The physics of the brightest low mass X-ray binaries and jet formation

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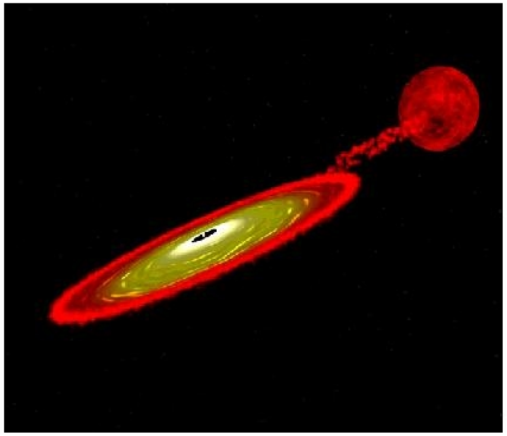
Accretion Process in X-rays: from White Dwarfs to Quasars, 13-15 July, 2010, Boston MA

Contents of talk



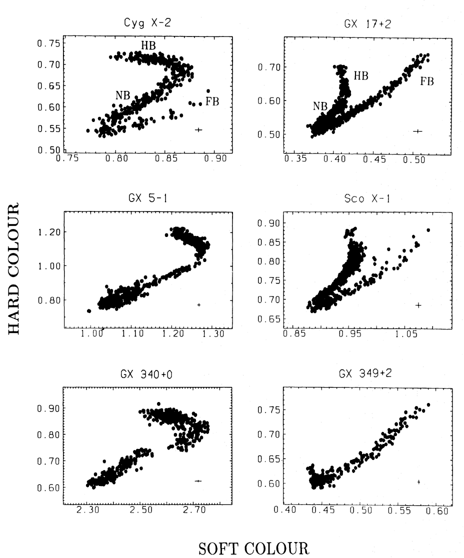
• Explanation of the super-Eddington Z-track sources

• The Extended Accretion Disc Corona

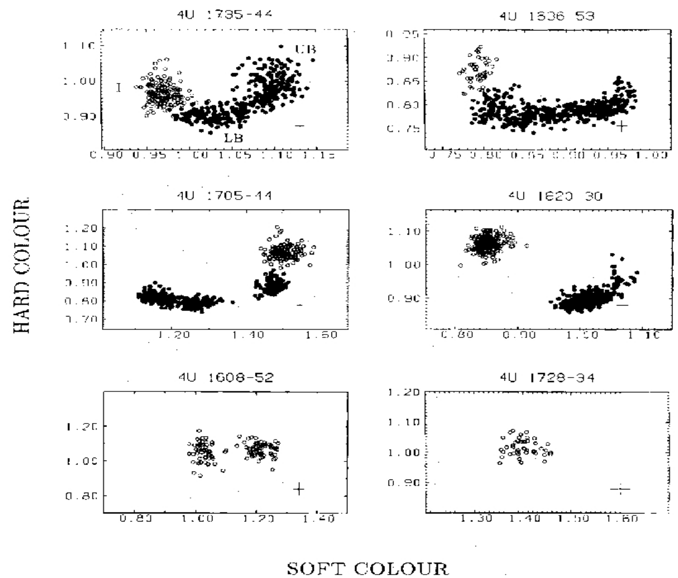
• Additional physics: radiation pressure and unstable nuclear burning

• Explanation of the Banana and Island states in Atoll sources

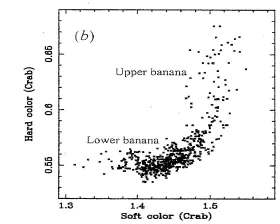
Z-track and Atoll

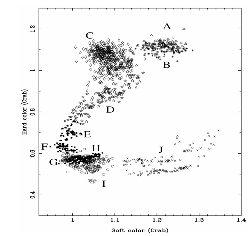


Hasinger & van der Klis 1989



GX 9+1 (van der Klis 2006)





4U 1608-52 (van Straaten et al. 2003)

Z-track sources:
L > 10^{38} erg/s (L_{Edd})

- **Horizontal, Normal & Flaring Branches:** => major physical differences at inner disc and neutron star – not understood
- **Cygnus X-2 like sources:** Cyg X-2, GX 5-1, GX 340+0
- **Sco X-1 like sources:** Sco X-1, GX 349+2, GX 17+2, LMC X-2, Transient: XTE J1701-462
- **Radio emission shows relativistic jets:** in Horizontal Branch only v/c=0.45 in Sco X-1 =>
- **Possibility of determining conditions needed for jet launching**

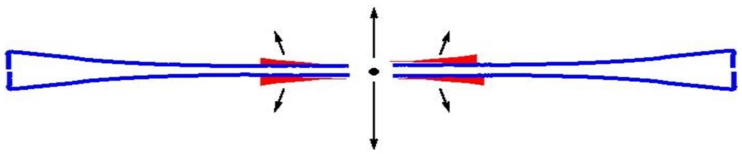
Atoll sources:
10^{36} – 10^{38} erg/s
2 states: Banana & Island

typical Atoll sources: 0.01 – 0.2 L_{Edd}
GX Atolls in the Galactic bulge: 0.2 -0.5 L_{Edd}

The Extended Accretion Disc Corona

Extended ADC Model

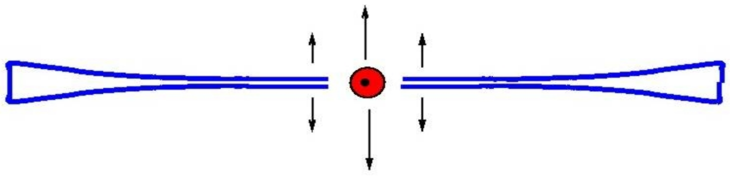
(Church & Bałucińska-Church 1995)



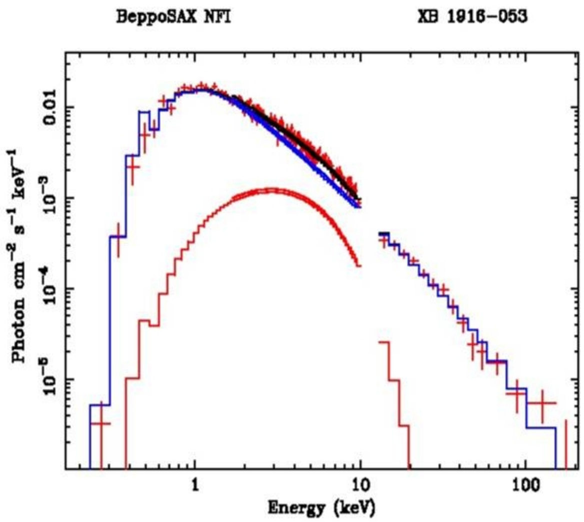
Two emission components:
Comptonization from an extended ADC
+ blackbody from Neutron Star

Eastern Model

(Mitsuda and co-workers 1989)



Two emission components: multi-colour disc blackbody
+ Comptonization in NS atmosphere / inner disc

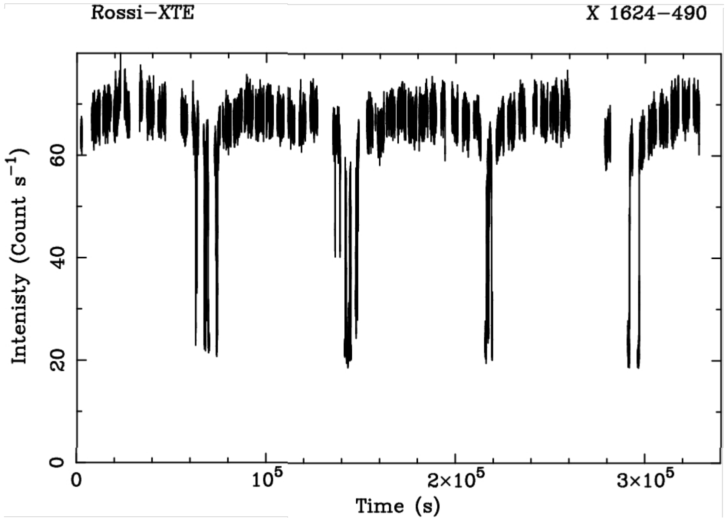


- **Comptonization:**
  dominates spectrum

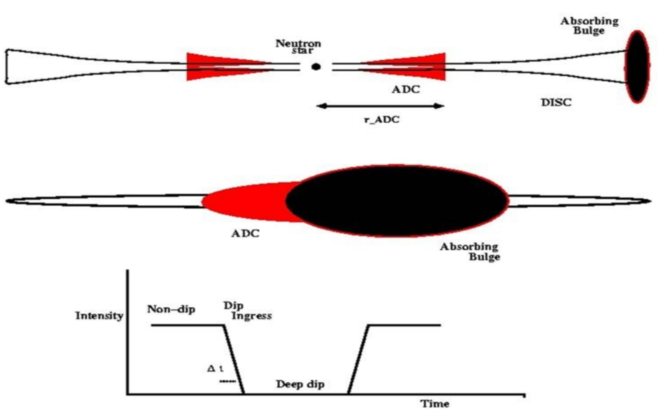
- **Form of Comptonization:**
  must reflect broadband spectrum of seed photons from disc

variations of the Eastern model:
e.g. Lin et al. (2009)

Measurements of the radial extent of the ADC



Dip ingress timing



$$\frac{2\pi r_{AD}}{P} = \frac{2r_{ADC}}{\Delta t} \qquad i.e. \qquad r_{ADC} = \pi r_{AD}\frac{\Delta t}{P}$$

- **r_{ADC} depends on luminosity:**

r_{ADC}= 20,000 – 700,000 km

Church & Balucinska-Church (2004)

Extended ADC: evidence from ADC lines

- **Chandra high resolution spectra of Cyg X-2:**
  Schulz et al. (2009) show broad H-like emission lines of Ne, Mg, Si, S and H - and He-like lines of Fe

- **Doppler widths:**
  due to Keplerian motion in ADC give radial positions:
  18,000 – 110,000 km
  good agreement with dip ingress timing:
  20,000 – 700,000 km

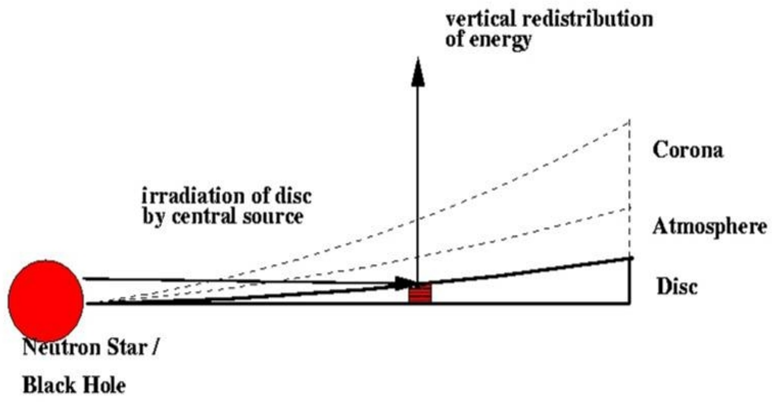
Table 2
X-Ray Line Properties

Ion	λ_{meas} (Å)	$Flux_{line}$ [a]	v_D (km s^{-1})
Fe XXVI	1.792 ± 0.009	0.39 ± 0.28	1120 ± 870
Fe XXV	1.861 ± 0.005	1.97 ± 0.27	3450 ± 710
S XVI Lyα	4.726 ± 0.011	0.79 ± 0.25	1860 ± 1140
Si XIV Lyα	6.188 ± 0.005	1.03 ± 0.15	1610 ± 290
Al XII	7.812 ± 0.003	0.38 ± 0.06	530 ± 110
Fe XXIV	7.973 ± 0.001	0.78 ± 0.05	370 ± 40
Mg XII Lyα	8.419 ± 0.004	1.26 ± 0.38	2730 ± 480
Ne X Lyα	12.13	$\lesssim 1.3$	$\lesssim 5600$

Note. [a] 10^{-4} ph s^{-1} cm^{-2}, uncertainties are 90% confidence.

Schulz et al. 2009

- **Line properties:**
  consistent with a stationary, hot ADC (log $\xi > 3$; $T > 10^6$ K)
  as in modelling of ADC (Jimenez-Garate et al. 2002;
  (Różanska & Czerny 1996)



- **The Extended ADC:**
  is inconsistent with the Eastern model

Resolving the nature of the Z-track sources

- **QPO variation around the Z:**
  has not resolved the nature of the sources

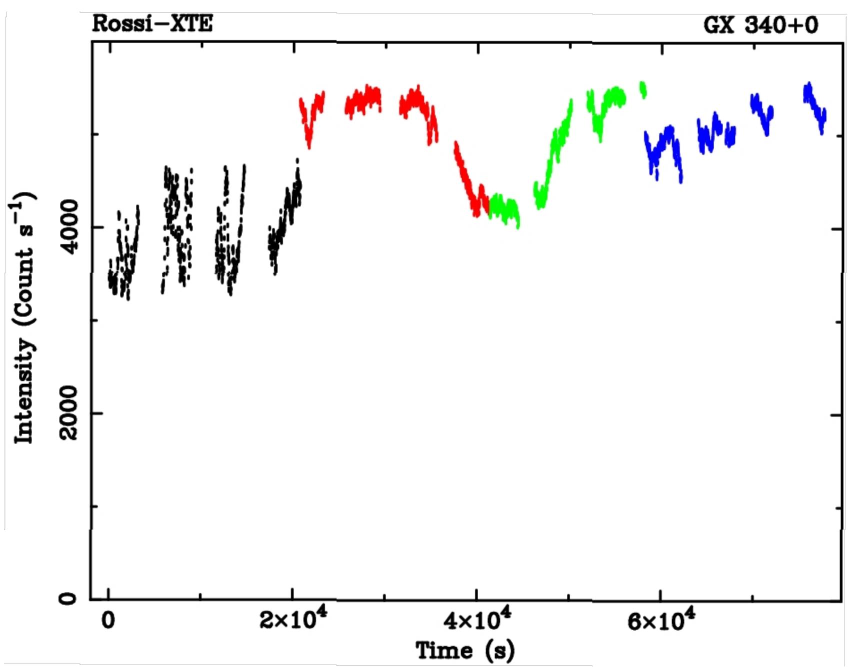
- **Spectral fitting should resolve the problem:**
  but all previous fitting used the Eastern model:
  Cyg X-2 – Done et al. (2002); GX 349+2 – Agrawal & Sreekumar (2003);
  Cyg X-2- di Salvo et al. (2002); XTE J1701-462 – Lin et al. (2009)

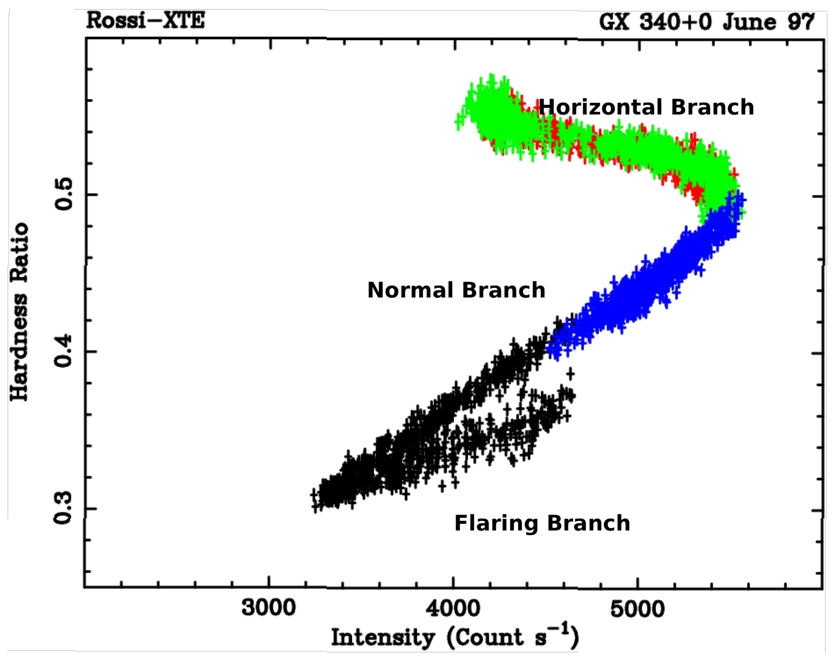
- **Standard assumption:**
  Mdot increases monotonically around Z (Hasinger et al. 1989)
  => Flaring due to increased Mdot
  limited evidence based on X-ray / UV correlation
  New evidence of Rykoff et al. (2009) + our work is contrary to standard model

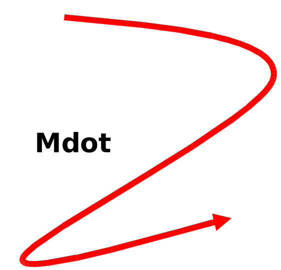
- **We have applied Extended ADC approach:**

Application of Extended ADC model

- **Rossi-XTE observations of the Cygnus X-2 like sources:** GX340+0



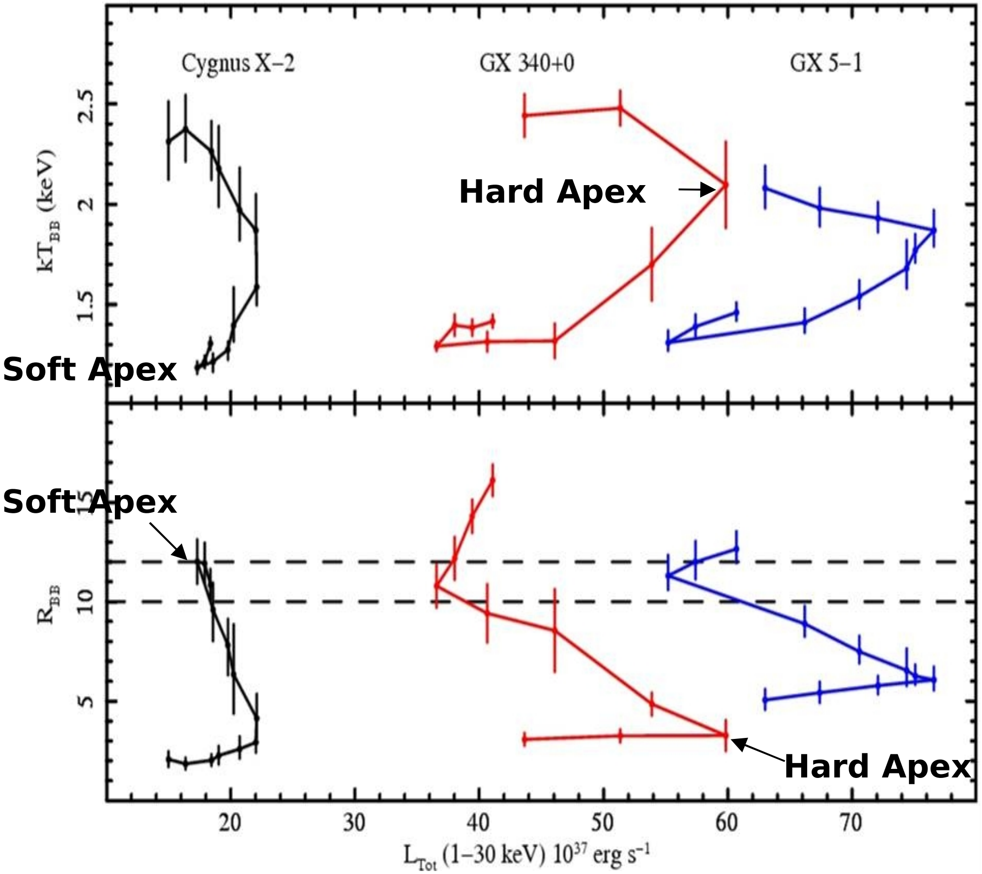


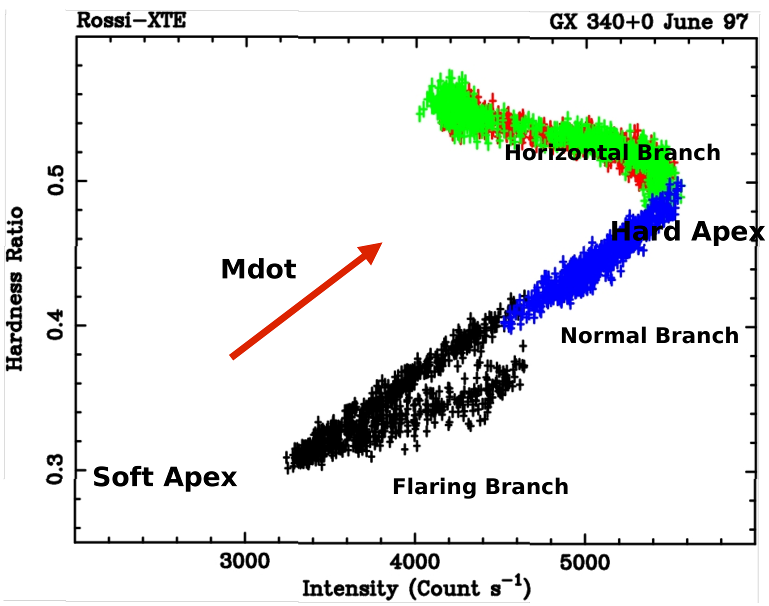


Neutron star blackbody emission

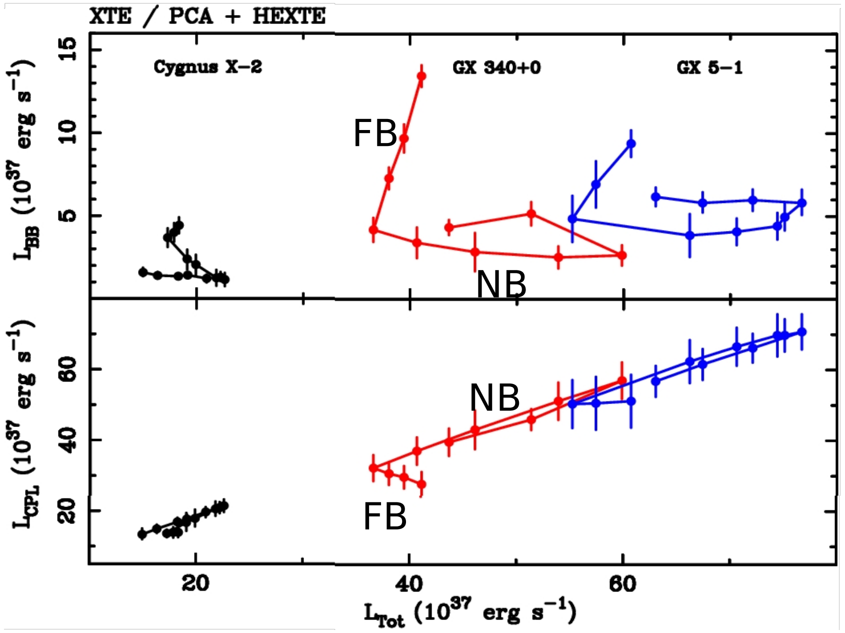
- **The Soft Apex**:
  kT_{BB} = 1.3 keV – minimum
  R_{BB} = 10 – 12 km
  => all neutron star emitting
  neutron star radius = 11.4 +/-0.6 km
  suggests a Quiescent State

- **Normal Branch**:
  kT_{BB} increases on NB and HB
  implies Mdot increases





Luminosities of Blackbody and ADC



- **Normal Branch:**
  L_{ADC} increases => increase of Mdot
  Consistent with X-ray intensity
  and heating of neutron star

- **Flaring Branch:**
  L_{ADC} constant => Mdot constant

Mdot does not increase monotonically around the Z-track

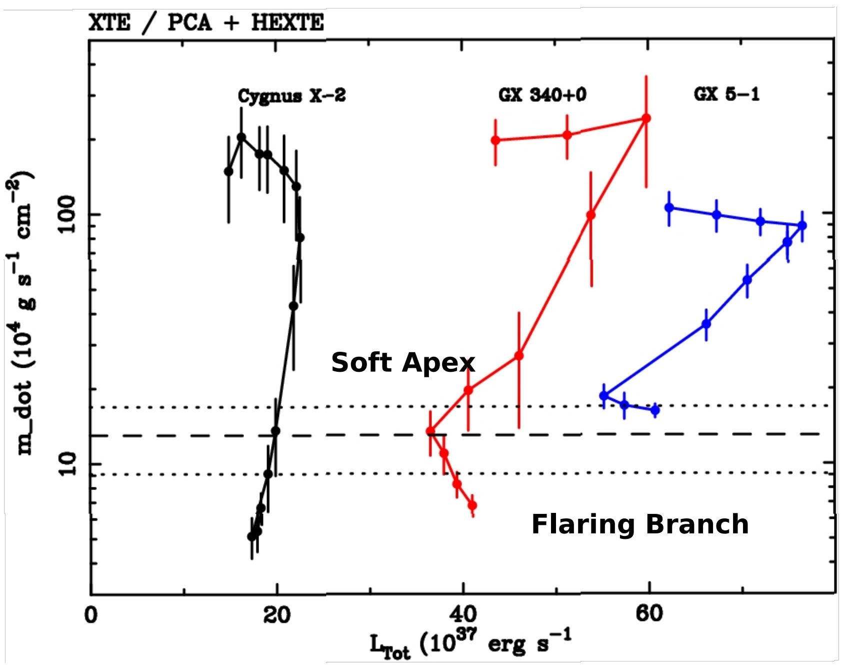
- **The nature of Flaring:**
  Blackbody luminosity increases => extra energy source on neutron star
  may be unstable thermonuclear burning

- **We will compare with theory of unstable burning:**
  Fujimoto et al. (1981); Fushiki & Lamb (1987);
  Bildsten (1998); Schatz et al. (1999)

Comparison with regimes of nuclear burning

I	II	III	IV
H and He unstable	He unstable	He unstable in H/He environment	H, He stable

$\dot{m}_{c2} = 1 \times 10^3$ g cm^{-2} s^{-1} $\quad \dot{m}_{c1} = 5 \times 10^3$ g cm^{-2} s^{-1} $\quad \dot{m}_{st} = 1.3 \times 10^5$ g cm^{-2} s^{-1}



STABLE

UNSTABLE

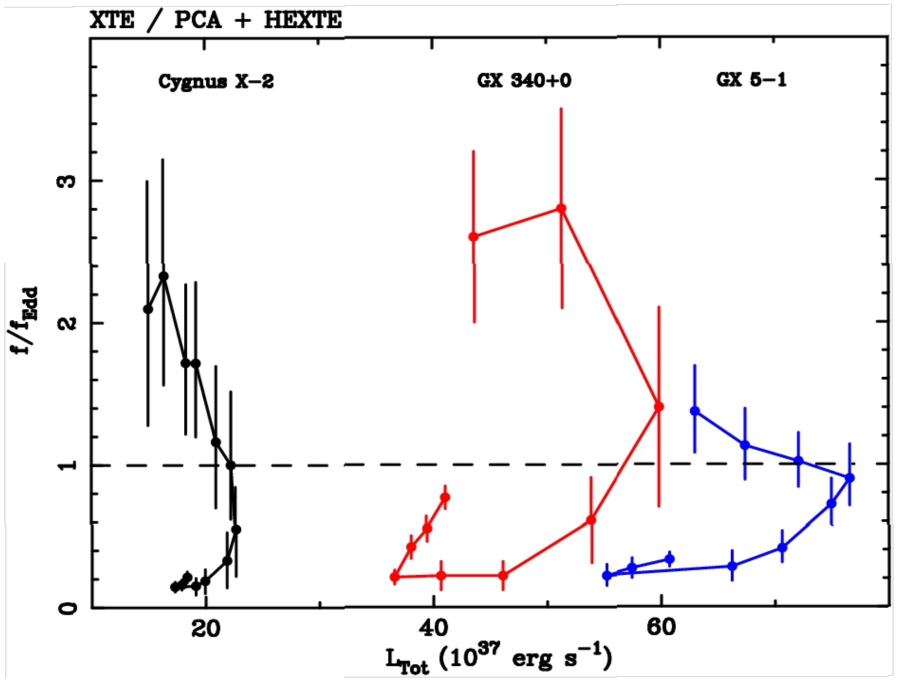
- **We measure mdot :**

  mdot = Mdot / 4π R_{BB}^2
  (Mdot from luminosity)

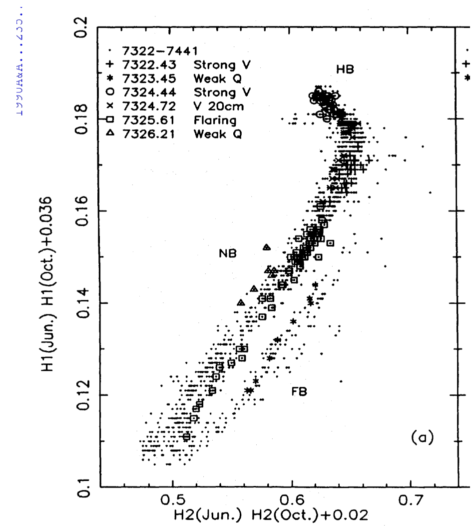
- **Soft Apex:**
  mdot = critical value (mdot$_{ST}$)
  for onset of unstable burning

Formation of radio jets

Balucinska-Church et al. 2010



Radio flux variation:
Hjellming et al. 1990



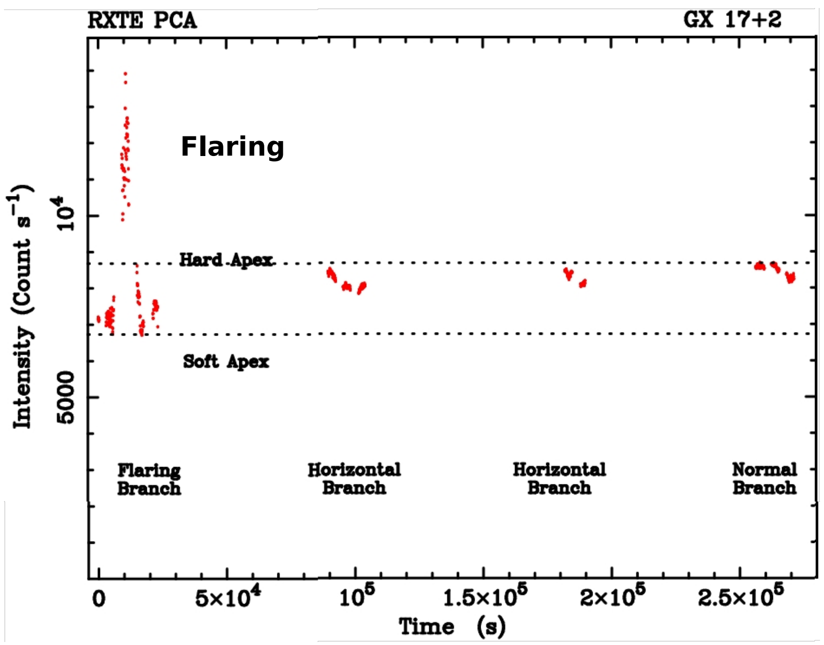
- **We show:** f/f_{Edd} the emissive flux of neutron star / the Eddington flux: $f_{Edd} = \frac{L_{Edd}}{4\pi \cdot R^2}$

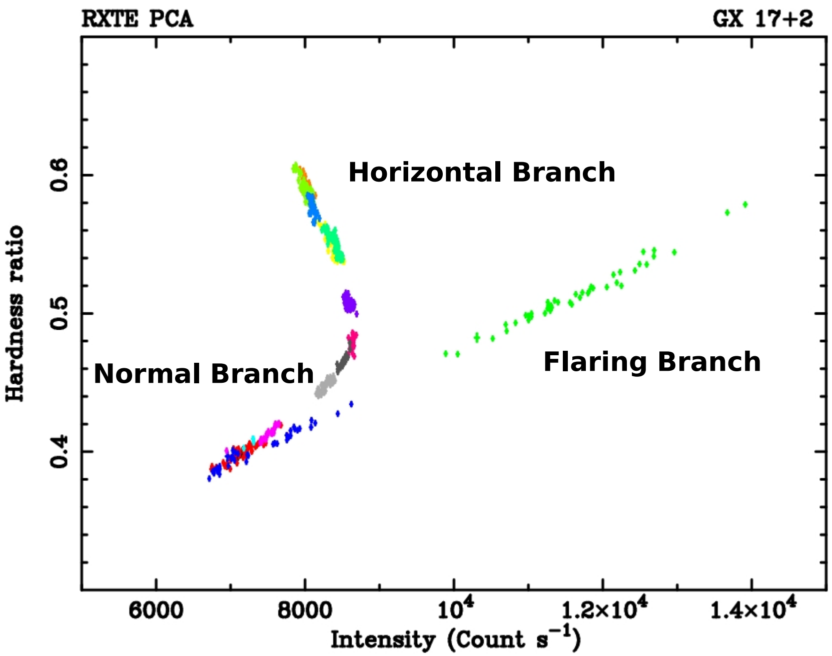
- **Soft Apex:** is sub-Eddington
- **Hard Apex:** at Eddington limit – strong local radiation pressure
- **Correlation:** with detection of radio jets
- **We propose:** radiation pressure --> disc disruption --> launching of jet

The Sco X-1 like sources: GX 17+2

- **Flaring:**
  is much stronger

- **We show:**
  observations of GX 17+2



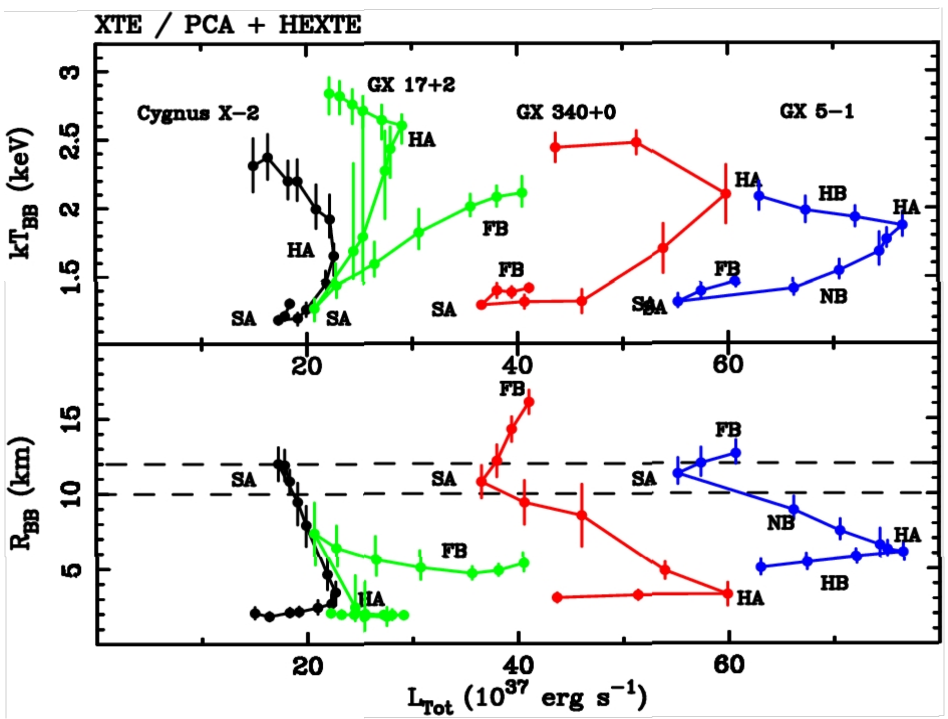


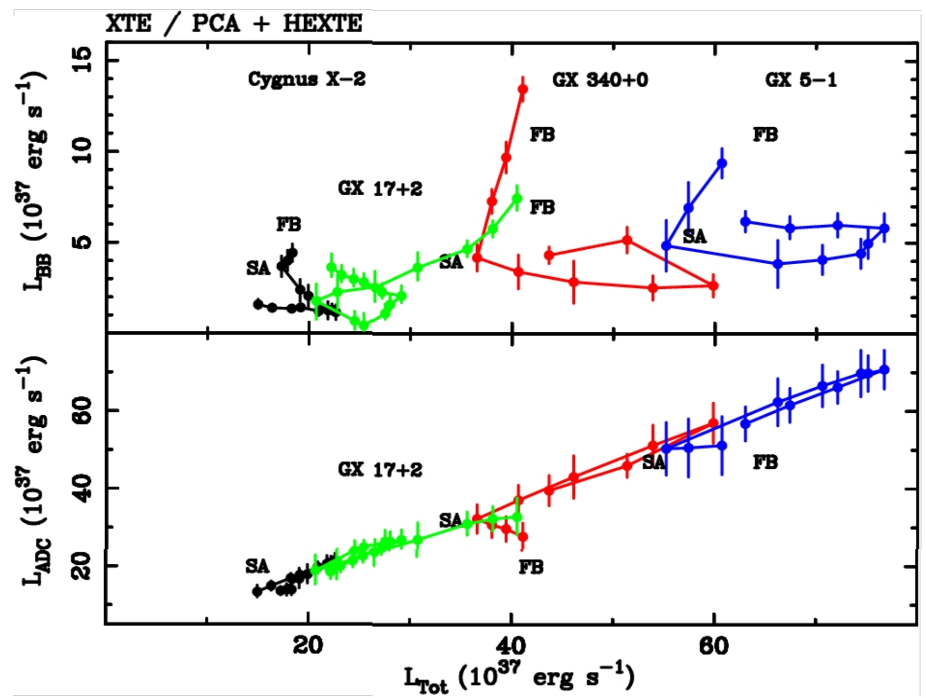
Balucinska-Church et al. 2010

GX 17+2: comparison with Cyg-like sources

- **Normal and Horizontal Branches:**
  same as Cyg-like sources

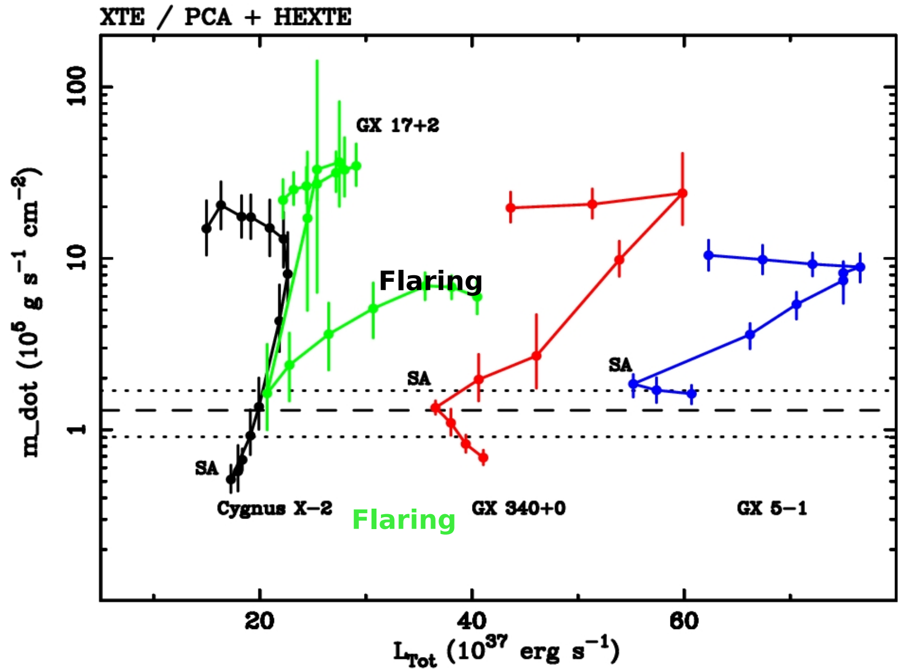
- **Flaring Branch:**
  L_{ADC} increases (unlike Cyg-like sources)
  => Mdot increases
  L_{BB} also increases
  => unstable nuclear burning





Balucinska-Church et al. 2010

Unstable nuclear burning in GX 17+2



- **Soft Apex:**
  mdot = critical value (mdot$_{ST}$)
  => unstable nuclear burning

- **Flaring Branch:**
  unstable burning
  +
  Mdot increase

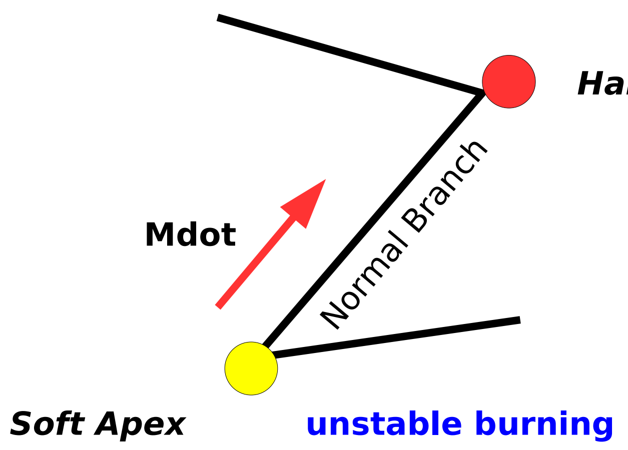
Difference between Sco-like and Cyg-like sources

- **Flaring in Cygnus X-2 like sources:**
  unstable nuclear burning

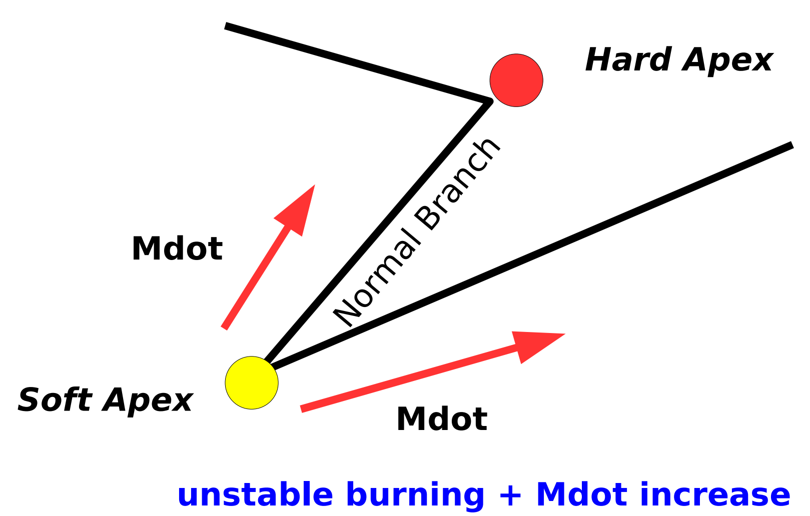
- **Flaring in Scorpius X-1 like sources:**
  Mdot increase + unstable nuclear burning

(Sco X-1 and GX 349+2 similar to GX 17+2)

Cyg-like sources



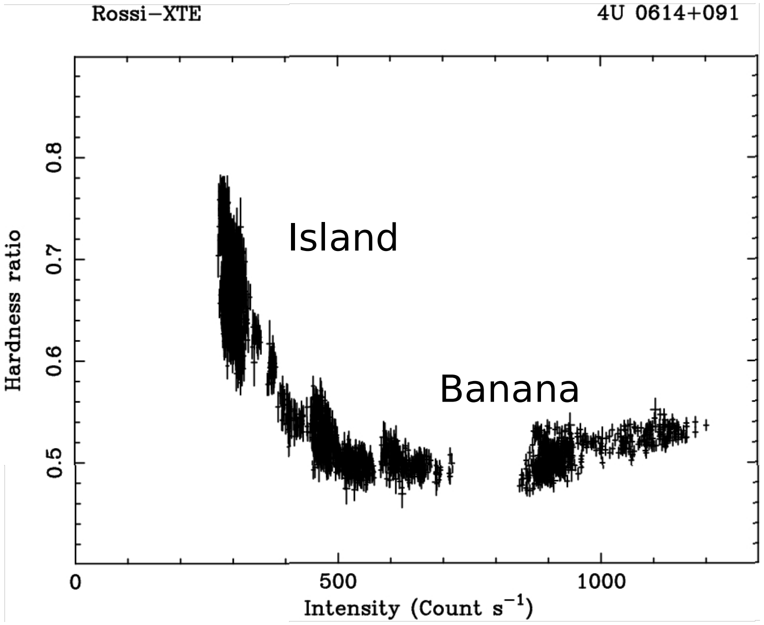
Sco-like sources



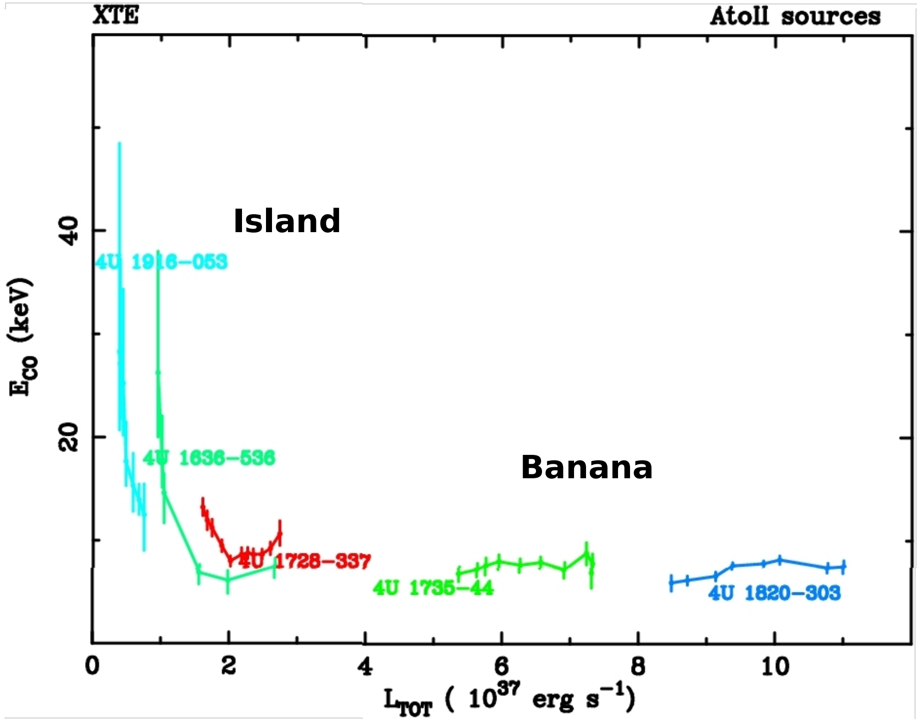
Atoll survey results

- **Island state:**
  a hardening of the spectrum
  for L < 2.10^{37} erg/s

- **Comptonization high energy cut-off:**
  causes the hardening

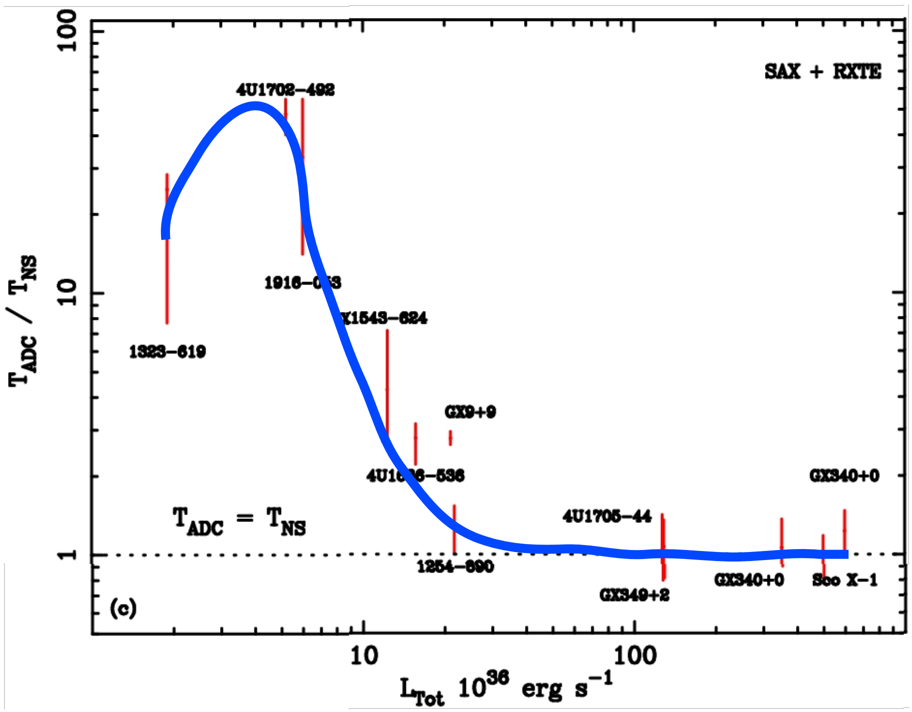


High energy cut-off -v- luminosity



- **Explanation:**
  is provided by our previous work

Survey of LMXB: ADC and Neutron Star temperature



- **We measure:**
  T_{ADC} from high energy cut-off
  T_{BB} from fitting

- **Thermal equilibrium:**
  L > 2 10^{37} erg/s:
  ADC in equilibrium with NS

- **Coronal heating:**
  L < 2 10 ^{37}erg/s: no equilibrium
  ADC hot - unknown heating mechanism

Cause of hardening in Island State

- **Island state:**

  ADC temperature increases --> E_{co} rises --> hardening of the Island state

Summary

Atoll sources:

• Only 2 tracks - not 3 as in Z-track sources:
Banana state = Normal Branch = changes of Mdot
Island state – not possible in Z-sources - only possible for L < 2.10^{37} erg/s
No Flaring Branch - unstable burning not possible **
(does not apply to transitional sources e.g. XB 1624-490
"GX-Atoll" type)

Z-track sources:

• We have proposed a model of Cygnus X-2 like sources
requiring physics *additional* to accretion physics:
high radiation pressure --> jets unstable nuclear burning --> flaring

• We are working to a unified model of Cyg-like and Sco-like sources
Flaring in Cyg-like sources = unstable burning
Flaring in Sco-like sources = unstable burning + Mdot increase

• **Difference between Atoll and Z-sources:**

Z-sources, ADC and NS are in thermal equlb
Island State of Atolls: ADC is hot