Outline

1. The variable X-ray sky
   - - X-ray Binaries
   - - Low Mass X-ray Binary Transients(LMXBTs)

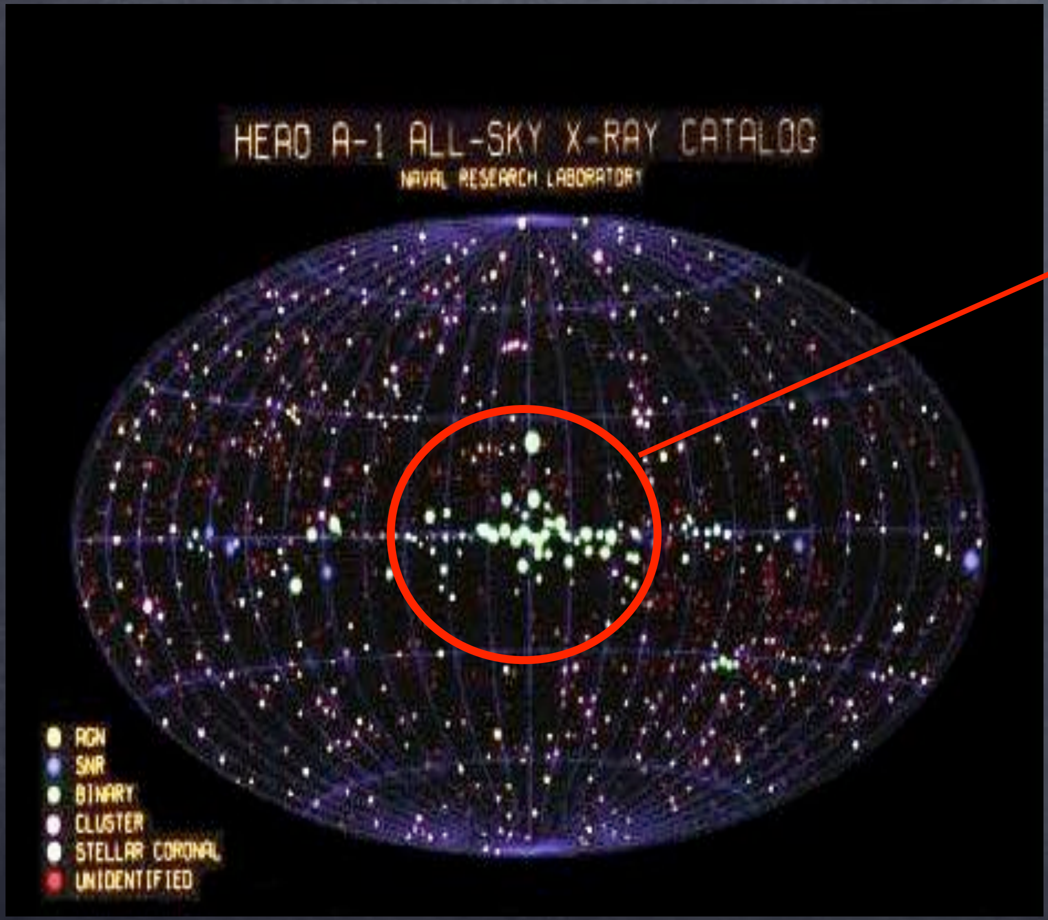
2. Science of X-ray monitoring

   - LMXBT outbursts
   - XRB spectral states and accretion physics
   - X-ray bursts (NS LMXBs, SGR)
   - ….

3. on SVOM's non-GRB science

   - SVOM's capability of ToOs and fill-in observations
   - favorable to ToOs of slow transients ?

The X-ray Sky



Galactic X-ray Binaries

- Brightest X-ray sources
- XRBs include LMXBs and HMXBs
- Majority of XRBs are transients
- BH and NS LMXB transients – majority are in the Galactic bulge

X-ray monitoring is the key to study the dynamic X-ray sky

SVOM/ECLAIRS vs. Swift/BAT

ECLAIRS

- FOV: 2 sr
- Area: 1000 cm2
- energy range: 4-150 keV

BAT

- FOV: 1.4 sr
- Area: 5200 cm2
- energy range: 15-150 keV

ECLAIRS:

low energy threshold at 4 keV opens new realm of bright soft X-ray transients
e.g. sensitive to transients with BB temperature above 1 keV or so

including BH and NS XRBs in soft state, type I X-ray bursts in NS LMXBs
bursts of soft gamma repeaters etc.

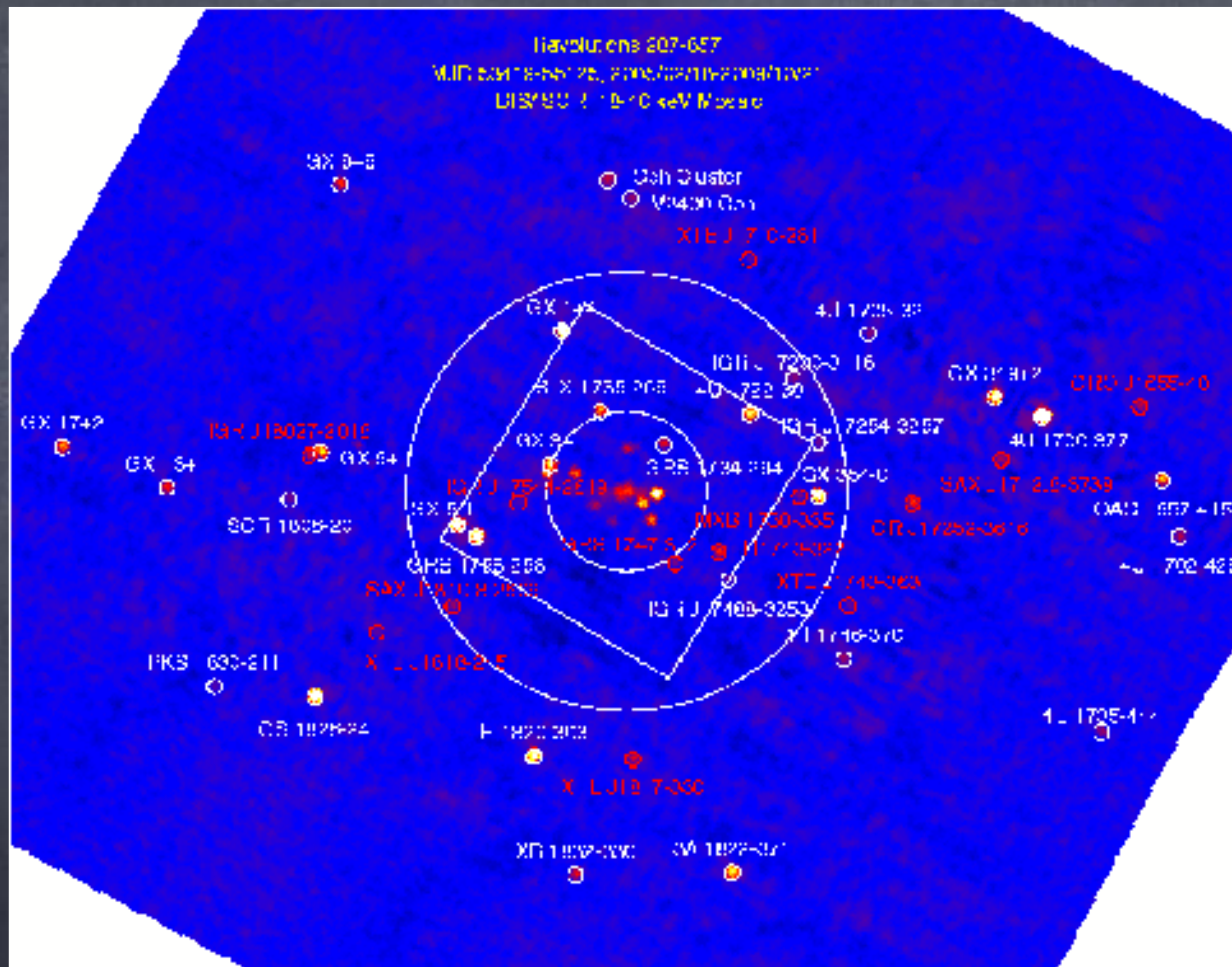
Outline

1. The variable X-ray sky
   - - X-ray Binaries
   - - Low Mass X-ray Binary Transients(LMXBTs)

2. Science of X-ray monitoring
   - LMXBT outbursts
   - XRB spectral states
   - X-ray bursts (NS LMXBs, SGR)

3. on SVOM's non-GRB science
   - SVOM's capability of ToOs and fill-in observations
   - favorable to ToOs of slow transients ?

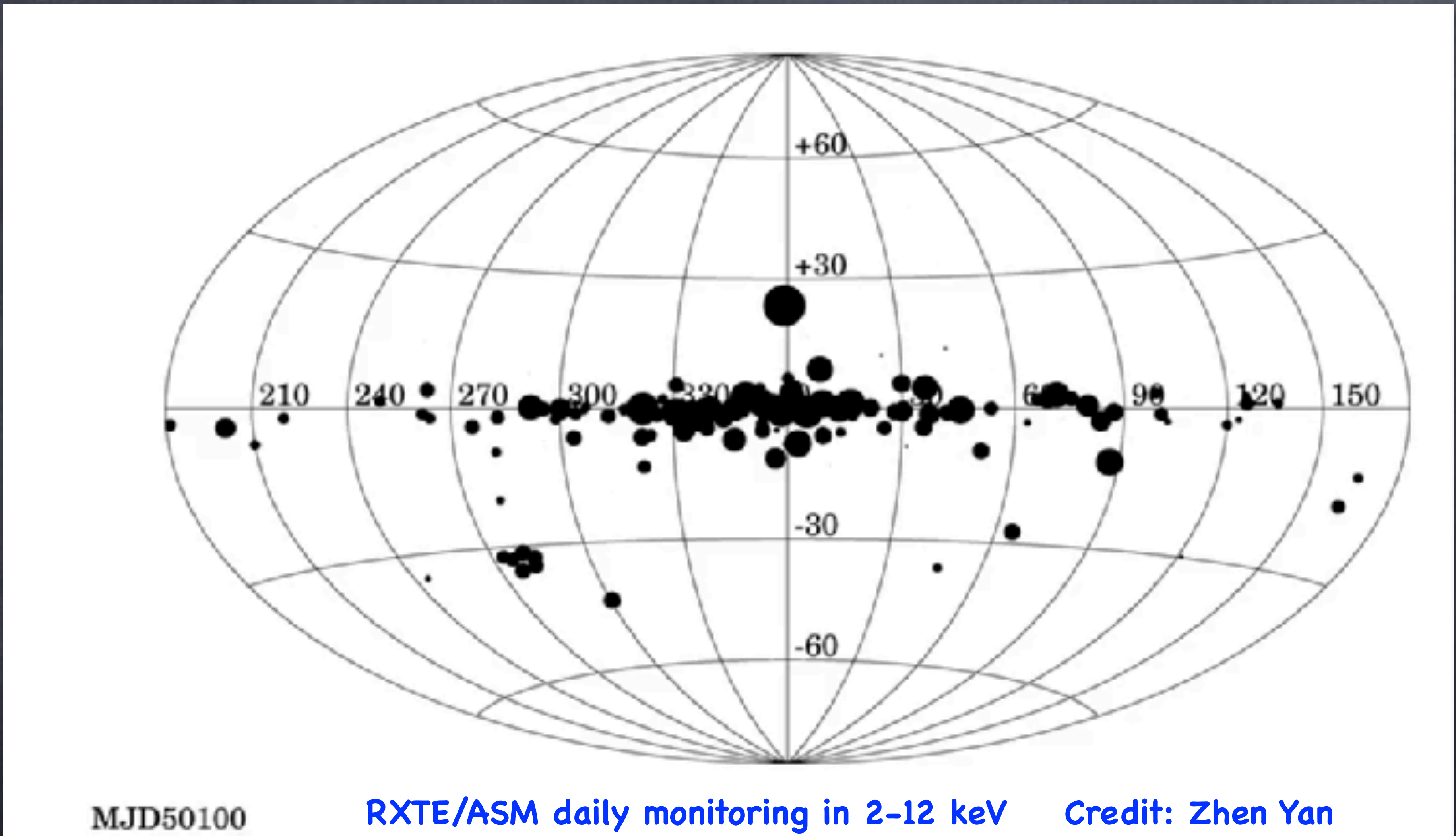
XRBs in the Galactic Bulge - Low Mass X-ray Binaries



Most LMXBs are transients - LMXBTs that spend most of their time in quiescence

- persistent sources in white, transient sources in red

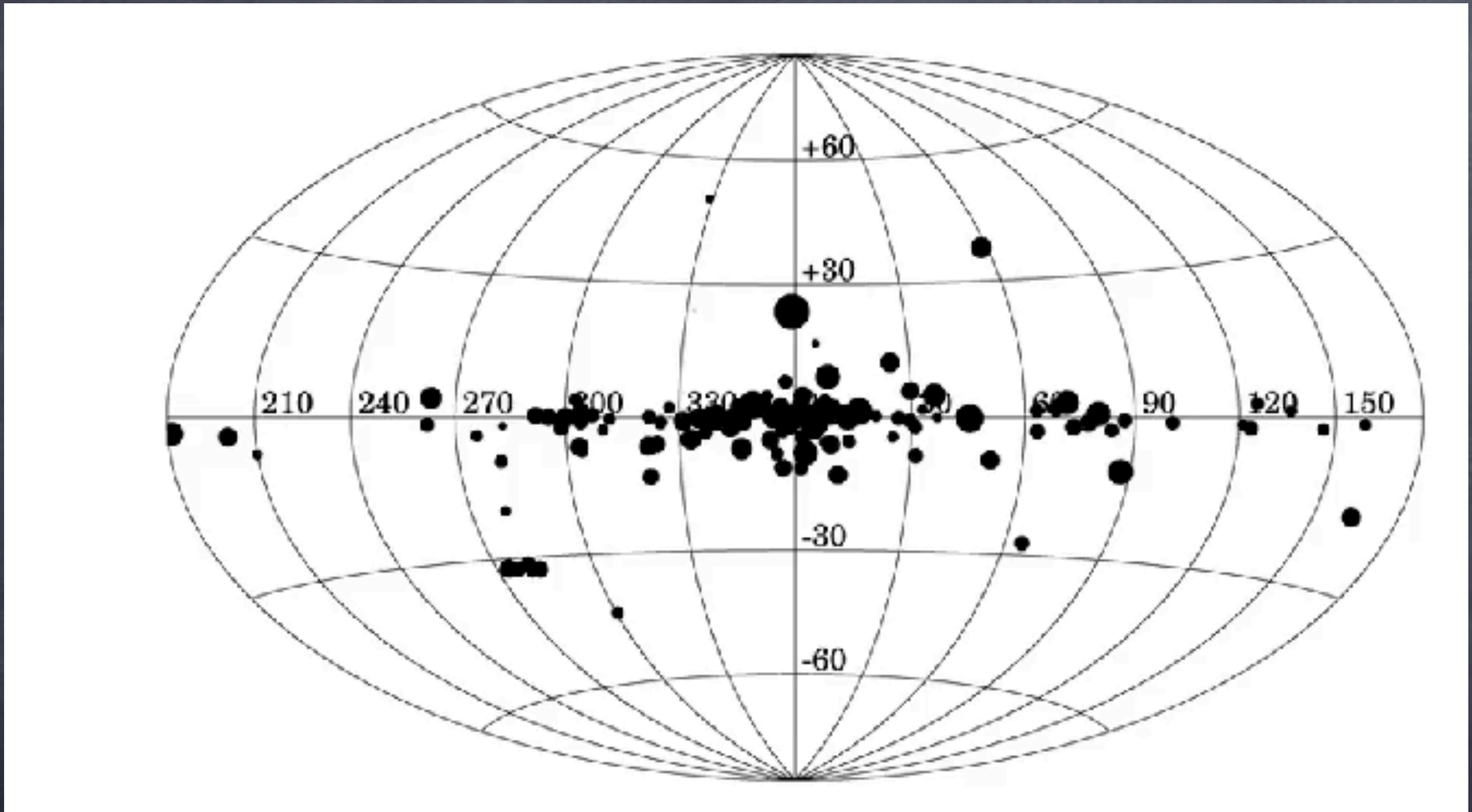
The Dynamic X-ray Sky and Galactic X-ray Transients



RXTE/ASM daily monitoring in 2-12 keV   Credit: Zhen Yan

Monitoring observations of X-ray transients are critical to explore the accretion physics in a large dynamical range of the mass accretion rate !

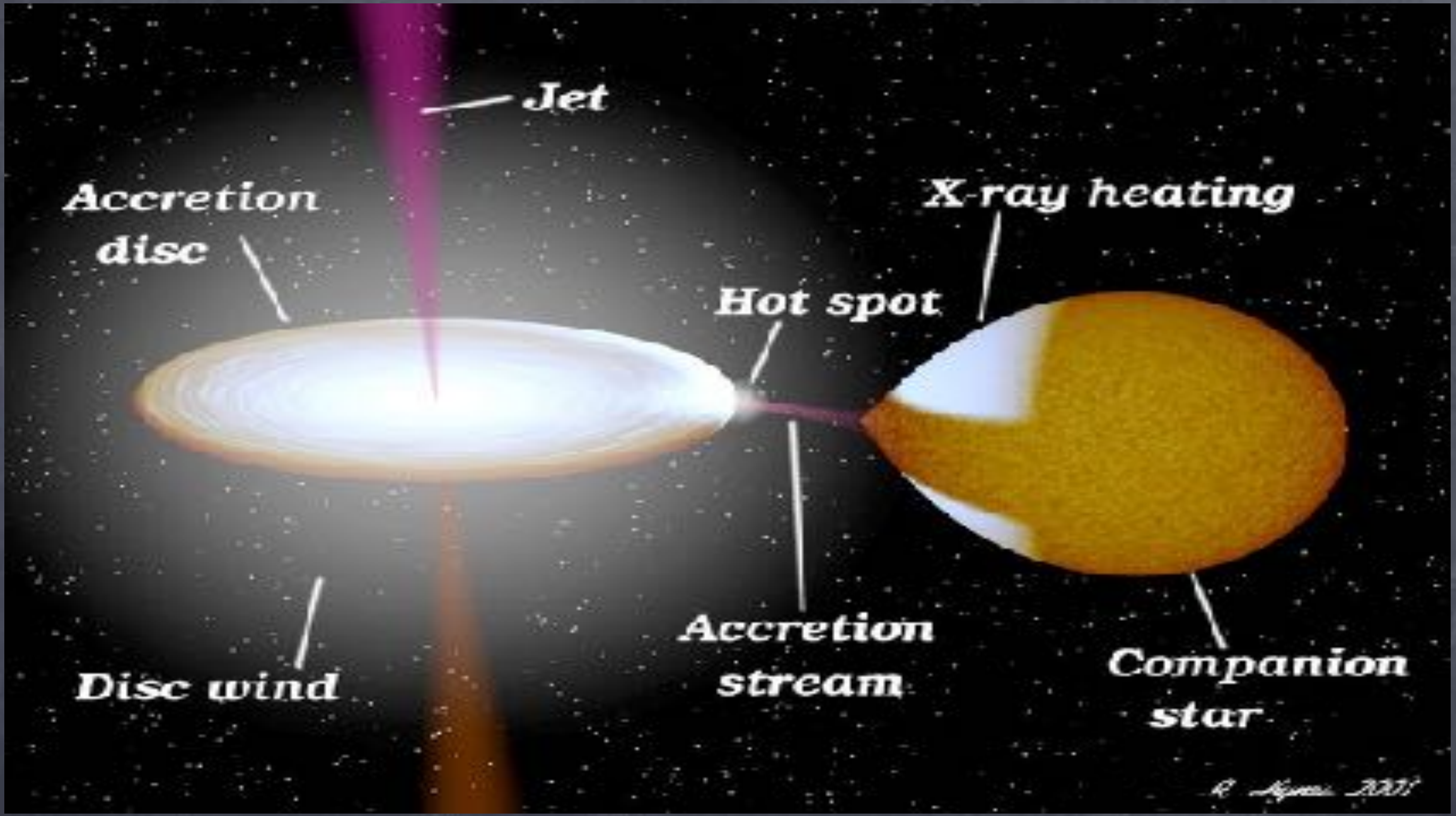
The Dynamic X-ray Sky and Galactic X-ray Transients



MAXI daily monitoring in 1-20 keV Credit: Zhen Yan

Monitoring observations of X-ray transients are critical to explore the accretion physics in a large dynamical range of the mass accretion rate !

Low Mass X-ray Binaries



X-ray: accretion disk or jet, vicinity of compact star (e.g. boundary layer of NSs)
Optical & UV: accretion disk & companion & hot spot & jet
Radio: jet emission

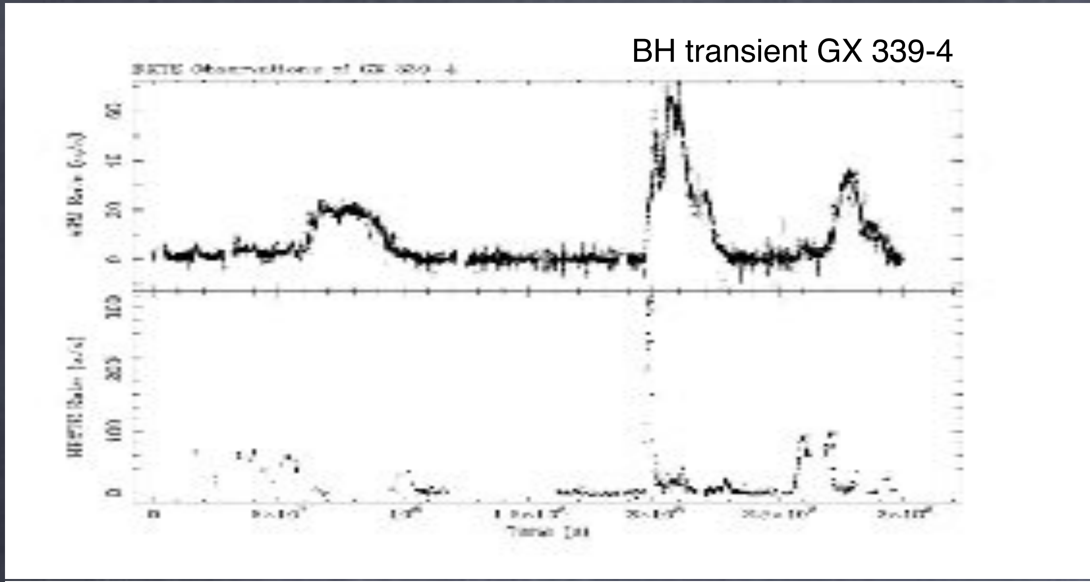
Outline

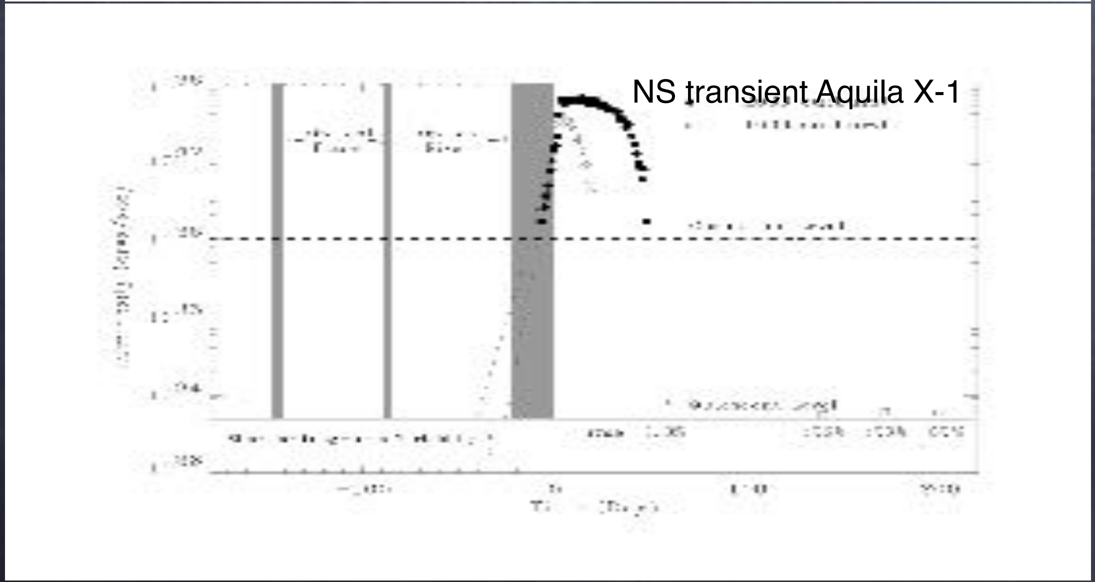
1. The variable X-ray sky
   - - X-ray Binaries
   - - Low Mass X-ray Binary Transients(LMXBTs)

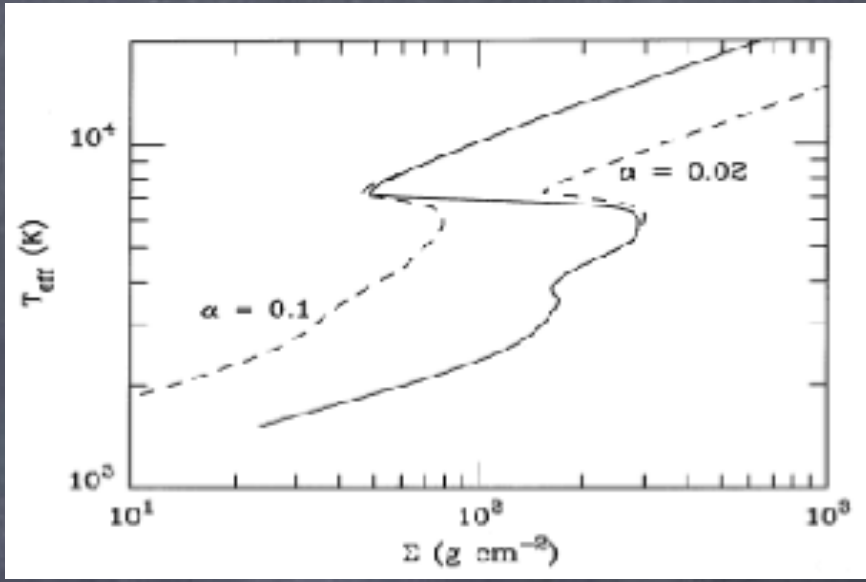
2. Science of X-ray monitoring
   - LMXBT outbursts
   - XRB spectral states
   - X-ray bursts (NS LMXBs, SGR)

3. on SVOM's non-GRB science
   - SVOM's capability of ToOs and fill-in observations
   - favorable to ToOs of slow transients ?

Low Mass X-ray Binary Transients (LMXBTs)







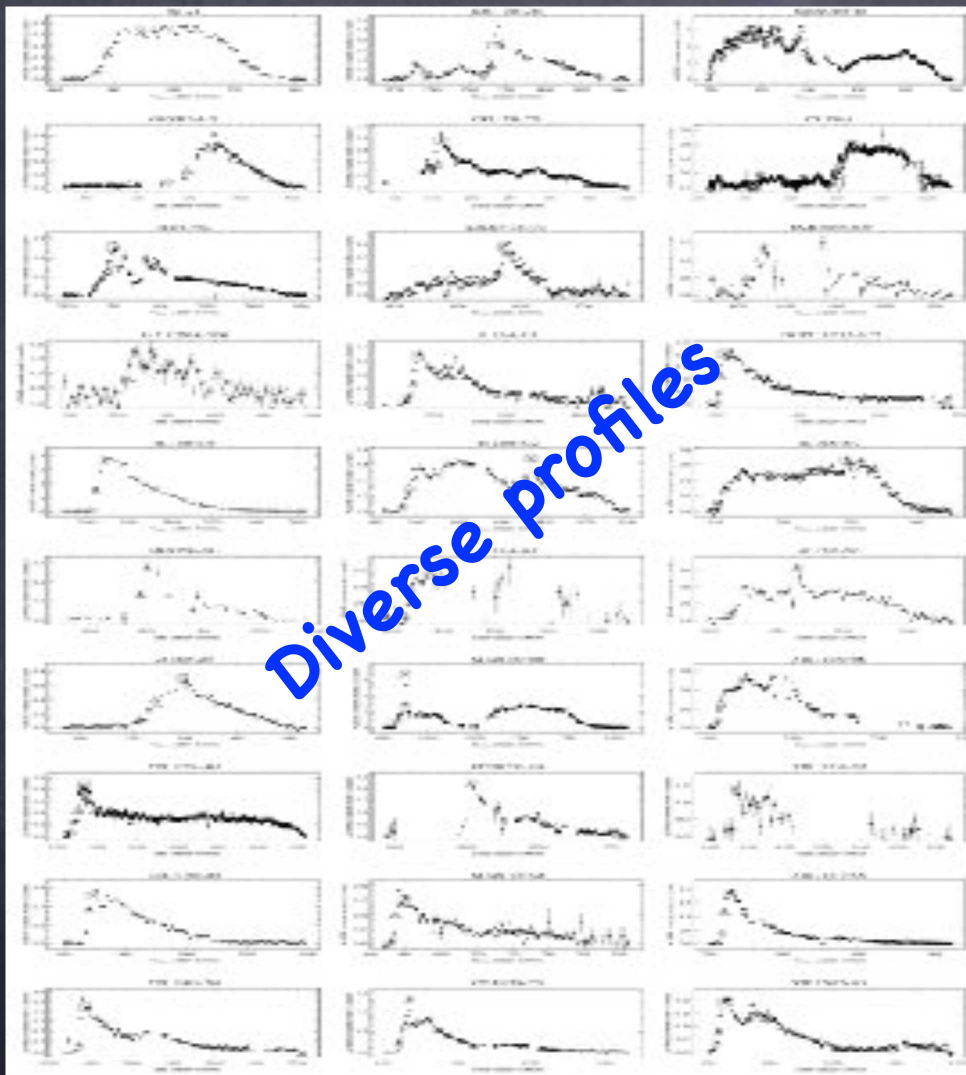
- The most popular explanation of the outburst mechanism is the disk-instability model (see Lasota 2001, New Astronomy Review, 45, 449)

Hydrogen ionization – opacity

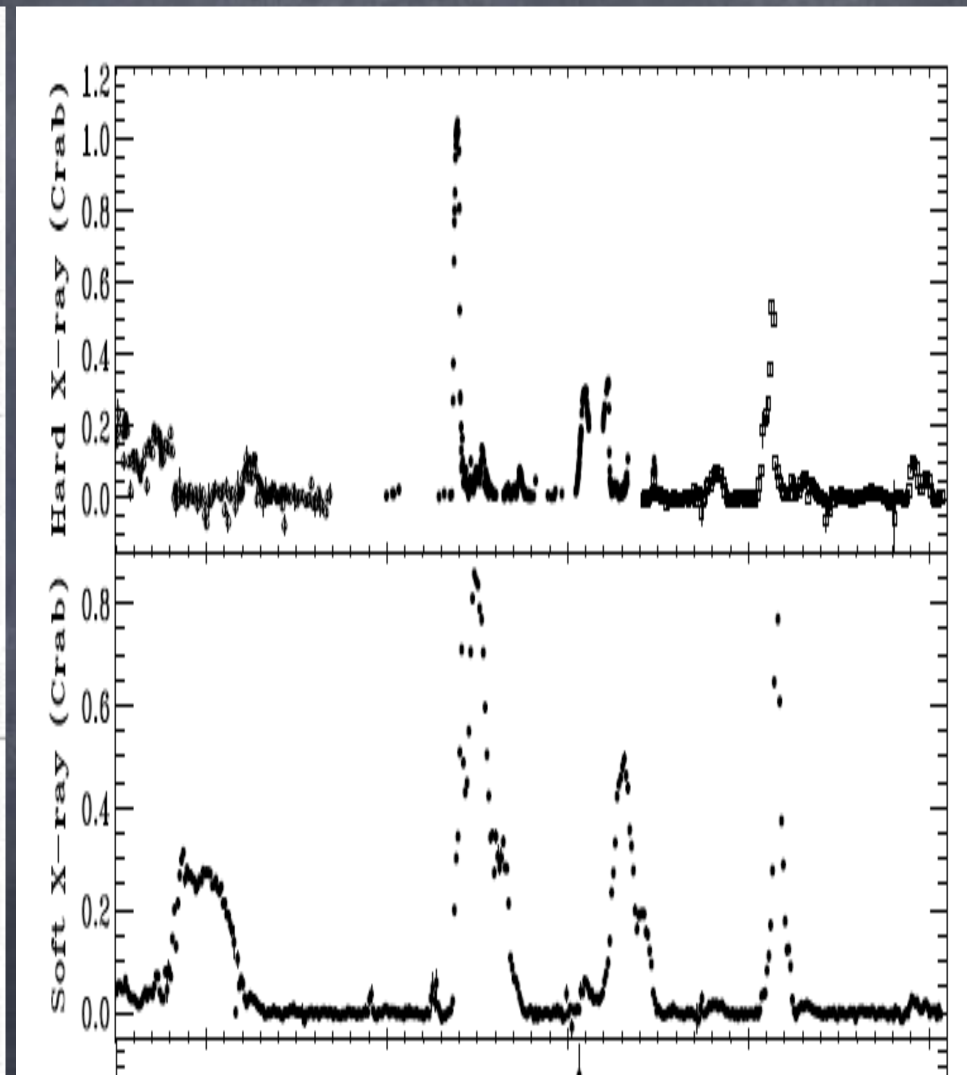
- Depending on the level of average mass transfer rate & orbital parameters, most of the LMXB sources known are not persistent sources but transients (van Paradijs 1996).

Best targets for the study of accretion physics !!

More outburst samples of LMXBTs: BHs

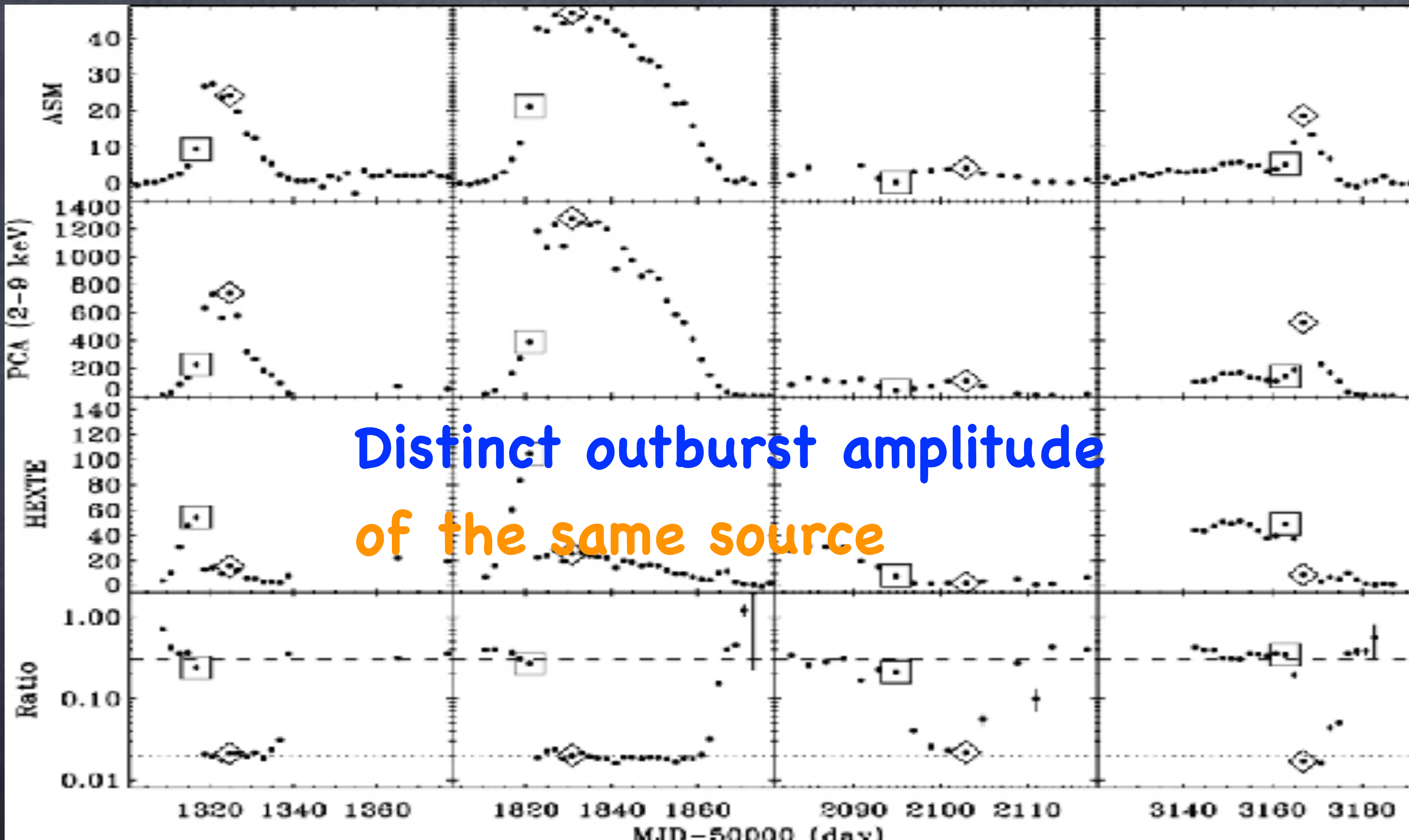


Yan & Yu 2015, ApJ



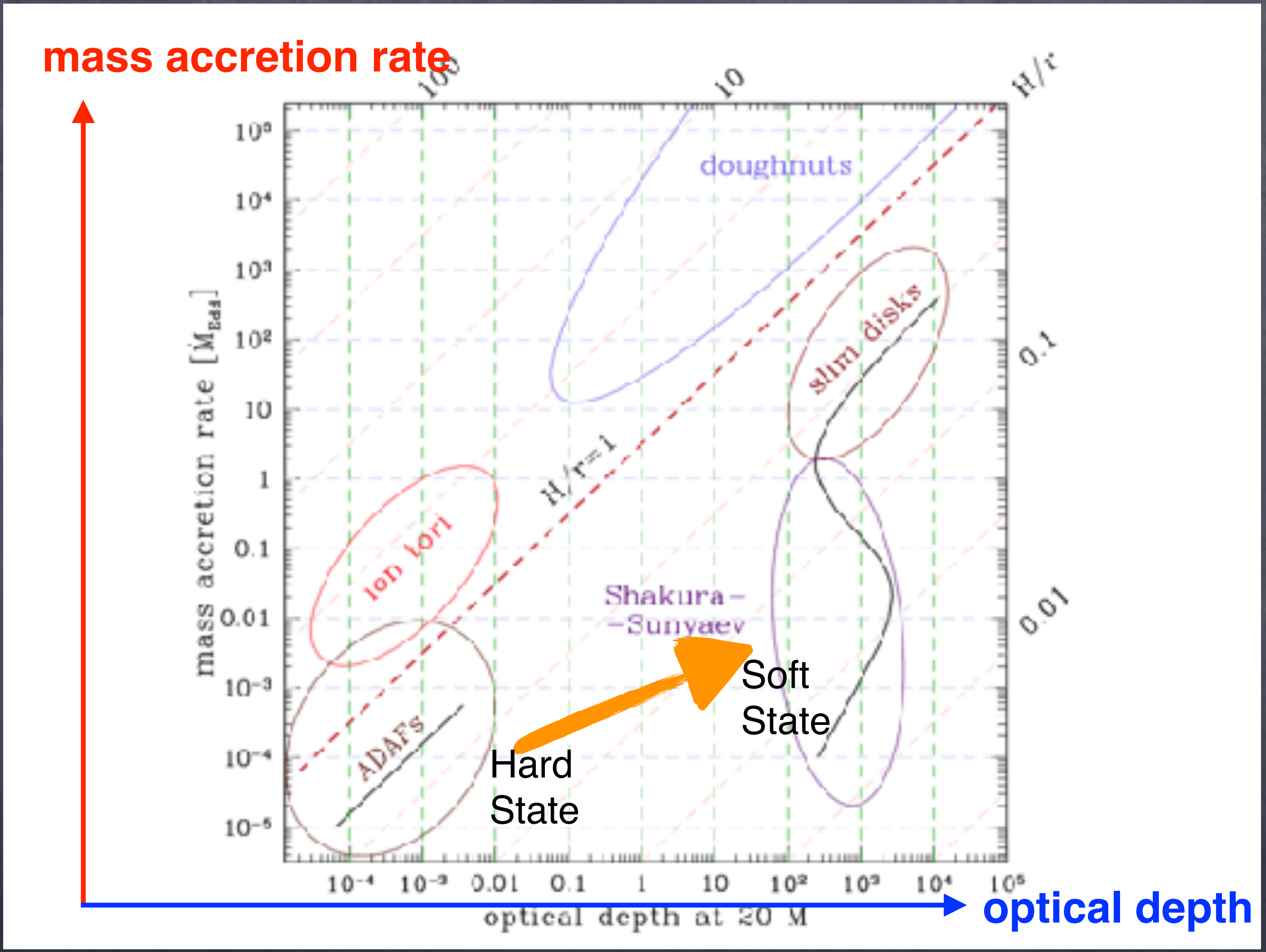
Wu, Yu et al. 2010, ApJ

More outburst samples of LMXBTs: NSs



Yu & Dolence 007, ApJ

Black Hole Accretion Regimes



Major solutions in black hole accretion theories: from low Mdot to high Mdot
Advection Dominated Accretion Flow (ADAF), standard disk, and slim disk

Alerts of LMXBT outbursts

New outbursts in BH and NS XRBs usually attract multi-wavelength follow-up observations for the understanding accretion & jet physics and relativistic astrophysics

XMM-Newton, NuStar, Integral, Swift, EPN, JVLA, GTC, etc.

- ATEL #10599 (Zhang et al. 2017 - a Galactic BH transient)

Based on Swift/BAT monitoring:

"Swift/BAT X-ray monitoring indicates a new outburst of the black hole transient H 1743-322"

- ATEL #10289 (Yan & Yu 2017 - a ULX in nearby galaxy)

Based on Swift/XRT monitoring:

"A new outburst of ESO 243-49 HLX-1 after being in quiescence for two years"

Two types of monitoring observations with Swift were involved !

Super-Eddington outbursts of Galactic source V4641 Sgr

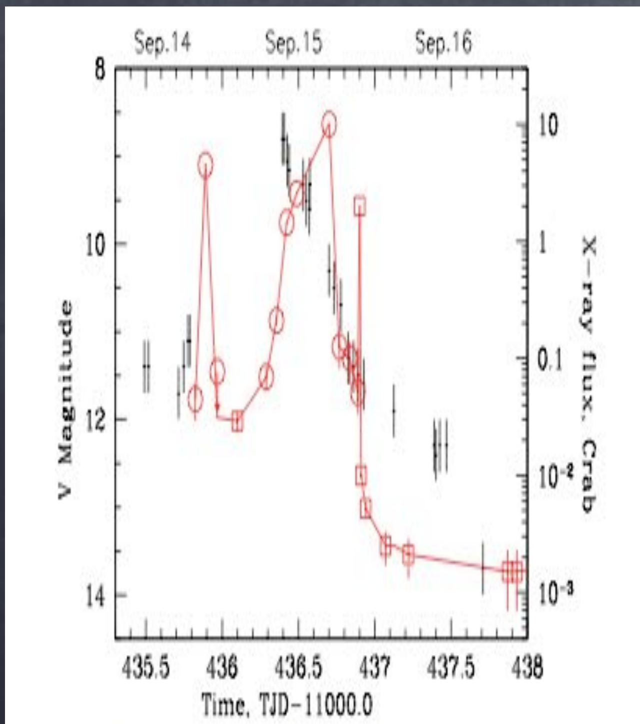
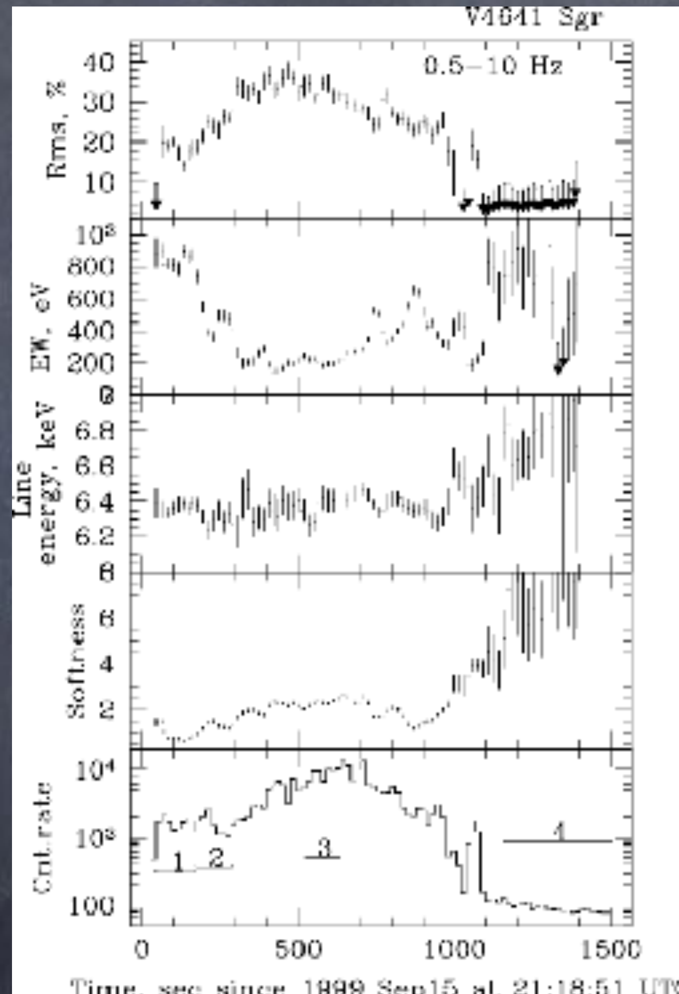
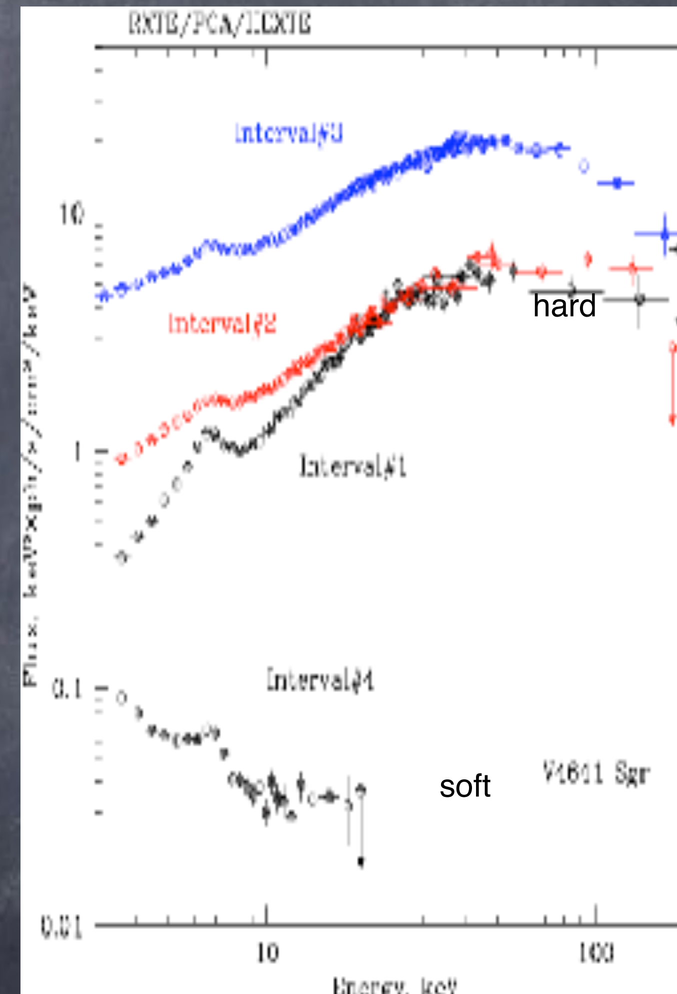


Fig. 1. The light curves of V4641 Sgr in the optical V-band (crosses, from Kato et al. 1999) and and in X-rays near the peak of main outburst in Sep. 1999. The RXTE/ASM points (1.5–12 keV) are shown by open circles, the RXTE/PCA (3–20 keV) – by open squares (Revnivtsev et al. 2002).

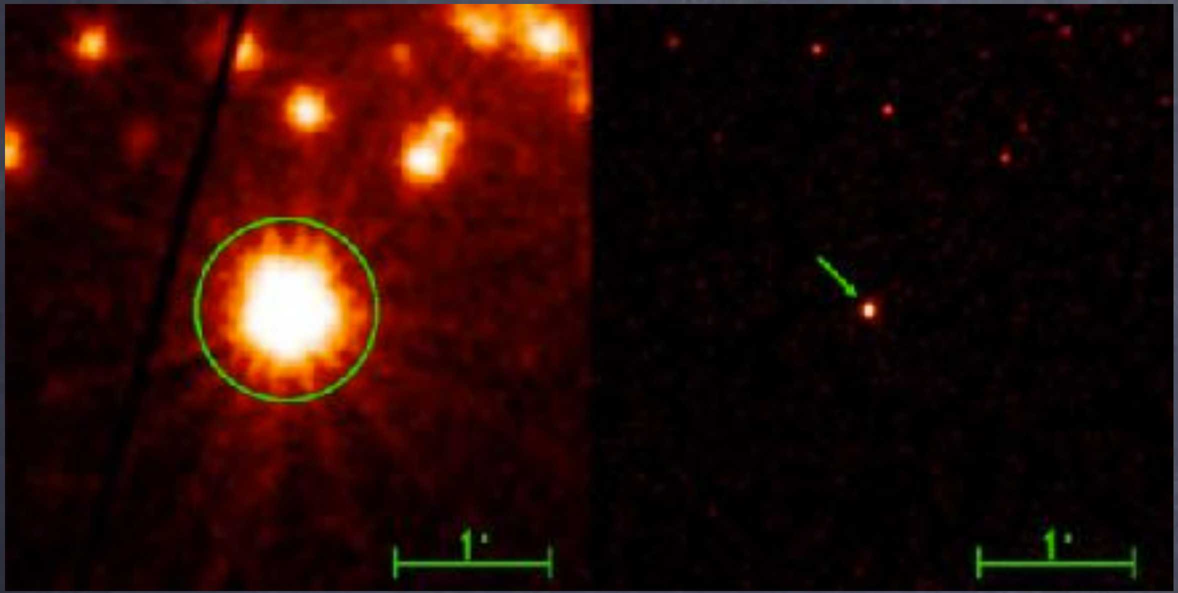


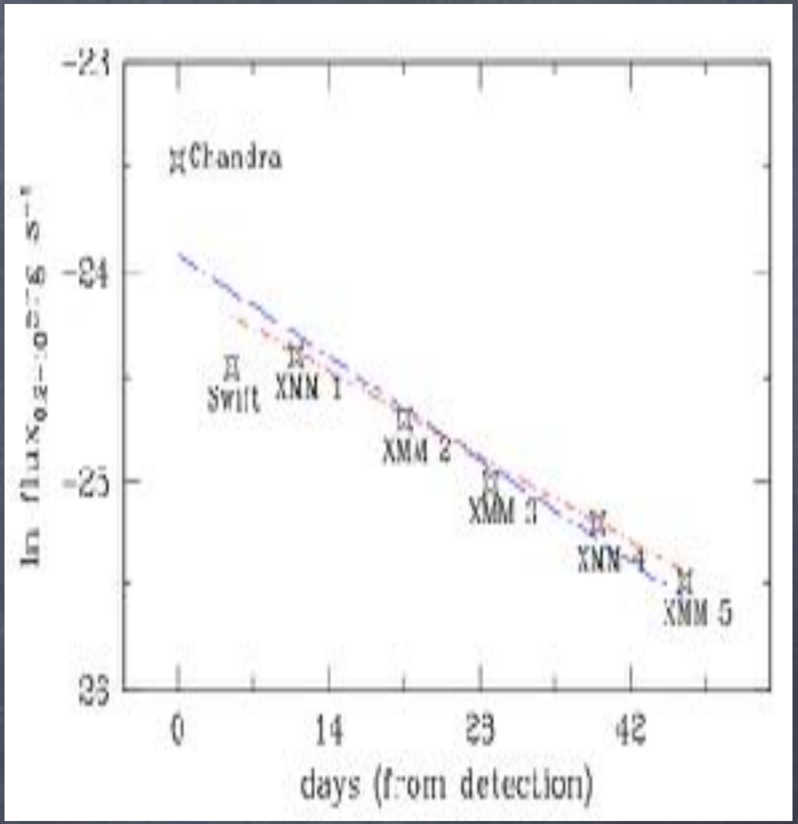


Revnivtsev et al. 2002: super-Eddington hard state and a short-lived soft state

The first ultraluminous X-ray transient in M31

CXOM31 J004253.1+411422





an exponential decay !
consistent with a FRED outburst

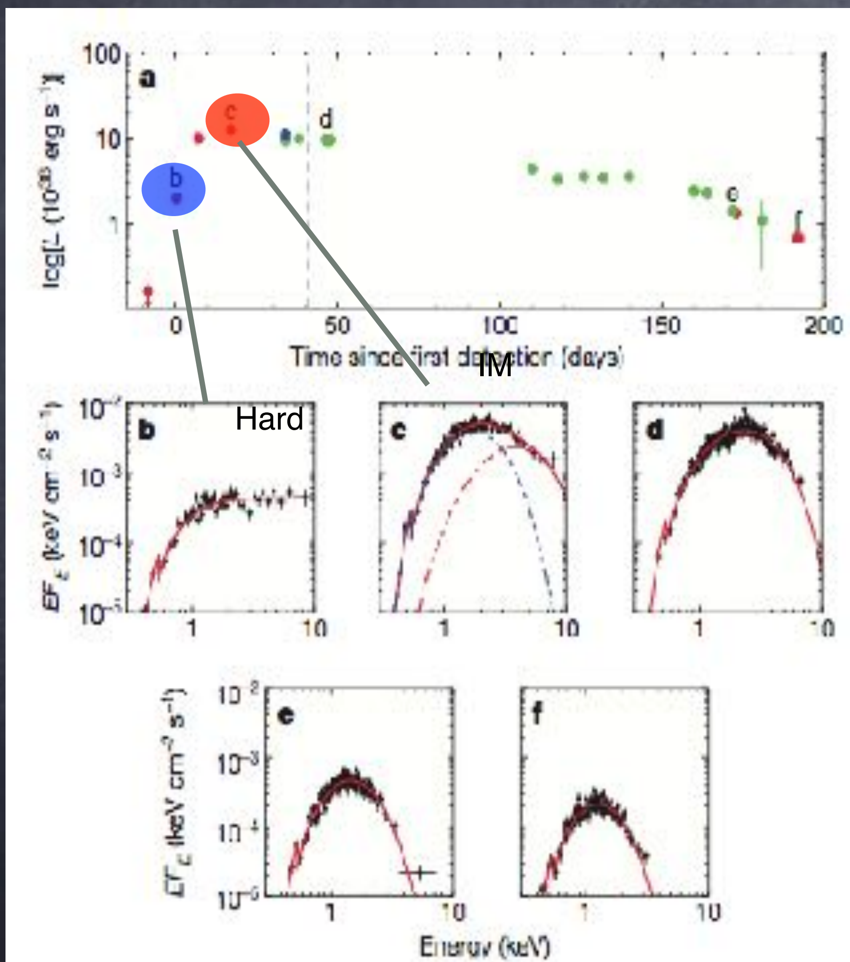
Kaur et al. 2012, A&A
"CXOM31 J004253.1+411422: the first ultraluminous X-ray transient in M 31"

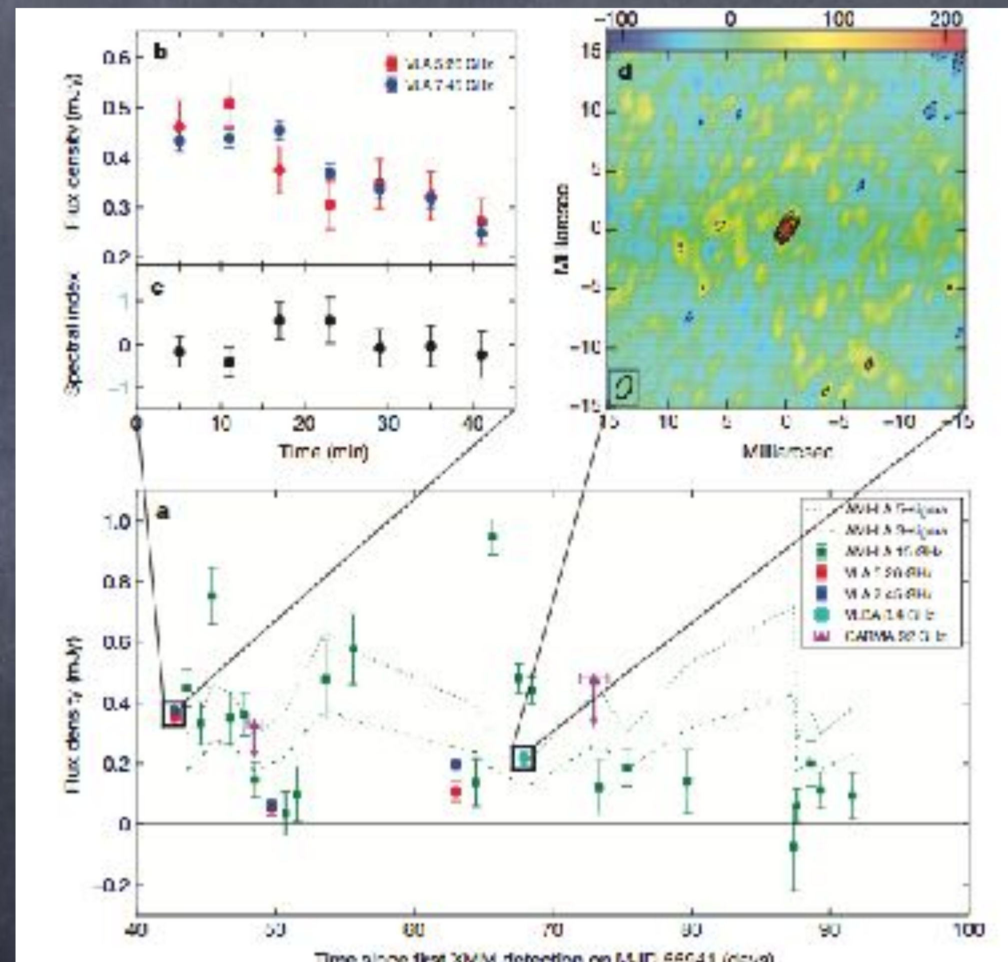
Middleton et al. 2012, MNRAS:
"The missing link: a LMXB in M31 as an ultraluminous X-ray sources"

Super Eddington X-ray outburst: episodic radio jet emission

The first LXMB ULX tranient in M31 :
CXOM31 J004253.1+411422

Middleton et al. 2013, Nature
"Bright radio emission from an ultraluminous stellar-mass microquasar in M 31"





The hard state reached about > 60 % Eddington luminosity (e.g., for a 10 solar mass BH)

Outline

1. The variable X-ray sky
   - - X-ray Binaries
   - - Low Mass X-ray Binary Transients(LMXBTs)

2. Science of X-ray monitoring
   - LMXBT outbursts
   - XRB spectral states
   - X-ray bursts (NS LMXBs, SGR)

3. on SVOM's non-GRB science
   - SVOM's capability of ToOs and fill-in observations
   - favorable to ToOs of slow transients ?

State Transition - the discovery

"remarkable transition" in Cygnus X-1 (Tananbaum et al. 1972)

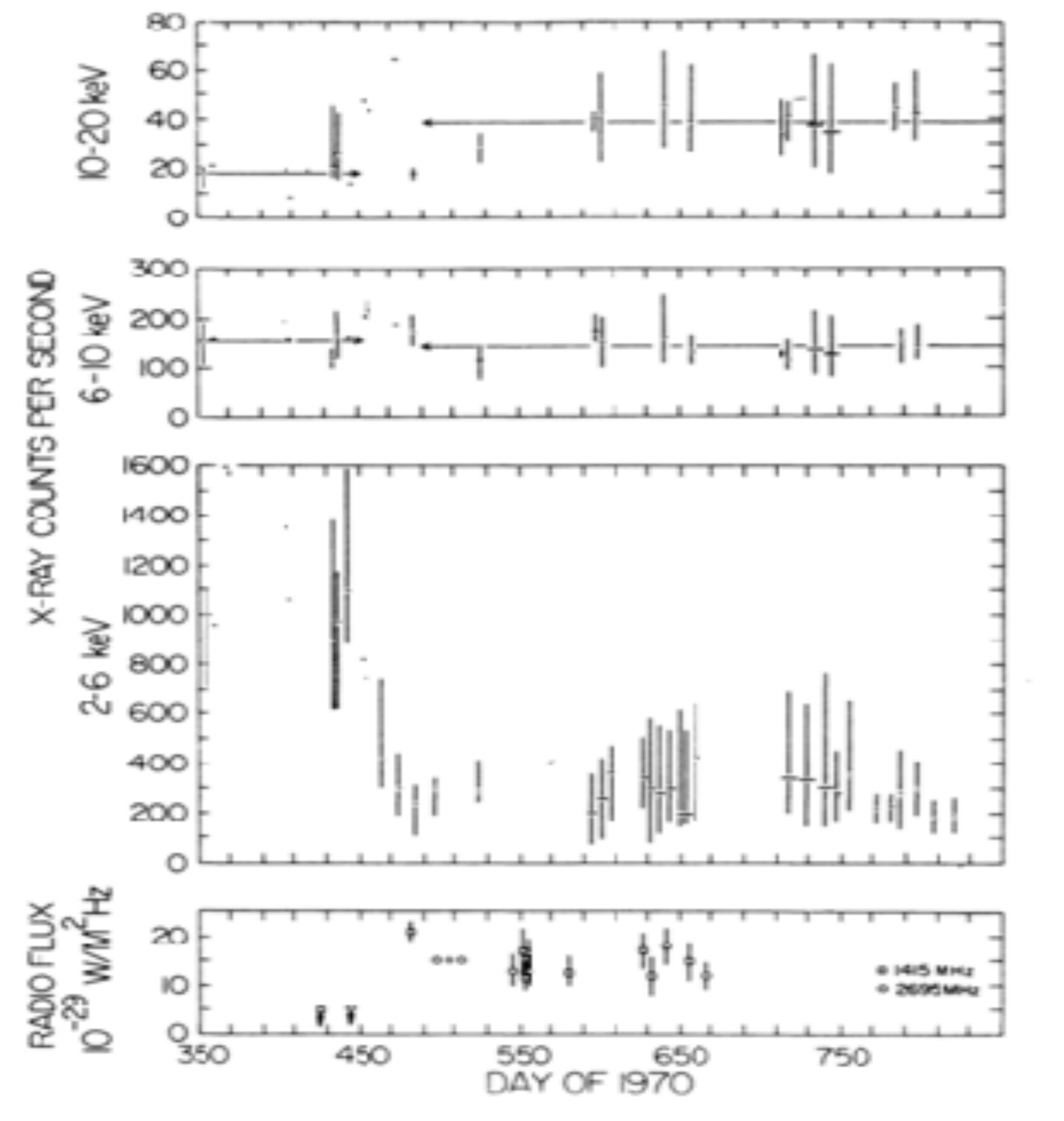


Fig. 1-2. X-ray and radio data of Cyg X-1. The transition of X-ray intensity and spectrum occurred in the period of March 1971 (Tananbaum *et al.*, 1972). The radio data also exhibit the transition in the same period.

High - Soft
radio quiet

Low - Hard
radio loud

State transitions in Cygnus X-1 (Zhang et al. 1997; Cui et al. 1997)

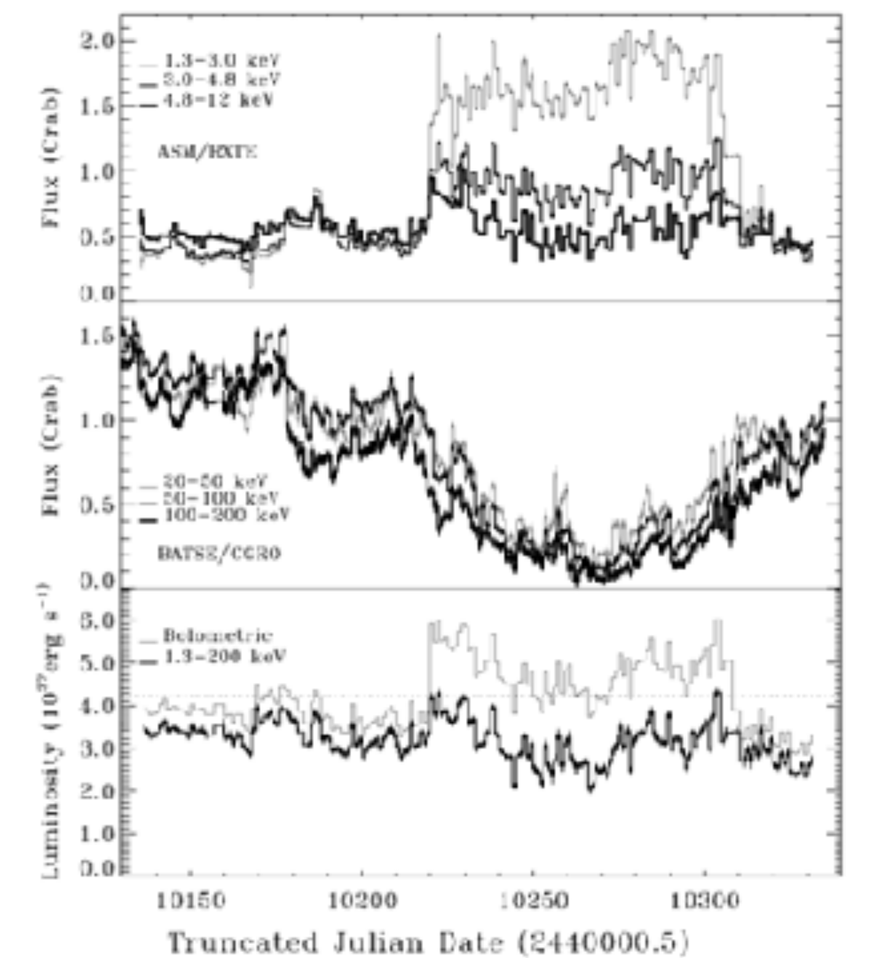
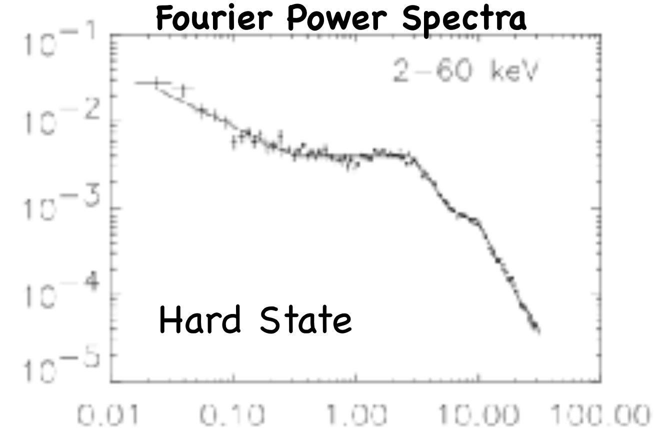
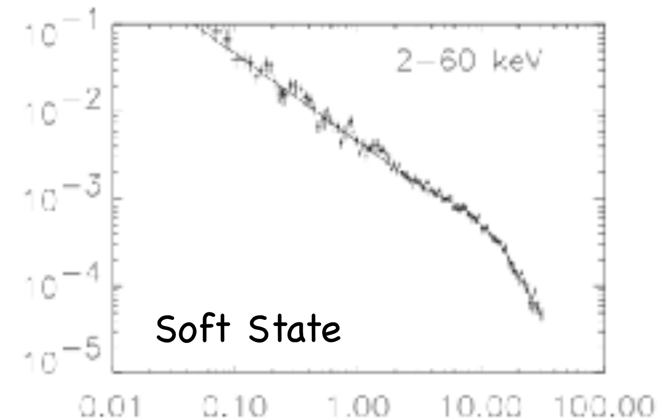


FIG. 1.—Cyg X-1 light curves and the 1.3–200 keV luminosity variations during its 1996 SS transition.



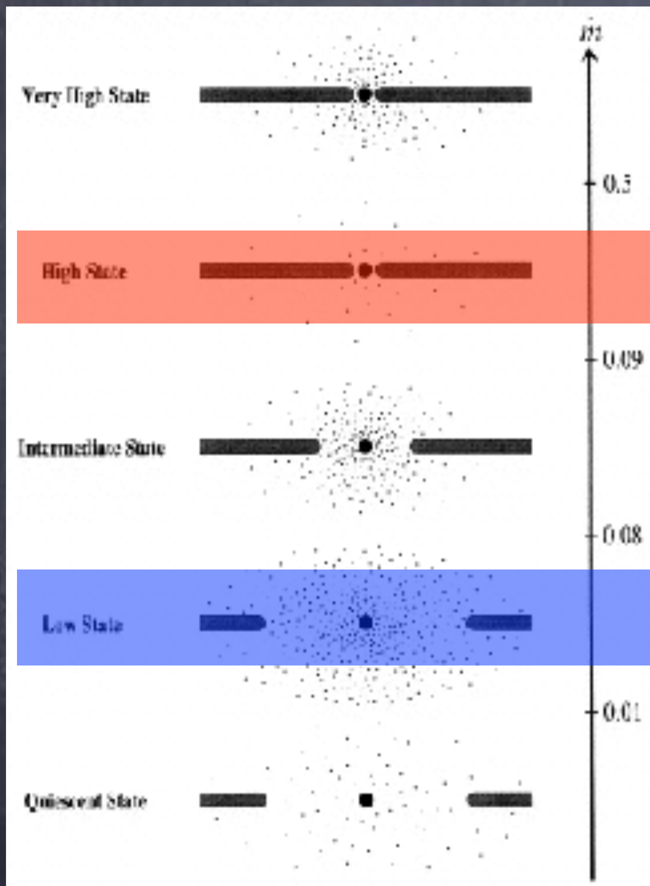


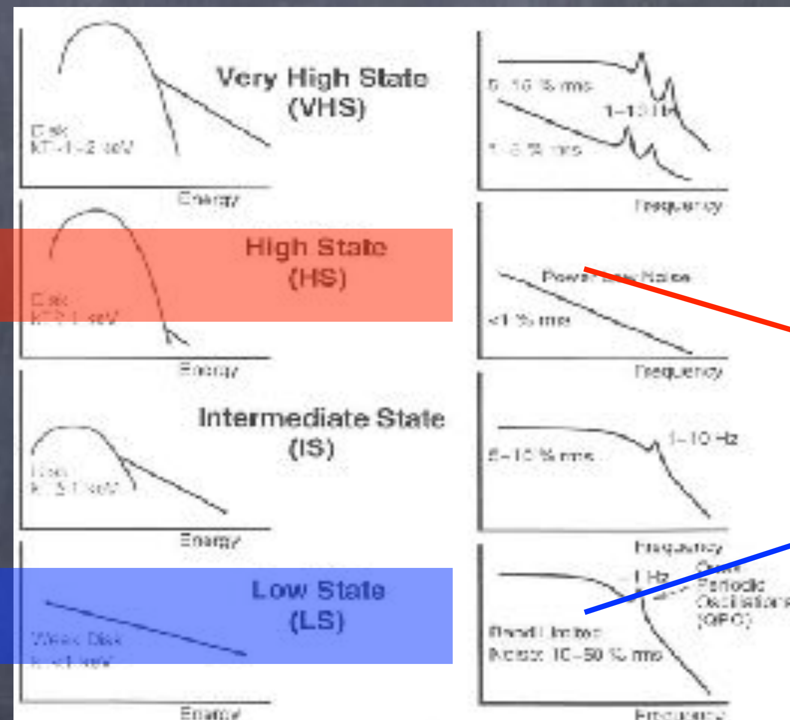
Bolometric luminosity during the hard - soft - hard varied by less than 15%
(Zhang et al. 1997, ApJ, 477, L95)

Black Hole X-ray Binaries

The classical picture of black hole spectral states

Accretion Geometry **Energy Spectra** **Fourier Power Spectra**





Photons:
- time
- energy
- direction

Two Major Spectral States

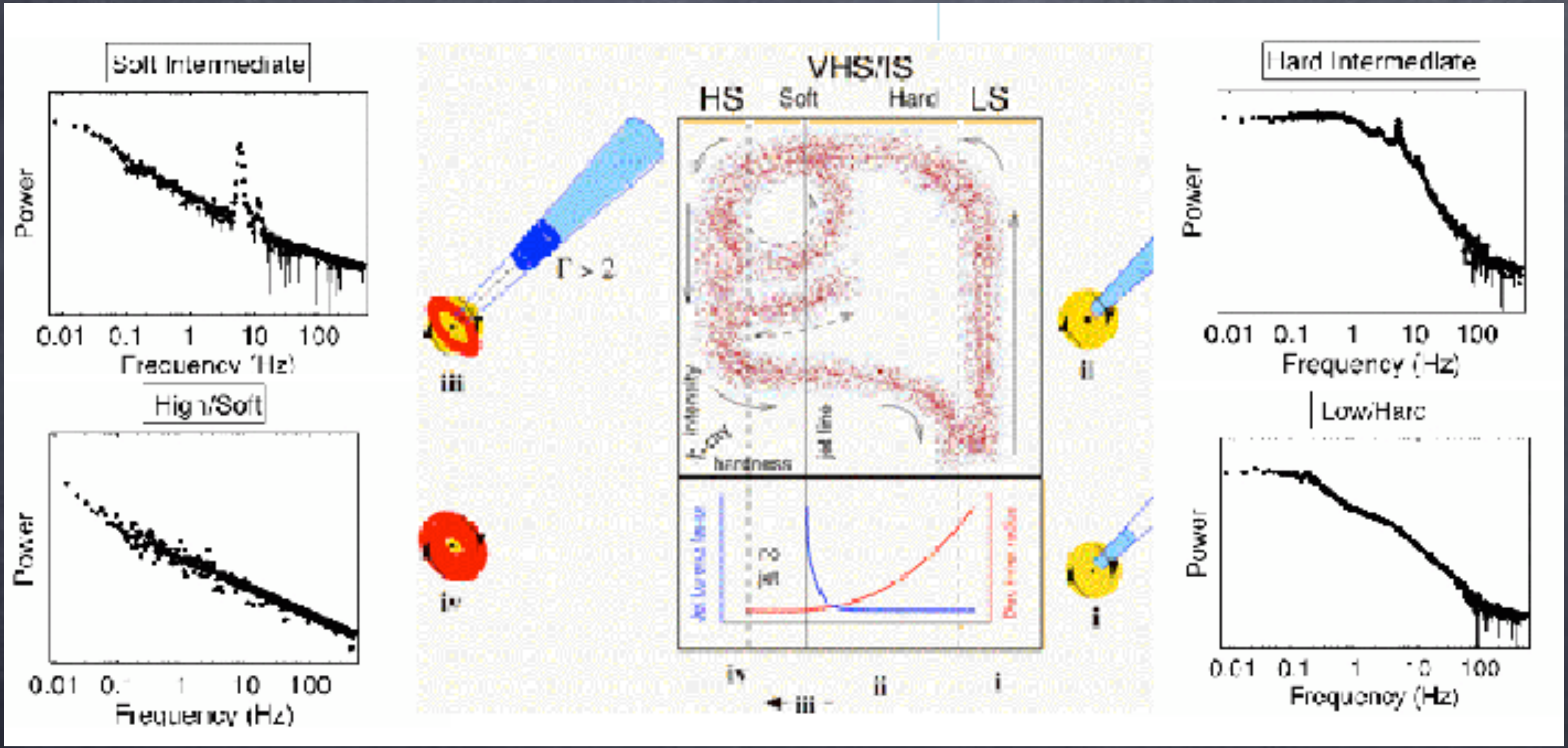
Under this picture, mass accretion rate is the primary parameter (see Esin et al. 1997)

The classical picture:

There is a correspondence between the spectral state and the power spectral state !

Black hole spectral states and radio jets

Schematic picture during an actual BH transient outburst (Fender & Belloni 2006)

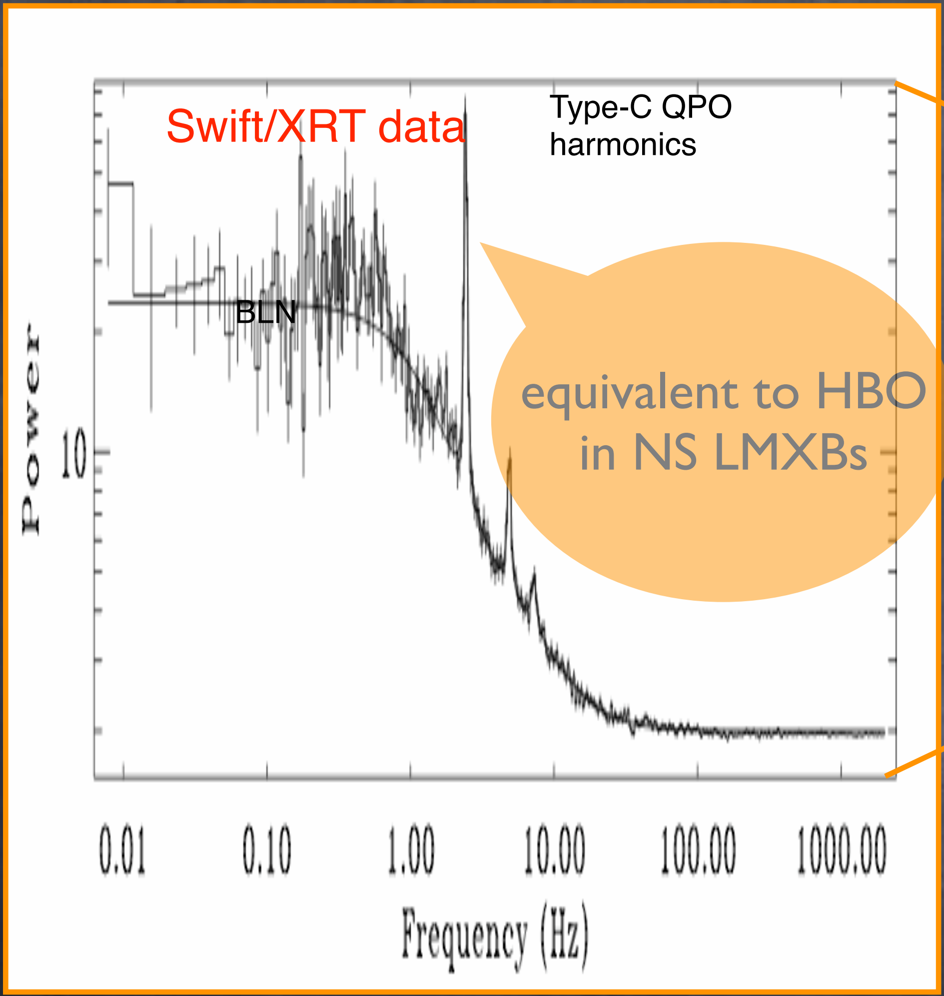


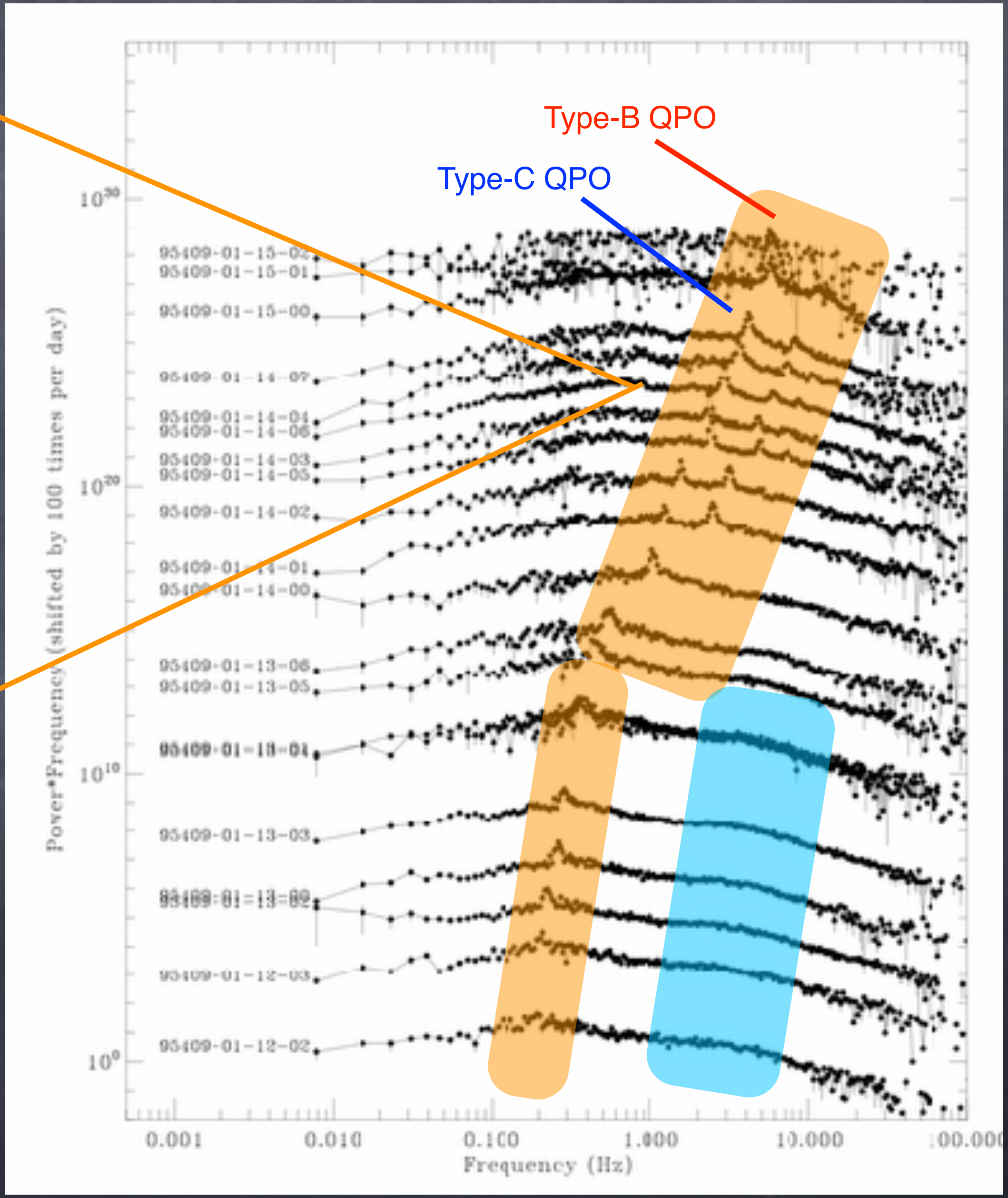
BUT It is not a single, universal "q-loop" ! - **Hysteresis problem**

- this is about additional parameters other than the mass accretion rate

Rich variability features, plenty of information underneath

Examples: X-ray variability in the hard or intermediate state of BH XRBs





Black hole transient GX 339-4 during the rising phase of the 2010 outburst (Swift/XRT, Yu 2010, ATEL # 2556)

Towards the extremes: the low luminosity end

ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES
DECEMBER III 1996, PAGE 187
Astron. Astrophys. Suppl. Ser. 120, 187-193 (1996)

Models of quiescent black hole and neutron star soft X-ray transients

I. Yi[1,2], R. Narayan[1], D. Barret[1], and J.E. McClintock[1]

Abstract. When the mass accretion rate onto a black hole (BH) falls below a critical rate, $\dot{M}_{\rm crit} \sim \alpha^2 \dot{M}_{\rm Edd}$, accretion can occur via a hot optically thin flow where most of the dissipated energy is advected inward. We present such an advection-dominated model fo
A 0620−00. This source has a
in quiescence, $\sim 6\,10^{30}$ erg s
accretion rate $\sim 10^{-10}$ $M_\odot$yr
The accreting gas makes a tra
at large radii to an advection
The transition occurs when
thin disc is $\sim 10^4$ K. Because of the very low accretion efficiency, $\sim 10^{-3} - 10^{-4}$, in the inner flow, the model fits both the optical and X-ray data. We also present models for V404 Cyg and Nova Mus 1991 in quiescence. Quiescent neutron star (NS) transients are expected to appear very different from BH systems because the advected energy is re-radiated from the NS surface whereas a BH swallows the advected energy. We discuss models for NS SXTs.

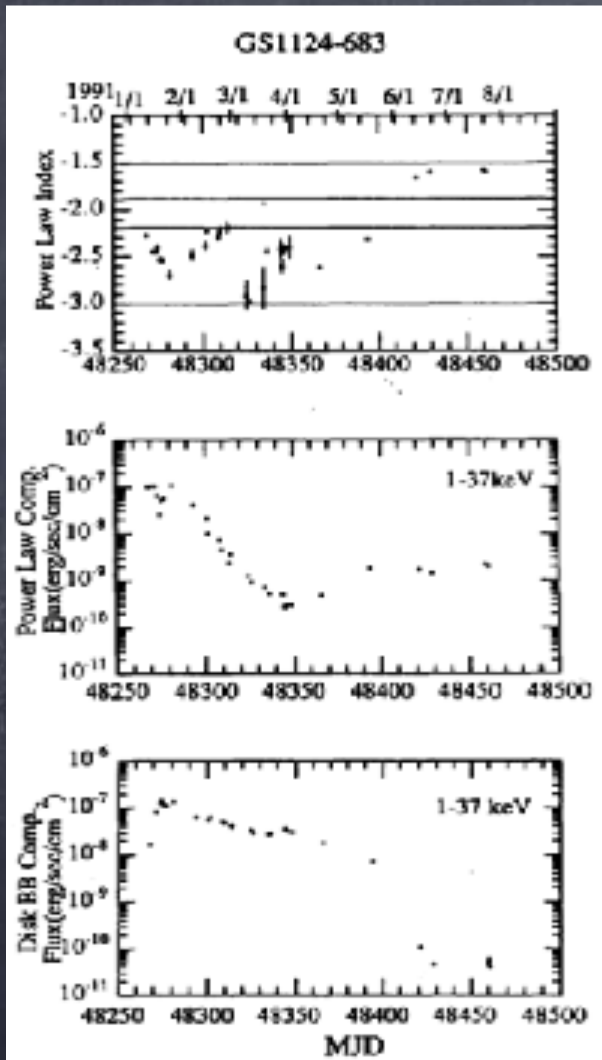
energy. The hot advection-dominated accretion flows are limited to accretion rates below the critical accretion rate, $\sim \alpha^2$ for BHs and $\sim 0.1\alpha^2$ for NSs (Narayan & Yi 1995b).

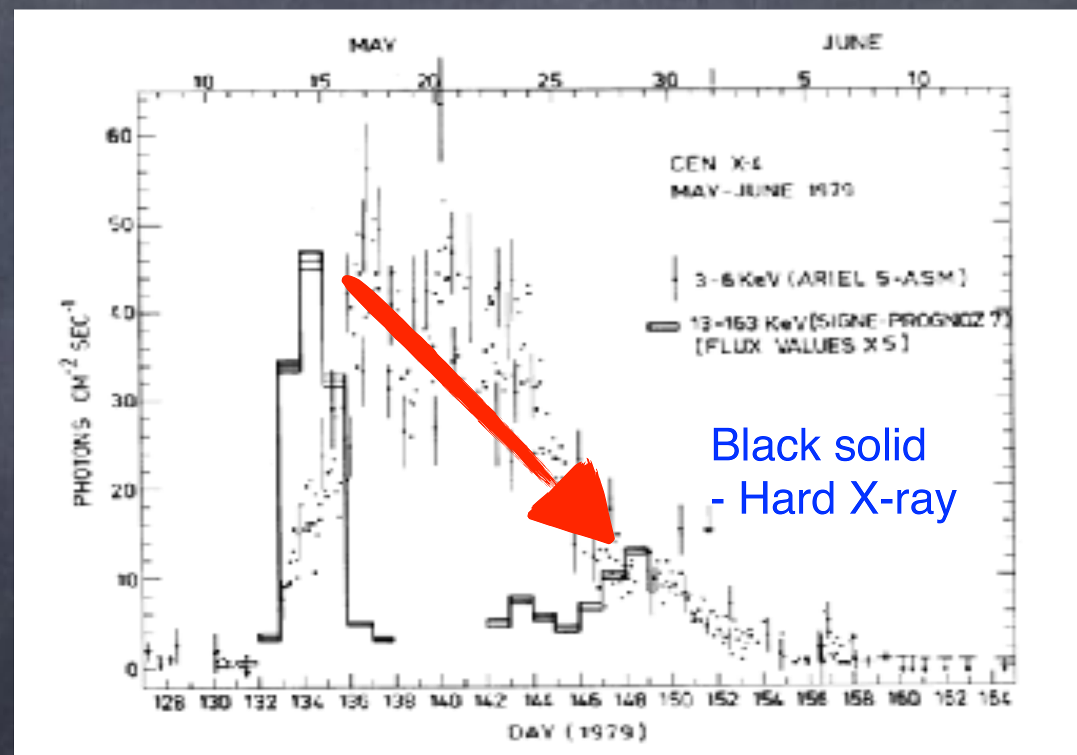
Observations: No difference !

Rule out ADAF model, and other radiative inefficient model for at least the bright hard state !!!

Hysteresis of Spectral Evolution: NS Transient Cen X-4

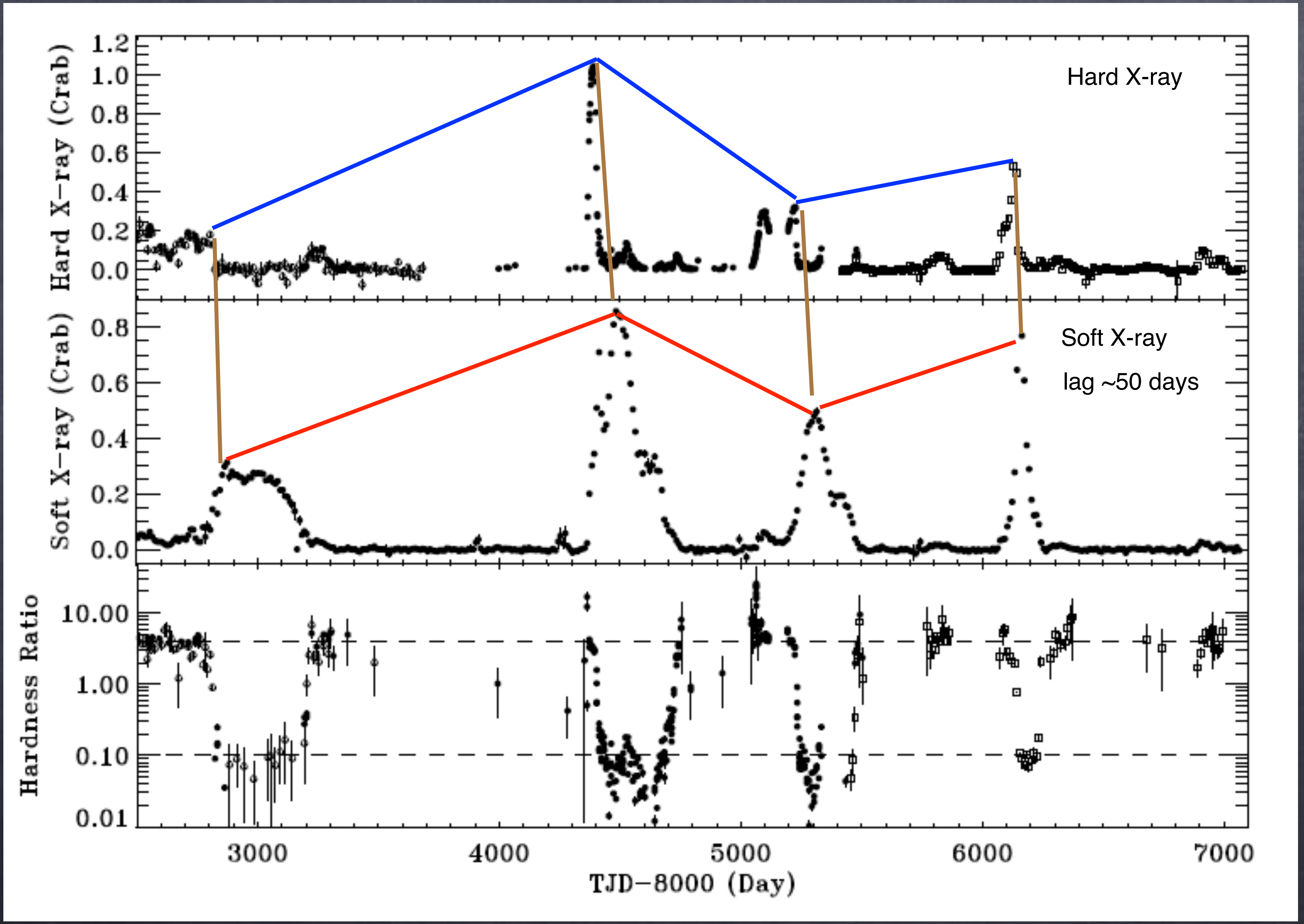
Black hole transient GS 1124-683
(Miyamoto et al. 1995)
Neutron star transient Cen X-4
(Bouchacourt et al. 1984)





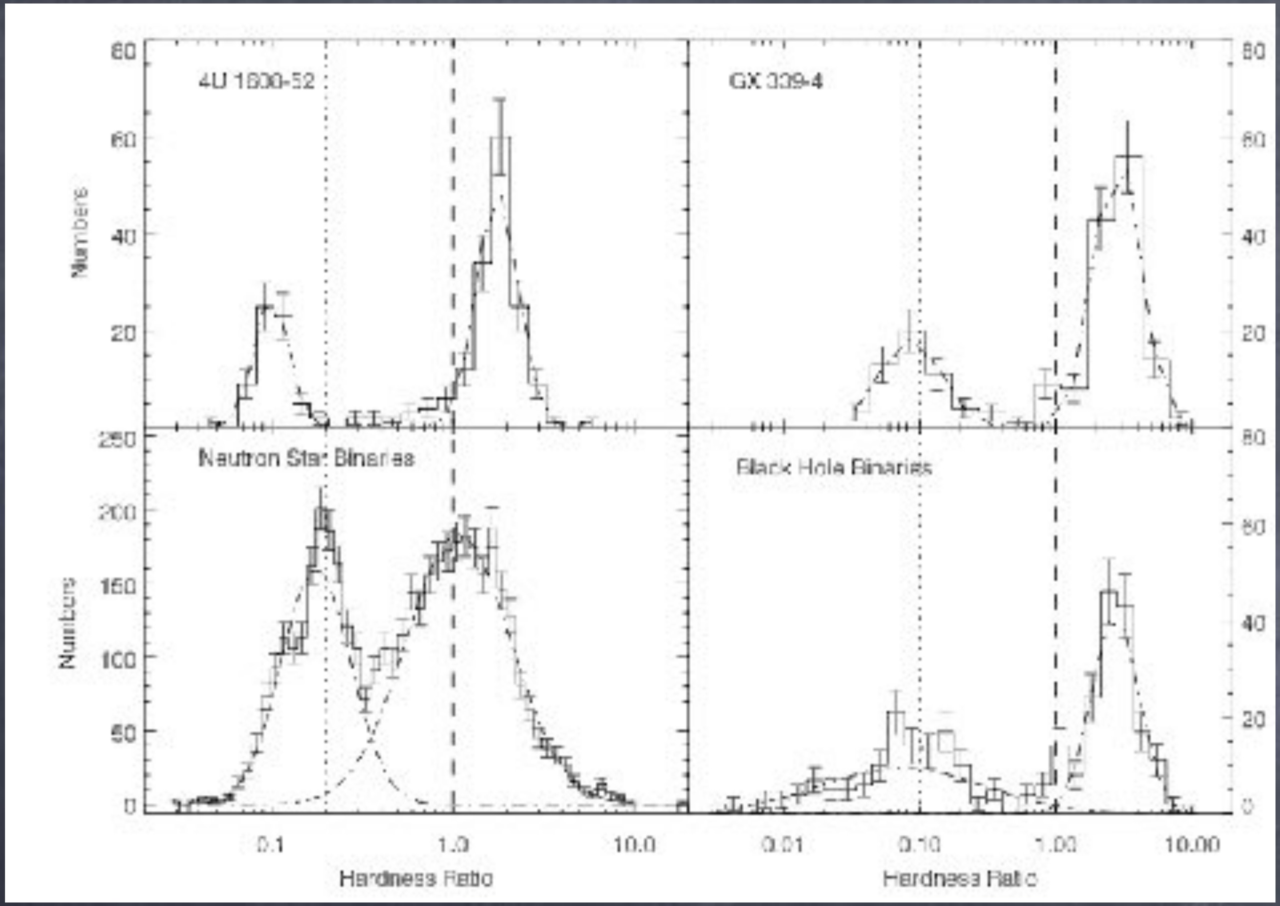
Different spectral states can correspond to the same mass accretion rate.

Proportionality in BH LMXB transient GX 339-4

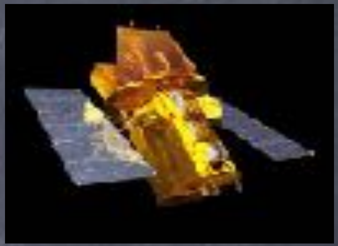


Yu, Lamb, van der Klis & Fender 2007

X-ray monitoring of major X-ray spectral states



RXTE/ASM 2-12 keV



Swift/BAT 15-150 keV

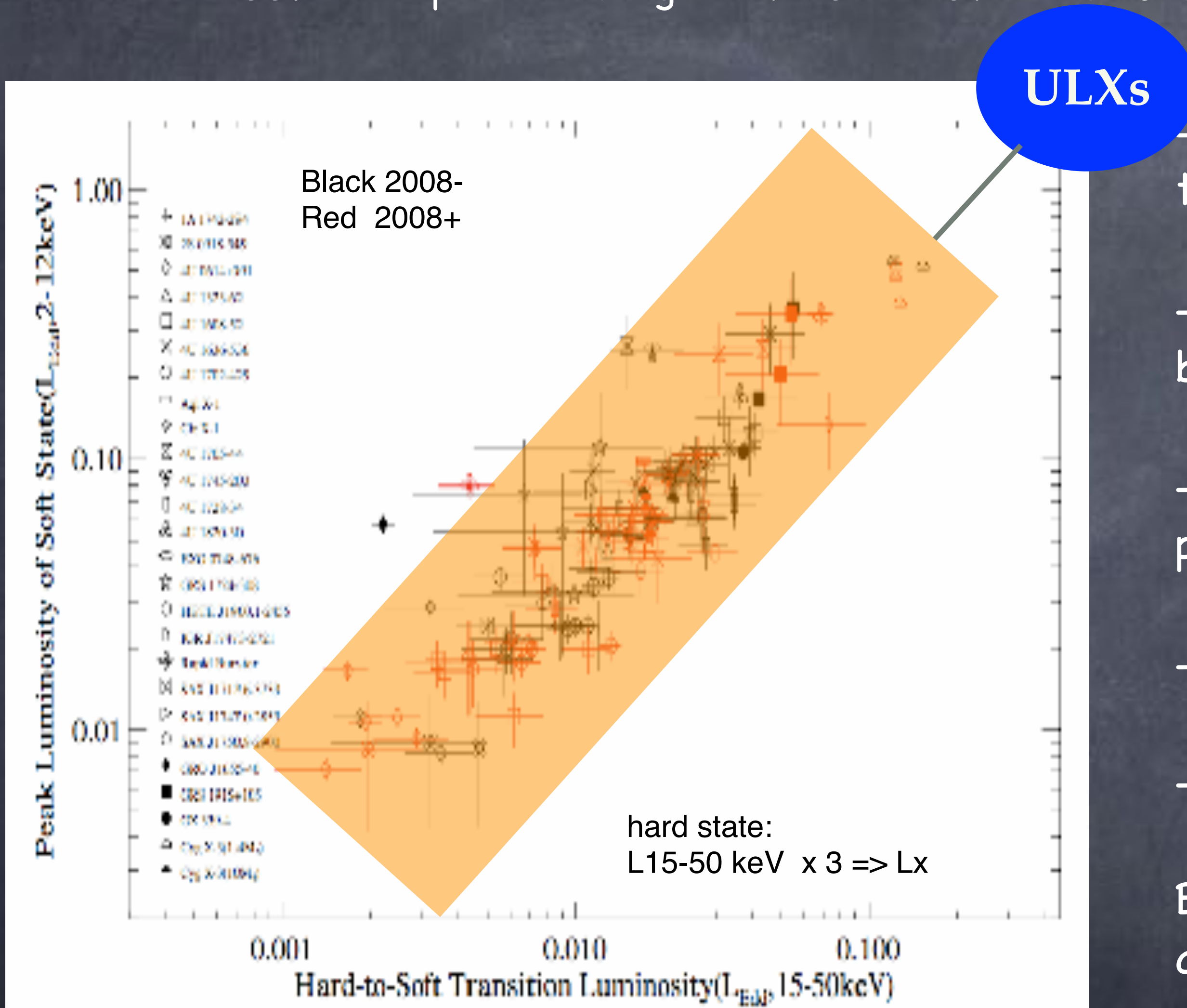
Yu & Yan, 2009
ApJ, 701, 1940

- Confirmation of two major spectral states for both black hole and neutron star XRBs

ECLAIRS itself covers 4-10 keV and 10-150 keV: capable of monitoring spectral states and state transitions

State transitions in bright Galactic XRBs

Yu & Yan 2009 and update in Tang et al. 2011: 120+ transitions



- holds over a luminosity range of two orders of magnitude

- holds for both mini-flares and bright outbursts

- holds for both transients and persistent sources

- holds for both BHs and NSs

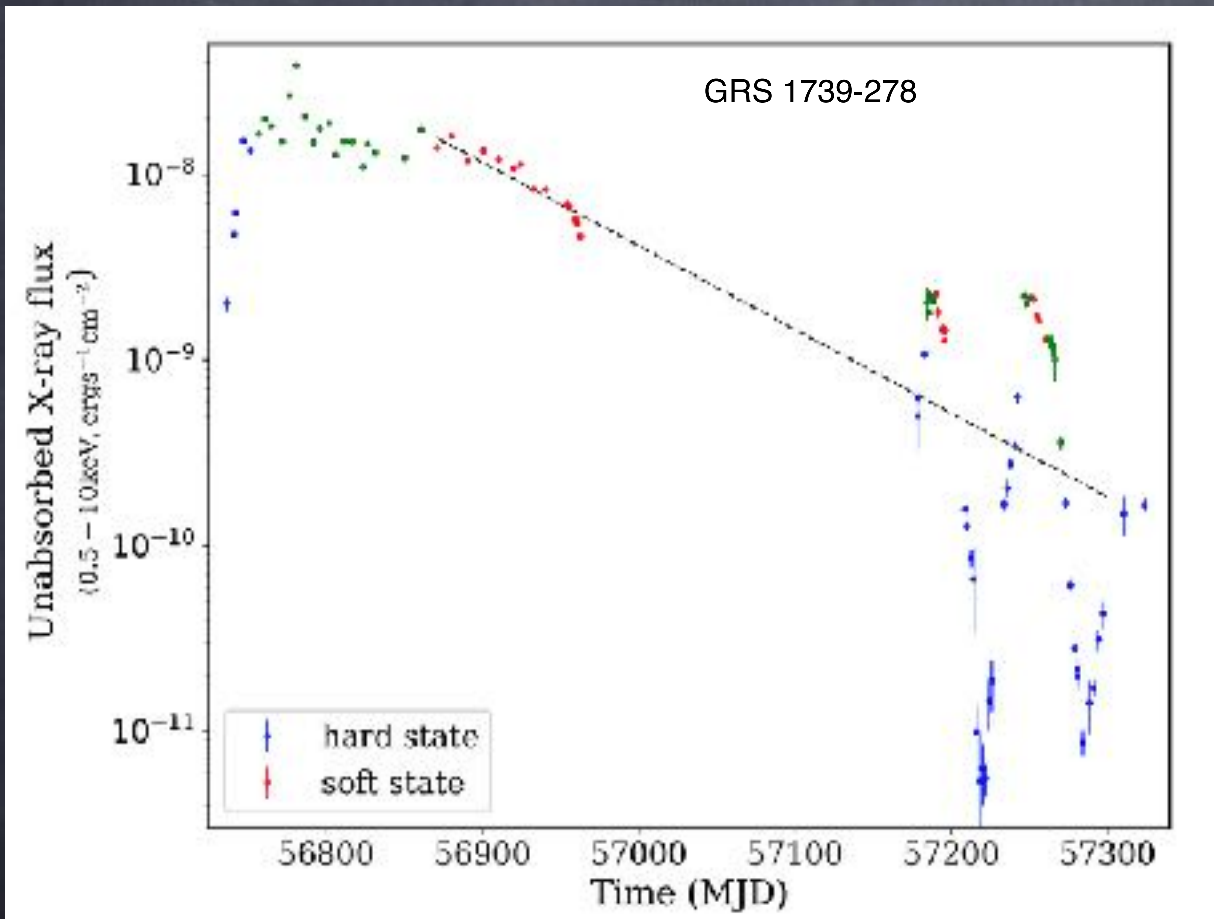
- no luminosity saturation

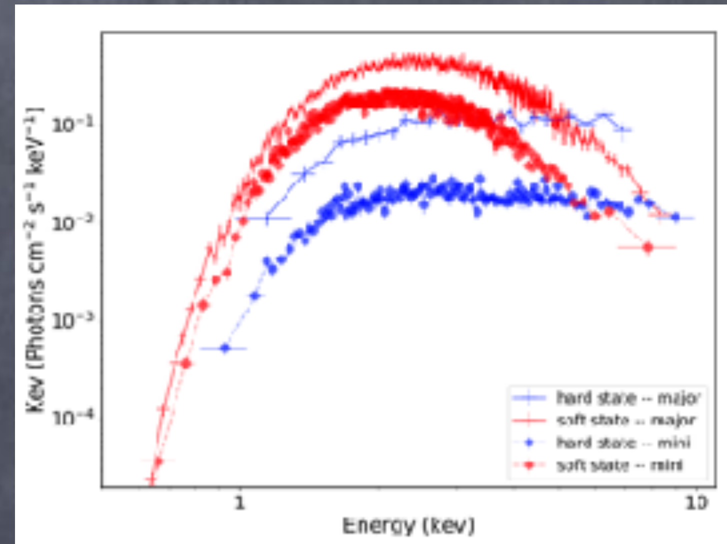
Brighter hard state/outburst is allowed by physics

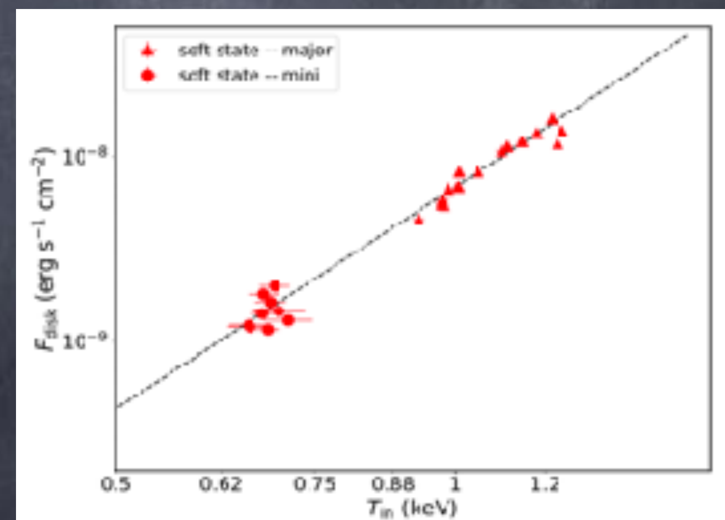
Hard state regime brighter than theory predictions - can be brighter than 30% LE
ADAF model predicts BH transition luminosity ~ a few percent LE (e.g., Esin et al. 1997)
while in NS systems transition luminosity should be ~ 10 times lower (Yi,Narayan et al. 1996)

Towards the extremes: the low luminosity end

Discovery of classical spectral state transition in the mini-outbursts of GRS 1739-278
(Yan & Yu 2017, MNRAS)



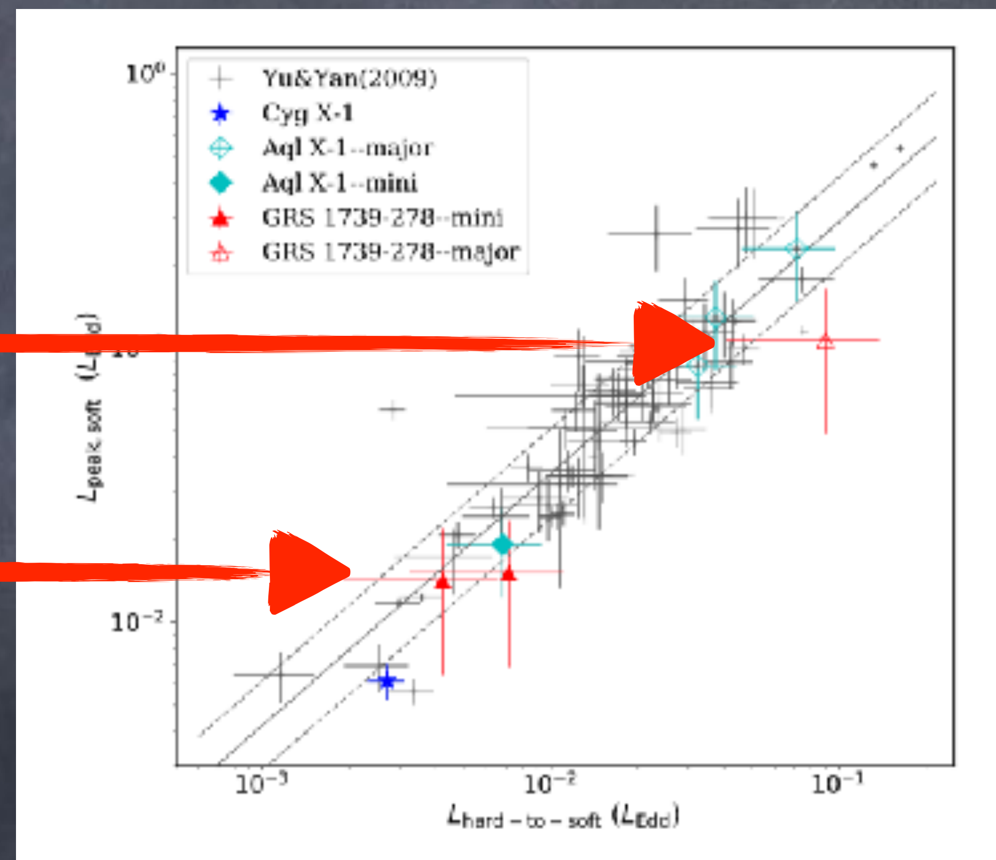




Towards the extremes: the low luminosity end

- GRS 1739-278: the first BH XRB with hard-to-soft transitions occurred in a luminosity range spanning by more than an order of magnitude.
- The transition luminosity approached the minimum seen in BH XRBs in the range around 0.01 LE - putting constraint on the critical mass accretion rate in ADAF model

(Yan & Yu 2017, MNRAS)



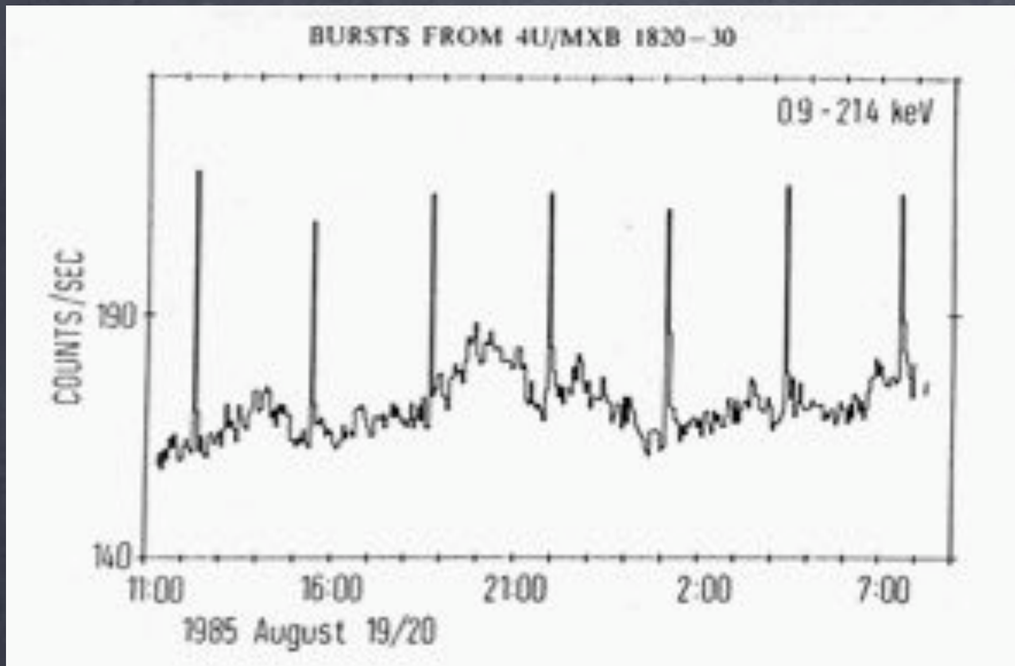
Outline

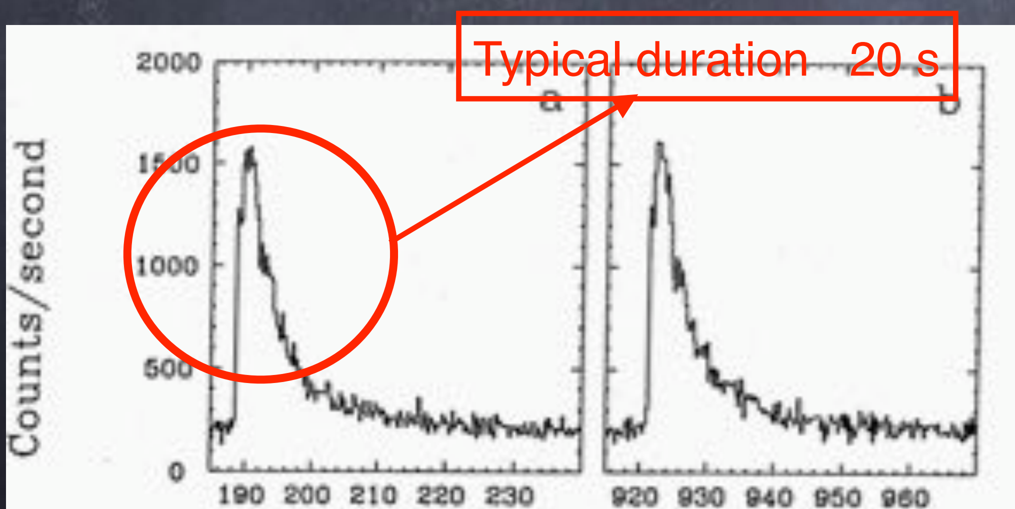
1. The variable X-ray sky
   - - X-ray Binaries
   - - Low Mass X-ray Binary Transients(LMXBTs)

2. Science of X-ray monitoring
   - LMXBT outbursts
   - XRB spectral states and accretion physics
   - X-ray bursts (NS LMXBs, SGR)

3. on SVOM's non-GRB science
   - SVOM's capability of ToOs and fill-in observations
   - favorable to ToOs of slow transients ?

Type I X-ray bursts in NS LMXBs





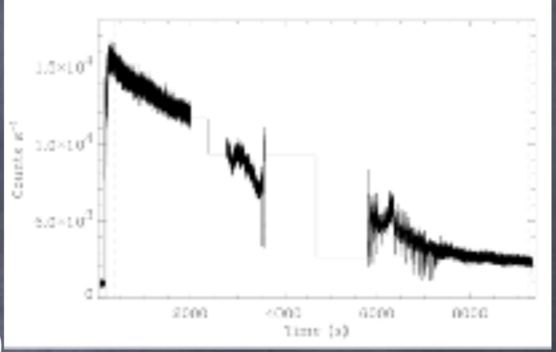
Thermonuclear burning on NSs (e.g., Woosley & Team 1976)

A type I X-ray burst is the radiative cooling after a thermonuclear shell flash occurring just ~1 m beneath the surface of a NS. During such a shell flash, the accreted mixture of hydrogen and/or helium is ignited due to a quick pressure build-up at the bottom of the accreted pile in the very large gravitational field strength on the NS.

Typical photospheric BB temperature reaches 1-3 keV

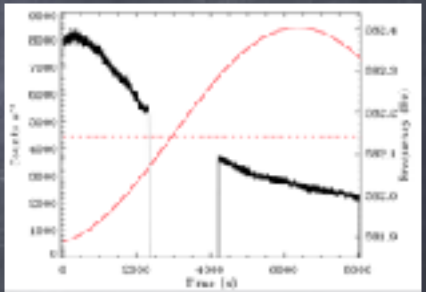
Long X-ray bursts in NS LMXBs

If the ignition is deeper, more mass needs to cool down and the cooling time is longer. This may range from 10- 30 min for so-called intermediate duration bursts to 1 d for superbursts (see In't Zand 2011)



- Intermediate duration bursts (10-30 minutes) are thought to be Helium flashes

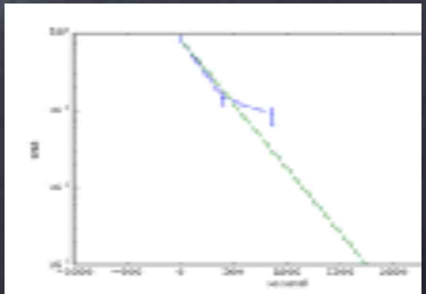
- Superbursts (hour to 1 day, e.g. Strohmayer 2014) ignition depth of about 100 m, thought to be Carbon flashes good probes of presumed NS crusts



- ATEL #11623 (Yu et al. 2018 - a superburst candidate)

Based on Swift/BAT orbital monitoring in 15-50 keV:

A hard X-ray flare of SAX J1712.6-3739: a superburst event ?



Summary

SVOM's non-GRB science - X-ray monitoring and ToOs

- SVOM's monitoring capability with ECLAIRS

  monitoring extended to 4 keV - cover a lot more transients
- SVOM's capability of ToOs and fill-in observations

  for most of the time SVOM won't be observing GRBs
- Less re-pointing and slewing than Swift ?

  favorable for ToOs on slow transients such as Galactic X-ray transients