BLACK HOLES (AND NEUTRON STARS) IN X-RAY BINARIES: Evolution and Accretion states

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**Low Mass X-ray Binaries (LMXBs)**

Normal ($< 1 \text{M}_{\text{SUN}}$) star transferring matter onto a compact object (Black hole / Neutron star)

XRBs provide the best laboratories to study BH/NS
Most of the **BLACK HOLES** are **TRANSIENT**

- **Quiescence**
- **Outburst**

Dynamical Studies

Credit: R. Hynes

Accretion Processes General relativity

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Most of the **BLACK HOLES** are **TRANSIENT**

**Quiescence**

**Outburst**

**Dynamical Studies**

**Accretion Processes**

**General relativity**

Credit: R. Hynes
I. Accretion state picture for black hole Binaries: similarities to Neutron stars

II. Inclination effects: how they do affect the Observed outburst evolution
**Corona:** Hard X-rays (up to 100 keV-1MeV)

**Accretion disc:** Soft X-rays (few keV) to Infrared

**Companion:** only through X-ray reprocessing

**Jet:** Radio to infrared/optical to high-energies(?) [NOT ALWAYS]
MULTIWAVELENGTH SOURCES

Radio  IR  Opt.  X

ν

Disc

Jet

Corona

Credit: Mickaël Coriat
BLACK HOLE IN OUTBURST: HYSTERESIS

Daily basis monitoring (RXTE)

Hardness-Intensity (Homan et al. 2001)

- X-ray Luminosity
- Variability

- Hardness
- How hard the spectrum is

- PCU2 count rate
- rms (%)
• Other state-dependent timing features (e.g. Oscillations)
TWO MAIN ACCRETION STATES

- Inner hot flow or corona (Hard emission)
- Disk (soft emission)

1 keV - 100 keV

Hard state:
- Hot corona
- Cold disk, large inner radius

How hard the spectrum is
TWO MAIN ACCRETION STATES

**(High) Soft state:**
- corona (different geometry?)
- hot disk, small inner radius

Hot inner flow or corona (Hard emission)

X-ray Luminosity

1 keV to 100 keV

How hard the spectrum is

Belloni 2010

soft component dominates
STATE-DEPENDENT RADIO JETS

- Compact jet
- X-ray/Radio correlation (Gallo et al. 2003)

X-ray Luminosity

How hard the spectrum is

Belloni 2010

- Soft component dominates
- Hard component dominates

1 keV 100 keV

Hard component

Soft component (disk)

High-Soft State

Soft-Intermediate State

Hard-Intermediate State

Low-Hard State

Anomalous
STATE-DEPENDENT RADIO JETS

Relativistic ejections

• Compact jet
• X-ray/Radio correlation
  (Gallo et al. 2003)

How hard the spectrum is

软成分占主导

高-软状态

软-中间状态

硬-中间状态

低-硬状态

贝尔诺尼 2010

软成分 (盘)

硬成分

软成分 (盘)

硬成分

1 keV 100 keV
STATE-DEPENDENT RADIO JETS

- Relativistic ejections
  - Compact jet
  - X-ray/Radio correlation (Gallo et al. 2003)

**Soft State: NO JET**
(e.g. Russell et al. 2011)

- How hard the spectrum is

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- Soft component dominates
- Hard component dominates

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**X-ray Luminosity**

- High-Soft State
- Soft-Intermediate State
- Hard-Intermediate State
- Low-Hard State

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**X-ray Luminosity** vs. **1 keV to 100 keV**

- Belloni 2010

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GLOBAL STUDIES: BLACK HOLES

- Large data base (~15 years of RXTE monitoring): systematic studies
- **25 Black Hole candidate studied** by Dunn et al.

Credit: Nasa

Dunn et al. 2010
GLOBAL STUDIES: BLACK HOLES

- Large data base (~15 years of RXTE monitoring): systematic studies
- 25 Black Hole candidate studied by Dunn et al.

Dunn et al. 2010
GLOBAL STUDIES: BLACK HOLES

- RXTE monitoring + Detailed studies using XMM and Chandra
TOWARDS A MORE COMPLETE PICTURE...

**Soft State: NO JET**
(e.g. Russell et al 2011)

How hard the spectrum is

<table>
<thead>
<tr>
<th>X-ray Luminosity</th>
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<tbody>
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<td>1 keV</td>
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- **Hard component** dominates
- **Soft component** dominates

Belloni 2010
TOWARDS A MORE COMPLETE PICTURE...

Winds: a new key ingredient

Soft State: NO JET (e.g. Russell et al 2011)

soft component dominates

How hard the spectrum is

hard component dominates
NEUTRON STARS CAN BE SIMILAR

• **Brightest and more numerous: Studied first**

• More complex behaviour (Extra component)

• **Most of them are persistent systems** (but a few transients as well)

• Some transients look similar to Black holes

Miller-Jones et al. 2012
BLACK HOLE EVOLUTION AND LINE-OF-SIGHTS

INCLINATION EFFECTS

- Large data base (~15 years of RXTE monitoring): systematic studies

Ponti et al. 2012
Inclination effects:
how they do affect the Hardness-intensity diagrams

- Belloni 2010
A CLOSER VIEW...

- RXTE absorption corrected fluxes (Dunn et al. 2010)

Low Inclination

High Inclination

Muñoz-Darias et al. 2013
A CLOSER VIEW...

• RXTE absorption corrected fluxes (Dunn et al. 2010)
A CLOSER VIEW...

- RXTE absorption corrected fluxes (Dunn et al. 2010)
ACCRETION DISCS AND GENERAL RELATIVITY

- Low inclination disc dominated by gravitational redshift

- Gravitational redshift starts to be compensated by blue shifting when looking at higher inclinations.
ACCRETION DISCS AND GENERAL RELATIVITY

- Low inclination disc dominated by gravitational redshift
- Gravitational redshift starts to be compensated by blue shifting when looking at higher inclinations.

★ Doppler beaming enhances blue-shifted light
★ Light bending effects

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ACCRETION DISCS AND GENERAL RELATIVITY

- Low inclination disc dominated by gravitational redshift.
- Gravitational redshift starts to be compensated by blue shifting when looking at higher inclinations.

Spin

Spin (a) = 0.9M

\( \theta_{\text{obs}} = 30^\circ \)

\( \theta_{\text{obs}} = 0^\circ \)
\( \theta_{\text{obs}} = 40^\circ \)
\( \theta_{\text{obs}} = 70^\circ \)
\( \theta_{\text{obs}} = 85^\circ \)

Li et al. 2005
DO WE REALLY SEE THAT?

Fits presented in Dunn et al. 2010 (Newtonian discs (DISKBB))

\[ T_{\text{OBS}} = T_{\text{PEAK}} f_{\text{COL}} f_{\text{GR}} [i,\text{spin}] \]

(see e.g. Zhang, Cui & Chen 1997; Cunnigham 1975)
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$$f_{GR \ [i,a=0.0]}$$
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(see e.g. Zhang, Cui & Chen 1997; Cunnigham 1975)
DOES IT EXPLAIN EVERYTHING?

Simulations using a KERRBB fully relativistic modeling
DOES IT EXPLAIN EVERYTHING?

Simulations using a KERRBB fully relativistic modeling

Other factors?