The Transient X-ray Sky

ASTROSAT workshop: January 2011

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Outline

- X-ray Surveys (2-10 keV); Types & Rates of X-ray Transients
- Science Values of X-ray Transients
- Source Examples:

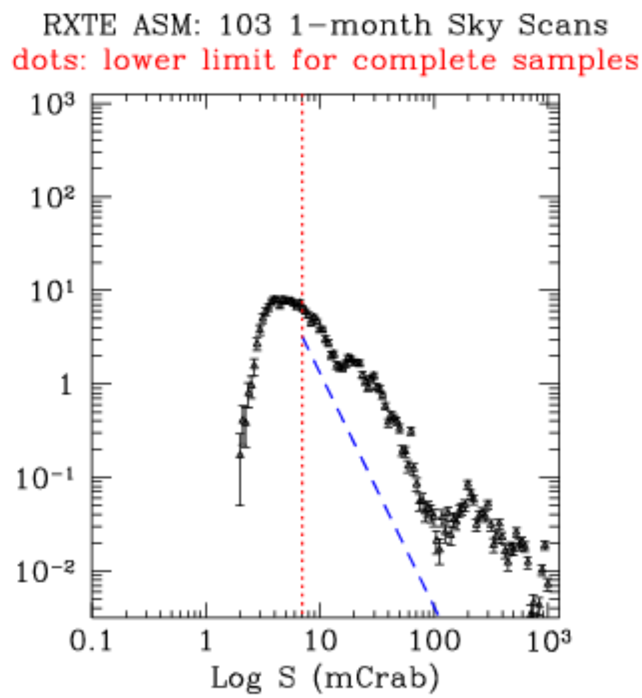
  Rapid Spectral Evolution in XTE J1550-564 (BH source)
  Unique properties of XTE J1701-462 (NS; first Z-source transient)
- Opportunities & Challenges for ASTROSAT

X-ray All-Sky Surveys, 2-10 keV

ASM: collection of monthly all-sky surveys

(RXTE years 2-10; prime ASM sensitivity)

Log d*N*/d*S*

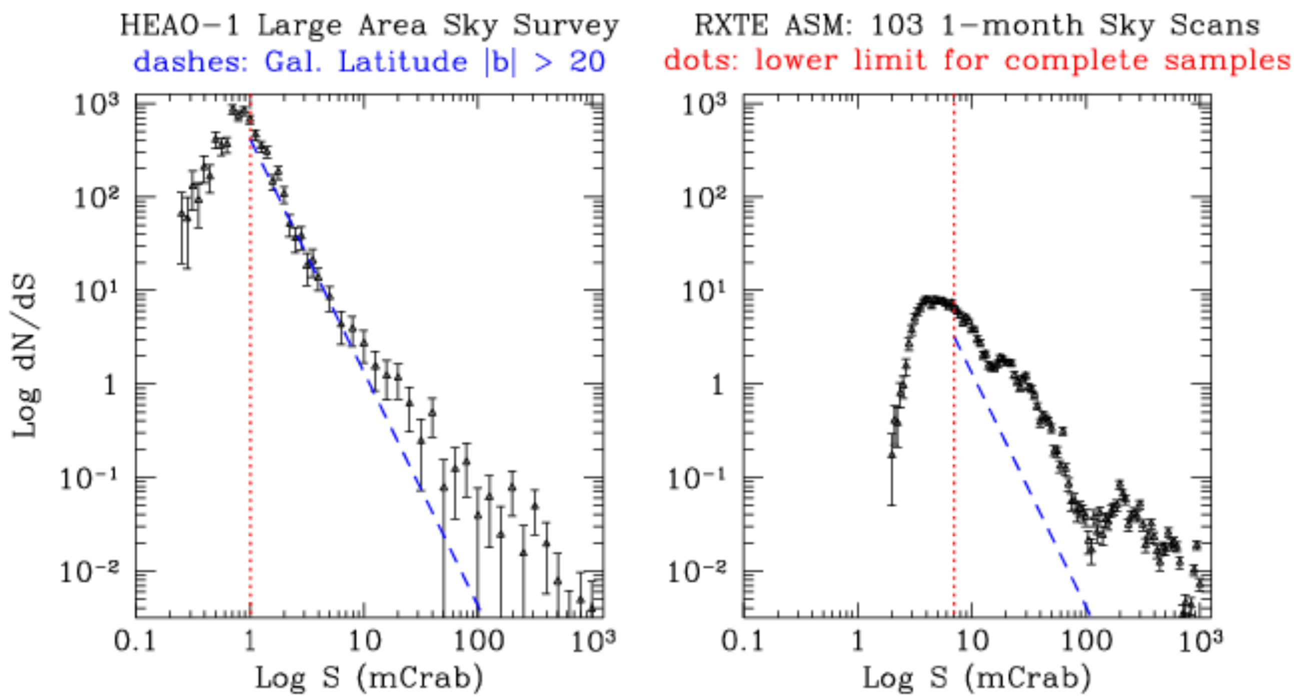


blue dashes:

reference line with slope -2.5,
from HEAO-1 Large Area Survey,
(Wood et al. 1984)

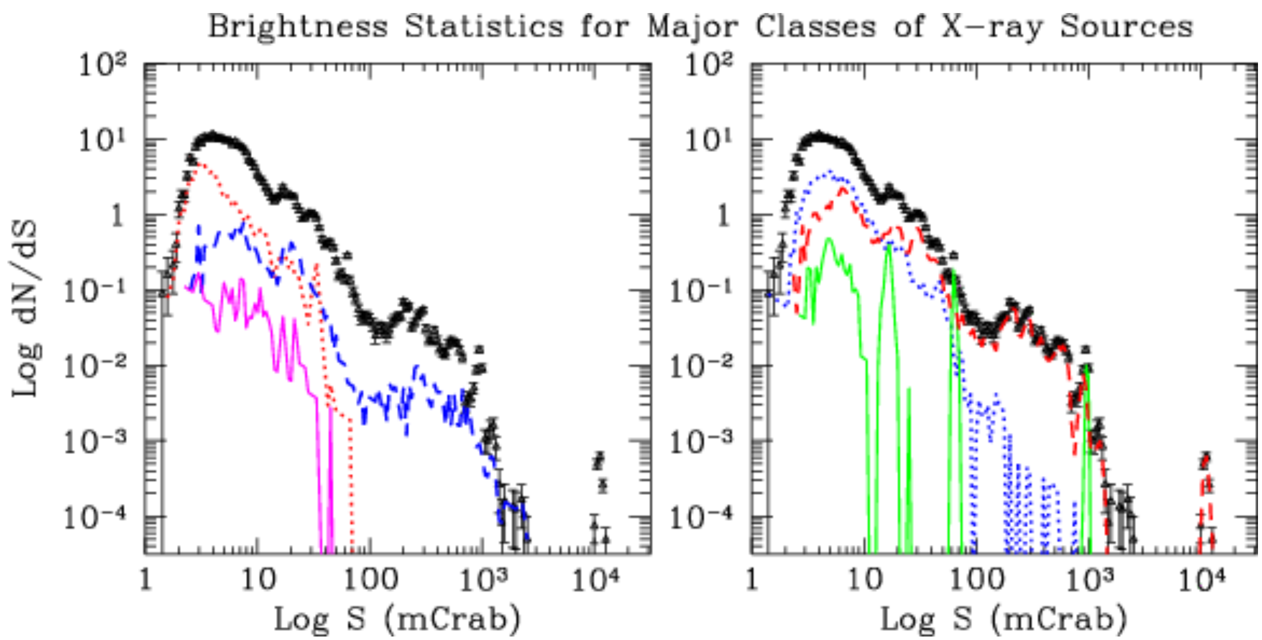
X-ray All-Sky Surveys, 2-10 keV

ASM: collection of monthly all-sky surveys



X-ray All-Sky Surveys, 2-10 keV

ASM: collection of monthly all-sky surveys



blue dashes: black holes
red dots: extragalactic
magenta: msex pulsars

blue dots: NS HMXBs
red dashes: NS LMXBs
green: SN remnants

Persistent X-ray Sources versus Transients

- ASM: Blurred Distinctions
  - Persistent Sources can dip into very faint hard states (e.g.,LMC X-3, 4U1705-44)
  - Transients can appear from years of quiescence, and last for 5 years or more (HETE J1900.1-2455, IGR J17098-3626, KS1731-260, Swift J1753.5-0127, XTE J1716-389, XTE J1759-220; plus never seen: 4U1755-33, 4U2129+47),

    or even decades (GRS1915+105)

- ASM Statistics
- (total above threshold)

Threshold mCrab	Number Persistent	Number Active Transients
1000	2	0.213
500	17	0.457
300	12	0.760
200	16	1.209
100	20	2.029
50	23	2.765
30	35	3.571
20	47	4.029
10	68	> 4.3 (incomplete)

- Transients max. > 10 mCrab: accreting black holes & neutron stars

  (Rest of talk focuses on accreting BH & NS astrophysics)

Science Values of X-ray Transients

- New Sources of Accreting BH & NS for Astronomy
  - Different compact object mass, spin
  - Find sources with low distance, preferred inclinations
  - New phenomenology

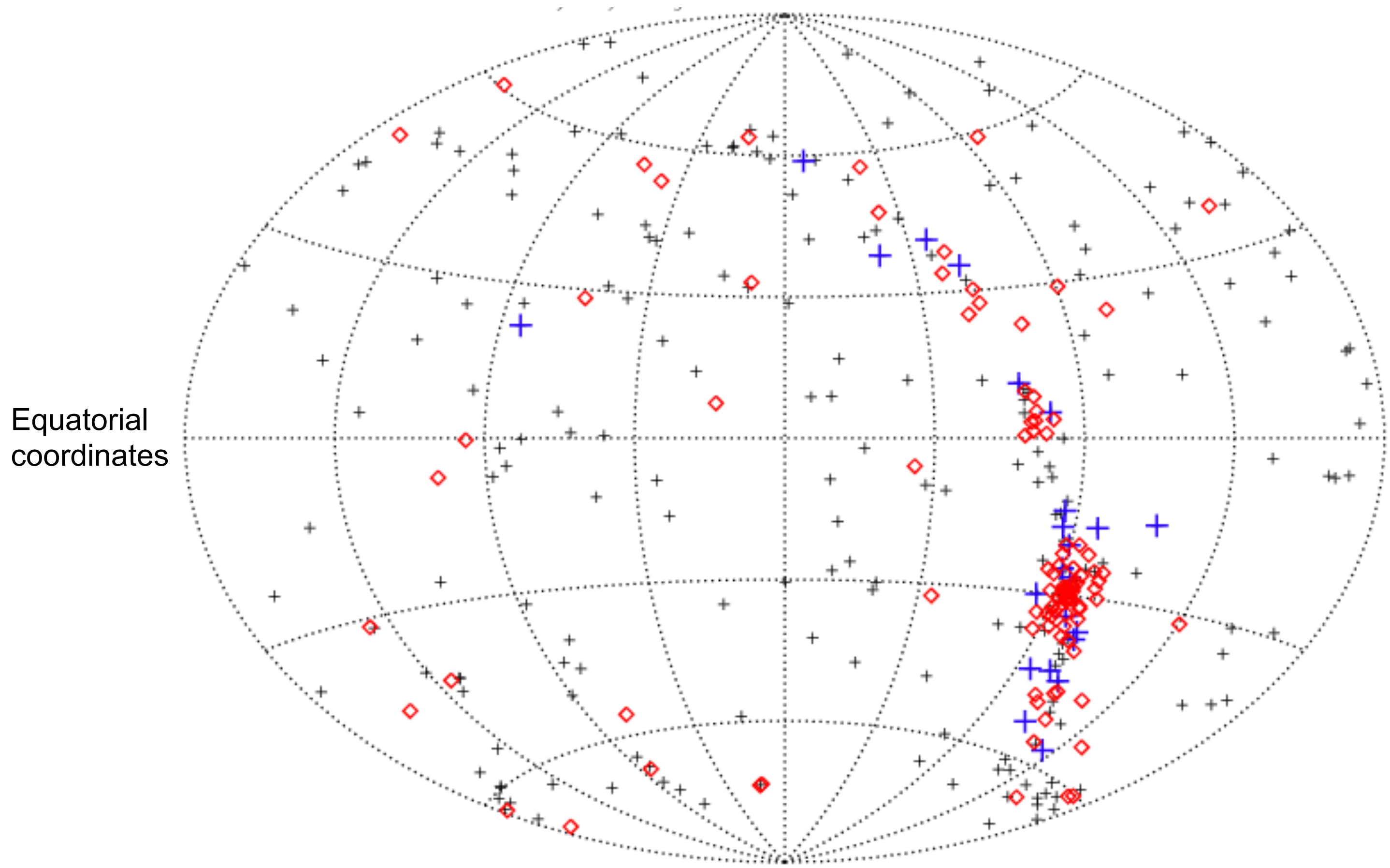
- Large dynamic range in accretion rate & luminosity
  - Different X-ray States
  - More state transitions
  - More robust tests of accretion physics
  - Quiescent phase to study companion star
  - Quiescent phase to study neutron stars

- At High Luminosity, historical number > persistent number

- Realized by **Dedicated** Monitoring
  - *Unique strength of RXTE*

X-ray All-Sky Surveys, 2-10 keV

ASM: 230 persistent sources > 1 mCrab (+) ; 23 persistent and > 50 mCrab (+)
& 140 X-ray transients (♦) detected ; 60 > 50 mCrab

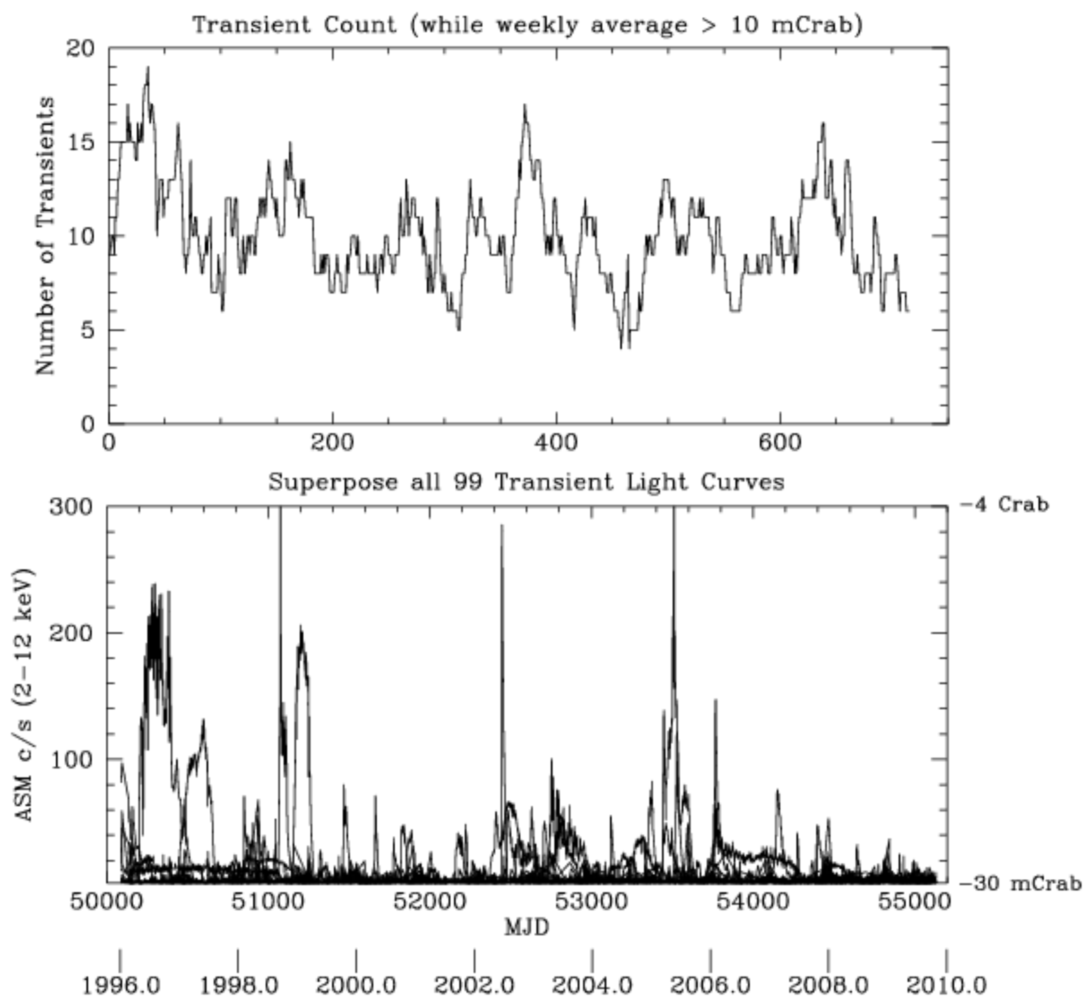


Importance of Transients

	Total	Transients
Dynamical Black Hole Binaries	22	**17**
Black Hole Candidates	27	**23**
Classical Accretion-Powered Pulsars	~80	**~60**
Msec X-ray Pulsars	16	**13**
Other Accreting NS (atolls, Zs)	**~100**	**~60**

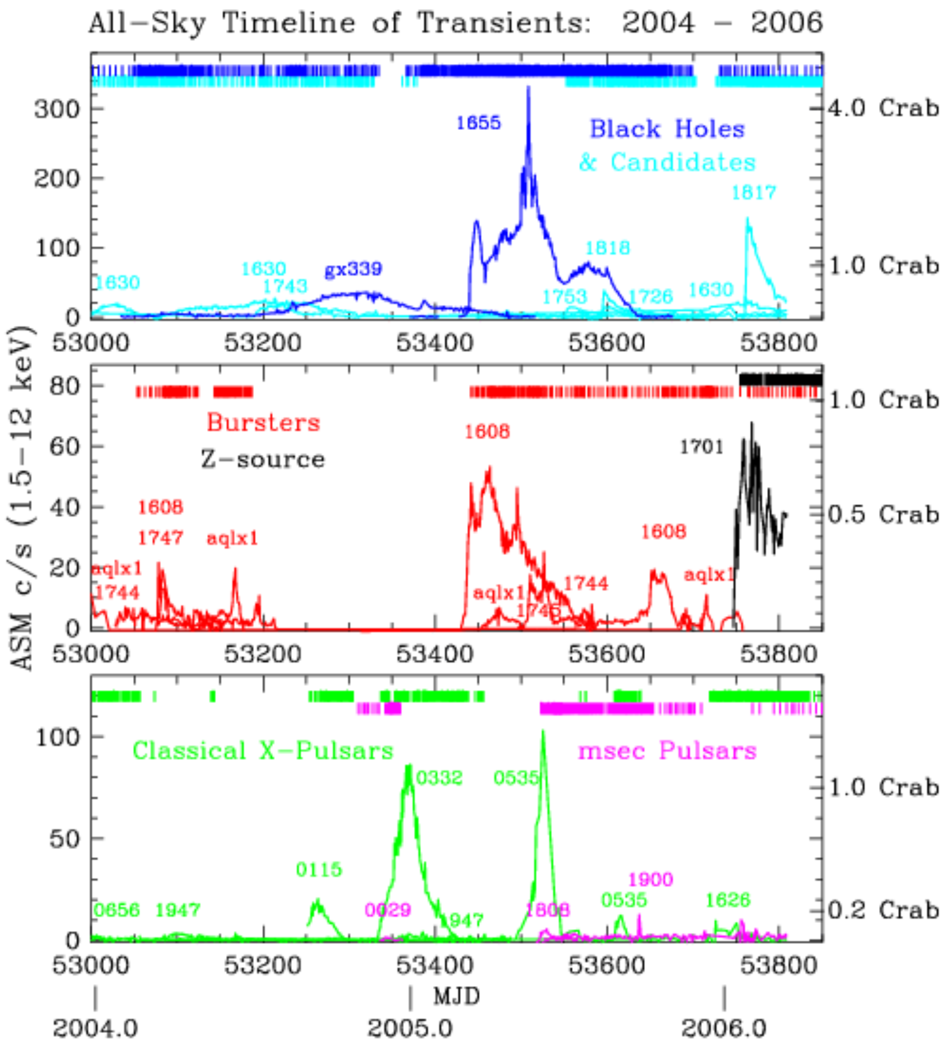
Transients provide the primary sources for many classes !

Rates and Brightness of X-ray Transients



X-ray Transients in the Milky Way

Variety of Accreting Black Holes & Neutron Stars



Science Drivers for New Large-Area X-ray Missions

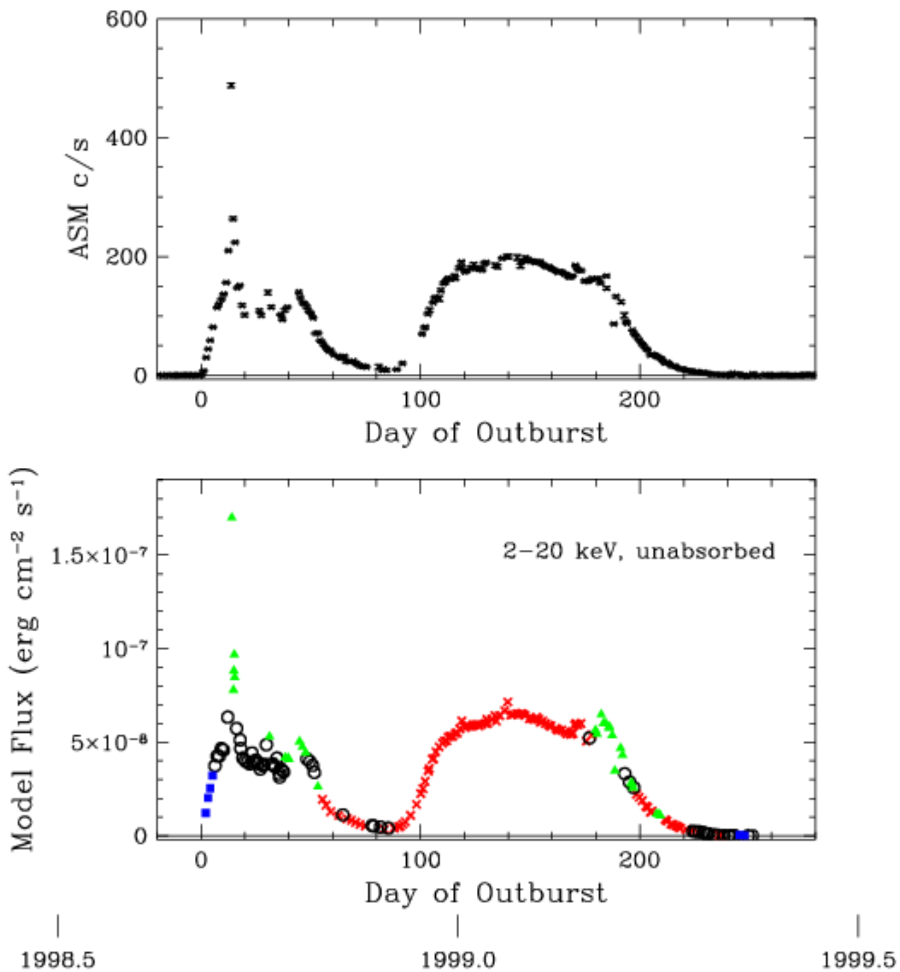
- **Black Hole Spin** (Mass from optical data)
  - **Thermal Continuum** and Relativistic Disk Models (thermal state)
    (first spin estimates 0.3 < a* < 0.999 now in literature)
  - **Fe K-α Emission Line Profile** (hard & steep power law)
    (first spin estimates now in literature; some disagree with continuum fitting)
  - **High-Frequency QPOs** (steep power law state)
  - **X-ray Polarization** (NASA GEMS : SMEX: 2014)
- **Anchor Multi-ν observations to model steady jet** (hard state)
  (better soft X-ray coverage; wide-angle radio facilitiies;
  radio/optical/IR partners with dedicated monitoring)

Science Drivers for New Large-Area X-ray Missions

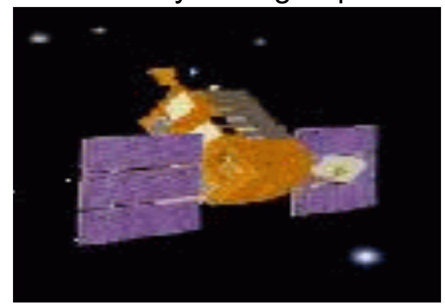
- **Neutron Star Equation of State: multi-method approach**
  - **Waveform of Burst Oscillations**
    (first measurements; model for M, R, light bending, evolution)
  - **Improved X-ray Spectra of Type I Bursts**
    (large samples; 1.5-40 keV; good resolution; no deadtime/pileup)
  - **Waveform of kHz QPOs**
    (first measurements; constrain model?; integrate to other techniques?)
  - **Msec Pulsars**
    (add to P distribution; model pulsations; use all methods for same source)

References: Bhattacharyya et al. 2005; Strohmayer & Bildsten 2006;
Ozel et al. 2009; Guver et al. 2010; Bhattacharyya 2010;

Example of BH Transient, XTEJ1550-564



Rossi X-ray Timing Explorer



X-ray states:

Thermal x

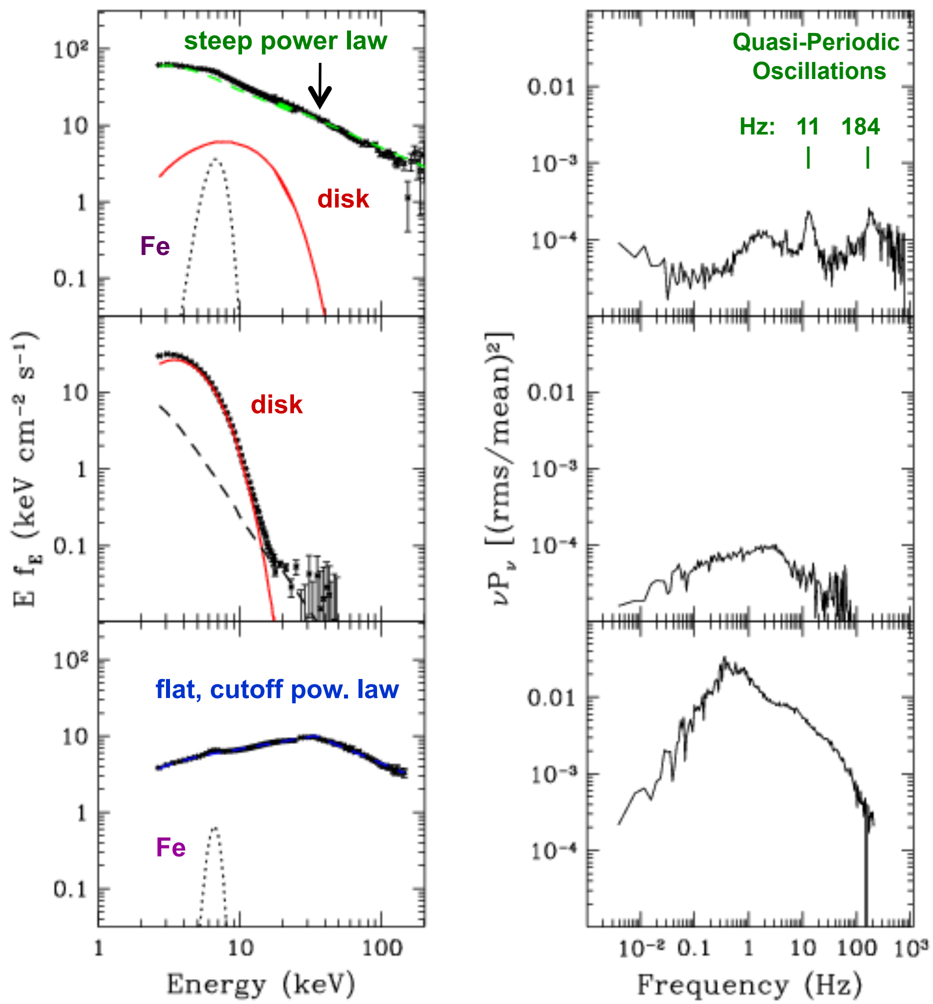
Hard (jet) ■

Steep Power Law Δ

Intermediate o

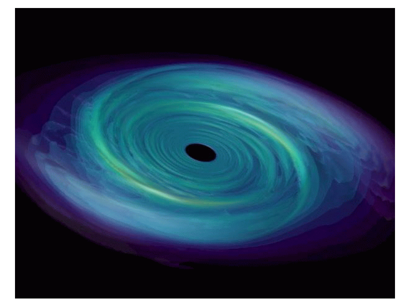
BH X-ray States (XTEJ1550-564)

Energy spectra | **Power density spectra** | **State**

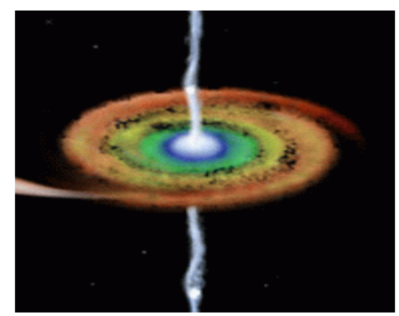


steep power law

Disk + ??

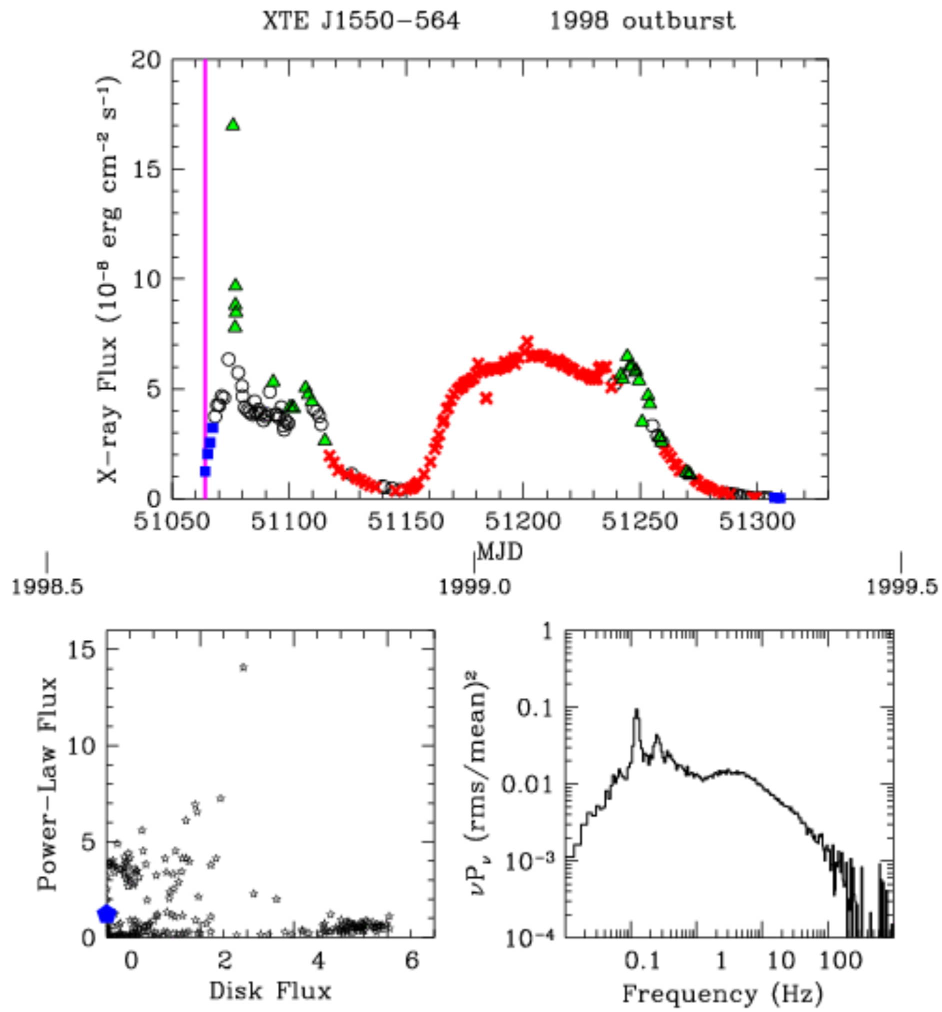


thermal



hard state

X-ray States in XTE J1550-564: The Movie



Example 2: NS Transient, XTE J1701-462

2006-2007

First ever Z-source (NS) transient

RXTE: 866 obs.
3 Ms archive

Dedication!

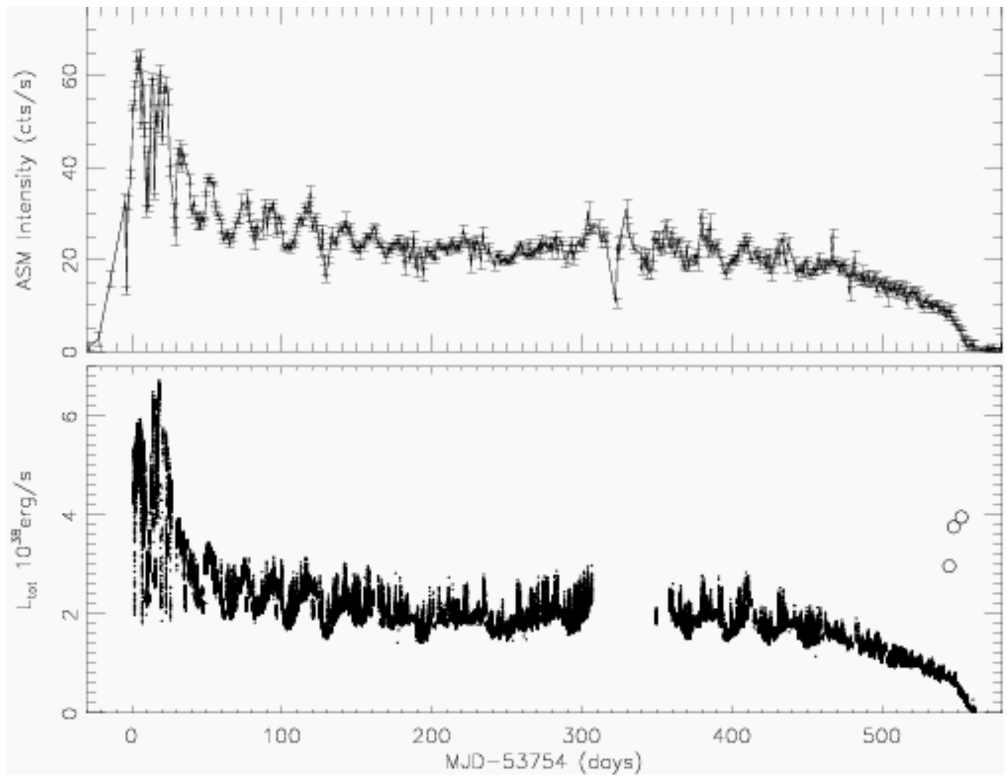
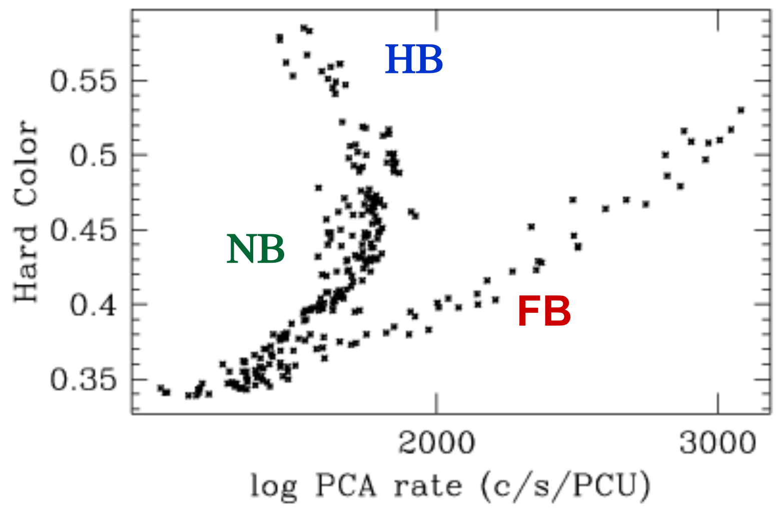


Illustration of Z sources branches

Hasinger & van der Klis 1990 proposed increasing ***dM/dt*** along

Horizonal Branch → Normal Branch → Flaring Branch



XTE J1701-462

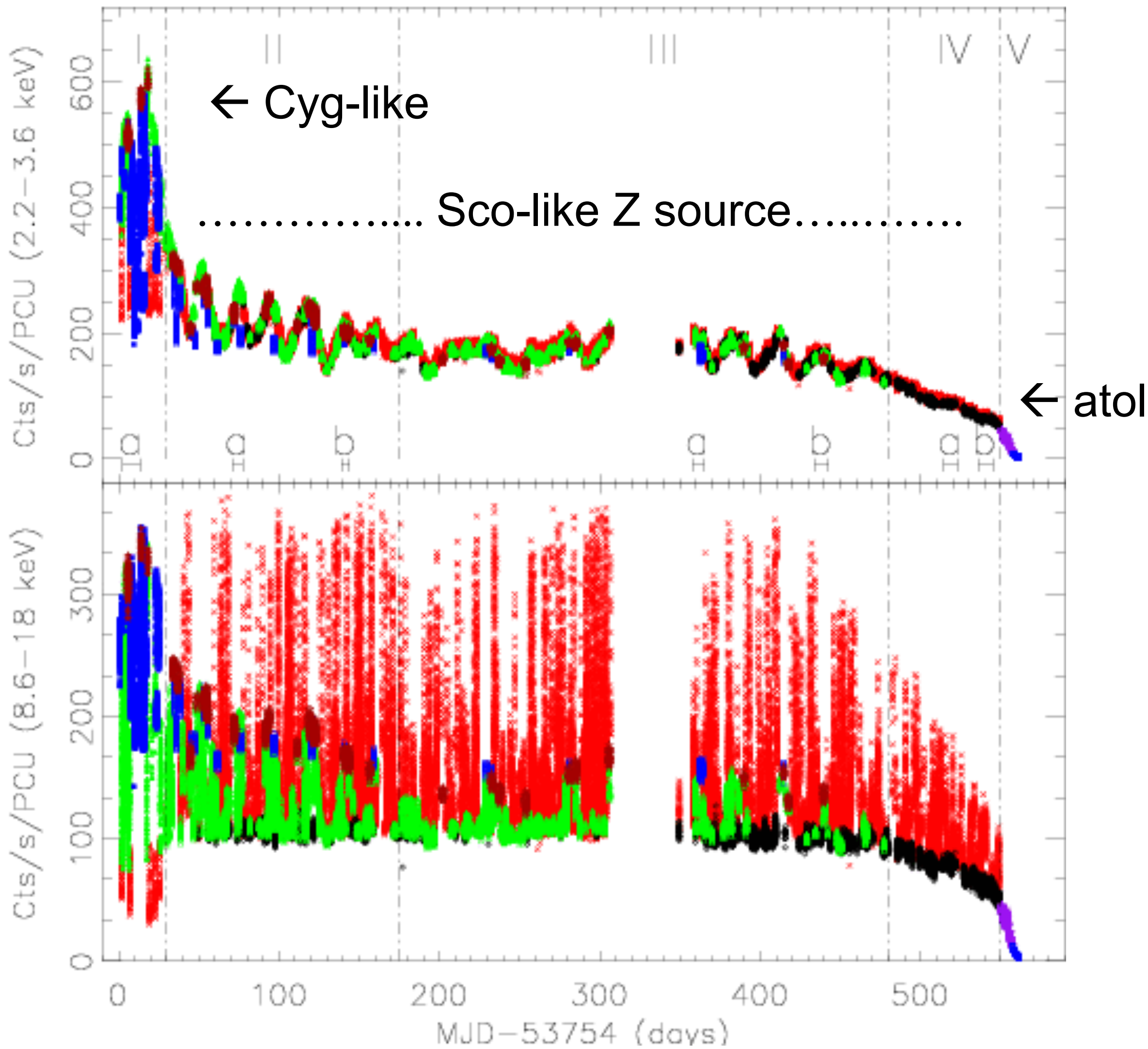
Horizontal (HB)

Normal (NB)

Flaring (FB)

NB-FB Vertex

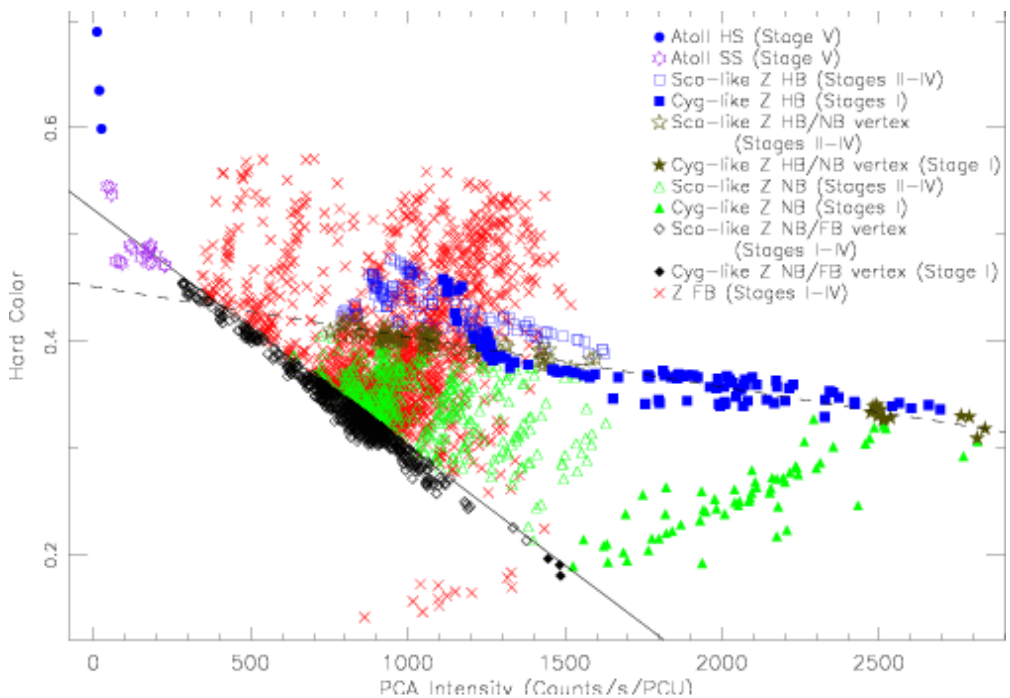
Lin, Remillard & Homan 2009



XTE J1701-462: Total Hardness-Intensity Diagram

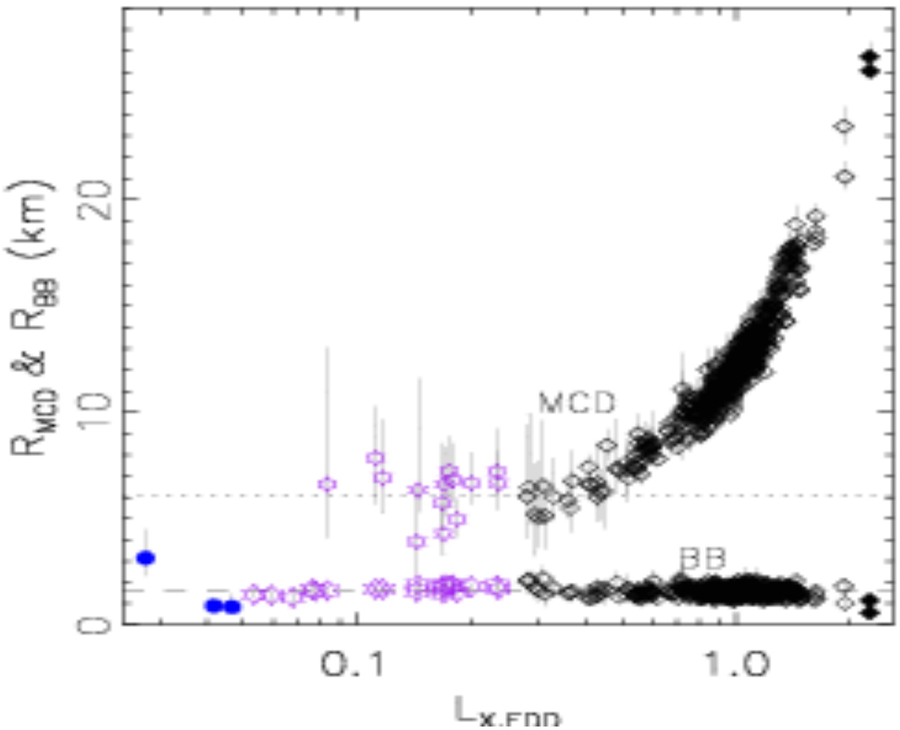
Upper and lower vertices: single lines on the HID.

Lower vertex is key to understand adjoining **FB**, **NB**



Spectral model: double-thermal + weak Comptonization

NB:FB Vertex: local Eddington limit in the accretion disk?



FB: disk tries to shrink toward ISCO from a point on this curve

Conclusions

- Transients that peak above 10 mCrab are mostly BH & NS
- Transient Provide Continual Critical Science Opportunities
- X-ray state transitions can occur on timescales < 1 day
- Black Hole & Neutron Star Astrophysics are Important Themes (e.g., new Missions proposed for NASA, ESA, Japan, etc.)
- ASTROSAT comes at a perfect time (improved instruments and new partners) to make important contributions to the development of astrophysics applications for general relativity

ASTROSAT

- ASTROSAT will cover (with MAXI?) the Transients Time-Line after RXTE
- Excellent pointing Instruments to capitalize on science opportunities; significant improvements and new instruments, compared to RXTE
- Excellent NEW Partners available for Multi-frequency Science (LOFAR, MWA, PANSTARRS, LSST, etc.)
- X-ray Transients have dimensionality: time; X-ray state; luminosity, and so dedicated (daily) monitoring observations are needed
- Questions for ASTROSAT transients:

  What Level of Dedicated Coverage for Transient Sources?

  How to gain early recognition of most important transients?

XTE J1701-462 (spectral model: diskbb + bb + weak Comptonization)

Color-color

spectral fit: L_x vs. T

Cyg-Like Z

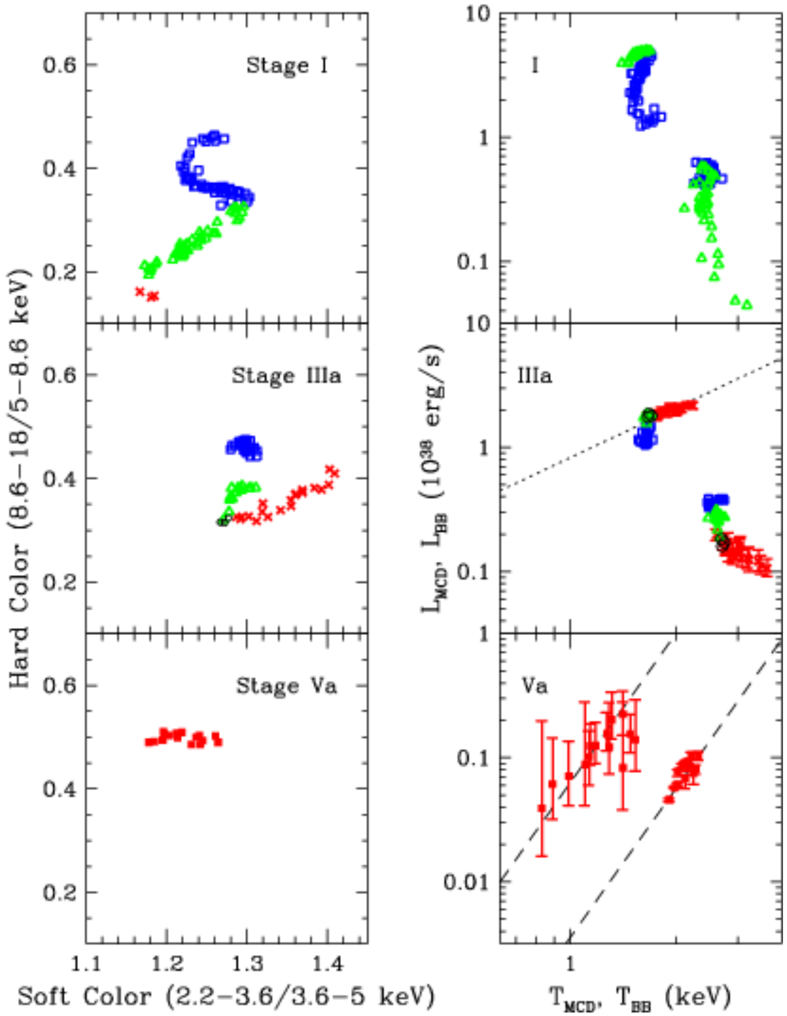
Sco-like Z

Atoll Stage

Disk & BB:

$L \propto T^4$

(constant R)



←**FB**: disk shrinks at constant dM/dt

$T_R \propto (M\ dM/dt\ R^{-3})^{1/4}$

$L \propto R^2\ T_R^4$

$L \propto (M\ dM/dt)^{2/3}\ T^{4/3}$

← Two reference lines:

Radius from bursts;

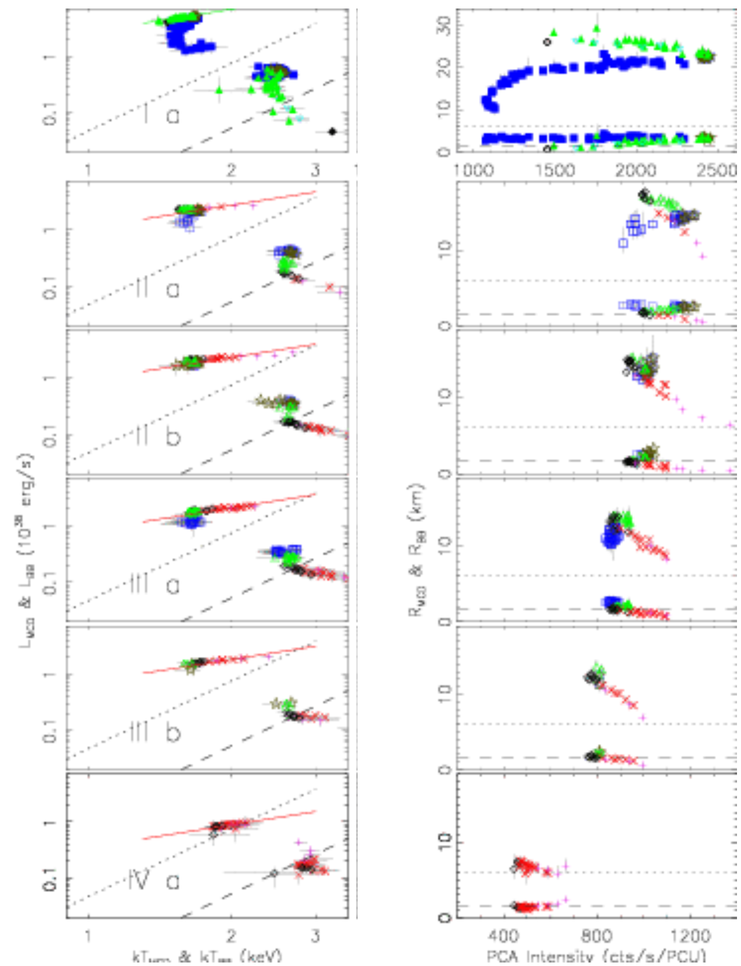
Fit to constant R_{BB}

XTE J1701-462 Spectral Results

Spectral Fit Results

L_x vs. T

R vs. count rate



double-thermal model

(disk + BB + CBPL)

Lin, Remillard, & Homan 2009

XTE J1701-462: summary

Secular increases in **dM/dt** shifts the **Z** in the HID and
shifts emphasis from **FB** / lower vertex → **NB** → upper vertex / **HB**

Local Eddington limit is first seen in disk, and the **NB:FB** vertex maps the disk response of $\boldsymbol{R_{MCD}}$ to $\boldsymbol{L_x}$ (i.e., **dM/dt**), while R_{BB} ~ constant.

Sco-like Z source phase:

From condition in lower vertex ($\boldsymbol{R_{MCD}}$ vs. $\boldsymbol{L_x}$), disk shrinks to ISCO along **FB**

Along the **NB**, the boundary layer brightens independently from the disk, perhaps with onset of a radial accretion flow (small fraction of total)

HB is onset of Comptonization; upper vertex: thick disk solution?

Little or No ***dM/dt*** change in a *time-local* *Z*

XTE J1701-462: summary

Cyg-like Z source phase (higher dM/dt):

FB is the dipping type; spectral model does not fit! (variable N_H?)

in **NB**, the boundary layer brightens (like the Sco-like) + changes in the disk, complicating interpretations

HB-upturn shows increased Comptonization, resembles Sco-like **HB**

non-upturn **HB**: large jump in ***rms*** without increase in Comptonization. boundary layer responsible for the ***rms*** power (mystery)