Wide Band X-ray Continuum Spectroscopy of Black Hole X-ray Binaries

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Plan

- Black hole spectral states
- Accretion disk geometry
- Spectral components
  - Disk blackbody
  - Compton scattering
  - Other components
- Spectral/ timing combined fitting
- Astrosat – observation strategy
**SPL/ VHS:**

- $\Gamma > 2.4$
- $R < 0.15$
- $F_d < 0.8$ with QPO
- Or $F_d < 0.5$ no QPO

*(HIMS/ SIMS)*

**TD/ HS:**

- $F_d > 0.75$
- No QPO ($< 0.005$)
- $R < 0.075$

**Hard:**

- $F_d < 0.2$
- $1.4 < \Gamma < 2.1$
- $R > 0.1$

Remillard & McClintock 2006
X-ray properties

Power spectra

- $\text{rms} < 5\%$
  - $\text{rms} \leq 5\%$
  - $\text{rms} 1-10\text{Hz}$
  - $\text{rms} 20-50\%$
  - $\text{rms} < 1\text{ Hz}$

Energy spectra

- $kT \sim 1\text{ keV}$
  - index $\sim 2.5$
- $kT < 1\text{ keV}$
  - index $\sim 1.5$

Energy (keV)

Radio properties

- Radio reduced by more than 30 times compared to Low state
- Steady Self-absorbed jet
- m ??

Accretion disk - time scales

Viscous time scale
Compton cooling time scale
Electron heating time scale
Jet production time scale

a few hundred to a few thousand sec
Spectral Components

- Disk blackbody
- Hard component
  - single
  - multiple
- Reflection component
- Fe line
Differential Keplerian rotation
Thermal emission: \( L = A\sigma T^4 \)
Temperature increases inwards
GR last stable orbit gives minimum radius \( R_{ms} \) - depends on spin \( 6 \rightarrow 1 \) \( R_{g}(a = 0 \rightarrow 1) \)

\[
\frac{1}{2} \Delta \left( \frac{GM\dot{M}}{r} \right) = 2 \times 2\pi r \Delta r \sigma T_{eff}^4
\]

\[
T_{eff} \propto \left( \frac{GM\dot{M}}{8\pi\sigma r^3} \right)^{1/4}, \quad T_{eff} \propto r^{-0.75}
\]
Disk-blackbody

- Multi-color disk – Viscous torque at inner boundary neglected (Mitsuda et al. 1984):

- Non-LTE models (scattering) – hardening factor
  \[ f = \frac{T_{\text{col}}}{T_{\text{eff}}} \sim 1.7 \]

- Zero torque inner boundary condition using pseudo-Newtonian potential – diskpn (Gierlinski et al. 99)
Comptonization

Hard (low $L/L_{Edd}$)

Soft (high $L/L_{Edd}$)
Reflection component

Soft Excess

Fe line

Compton Hump

Power Law

$E^2 F(E)$

Energy (keV)
OSSE spectra of GRS 1915+105

- OSSE spectra shows power-law at higher energies
- Hybrid model “eqpair” fits wide band X-ray spectra
GRS 1915+105

Zdziarski et al 05
GRS 1915+105: non-thermal electrons

Comptonization:

- kT, tau, above Gamm_min – powerlaw
- Spherical geometry; diskbb seed.
- kT is calculated from thermal balance (power to electrons & seed photons independent parameters)

Ionized reflector
Abs*(diskbb+CompST)
Variability analysis

$r_{bb}, r_{sc} = 0, 0.2$

DH: $r_{bb}, r_{sc} = 0.06, 0.335$

TP: $r_{bb, max}, r_0, r_{pl} = 1.4, 0.11, 0$

VP 813
Three spectral components

Rao et al. 2000
Compton delays

Frequency resolved delays:

- size too large for the central compact corona

Low frequency delays: shape of the shots ??

Delay due to Compton scattering

- a few ms in Galactic sources
- a few days in quasars
- a few thousand seconds in low mass AGNs

XMM-Newton:

- Mrk 110  Dasgupta & Rao 2006
- Akn 564 & Mrk 1044: Dewangan, Griffiths, Dasgupta & Rao 2006
- NGC 4593: Brenneman et al.2007; Sriram et al. 2008;
Transients

ASM: 1 Crab = 75 c/s
XTE J1118+480; 4U 1543-47:
XTE J1550-564; GRO J1655-40;
V4641 Sgr: XTE J1859+226

ASTROSAT: Continuous monitoring during outbursts:
1 Ms; twice a year
Steady/ transients

LMC X-3:

GX 339-4:

GRS 1915+105:

Cyg X-1 :

ASTROSAT:

long look : 0.5 Ms each

(GRS thrice)

+ 1 Ms for GX339 transinet
Spectroscopy requirements

- Ensure sufficient overlapping energies
  - LAXPC low energy: lower than RXTE-PCA
  - CZT-I: as low as possible (< 10 keV ?)

- Decide degrees of freedom based on energy resolution and count rates – recipe for grouping

- Overall efficiency: hard bounds on relative areas.
New tools …

- Simultaneous spectral and variability analysis
  - start with spectral models
  - variability models
  - convolve through response for energy spectra
  - fold on to energy dependent rms.
- FIT simultaneously
Conclusions

- Good phenomenological understanding of accretion process available
- Use ASTROSAT spectroscopy to quantify these
Thanks
Candidates

4U 1354-64:
GRS 1739-278:
XTE J1748-288:
XTE J1755-324:
XTE J2012+381:
Candidates

LMC X-1: BH
4U 1630-47: 600 days
GRS 1758-258:
4U 1957+11:
Wide-Band detectors
X-ray detectors are individual photon counting devices.

- $F_{\text{min}} : \sqrt{\frac{B}{A \cdot T}}$ Non-focusing
- $F_{\text{min}} : \frac{1}{AT}$ Focusing
Source and background Measurements

GRS 1915+105  RXTE–PCA

normalized counts/sec/keV

channel energy (keV)

GRS 1915+105  RXTE HEXT

normalized counts/sec/keV

channel energy (keV)

PCA

HEXTE
Suzaku

Resn.: $\sim 16\%$ @ 22 keV
(similar to Astrosat CZT-I)
$L \propto T^4$
Wide: having great extent 365 (276)

Broad: having ample extent ... 791 (613)
Spin measurement
Blackbody Spectral fitting

Narayan & McClintock

- Inner radius → BH spin

Spin measurement by Blackbody Spectral fitting

\[ L \propto T^4 \]
Implications for spin measurements

Zdziarski et al., McClintock, Narayan et al. 2007