



Cataclysmic Variables and Disk structure Using the X-ray Wavelengths

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Nonmagnetic CVs

- **Dwarf Novae**

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

U Gem Type: $P_{\text{orb}} > 3\text{hrs}$, No Superoutbursts

Z Cam Type: Standstills

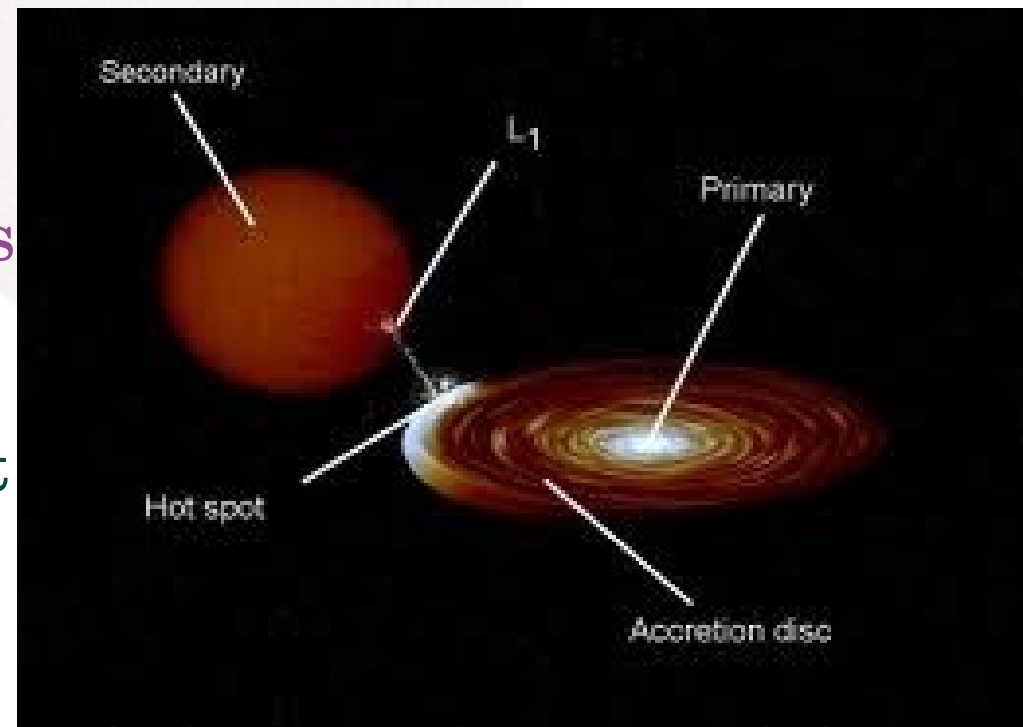
SU UMa Type: $P_{\text{orb}} < 2\text{hrs}$

Superoutbursts

- **Nova-like Variables**

- **Classical and Recurrent**

Novae (10^{43} - 10^{46} erg)



X-ray Emission from Nonmagnetic CVs

Boundary Layer (BL)

$$L_{\text{BL}} \approx L_{\text{disk}} = GM_{\text{wd}} \dot{M}_{\text{acc}} / 2R_{\text{wd}} = L_{\text{acc}} / 2$$

**matter decelerates from
Keplerian velocities to the
slowly rotating WD $L_{\text{BL}} \approx L_{\text{x}}$**

(Patterson & Raymond 1985;
Narayan & Popham 1993, Popham
& Narayan 1995, Godon et al. 1995,
Hertfelder et al. 2013)

Optically thick BL

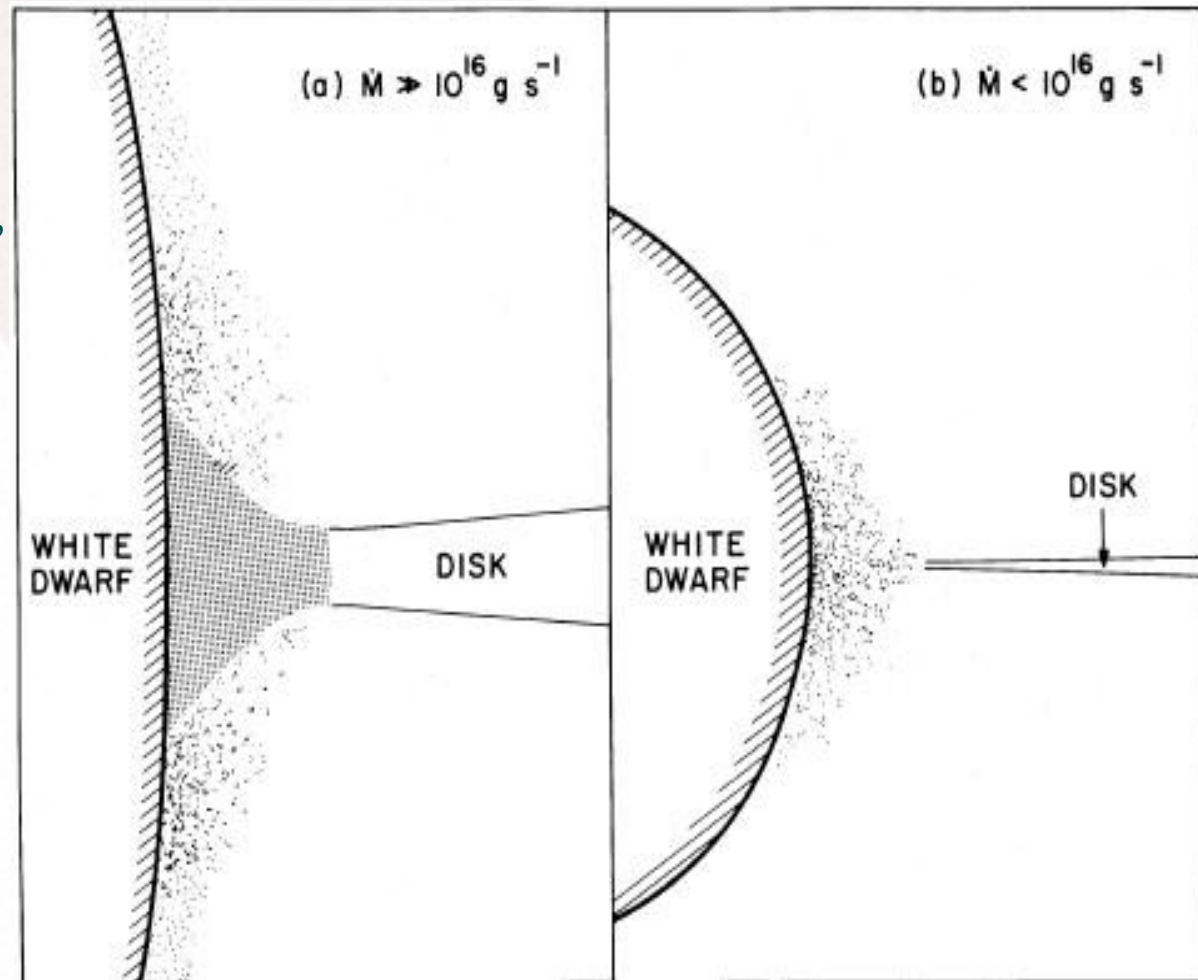
→ Soft X-rays $\sim 10^5$ K

$$\dot{M} > 10^{-9} M_{\odot} / \text{yr}$$

Optically thin BL $\sim 10^8$ K

→ Hard X-rays

$$\dot{M} < 10^{-9} M_{\odot} / \text{yr}$$



Dwarf Novae in QUIESCENCE -- X-rays

Low-mass accretion, $\dot{M}_{\text{acc}} = 10^{-12} - 10^{-10} M_{\odot} / \text{yr}$ ($L_{\text{x}} \sim 10^{31-32} \text{ erg/s}$), BL \rightarrow optically thin \blacktriangleright hard X-ray emission, Multi-temperature isobaric cooling flow model plasma emission with $T_{\text{max}} = 9-55 \text{ keV}$

(see **Baskill et al. 2005**, **Kuulkers et al. 2006**; **Pandel et al. 2005**, **Rana et al. 2006**, **Singh et al. 2006**, **Balman et al. 2011**)

Dwarf Novae in OUTBURST – X-rays

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**)

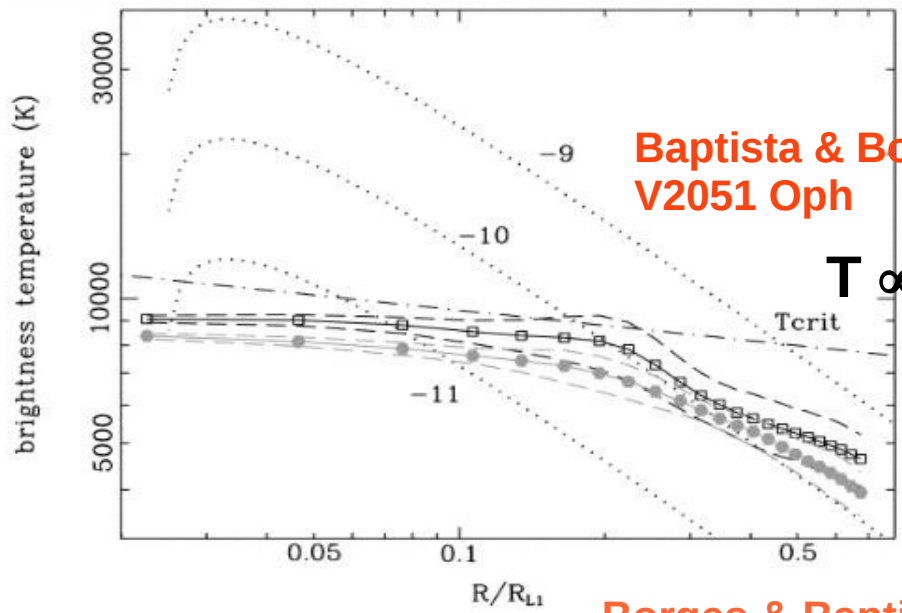
BL with $10^5 - 10^6 \text{ K}$ emitting in the soft X-ray to EUV ($kT \sim 5-30 \text{ eV}$, **(Mauche et al. 1995; Mauche & Raymond 2000, Mauche 2004, Byckling et al. 2009)**)

Suppressed (low Flux) hard X-ray emission during optical bright phases (peak) **(MacGowen et al. 2004, Wheatley et al. 2003, Collins & Wheatley 2010, Fertig et al. 2011)**. Some systems U Gem (**Güver et al. 2006**) GW Lib (**Byckling et al. 2009**) show increased X-ray emission. $L_{\text{x}} \sim 10^{31-33} \text{ erg/s}$ in outburst.

UV and X-ray delays in rise to outburst (w.r.t. Optical).

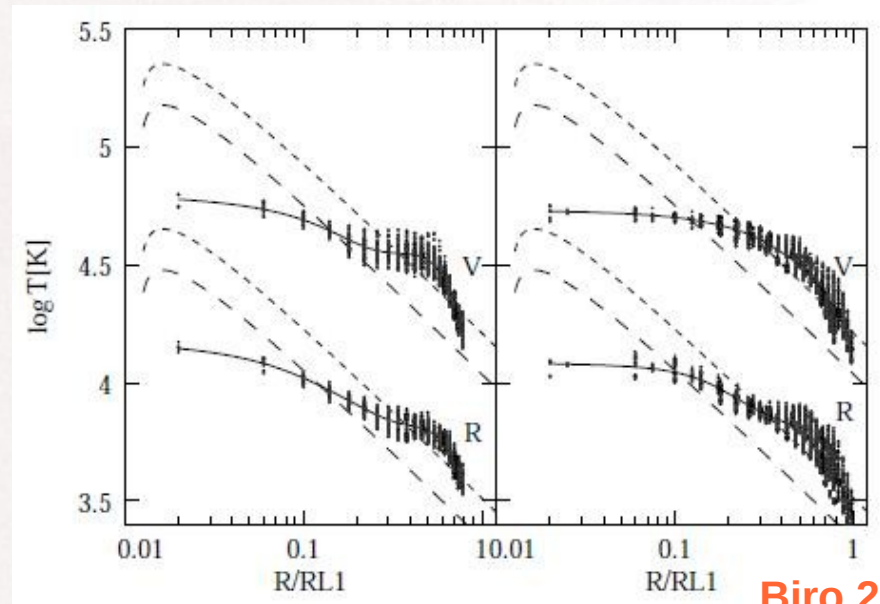
During outburst -- no eclipses seen or much orbital variations.

Eclipse Mapping of DN

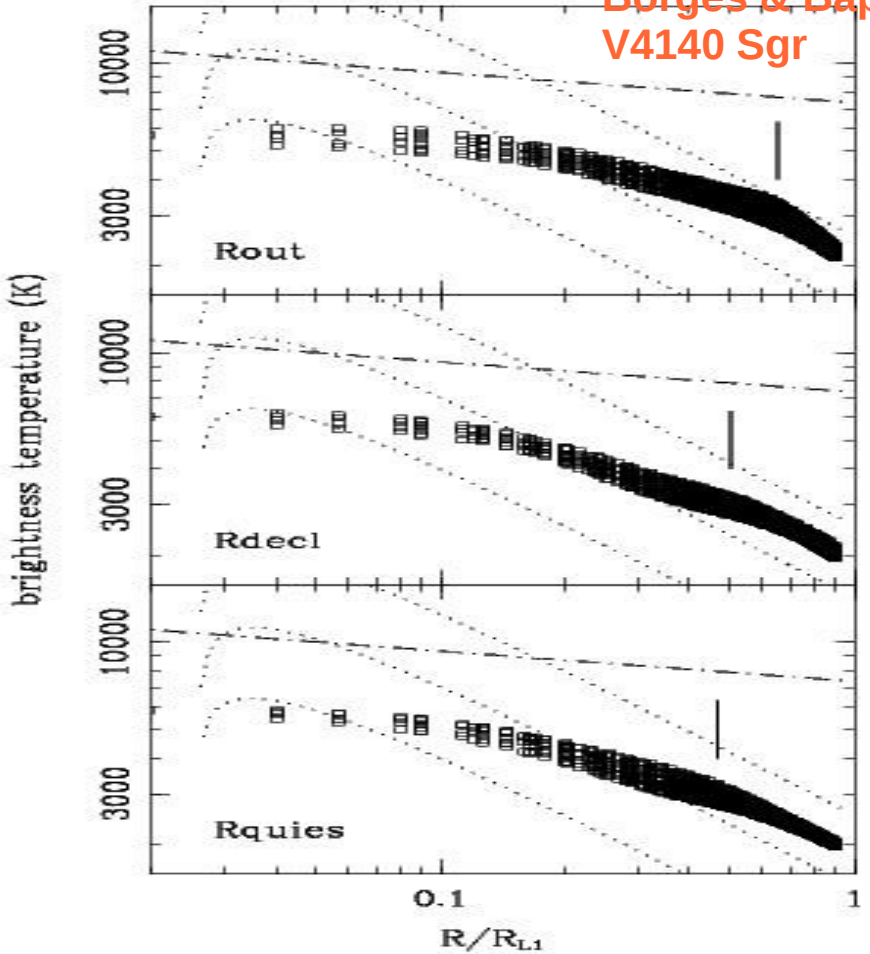


Baptista & Bortoletto 2004
V2051 Oph

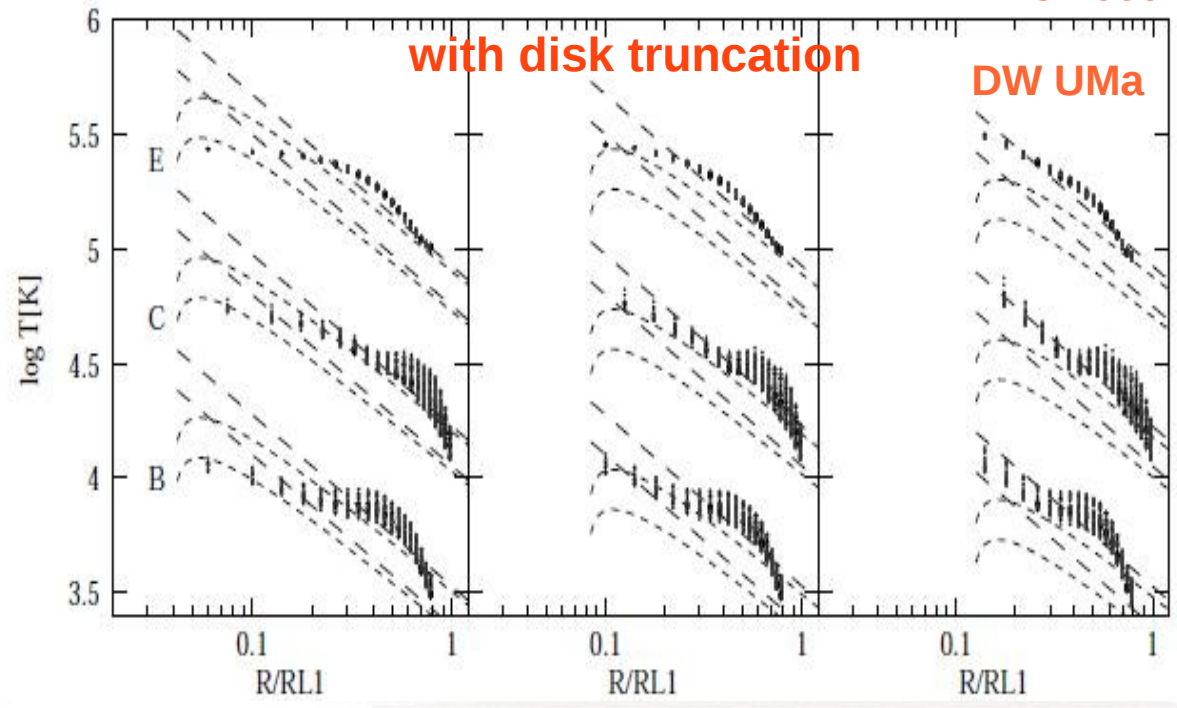
$$T \propto r^{-3/4}$$



Biro 2000

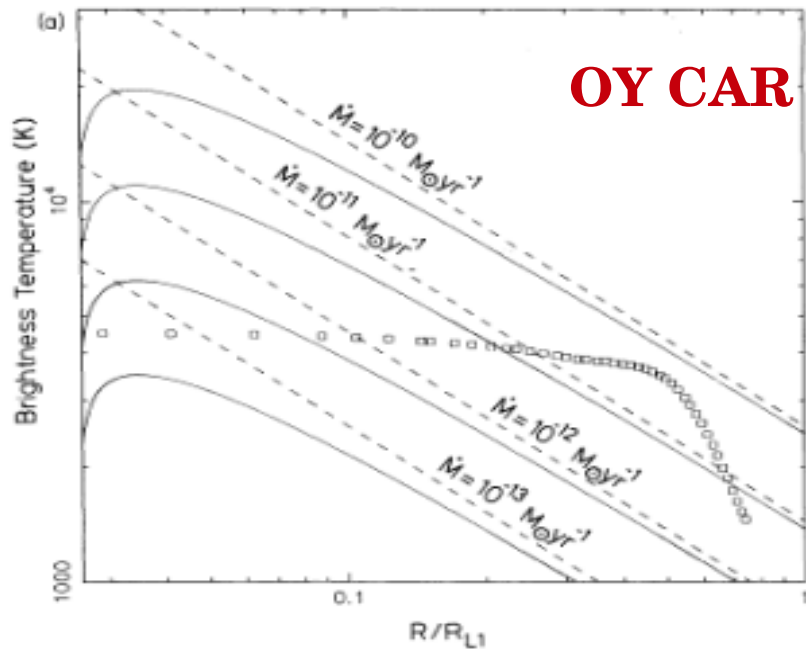


Borges & Baptista 2005
V4140 Sgr

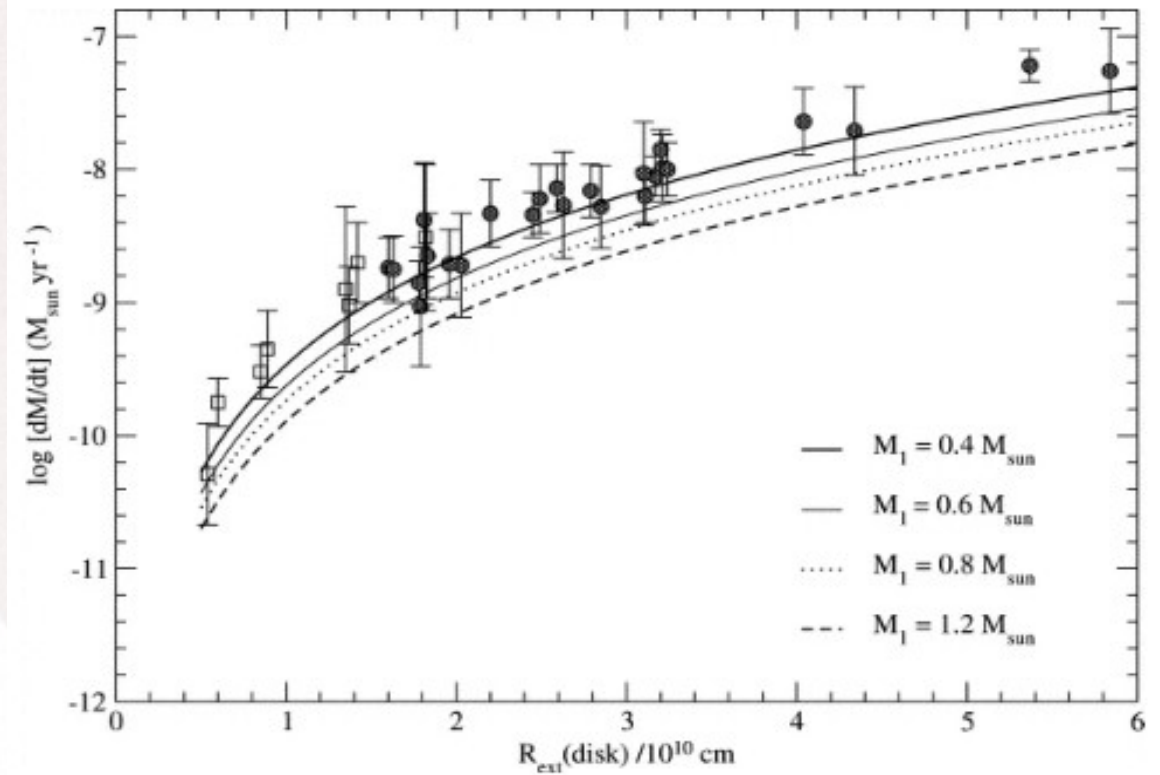
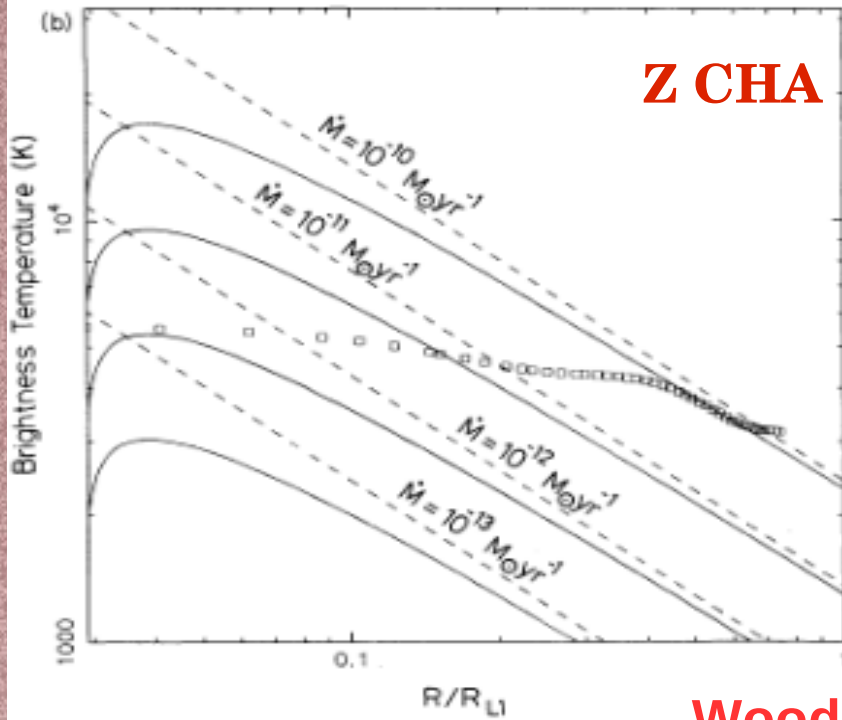


DW UMa

OY CAR



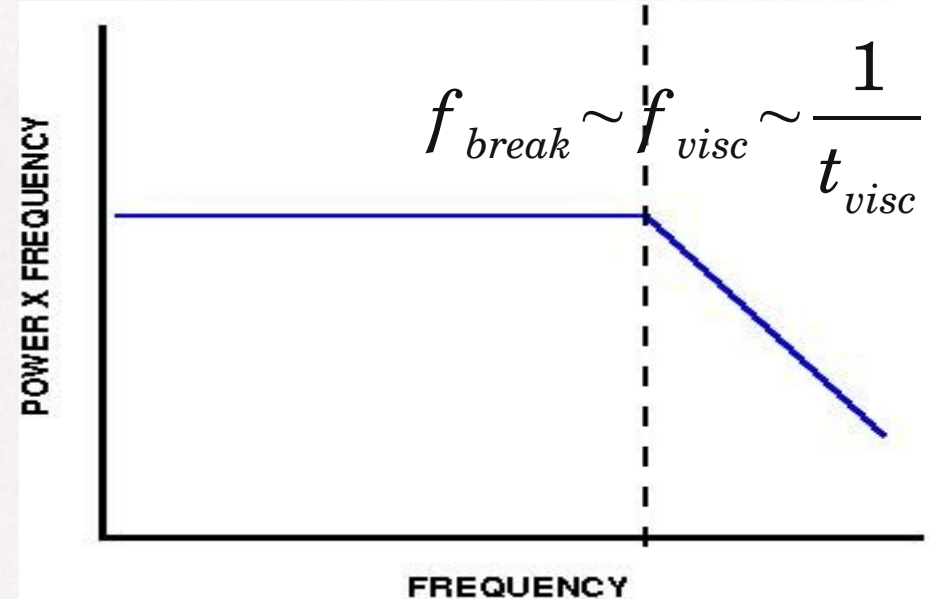
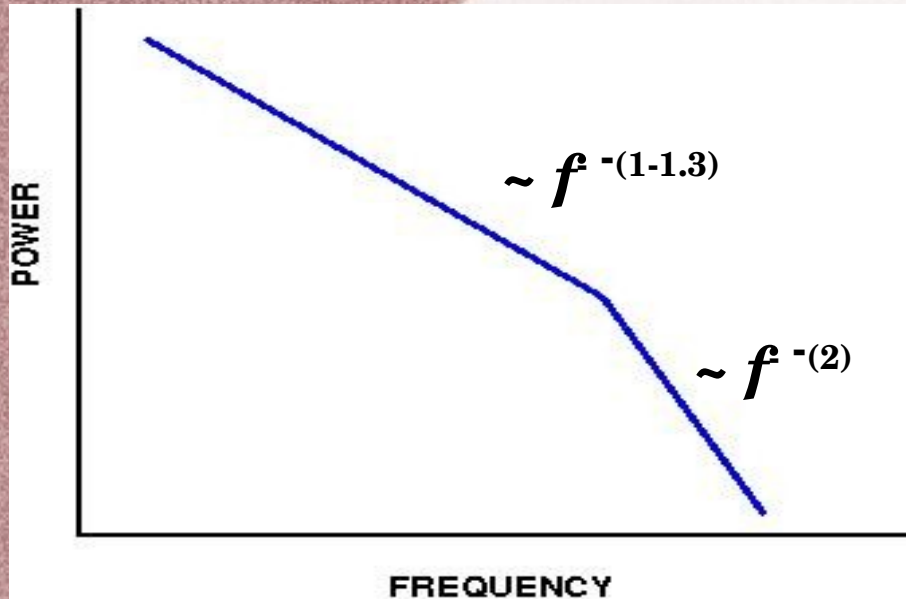
Z CHA



Puebla et al. 2007

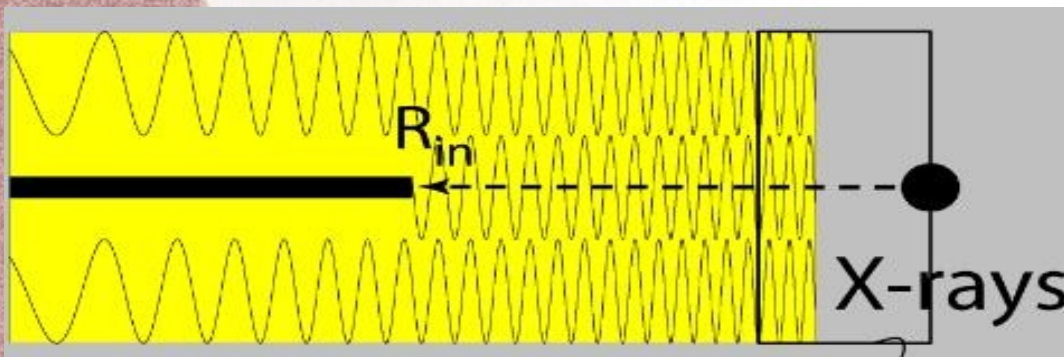
Woods et al. 1990

Accretion Flows--Matter Fluctuations-- Broadband Noise



In the framework of propagating matter fluctuations in the accretion disk

(Churazov et al. 2001, Revnivtsev et al. 2009, 2010, Uttley & McHardy 2001, Uttley et al. 2011, Scaringi et al. 2012)



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

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

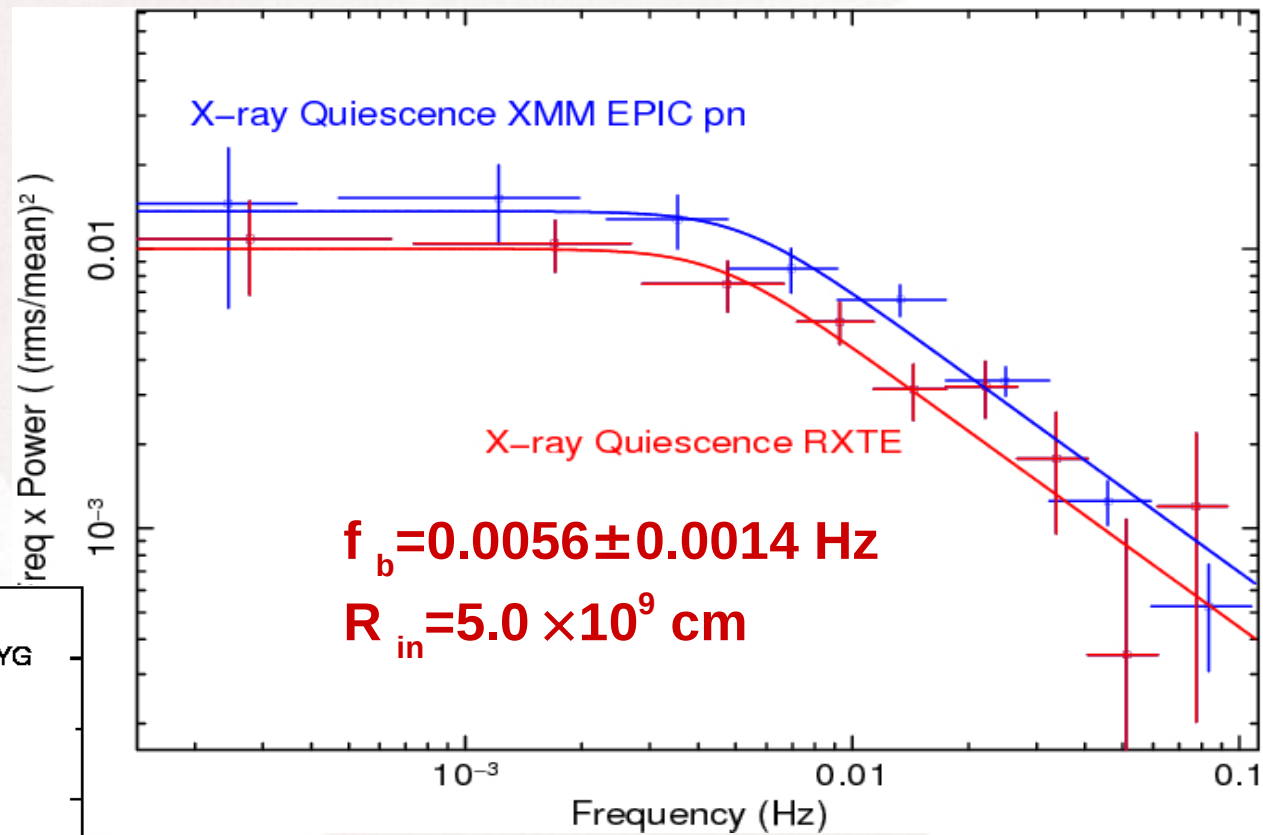
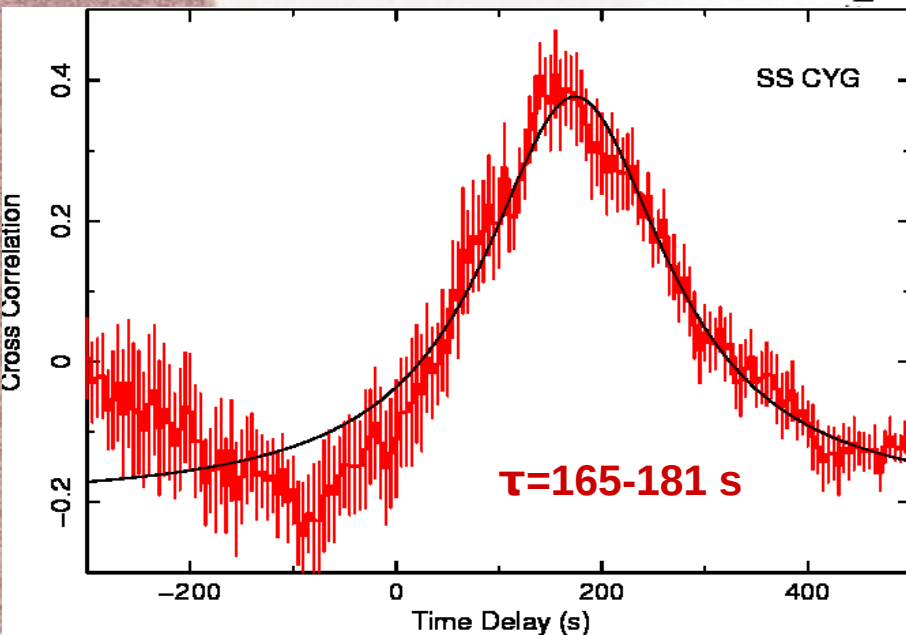
Investigating DNe Inner Disk Structure with Broadband Noise

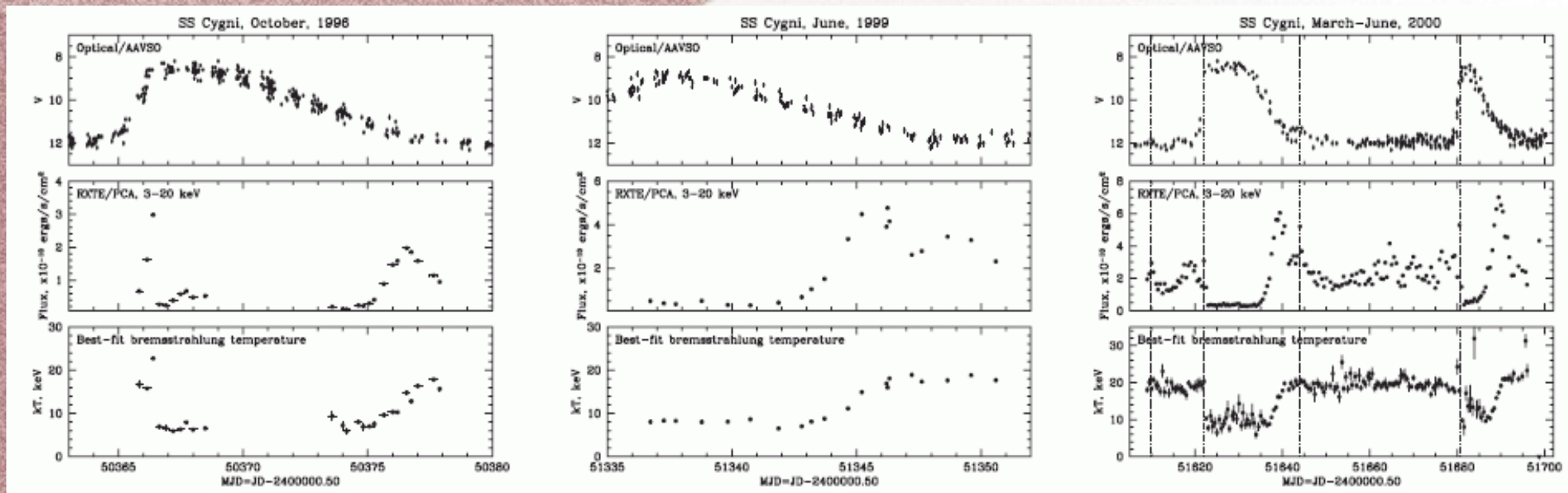
SS Cyg

40 d, 15-20 d

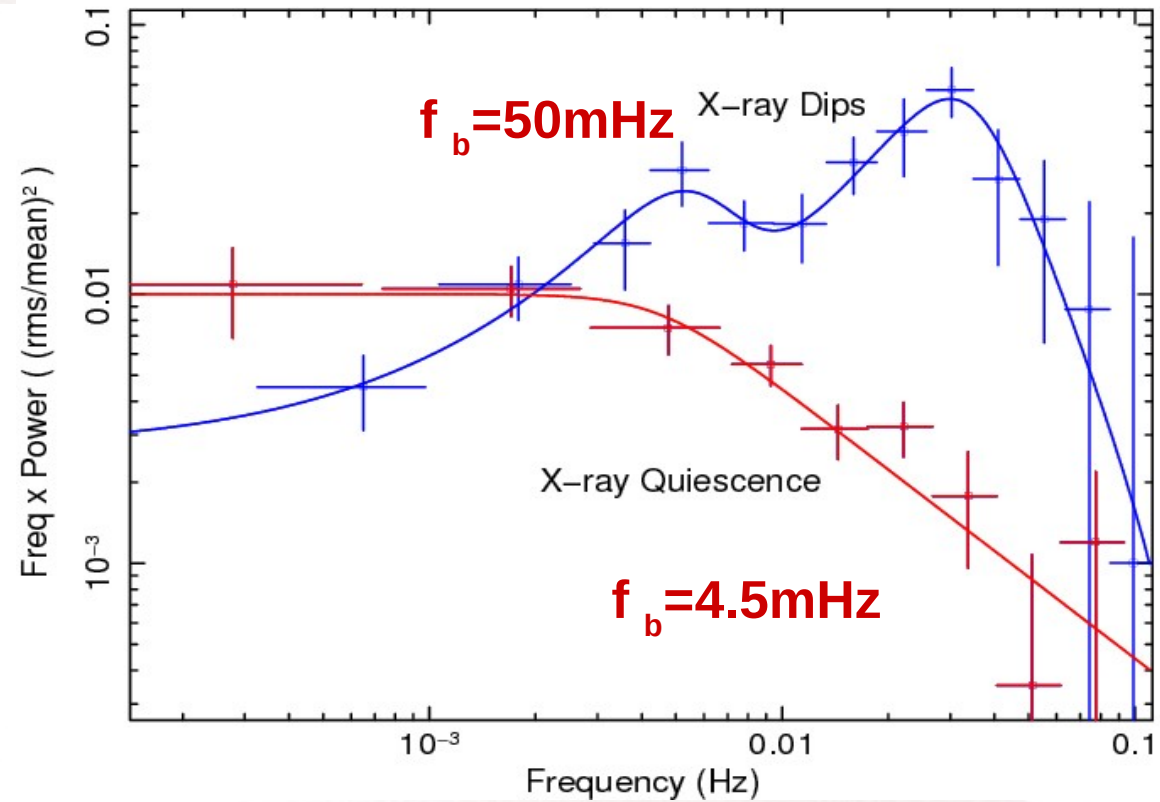
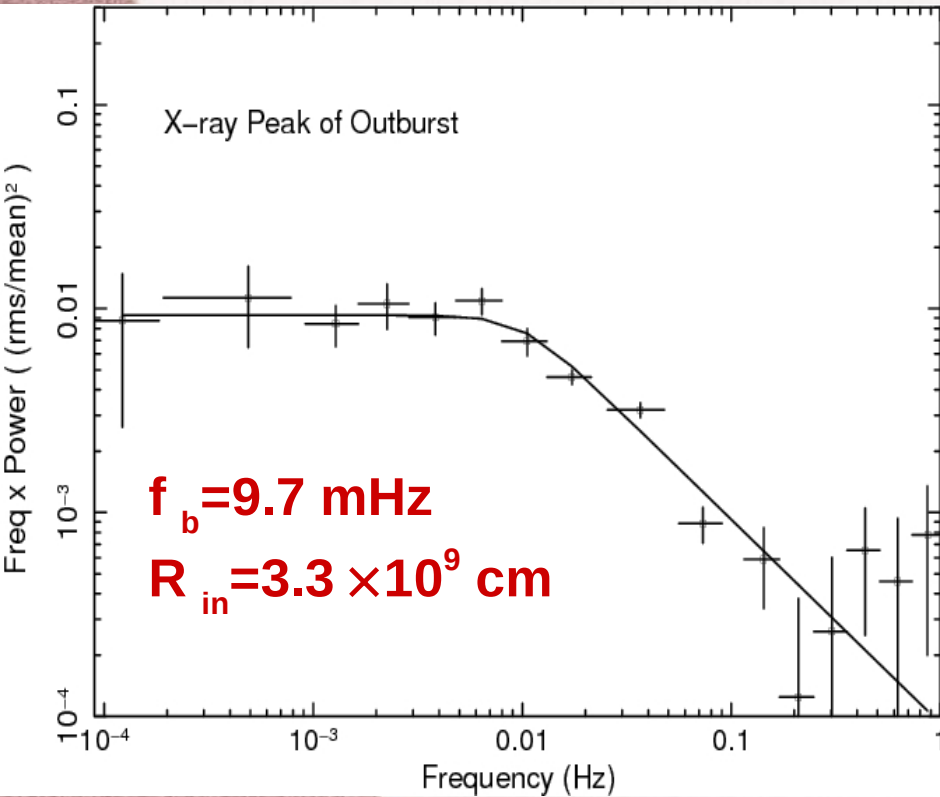
6.6 hrs

~20 keV





McGowan et al. 2004; (see also Wheatley et al. 2003)



Balman & Revnivtsev 2012

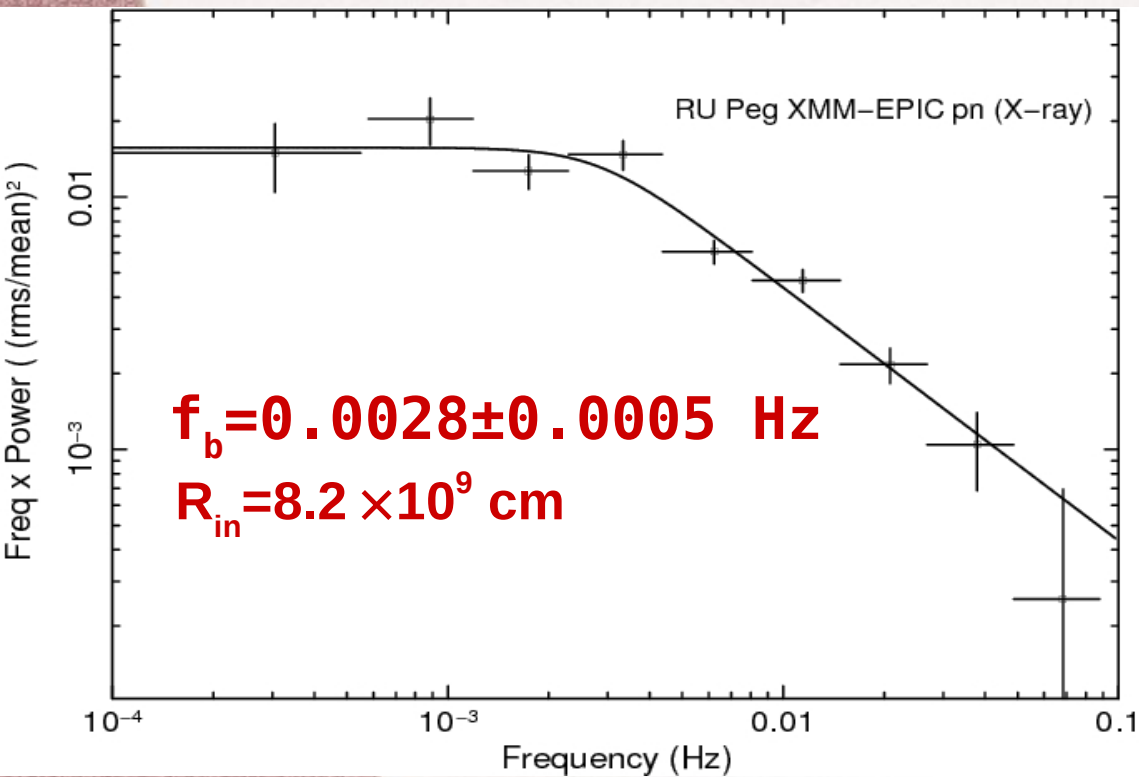
$R_{in} = 1.1 \times 10^9$ cm \rightarrow 5.5×10^9 cm

RU Peg

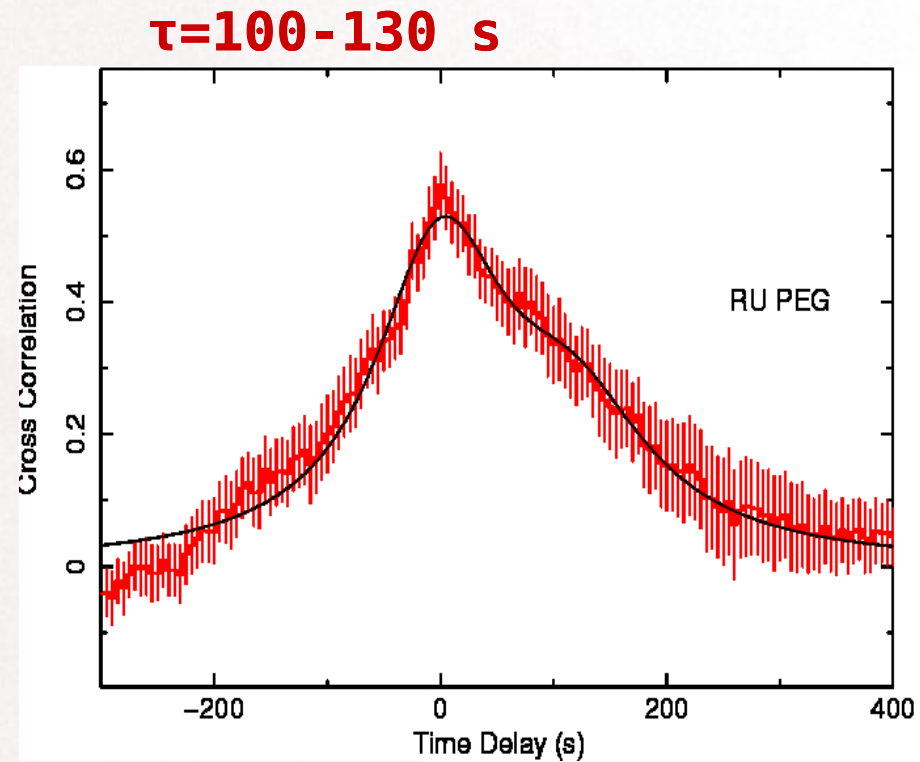
50 d, 20 d

8.99 hr

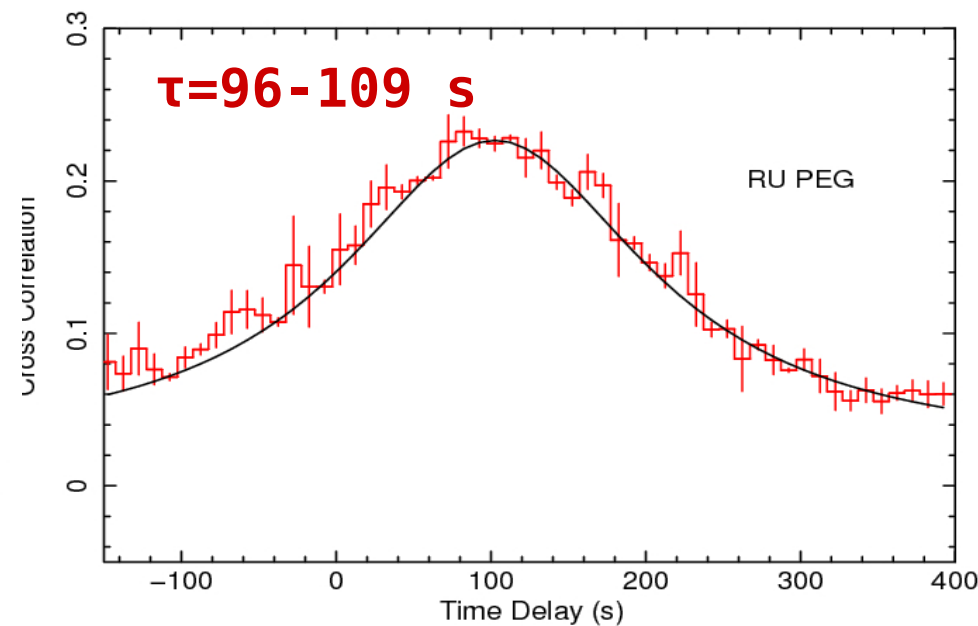
~31 keV



Balman & Revnivitsev 2012



Balman et al. 2011

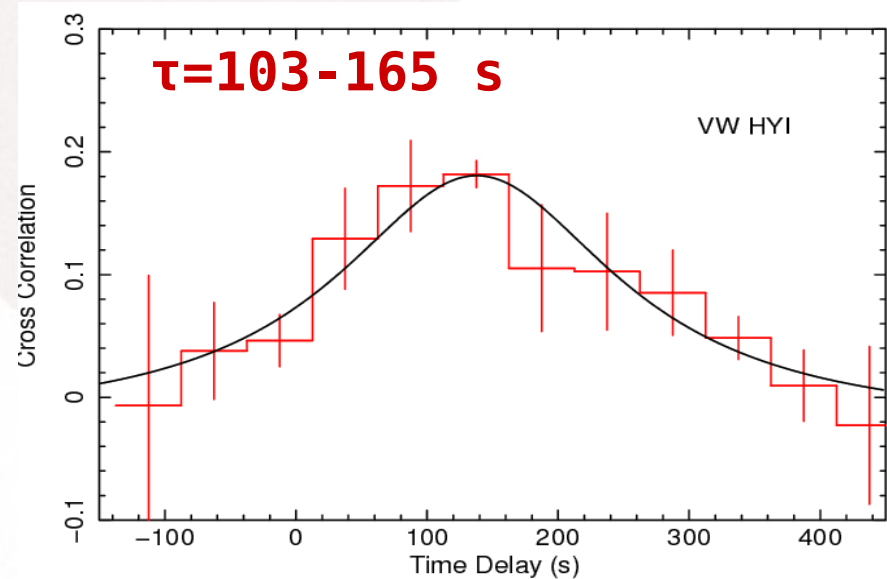
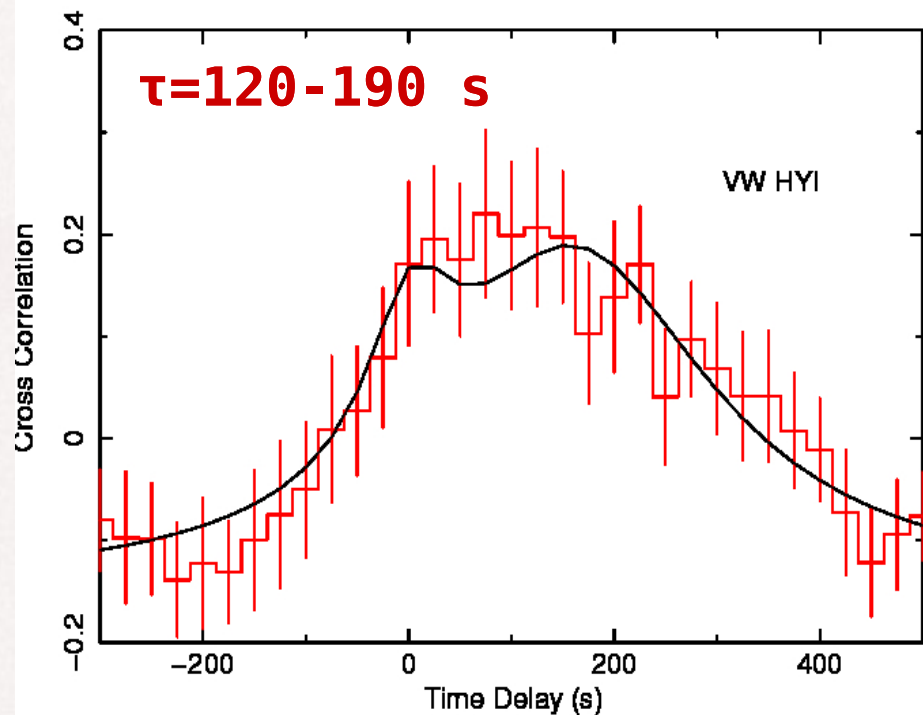
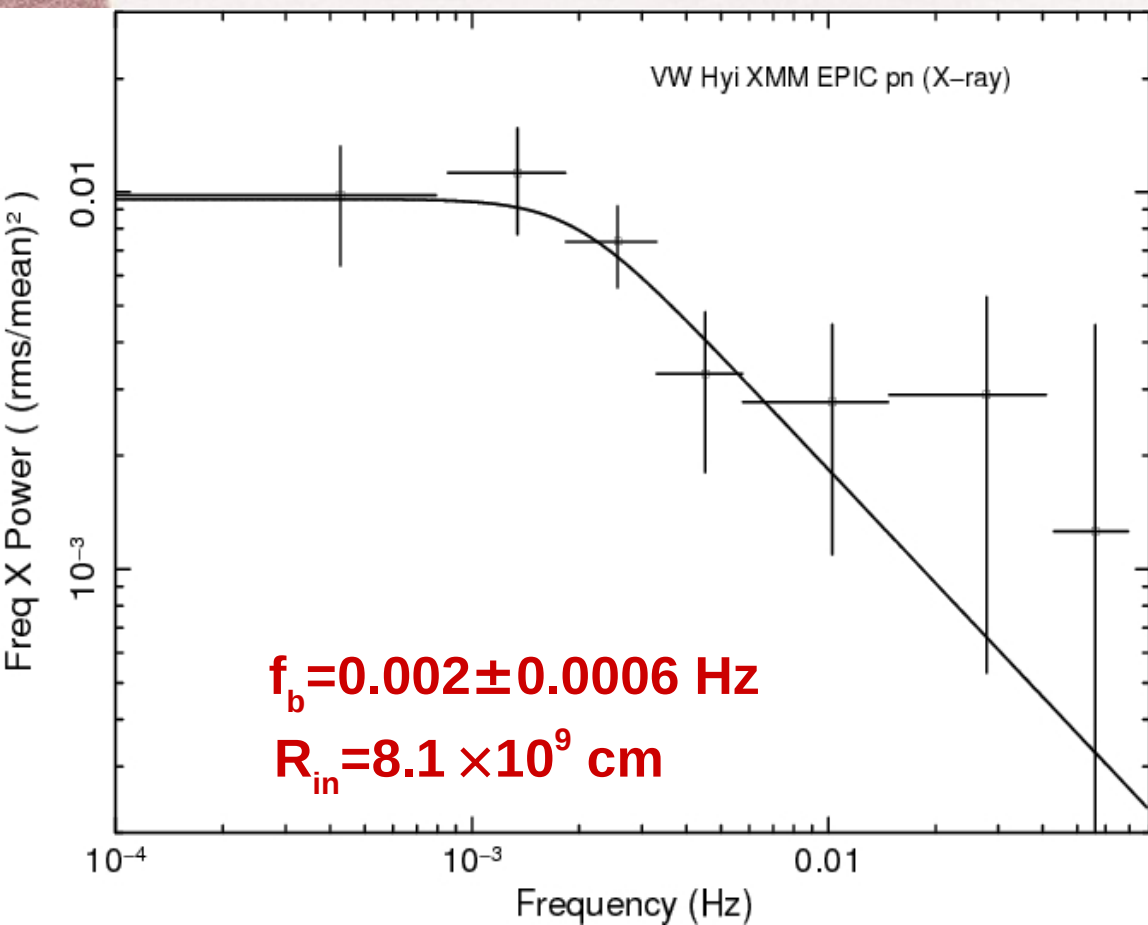


VW Hyi

28 d, 179 d

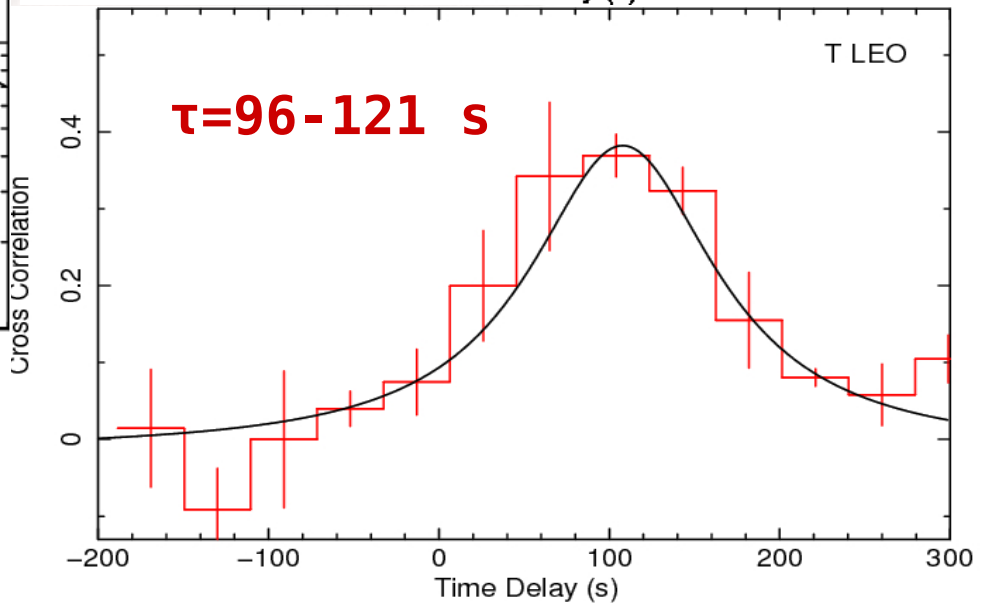
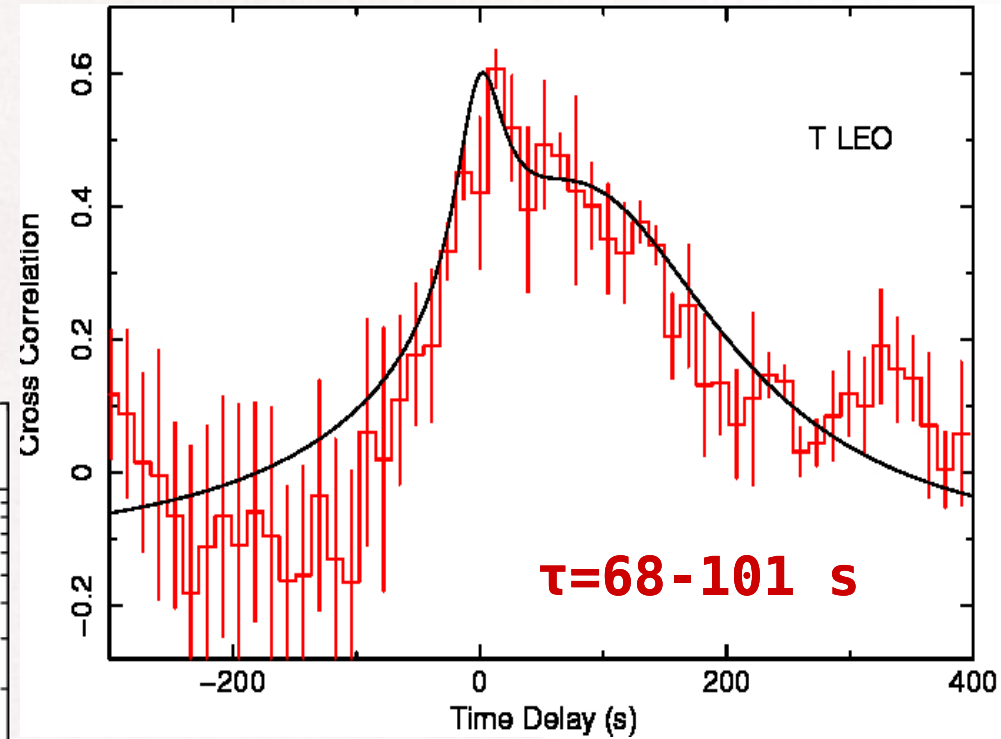
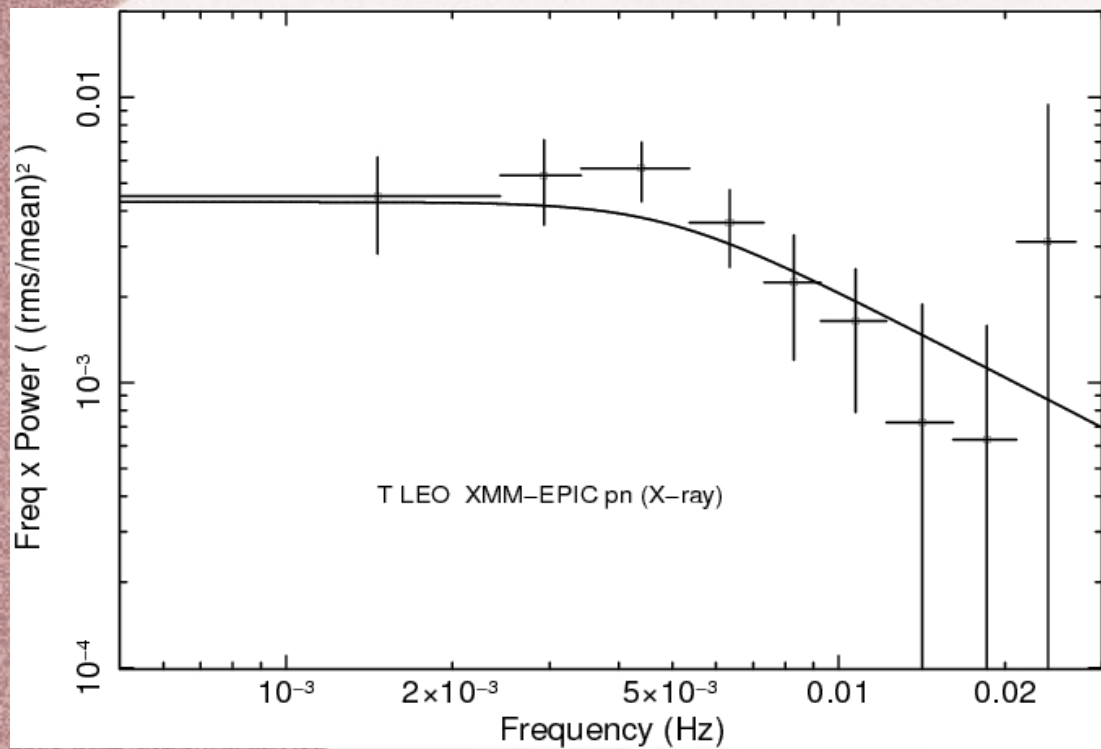
107 min

~9 keV



Balman & Revnivtsev 2012

T Leo
?? , 420 d
84.7 min
~11 keV



$$f_b = 0.0045 \pm 0.0015 \text{ Hz}$$

$$R_{in} = 4.0 \times 10^9 \text{ cm}$$

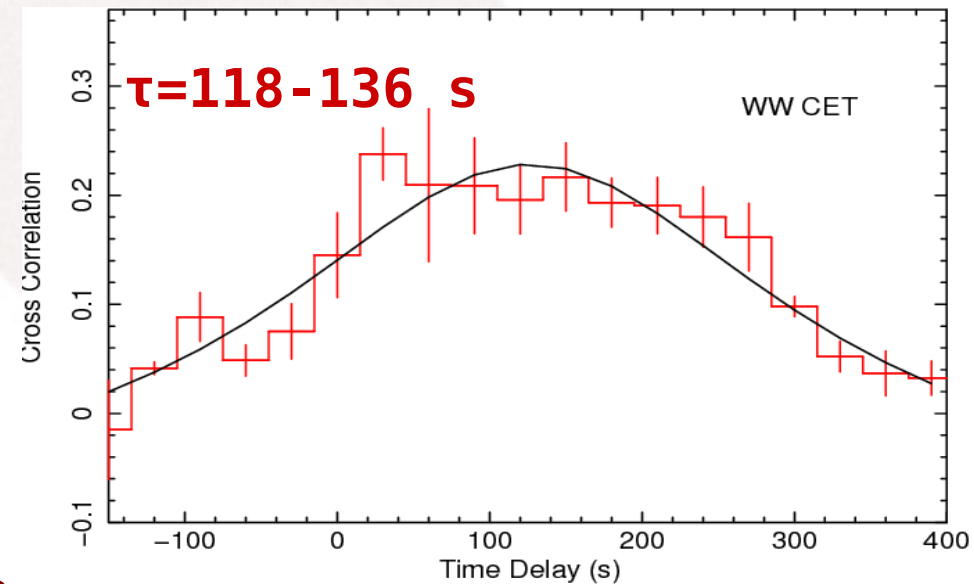
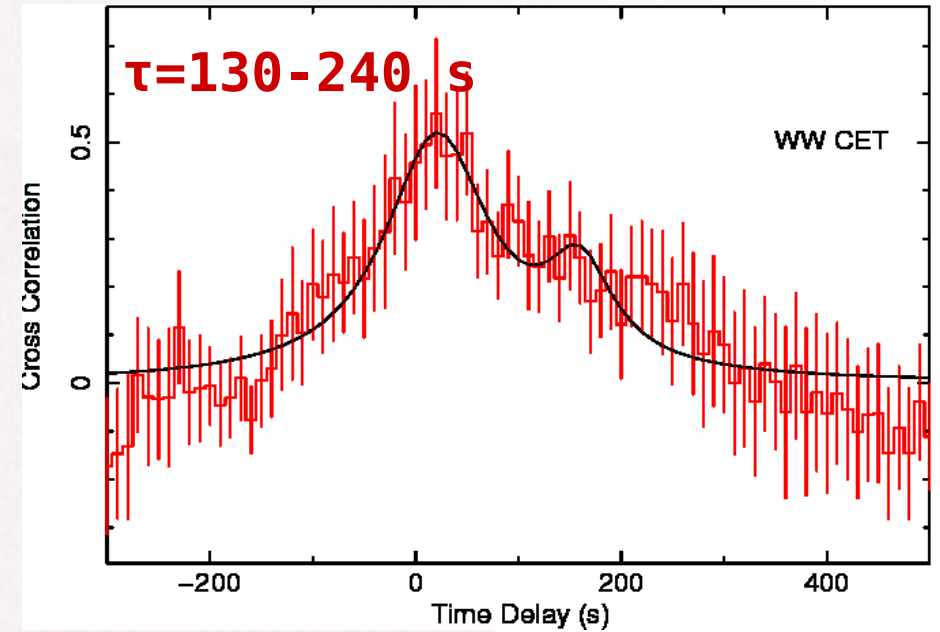
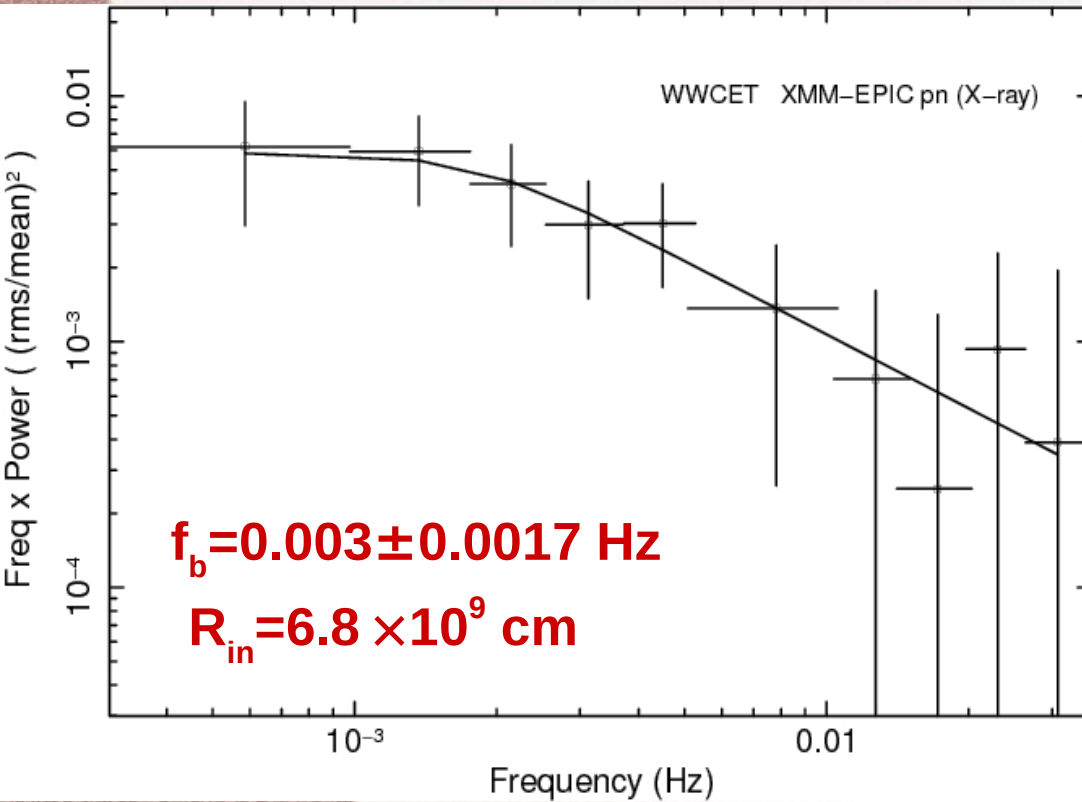
Balman & Revnivtsev 2012

WW Cet

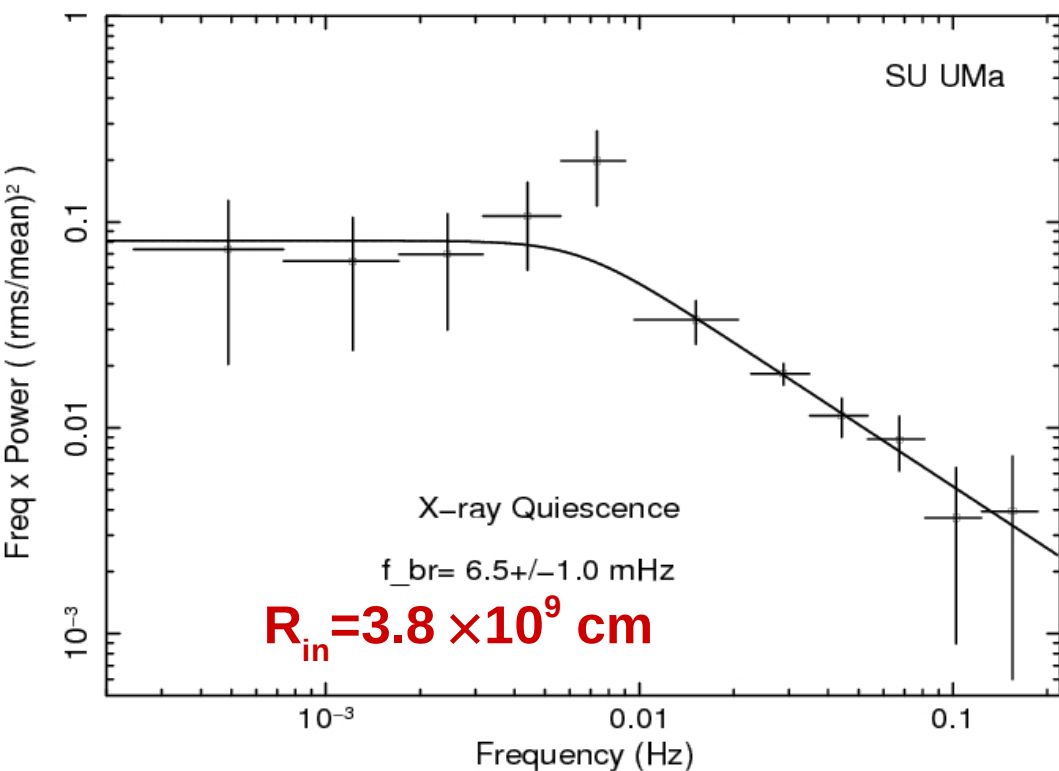
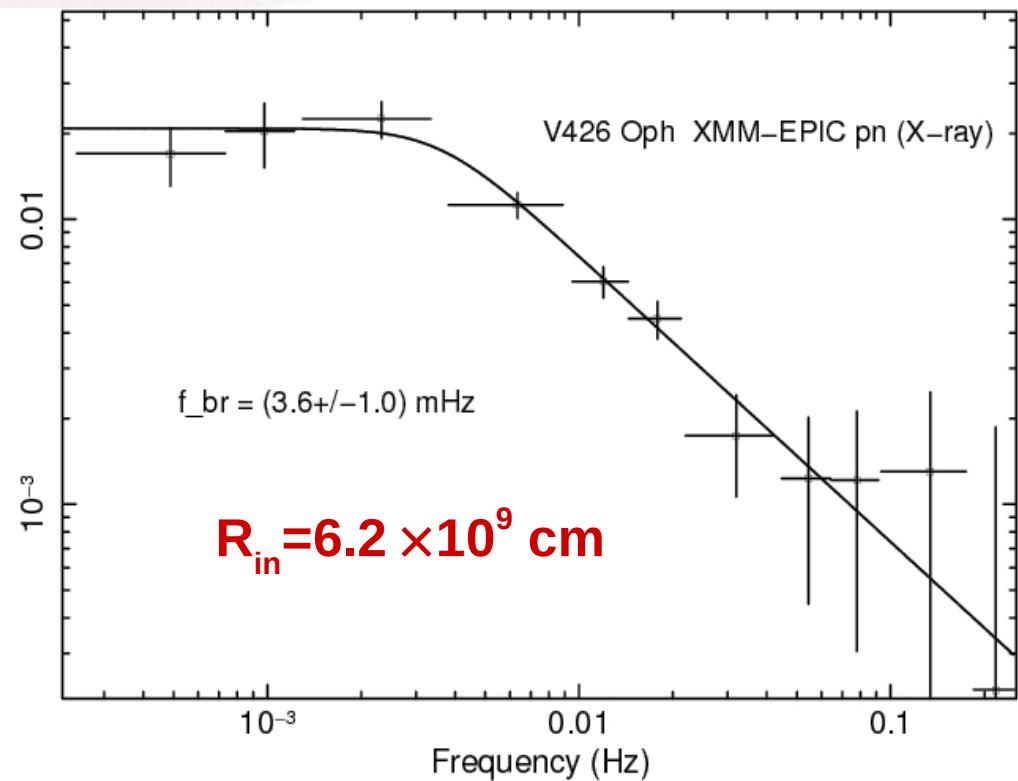
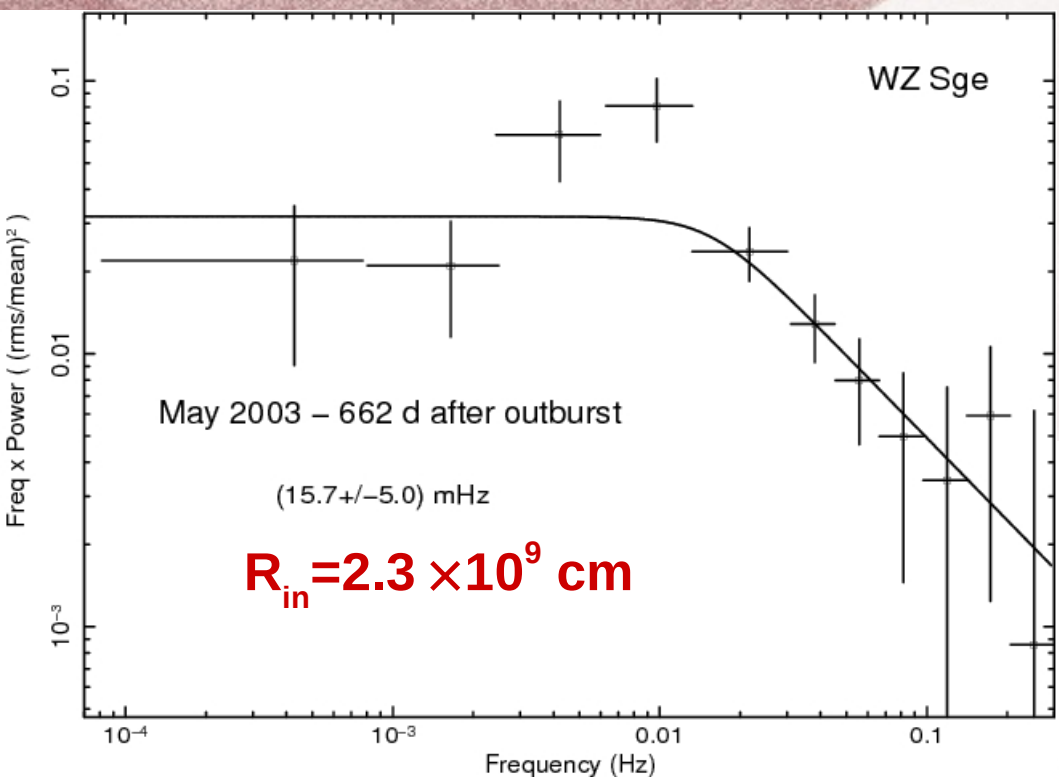
45 d

253 min

~15 keV

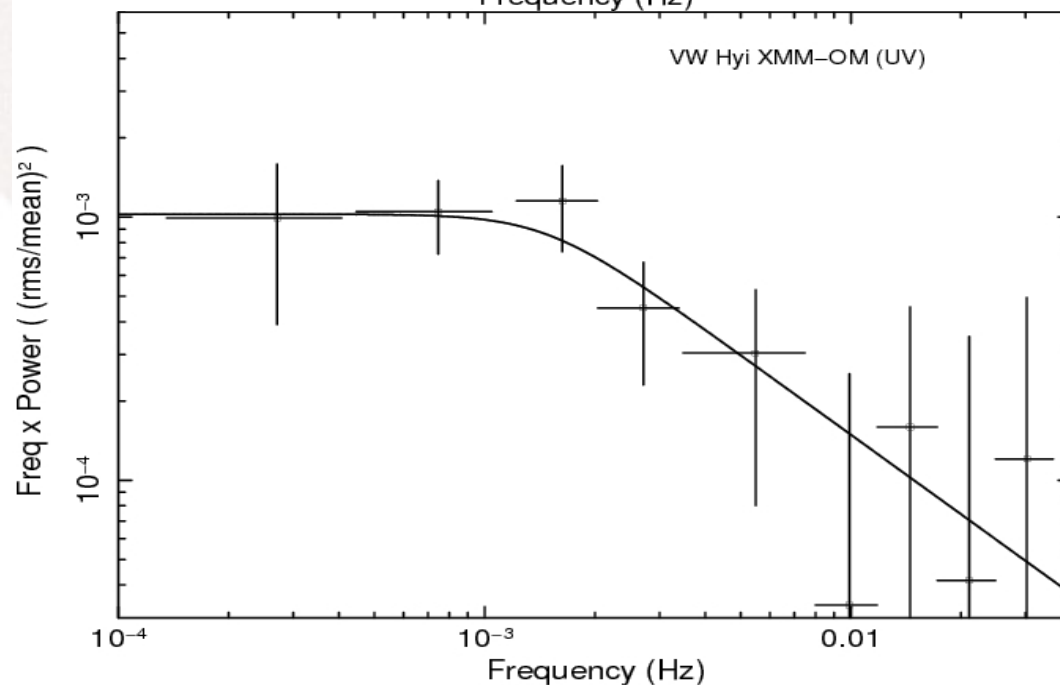
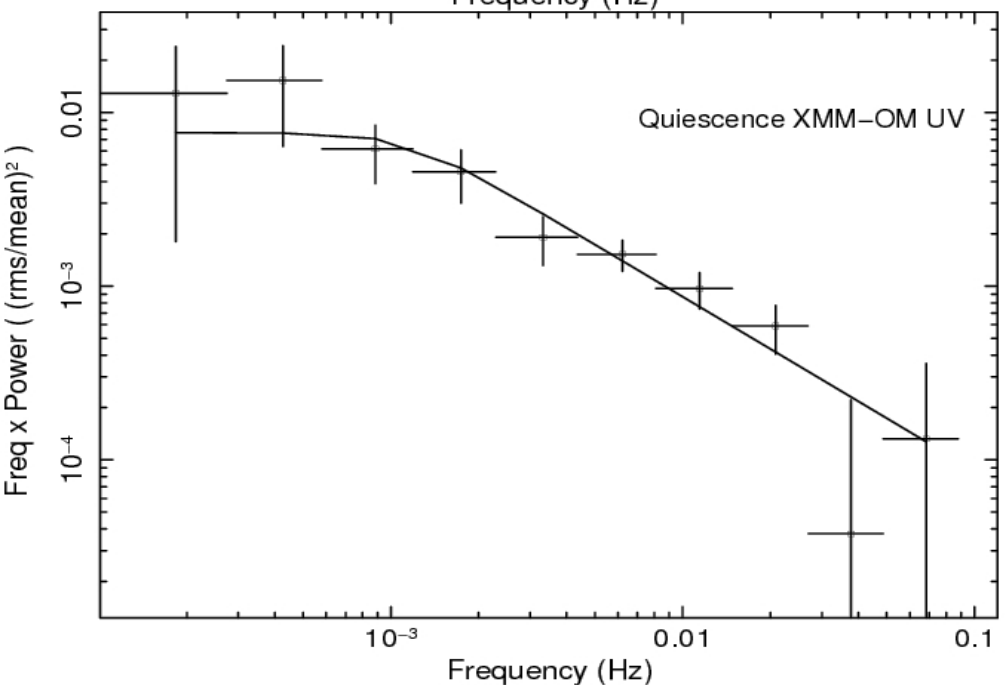
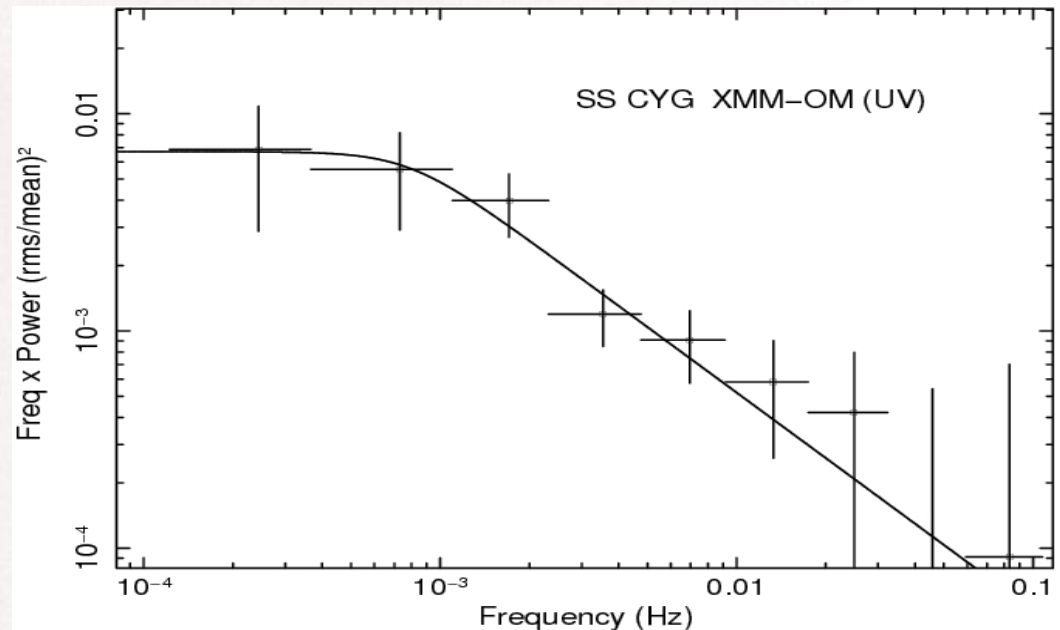
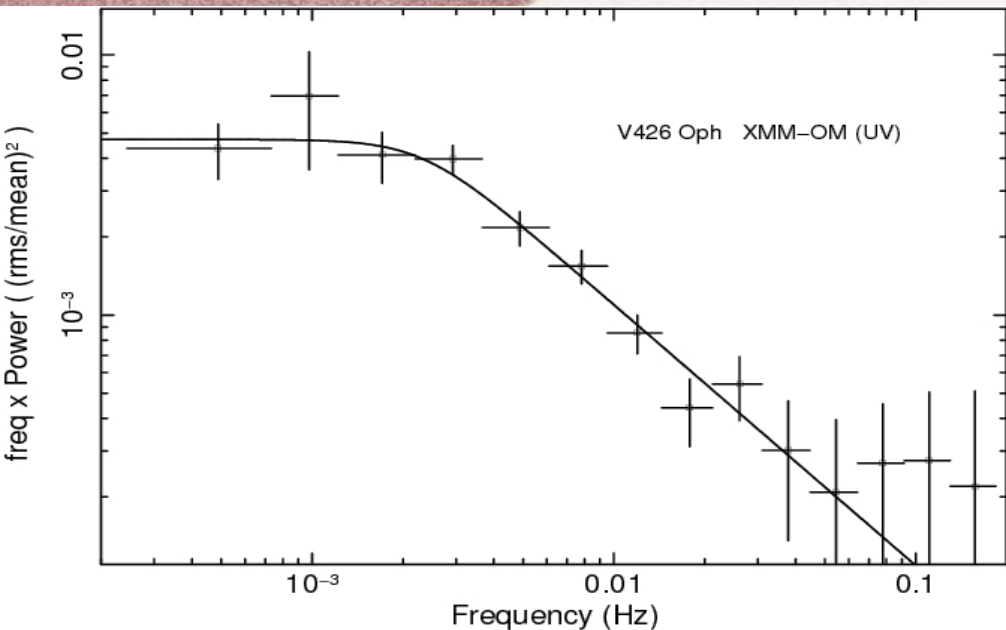


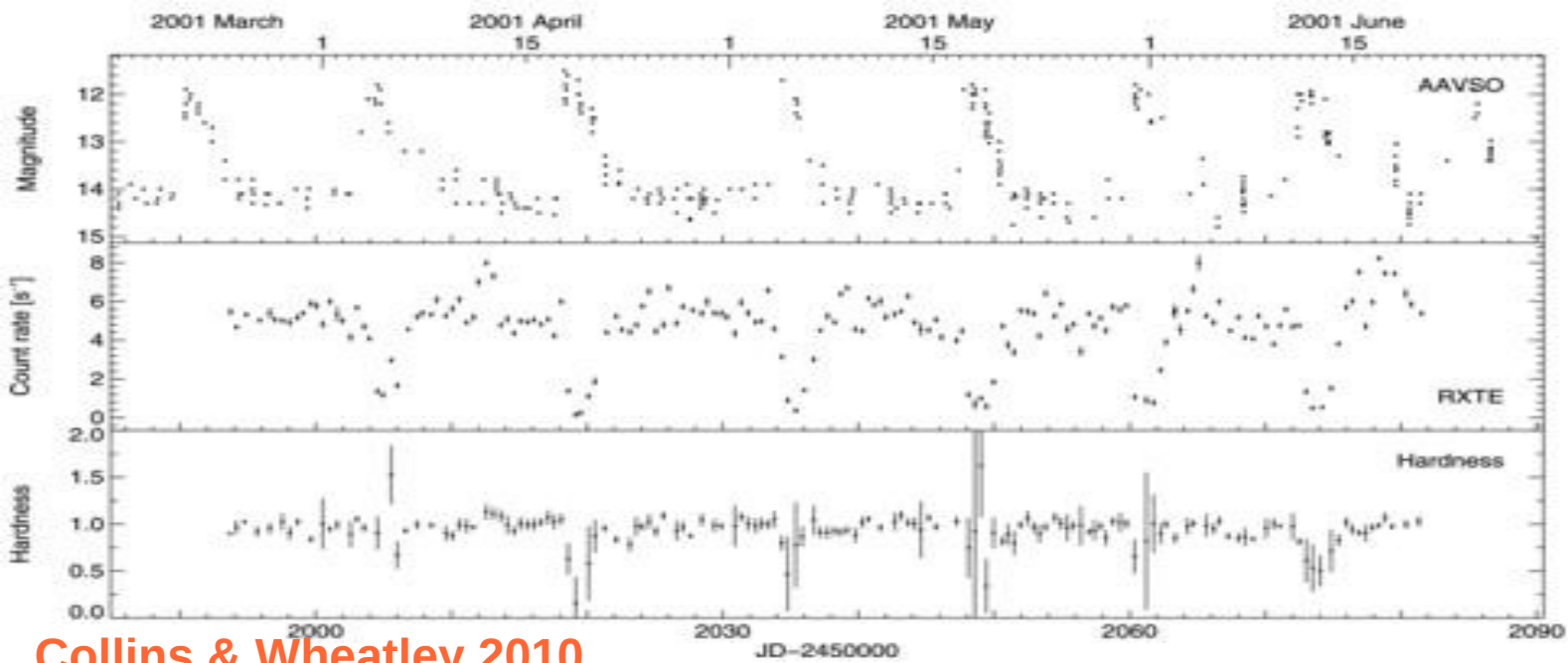
Balman & Revnivtsev 2012



UV Power Spectra

XMM-Newton OM
UVW1 filter 240-340 nm



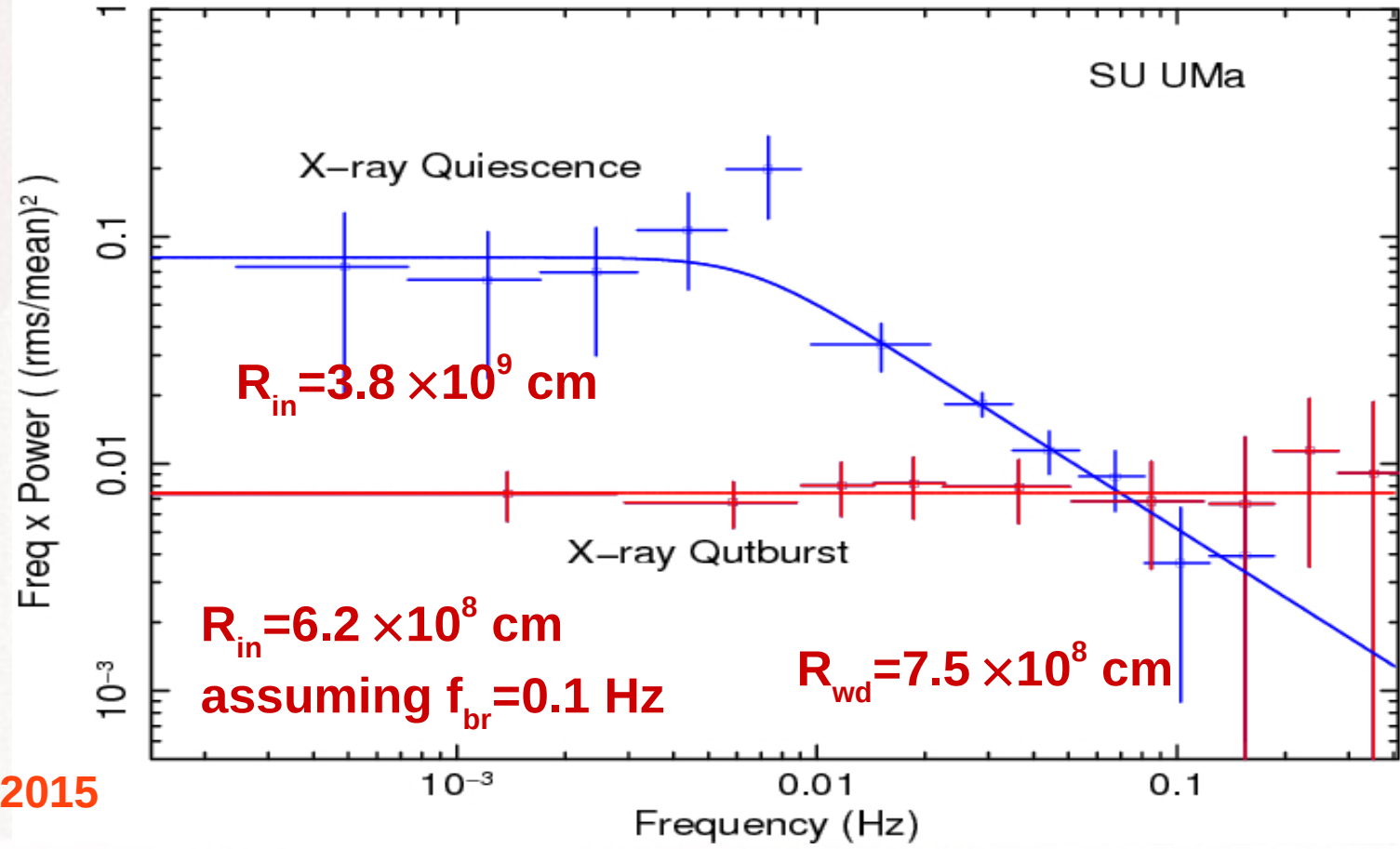


SU UMa

11-17 d
109.9 min

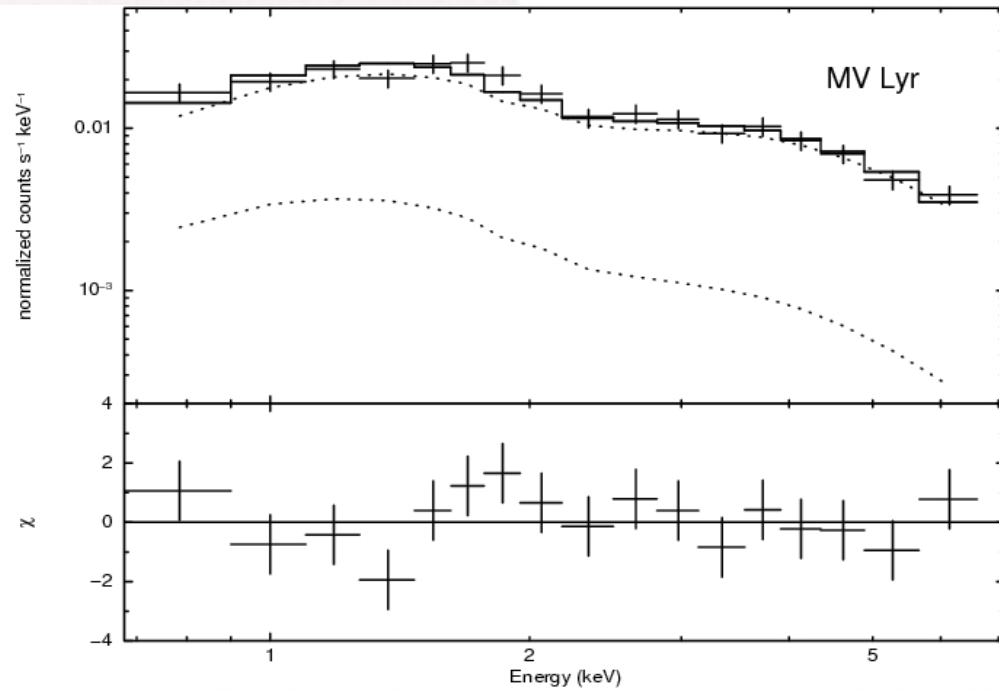
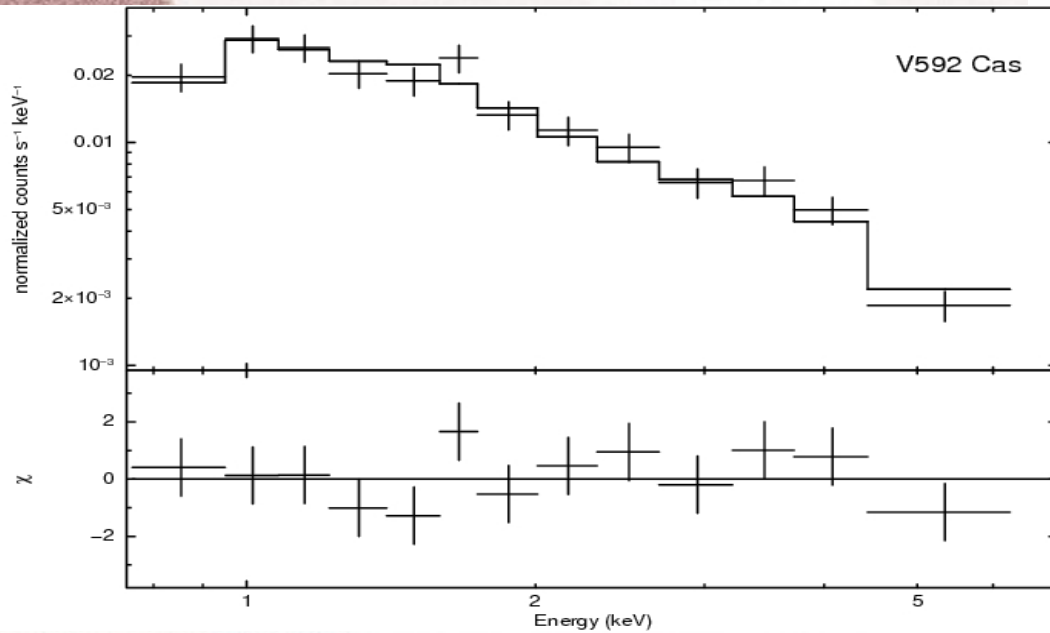
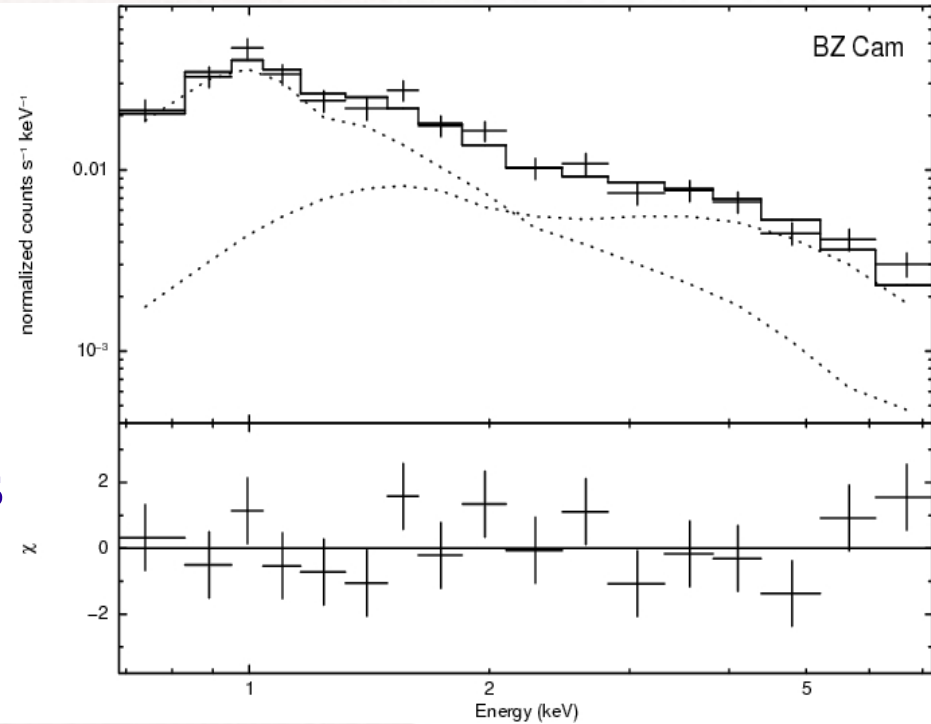
$kT_{\text{qui}} \sim 12 \text{ keV}$
 $kT_{\text{out}} \sim 4 \text{ keV}$

Collins & Wheatley 2010



Balman 2015

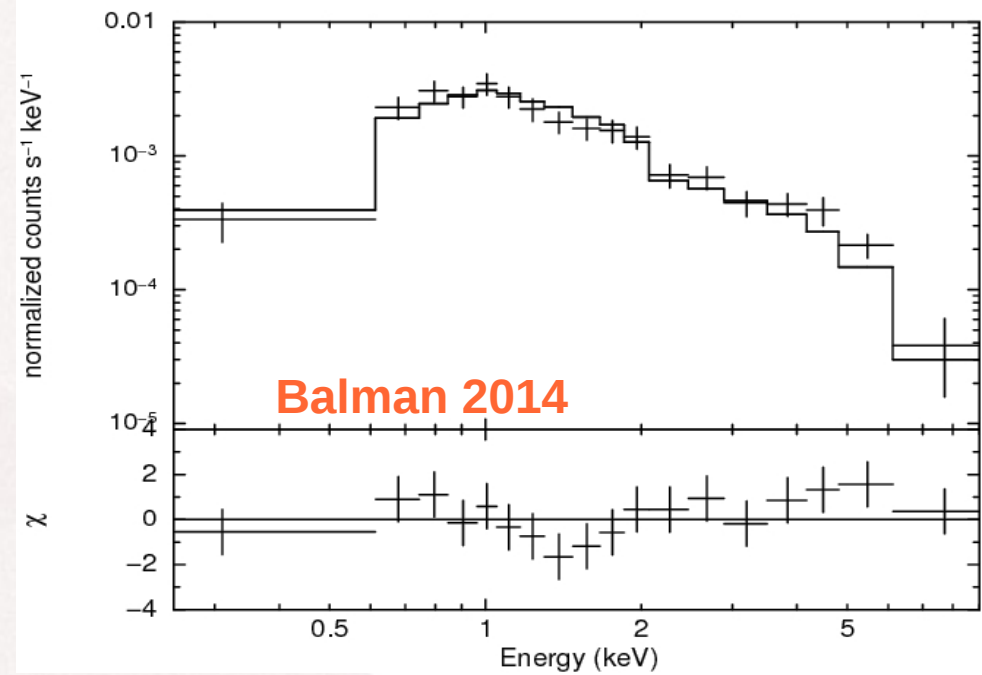
Balman, Godon, Sion 2014 – some Nova-like CVs at high accretion rates ($0.1-1 \times 10^{-8} M_{\odot} / \text{yr}$) have optically thin BLs merged with advective hot flows (ADAF-like flows). These objects show similar multi-temperature cooling flow-like plasma emission to DN in the X-rays with $kT_{\text{max}} = 21-50 \text{ keV}$, Efficiency : $L_x / L_{\text{disk}} \approx 0.01-0.001$ WD effective T 45000-50000 K



- **ADAFs** → **α -prescription** of the disk → viscously dissipated energy is stored in the gas → advected to the central object rather than being radiated (Esin+ 1997, Narayan+ 1997, Narayan & McClintock 2008).
- **RIAF ADAFs!!** and Slim Disk Approx.
- LMXBs (BH) ► inner advection dominated flow from the BH horizon to the transition radius ► above the disk there is a hot corona as the continuation of the inner ADAF.
- L_x/L_{disk} discrepancy common: 0.1 SU Uma-type, 0.01 U Gem-type, 0.001 Nova-likes (Kuulkers+ 2006)
- Low efficiency , high temperature hard X-ray emission with no soft X-ray component associated at high states. CVs indicate RIAF ADAF-like flows.

The Recurrent Nova *T Pyx*

$$F < (0.9-1.5) \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$$
$$L < (1.2-2.2) \times 10^{32} \text{ erg s}^{-1} \text{ (0.1-50 keV)}$$
$$kT > 37 \text{ keV} \quad (2\sigma)$$



- ◆ The recurrent nova *T Pyx* ejects about $3 \times 10^{-5} M_{\odot}$ in very eruption about 20 to 40 yr recurrence time with a 0.7-1.0 M_{\odot} WD.
- ◆ The binary has never been detected as a SSS since 1998 and final upper limits : $F_{\text{BB}} < 1.5 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$, $L_{\text{BB}} < 2 \times 10^{33} \text{ erg s}^{-1} \text{ (0.1-10.0 keV)}$, $kT_{\text{BB}} < 25 \text{ eV}$, with $\dot{M} < 1 \times 10^{-7} M_{\odot}/\text{yr}$. These are not in accordance with a BL scenario for a near-Chandrasekhar WD either.
- ◆ Optically thin BL region merged with ADAF-like hot flows and/or accretion disk corona which heats the WD as well. $L_x/L_{\text{disk}} \sim (2-7) \times 10^{-4}$. *T Pyx* shows irradiation effects and a warped disk structure → AGNs & XRBs.
- ◆ The advective heating of the WD (0.7-1.0) M_{\odot} may explain the onset of a TNR together with the high accretion rate of the system causing the RN event.

Magnetic CVs

- **Polars (P) & Intermediate Polars (IP)**

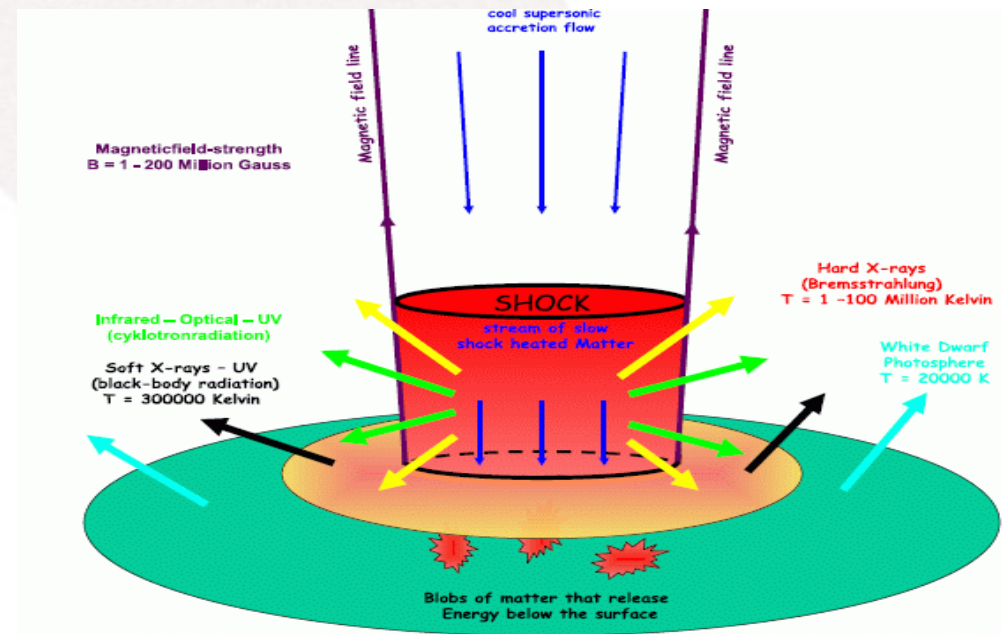
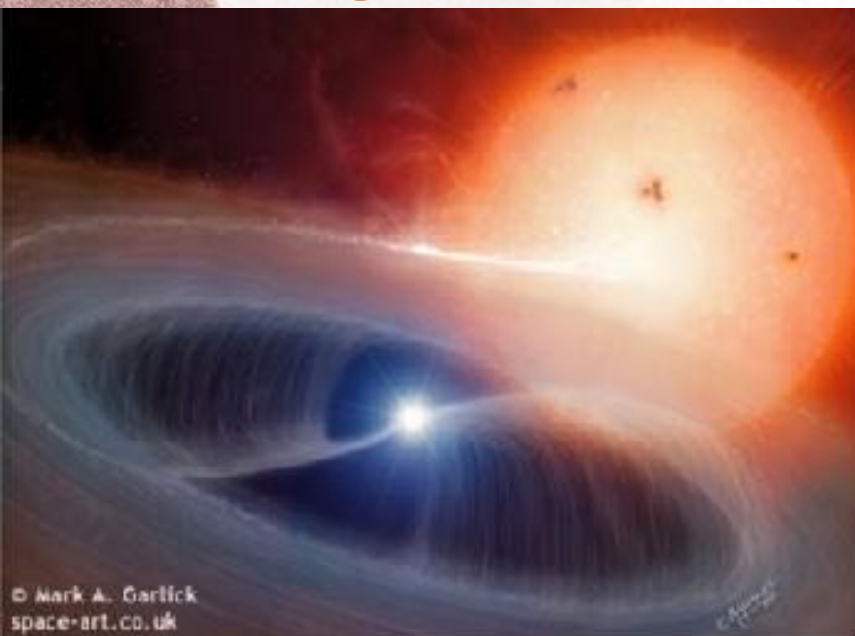
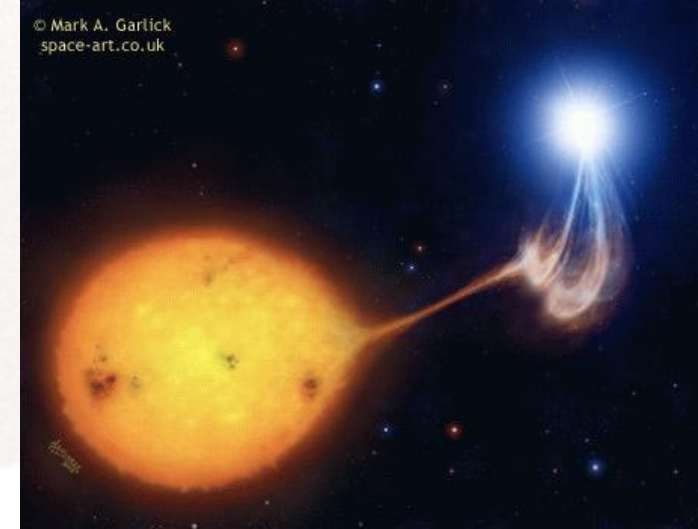
depending on B

(1-20 MG for IPs and >20 MG for Ps)

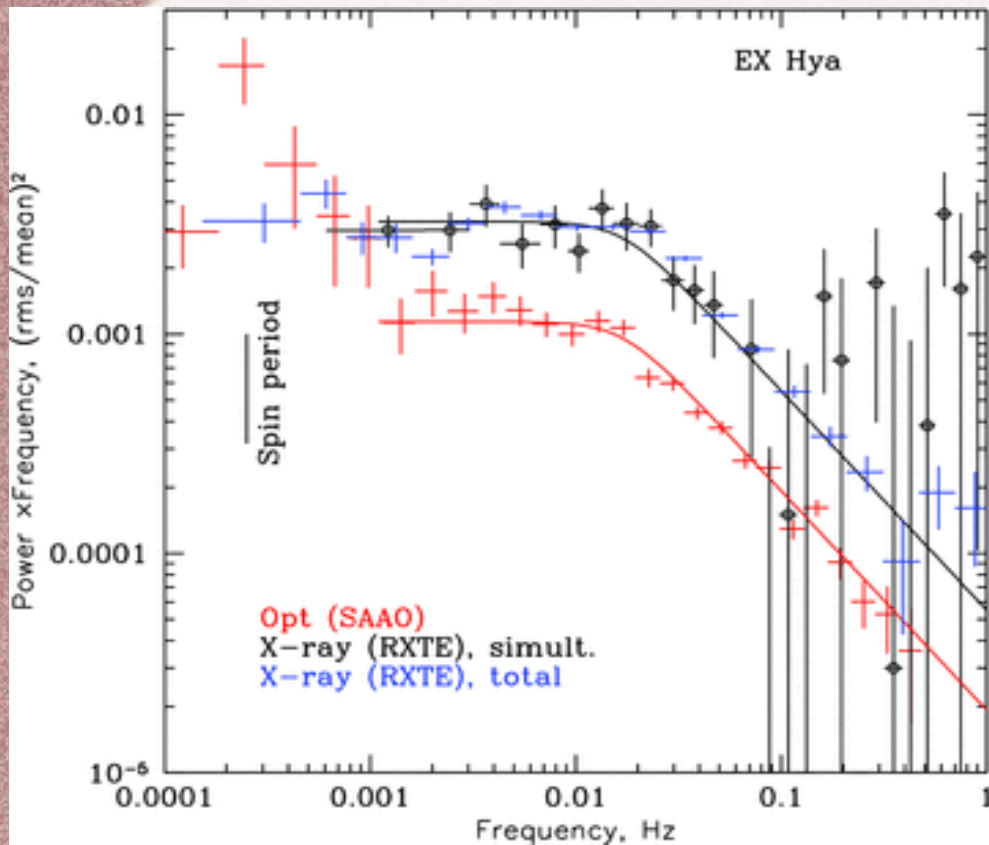
- IPs have truncated accretion disks -- accretion curtains --

- X-ray emission from strong shock near the surface of the WD as the post-shock region is heated to 10-95 keV with

$L_x \lesssim$ a few $\times 10^{33}$ erg/s (Patterson 1994, Hellier 1996, de Martino et al. 2008, Brunschweiler et al. 2009, Yuasa et al. 2010, Bernardini et al. 2012)



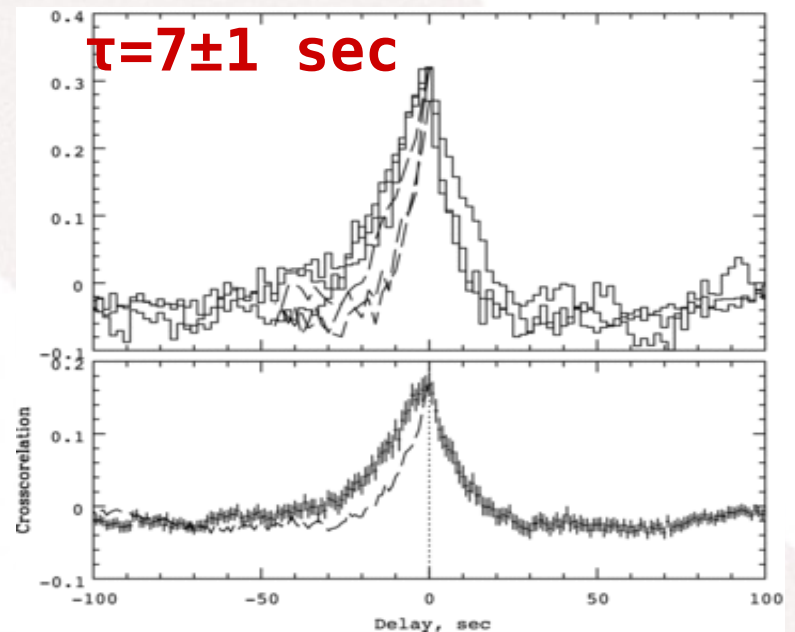
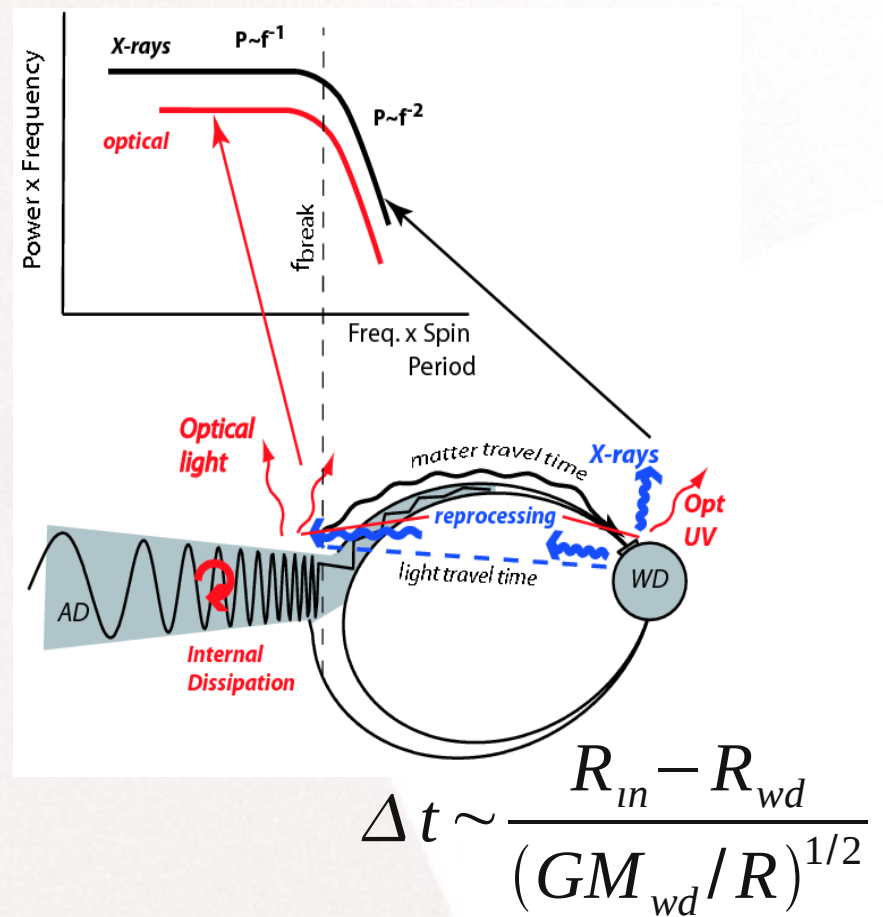
Intermediate Polars and Disk Truncation radii

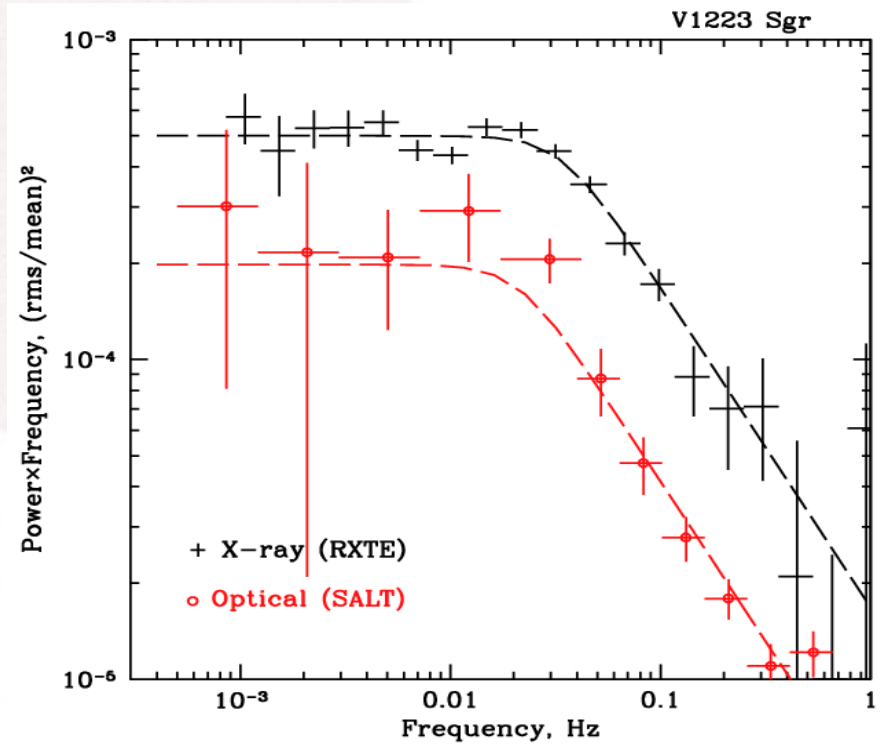
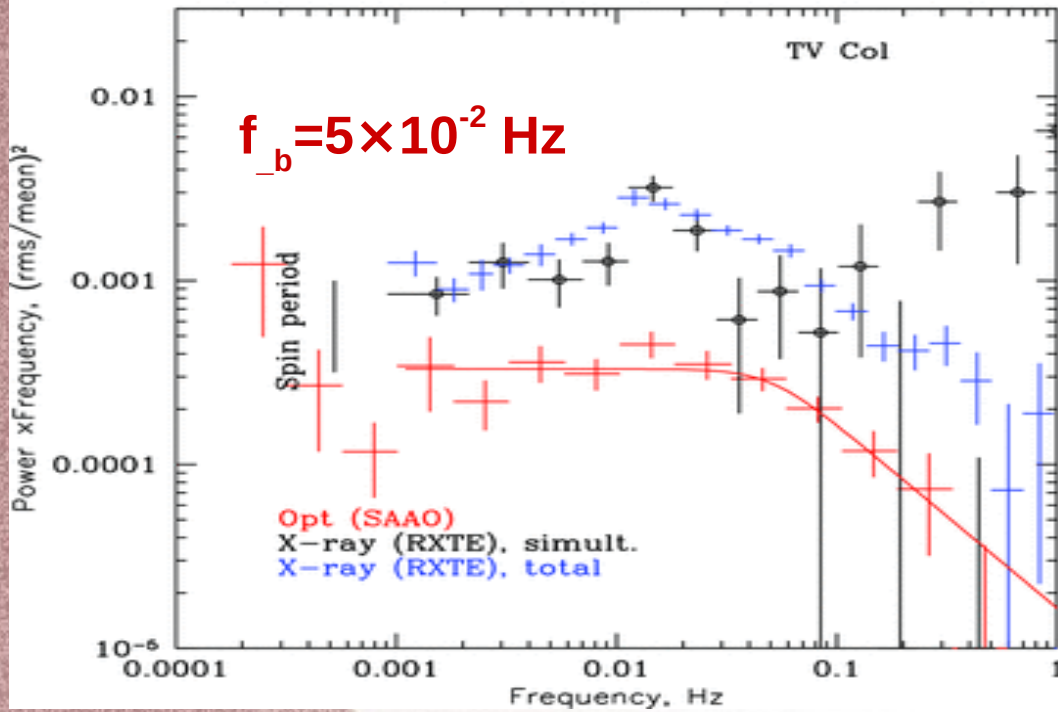
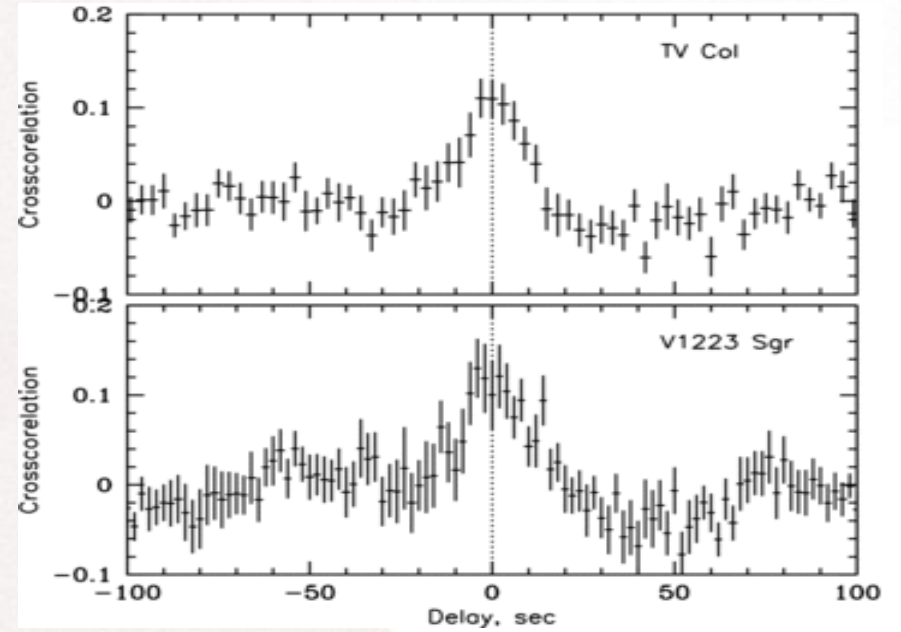
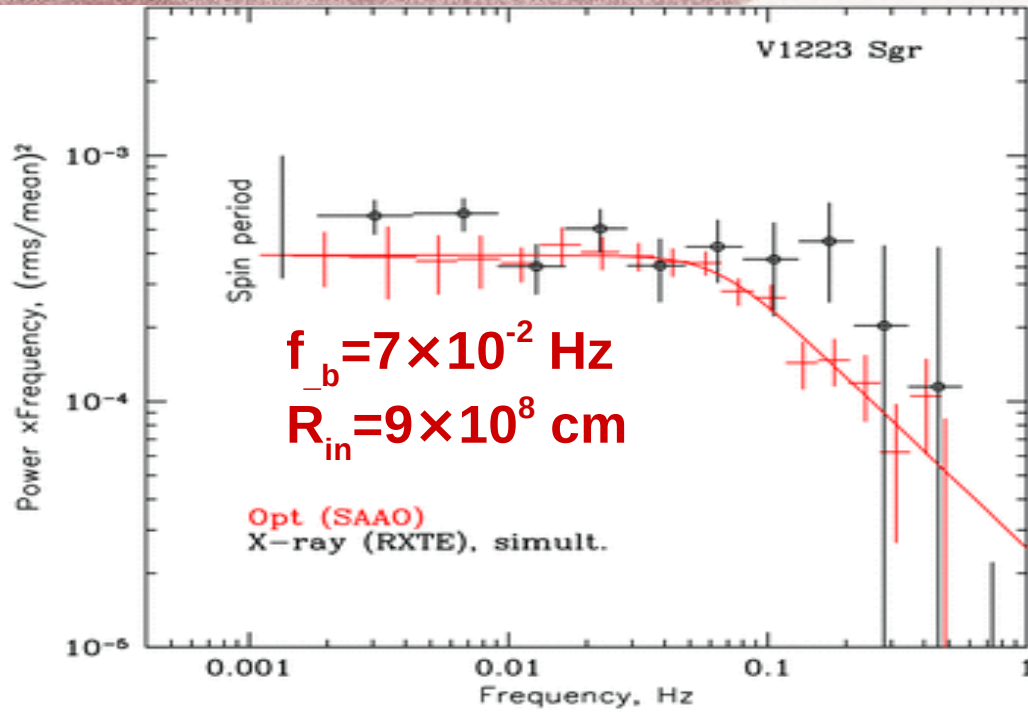


$$R_{in} = 1.9 \times 10^9 \text{ cm}$$

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

Revnivtsev et al. 2011





Conclusions

- Detect large scale truncation in the Disks of Dwarf Novae (DN) in at least 9 systems with radii in a range $R_{tr} \approx 0.3-1.0 \times 10^{10}$ cm ($f_{br} = 1-6$ mHz). The Magnetic CVs (MCVs) show rather smaller truncation radii $\sim 0.9-1.9 \times 10^9$ cm.
- Find time delays in X-rays of the order of 90-180 sec in a sample of DN (7 objects). This value is about 6-8 sec for the Intermediate Polar EX Hya.
- Suggest that most of these systems (DN) have truncated disks with hot flows dominating in the inner disks (ie. ADAF-like flows/ rotating hot coronal flows). This is also true for Nova-Like CVs and even in novae during quiescence.
- Evidence is found that the disk truncation varies with accretion rate changes in quiescence together with outburst.
- These characteristics ---> CV s --> XRBs even to AGN

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İSTANBUL

IN 2016



30th July--07th August 2016



Assembly Venue:

İstanbul Congress Valley

Assembly Web Site: <http://cospar2016.tubitak.gov.tr/>



TÜBİTAK



COSPAR-2016-E1.14: *Novae and Cataclysmic Variables: A Multi-Dimensional Perspective Where Multi-Wavelength Observations Meet Theory*

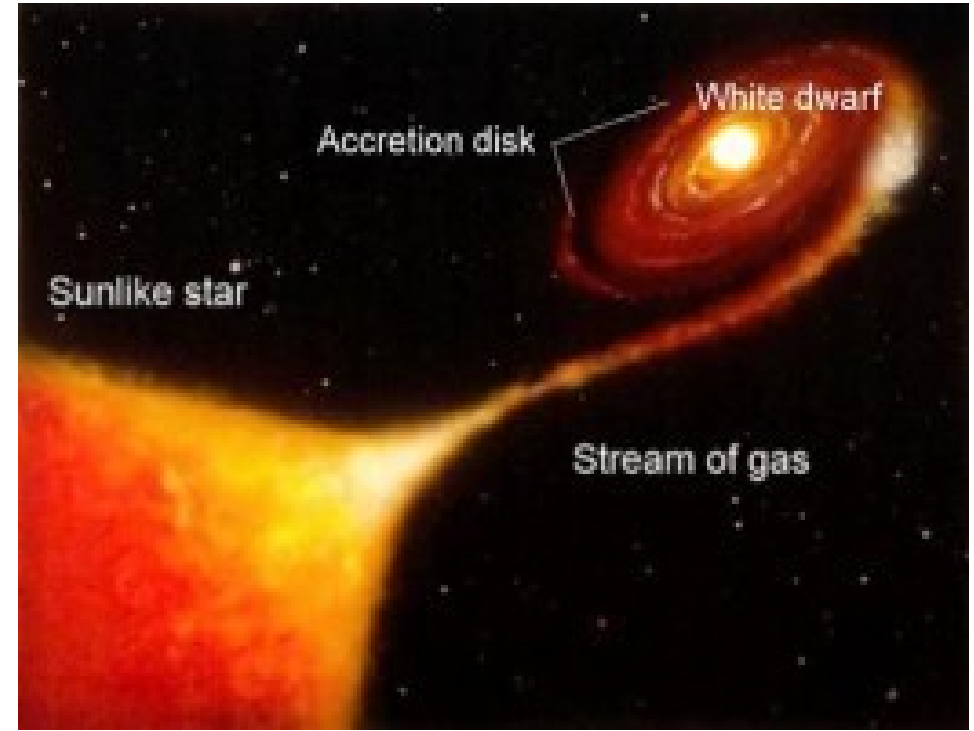
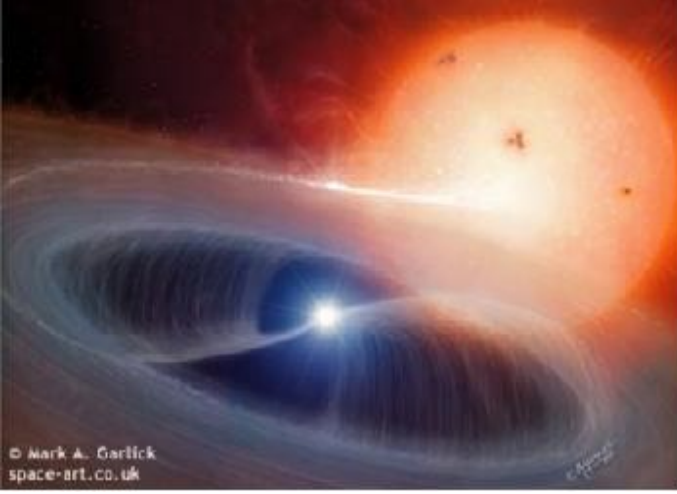
<https://www.cospar-assembly.org/>



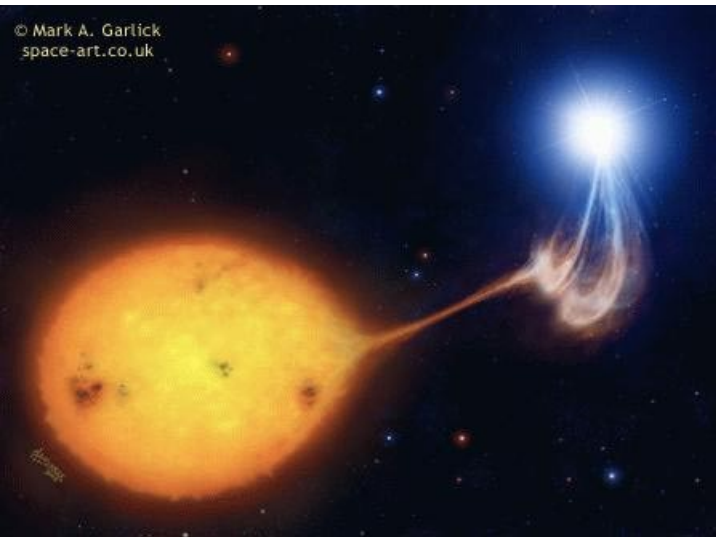
MSO: Şölen Balman (METU, TR)

DO: Rosario Gonzalez-Riestra (ESA/ESAC, ES)

SOC: Ramundo Baptista(UFSC,BR), Dimitry Bisikalo (RAS,RU), Michael Bode (Liverpool JMU,UK), Rene Hudec (ASU-CAS,CZ), Jordi Jode (UPC,ES), Domitilla de Martino (INAF-Napoli,It), Paul Mason (NMSU,USA), Jan-Uwe Ness (ESA/ESAC,ES), Marina Orio (INAF-Padova-UW,IT-USA), Julian Osborne (Univ. Leicester, UK), Linda Schmidtbreick (ESO,CHL), Edward Sion (Univ. Villanova,USA), Sumner Starrfield (ASU, USA),Valery Suleimanov (Univ. Tübingen,DE),Gahik Tovmassian (UNAM,MEX)

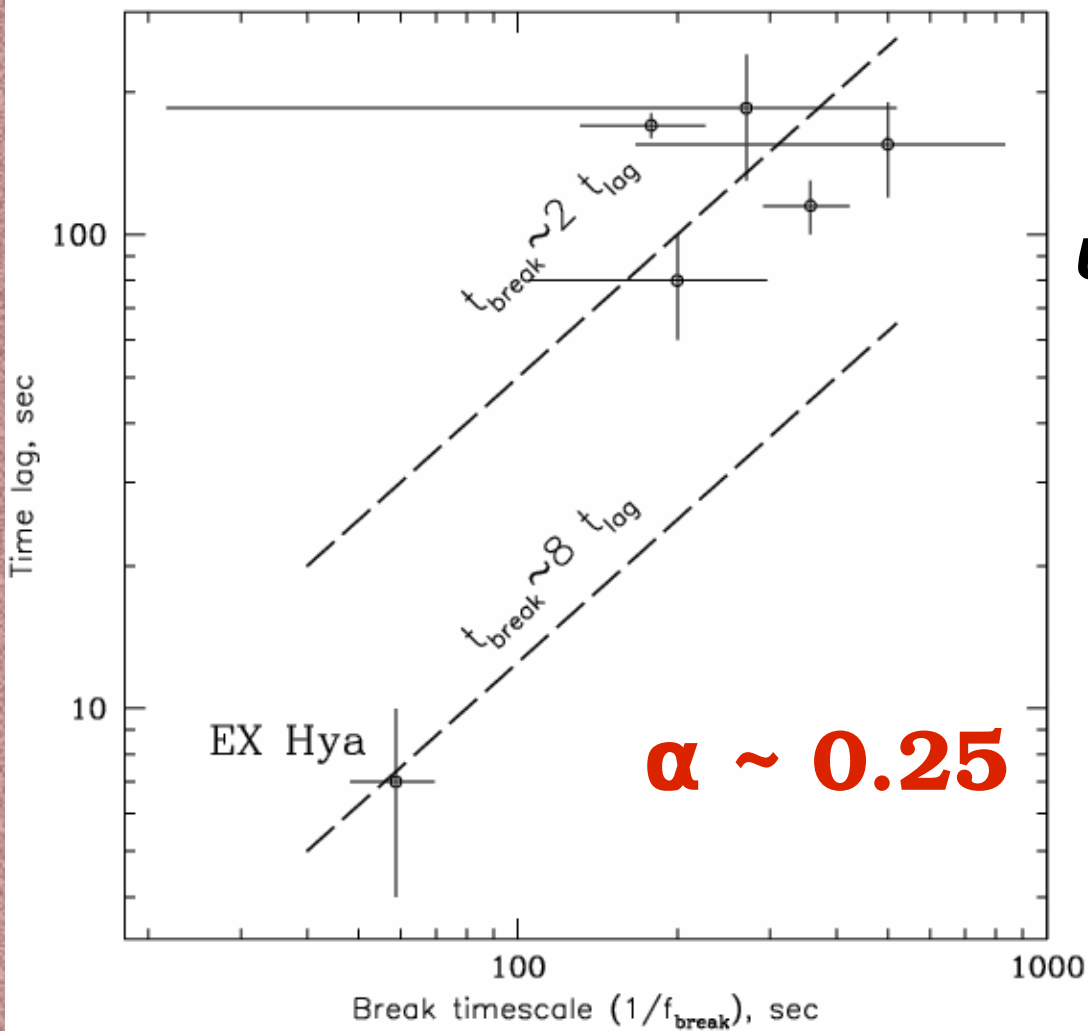


Kataklişmik Değişkenler --- Roche Lobe taşması --- donör geç-tip Anadol yıldızı (1.4-14 sa)



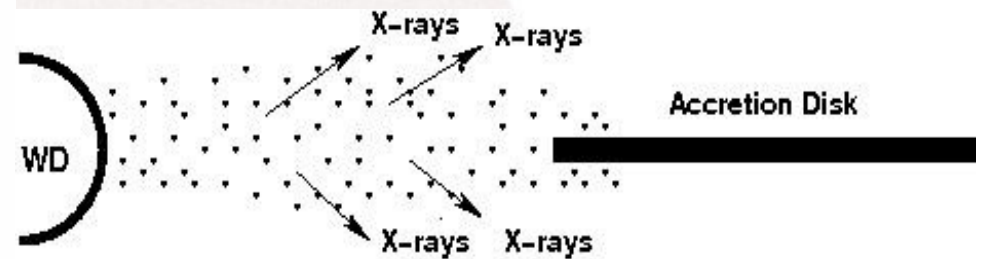
AM CVn ler --- Roche Lobe taşması --- çift-dejenere yıldızlar --- ultra küçük sistemler (10-65 dak.)

Simbiyotikler --- Rüzgar aktarımı --- donör geç-tip dev Mira sistemleri --- Orbit dönemleri yıl mertebesinde



$$U_r \propto \alpha V_K \quad \text{Non-magnetic CV}$$

$$U_r \propto V_K \quad \text{Magnetic CV}$$

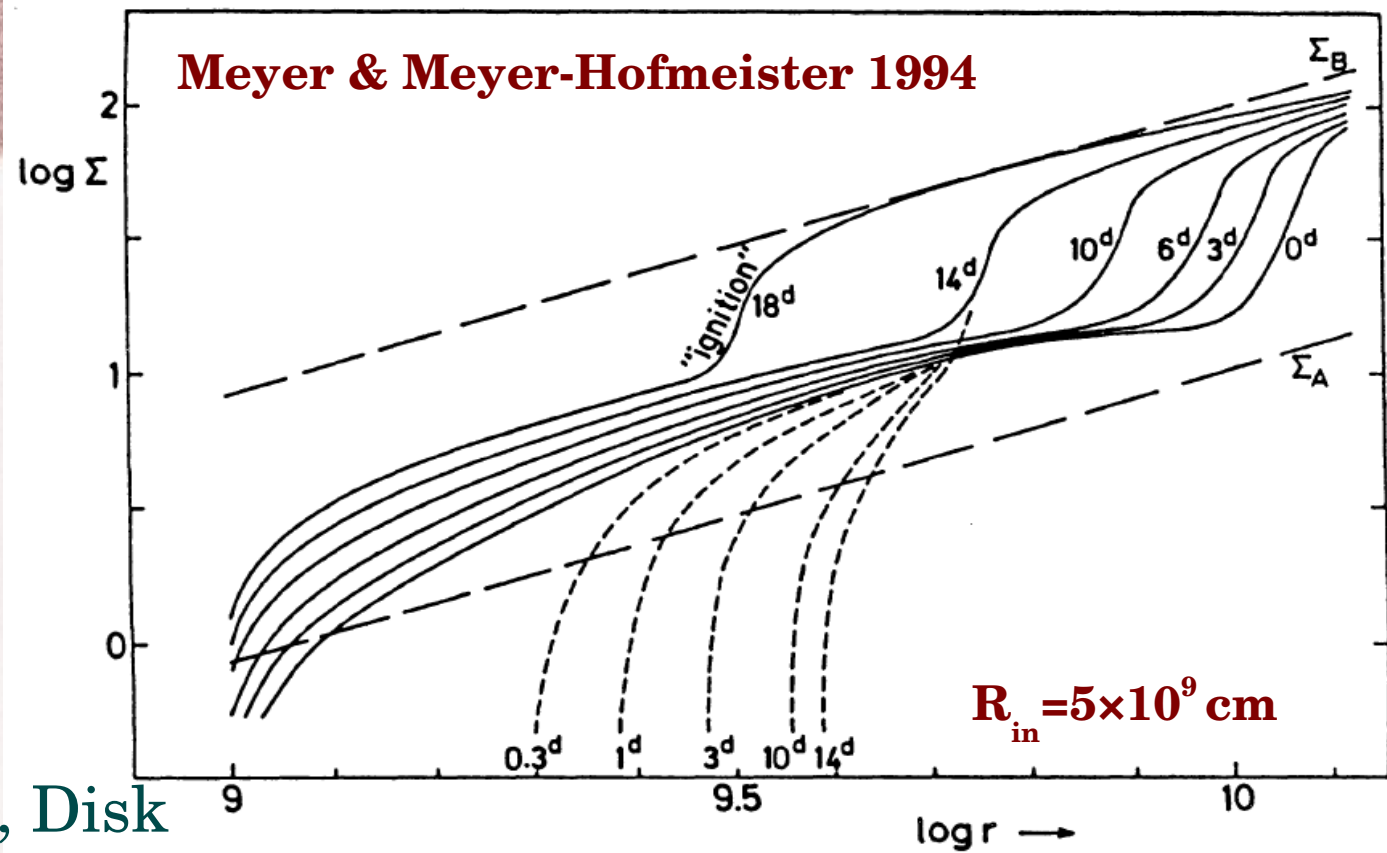


Standard Disk & Boundary Layer

(Kippenhahn & Thomas 1978, Patterson & Raymond 1985, Narayan & Popham 1993)

Optically thick cold outer disk and optically thin inner corona

(Esin, McClintock & Narayan 1997)



→ Coronal siphon-flow, Disk evaporation (Meyer & Meyer-Hofmeister 1994(2001), Liu et al. 1995 1997, Meyer et al. 2000) (see also de Kool & Wickramasinghe 1999, Mineshige et al. 1998)

--- $2-6 \times 10^9 \text{ cm}$

→ WD Irradiation (King 1997)

$(1-5)R_{WD}$

$T_{cor} < T_{vir} (10-30 \text{ keV}--M_{wd})$
 $10^{-13} M_{\odot}/\text{yr} \rightarrow 10^{-11} M_{\odot}/\text{yr}$
 Frictional and Thermal
 Boundary Layers

Accretion Flows-Matter Fluctuations and Broadband Noise

- Self-similar variability of accretion rate in the disks → **flicker noise** (Lyubarskii 1997, for CVs see : Warner & Nather 1971, Bruch 1992, 2000, Baptista&Bortoletto 2004)
- Variable instant mass accretion rate in the region of energy release → variable flux from the disk → inserted at all radii (Churazov et al. 2001, Revnivtsev et al. 2009, 2010, Uttley & McHardy 2001, Uttley et al. 2011, Scaringi et al. 2012)
- **Propagating fluctuations** of low frequency in the outer disk → carried into the inner disk and finally to the X-ray emitting region.

