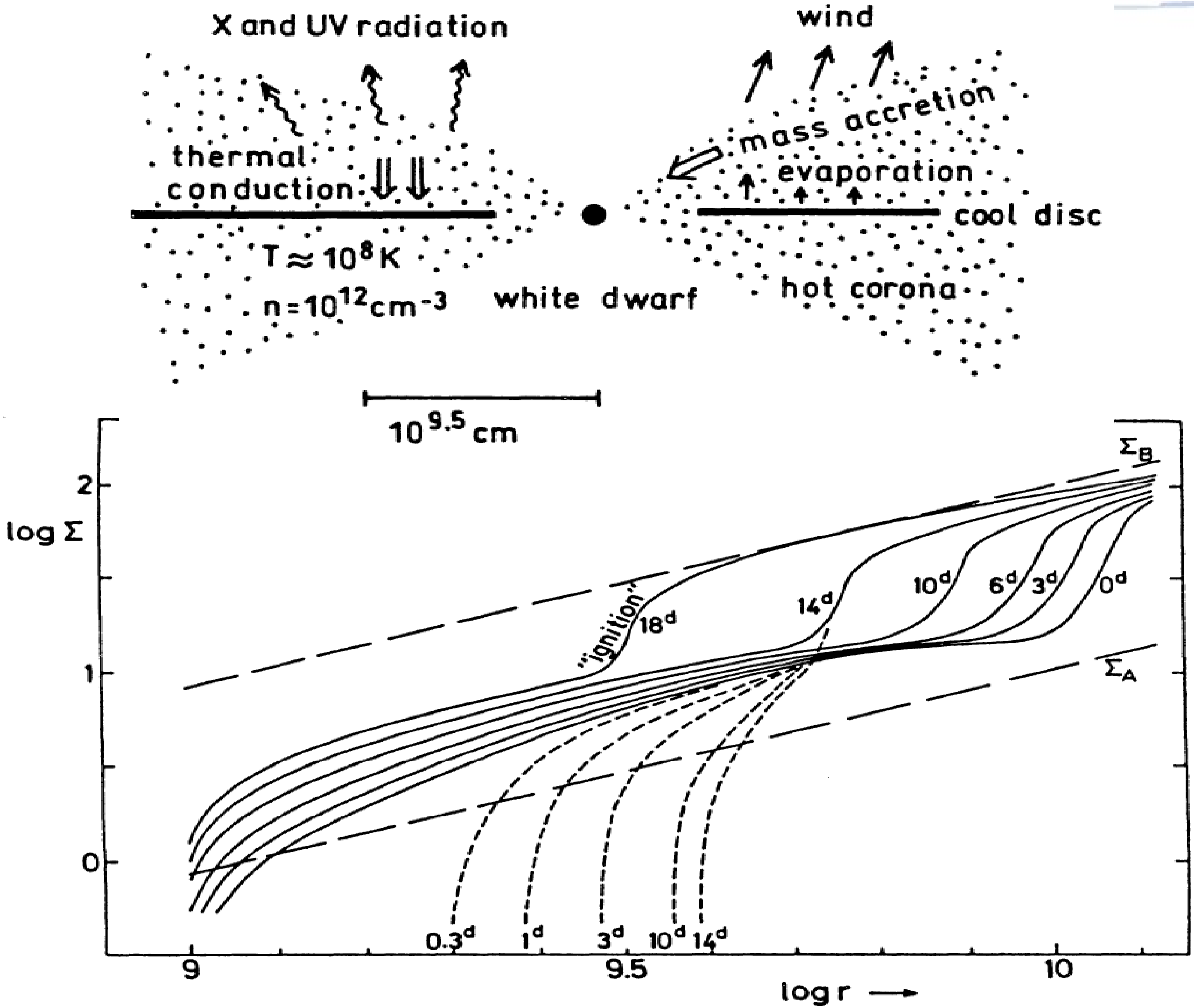
UV delays, (optical rise to UV rise and X-ray suppression)

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

- Disk like Boundary Layer – Standard 1-D theory (Narayan & Popham 1993, Popham 1999)
- Coronal siphon-flow, Disk evaporation (Meyer & Meyer-Hofmeister 1994(2001), Liu et al. 1995, Meyer et al. 2000) (see also de Kool & Wickramansinghe 1999)
- WD Irradiation (King 1997)
- Spherical corona (Mahasena & Osaki 1999)
- Hot settling flow (Medvedev & Menou 2002)



X and UV radiation
wind
mass accretion
thermal conduction
evaporation
cool disc
T ≈ 10^8 K
n=10^12 cm^-3
white dwarf
hot corona
10^9.5 cm
log Σ
log r →
Σ_B
Σ_A
"ignition"
18^d
14^d
10^d
6^d
3^d
0^d
0.3^d
1^d
3^d
10^d
14^d
0
1
2
9
9.5
10

- 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 → rotating gas cloud at high temperatures close to the W. $T_{cor} \sim 0.01 \times T_{vir}$
- 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 ($T_{cor} \rightarrow T_{photo}$)
- Siphon-flow allows higher accretion rates → $10^{-11}\ M_{\odot}/yr$
- Low accretion rates → **larger truncation radii**
- Typical α~**0.3** .....the evaporation maximizes at smaller radii over the disk for high α

Accretion Flows-Matter Fluctuations and Broadband Noise

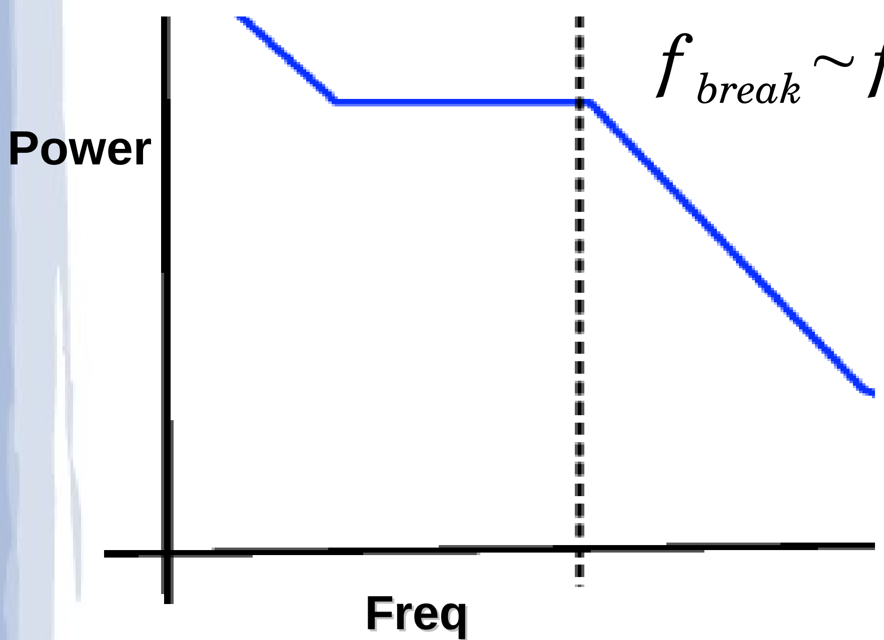
- Variable instant mass accretion rate → variable flux from the disk → **flow propagation**
- Low frequency perturbations are generated in the outer disk and propagate to the inner disk and finally to the X-ray emitting region.
- Self-similar variability of accretion rate in the disks → **flicker noise** (Lyubarskii 1997)
- Variations occur at any radii on dynamical or viscous timescales, most variability emerges from the inner regions

PDS (power density) uncorrelated events → flat PDS

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

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

with a break at



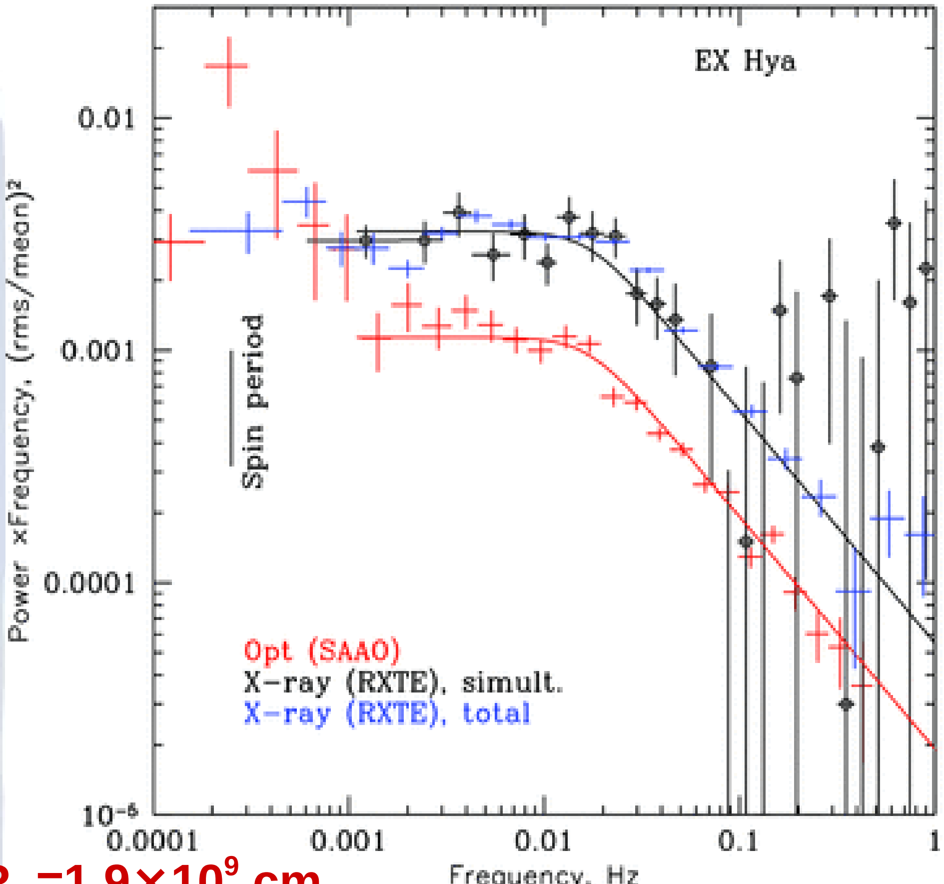
$$f_{break} \sim f_{visc} \sim \frac{1}{t_{visc}}$$

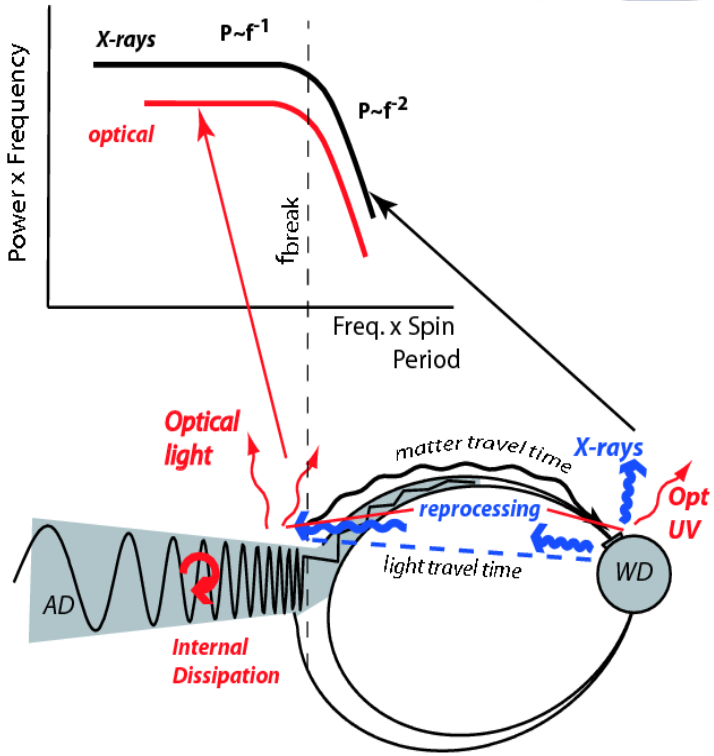
$$t_{visc} \simeq \frac{R_{disk}^2}{\nu}$$

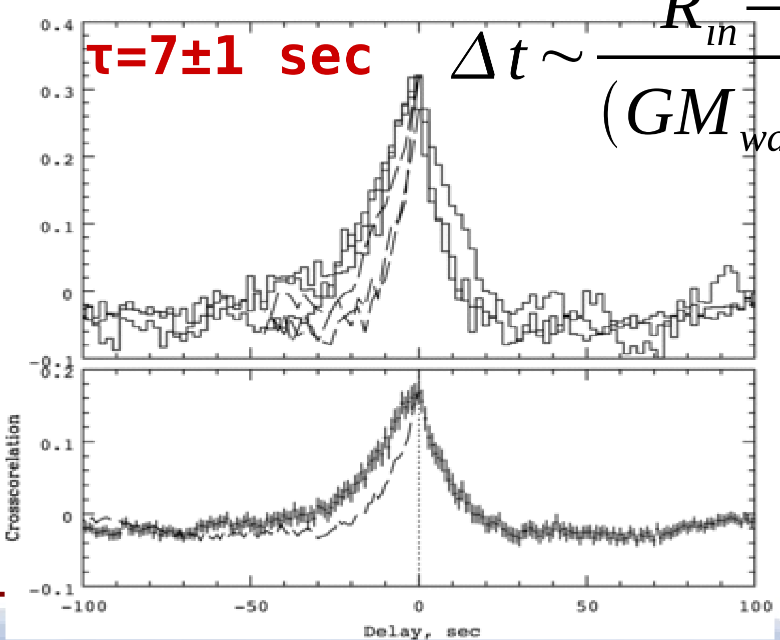
$$\nu = \alpha H c_s$$

$$t_{visc} = \alpha^{-1}\left(\frac{H}{R}\right)^{-2} \Omega_K^{-1}$$

Intermediate Polars and Disk Truncation radii





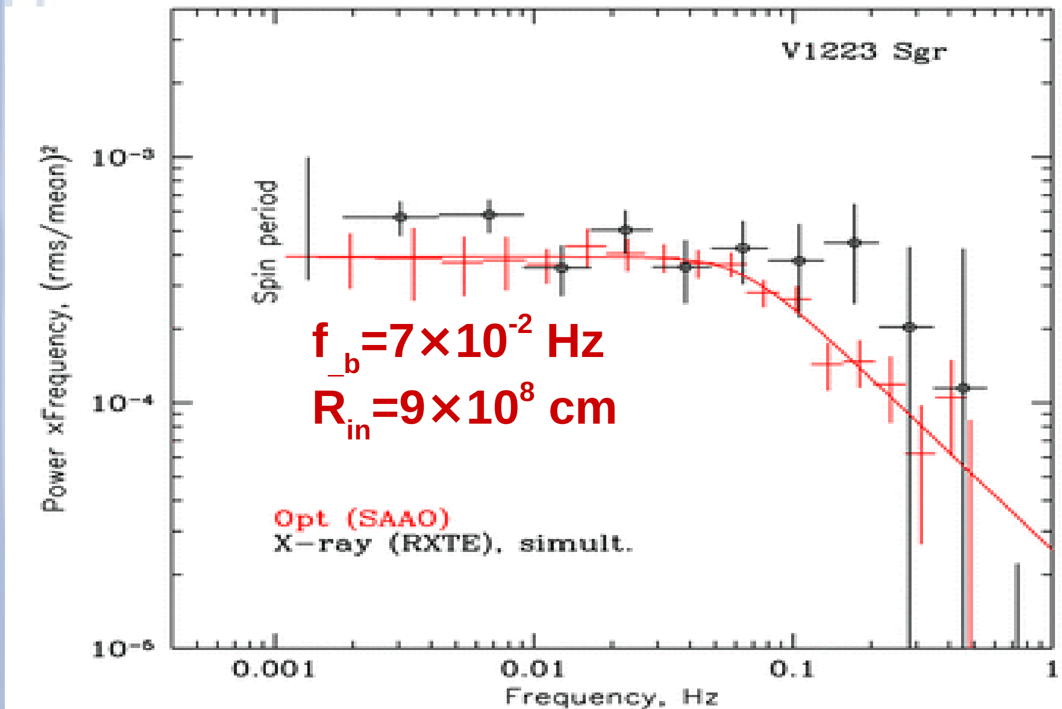


$$\Delta t \sim \frac{R_{in} - R_{wd}}{(GM_{wd}/R)^{1/2}}$$

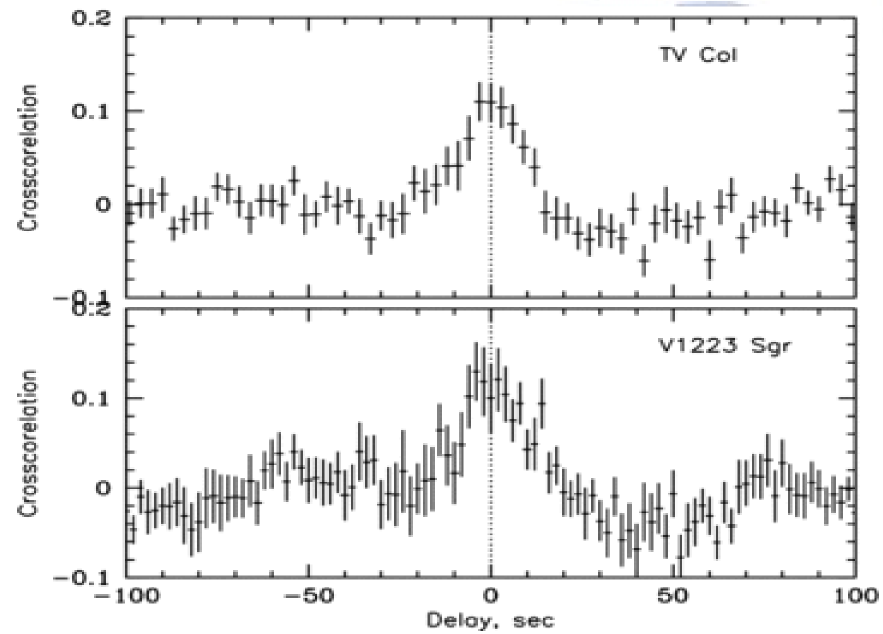
R_{in}=1.9×10^{9} cm

$f_{\_b}$=2.1±0.1×10^{-2} Hz

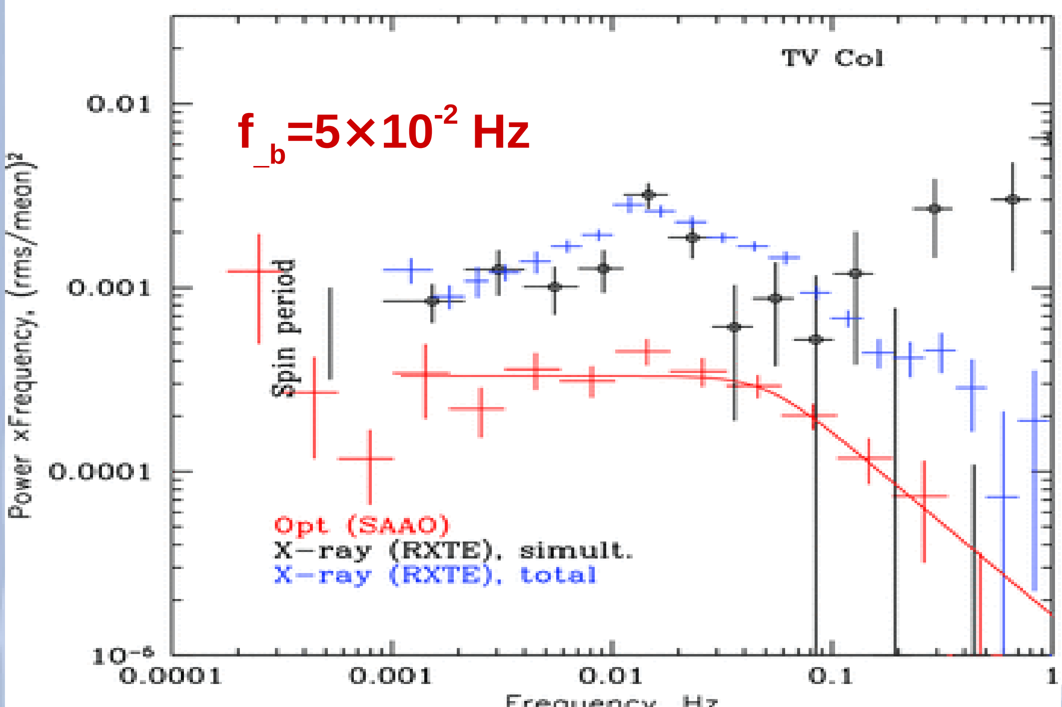
Revnivtsev et al. 2011



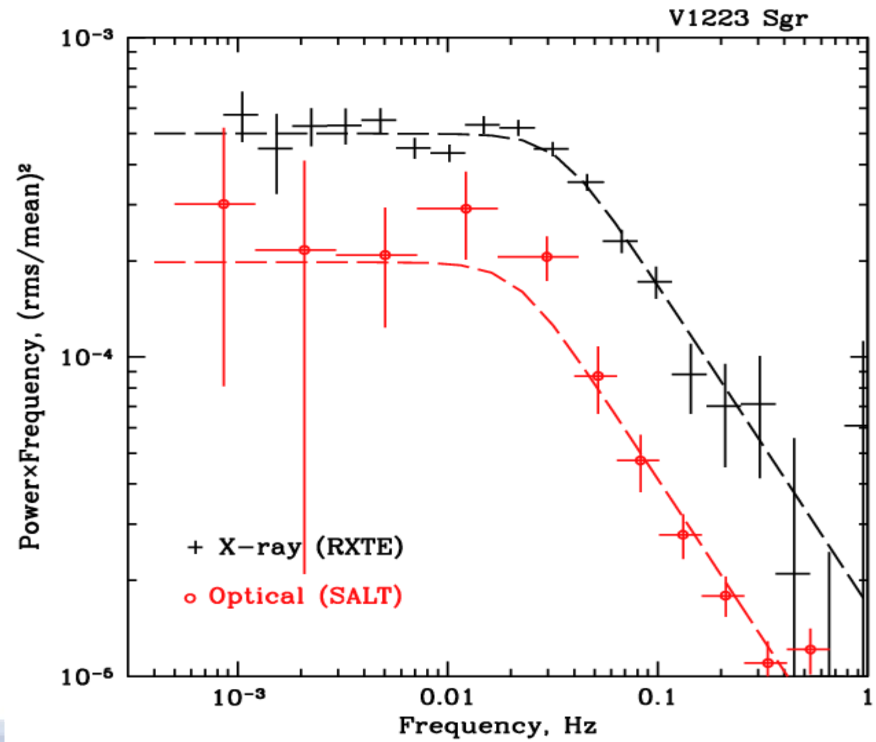
V1223 Sgr
Spin period
f_b=7×10^-2 Hz
R_in=9×10^8 cm
Opt (SAAO)
X-ray (RXTE), simult.
Power xFrequency, (rms/mean)²
Frequency, Hz



TV Col
V1223 Sgr
Crosscorelation
Deloy, sec



TV Col
f_b=5×10^-2 Hz
Spin period
Opt (SAAO)
X-ray (RXTE), simult.
X-ray (RXTE), total
Power xFrequency, (rms/mean)²
Frequency, Hz



V1223 Sgr
+ X-ray (RXTE)
o Optical (SALT)
Power×Frequency, (rms/mean)²
Frequency, Hz

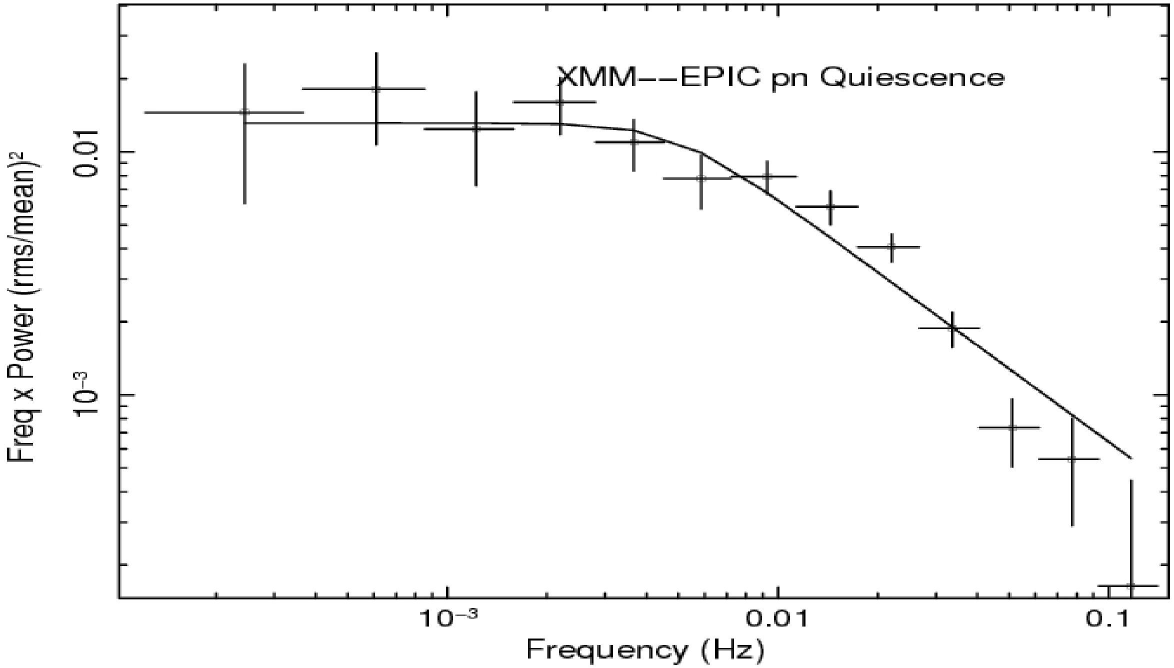
Investigating DNe Inner Disk Structure with Broadband Noise

SS Cyg

40 d, 2.4 d

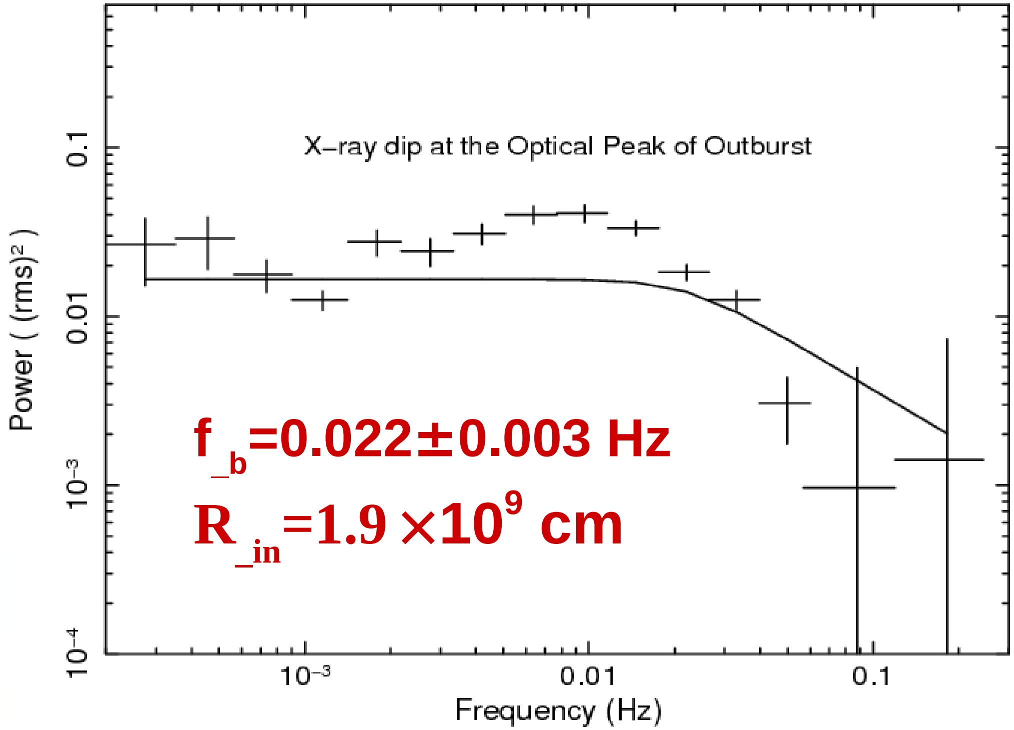
6.6 hrs

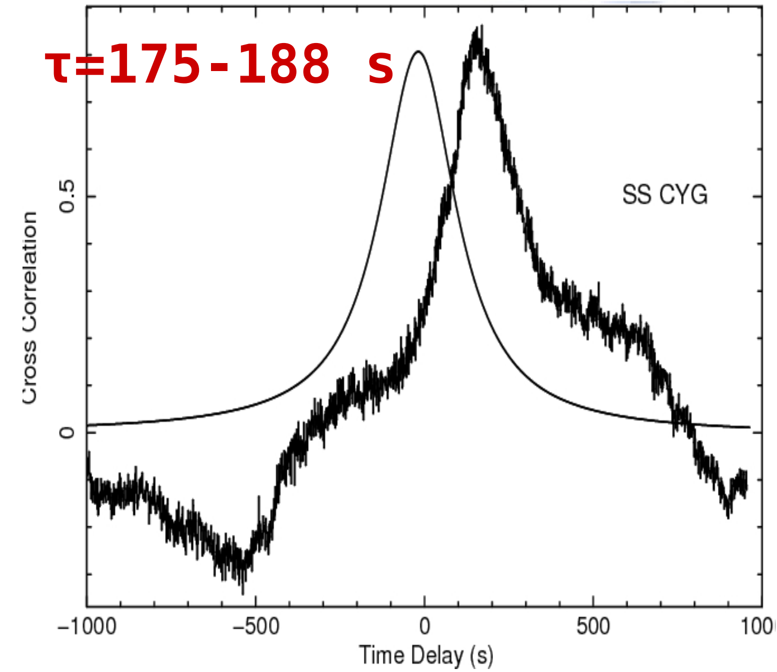
~19 keV

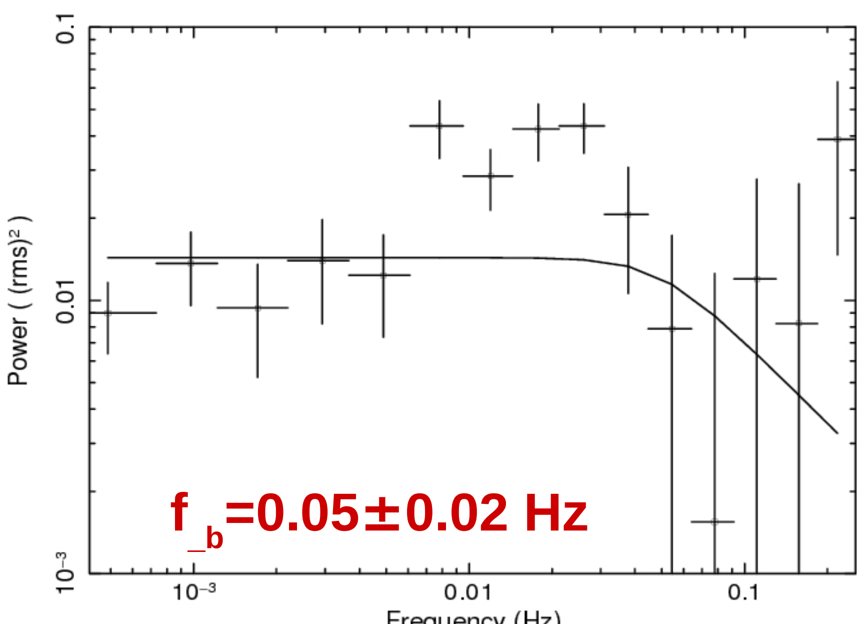


$f_{\_b}$=0.0056±0.0014 Hz

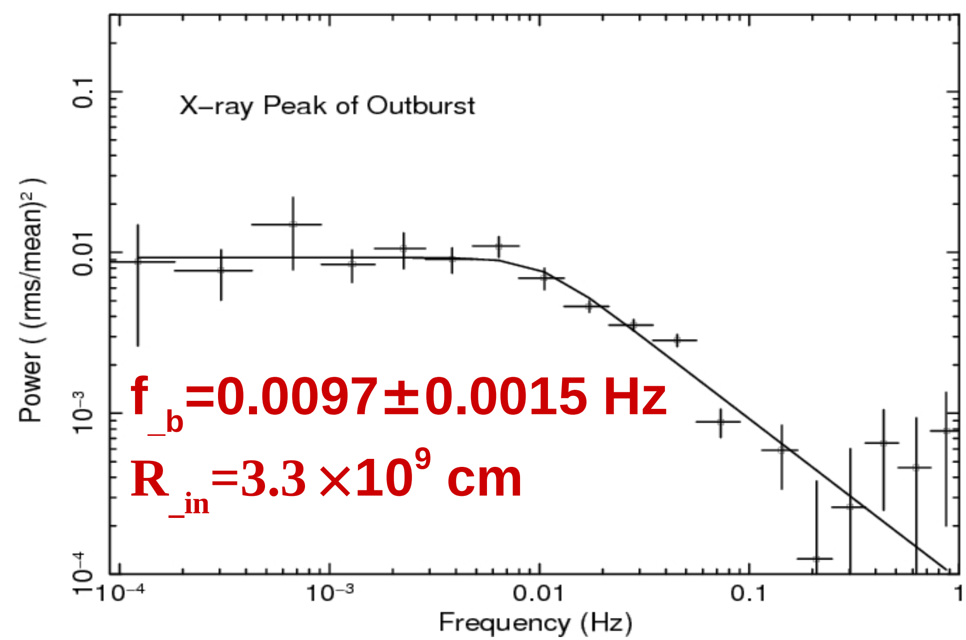
$R_{\_in}$=4.8 ×10^9 cm







$R_{\_in}=1.1\times10^9$ cm

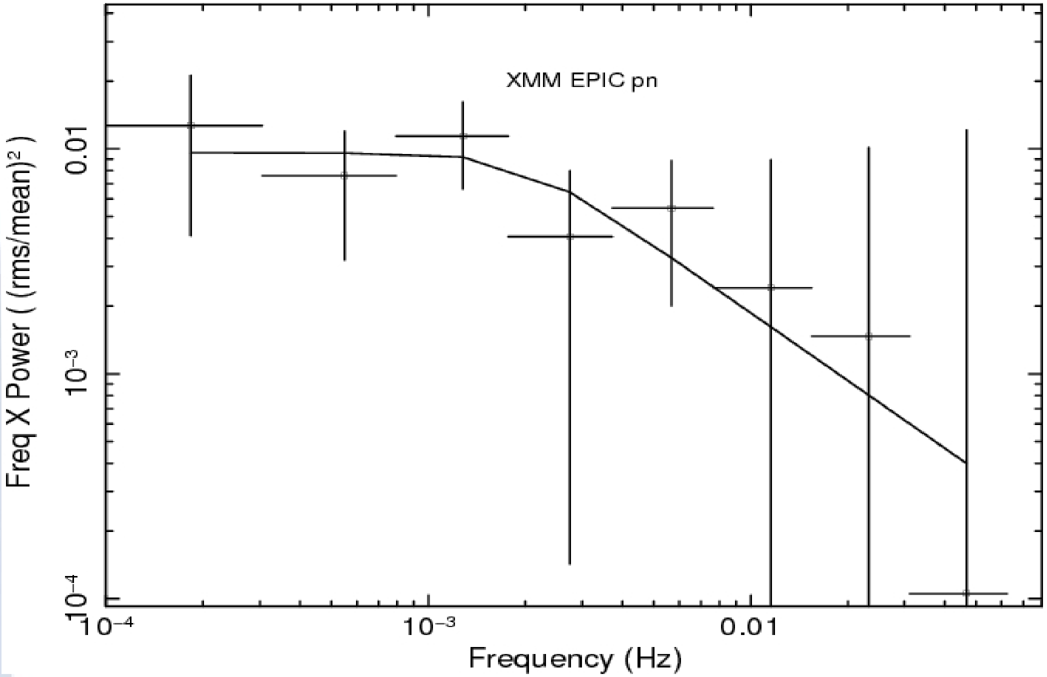


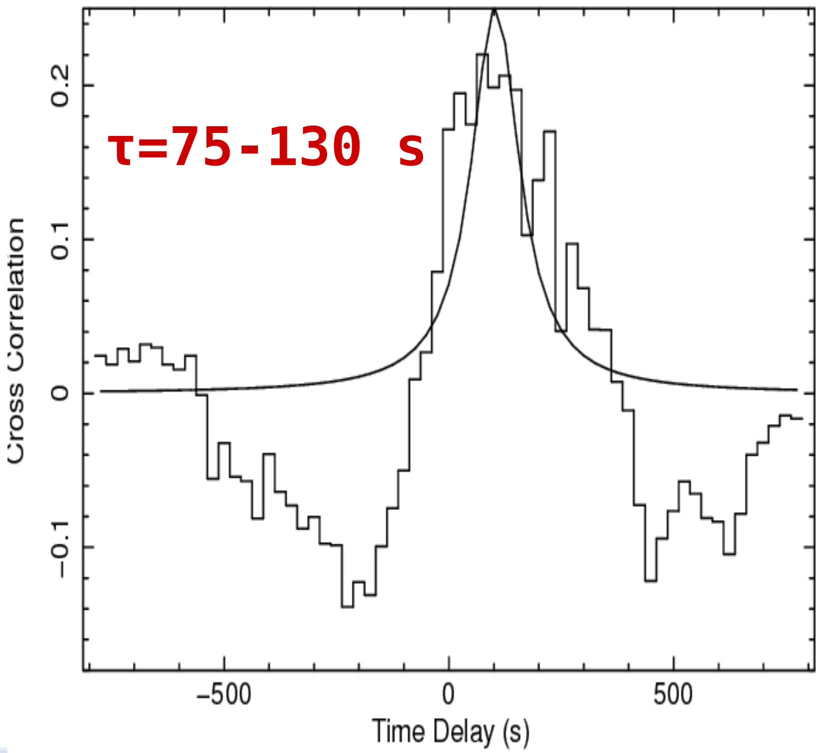
VW Hyi

28 d, <1 d, 179 d

107 min

~9 keV





$R_{\_in}$=8.1 ×10^9 cm

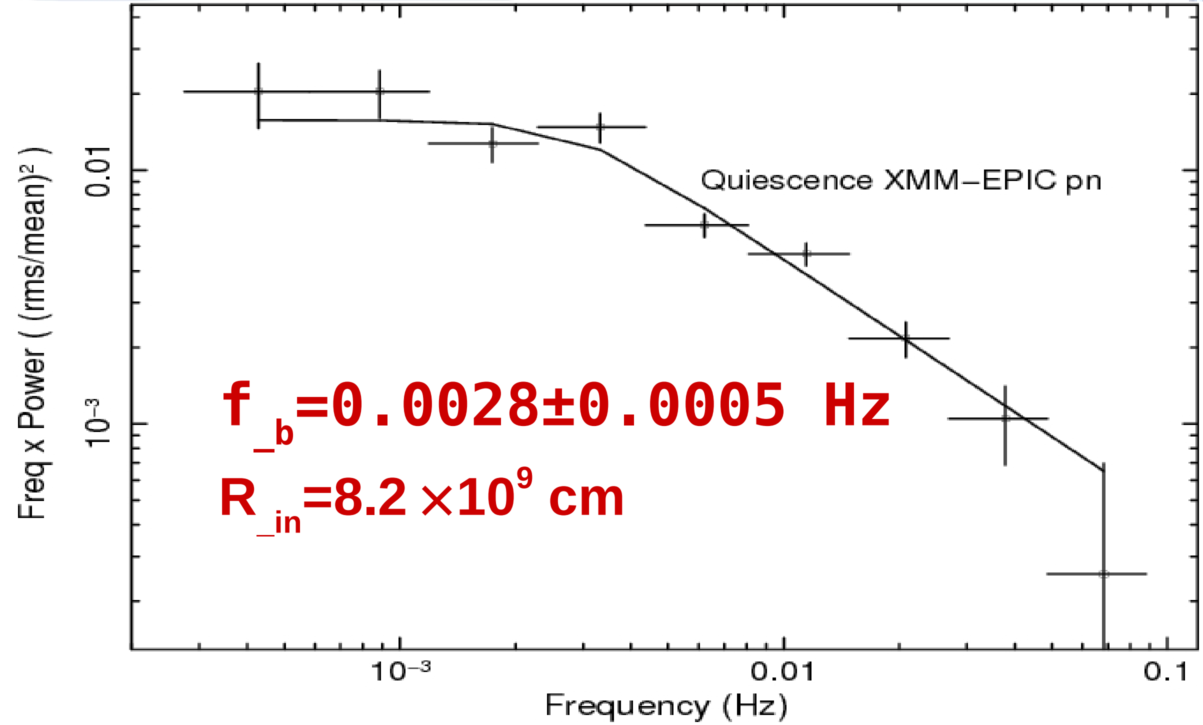
$f_{\_b}$=0.002±0.001 Hz

RU Peg

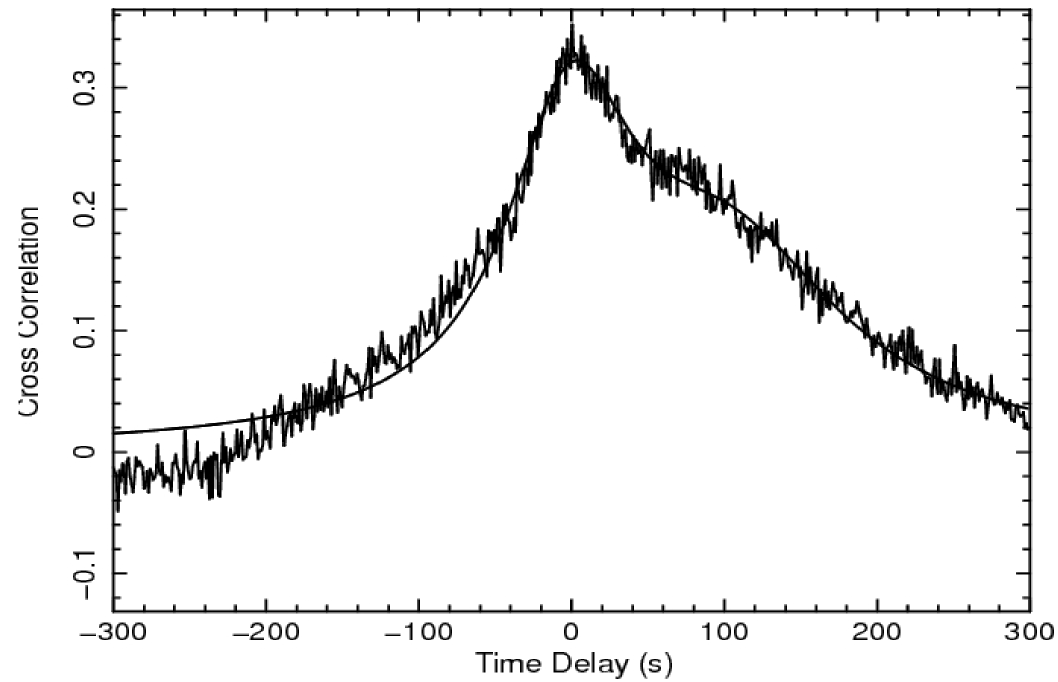
50 d, 20 d

8.99 hr

~31 keV



τ=100-130 s



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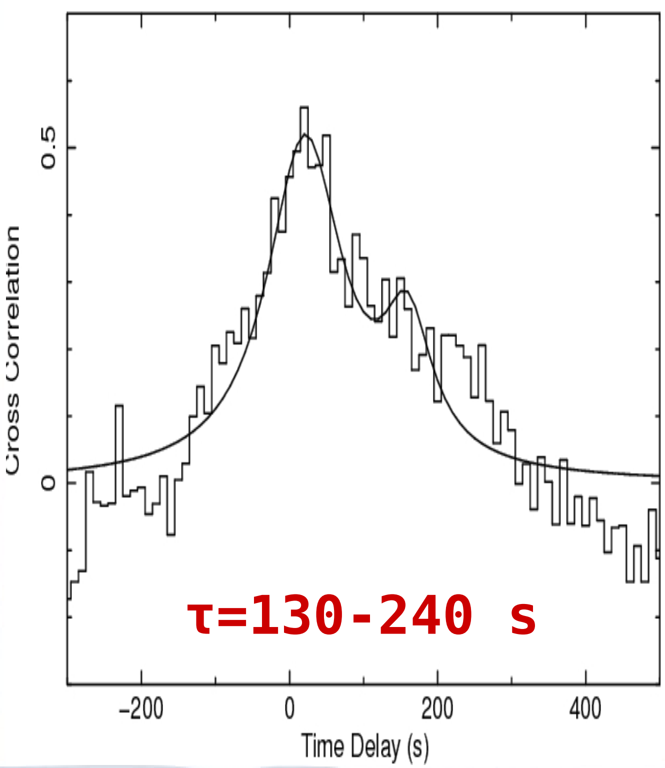
WW Cet

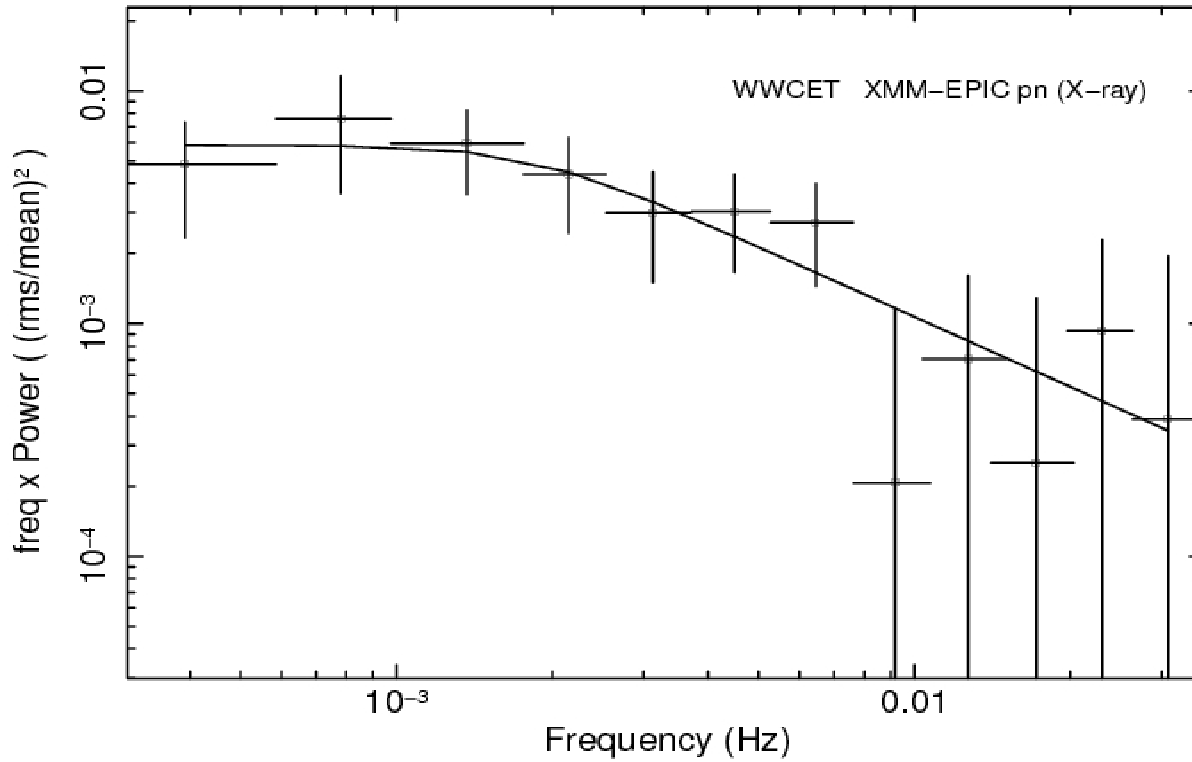
45 d

253 min

~15 keV



τ=130-240 s



$f_{\_b}$=0.0018±0.0009 Hz

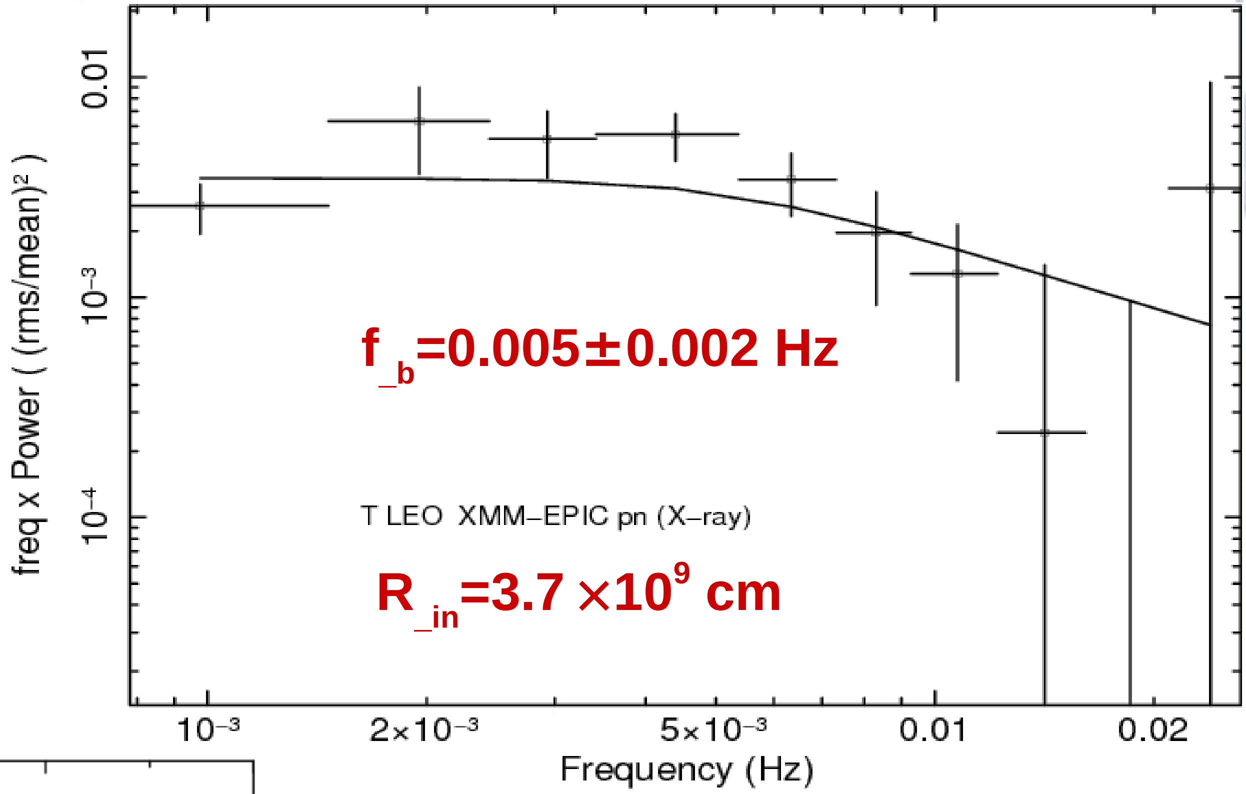
$R_{\_in}$=9.6 ×10^9 cm

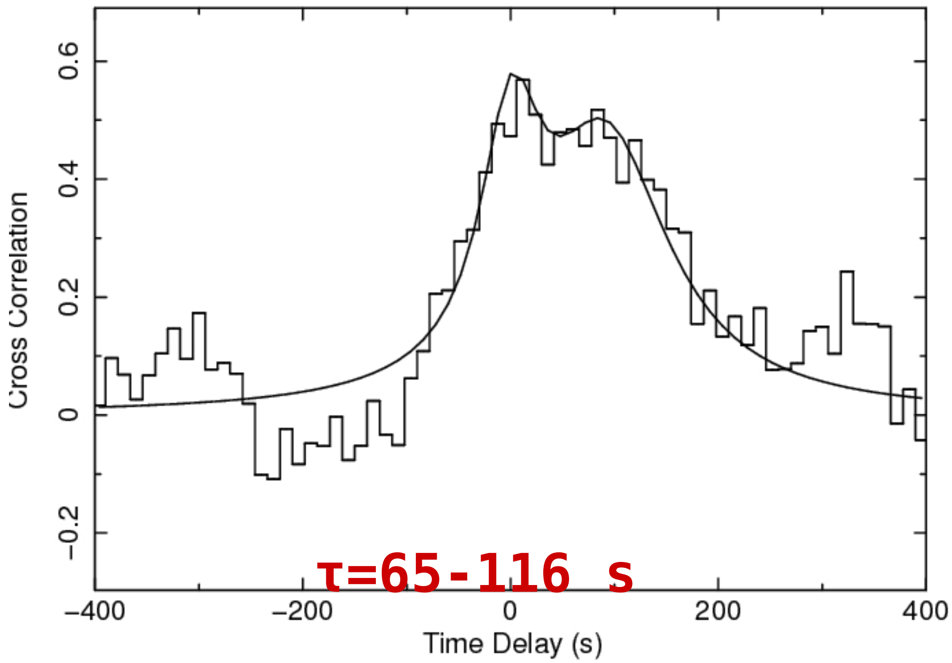
T Leo

?? , 420 d

84.7 min

~11 keV





Conclusions

- We detect large scale truncation in the Disks of Dwarf Novae (DN) in at least 5-7 systems with radii in a range $R_{tr} \simeq 0.5\text{-}1.5\times10^{10}$ cm. The Magnetic CVs (MCVs) show rather smaller truncation radii ~$0.9\text{-}1.9\times10^{9}$ 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.