Exploring the relationship between (RL) Quasars and Microquasars

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Outline

- Introduction
- Some X-ray binary phenomenology
- XRB state $\leftrightarrow$ AGN class mapping?
- Conclusions and outlook
Jargon: Microquasars are just “outgoing” X-ray binaries
Black hole jets: similar across the mass scale?

(Mirabel et al. 92, 98)
XRB Behavior: The Hardness-Intensity Diagram (HID) — schematic view

- **X-ray Intensity**
- **X-ray spectral hardness**

**Thermal Dominated**
- $\sim 10-30\% L_{\text{Edd}}$

**Nonthermal Dominated**
- $\sim 1-2\% L_{\text{Edd}}$
- $\ll 10^{-5} L_{\text{Edd}}$

**quiescence = “ground state”**
XRB Behavior: The Hardness-Intensity Diagram — X-ray spectrum

(Done, Gierlinski & Kubota 2007)
XRB Behavior: The Hardness-Intensity Diagram (HID)—real data with states

Spectral Hardness (spectral slope, soft=steep, hard=flat)
XRB Behavior: The Hardness-Intensity Diagram — what are the jets doing?

HIM/SIM transition = ballistic jets

Hard state: = steady jets
So how does all this relate to AGN?

Backing up, *should* this all relate to AGN??

- For black holes with roughly the same spin, does accretion behavior scale predictably with mass/power?
  - Accretion off single star vs. off central cluster/gas
  - Spin depends on formation/accretion history, and we don’t yet have a surefire way to measure it
  - We don’t have a fully self-consistent theory of everything going on in accretion
So how does all this relate to AGN?

Mass scaling makes testable predictions

- The main effect of black hole mass difference will be in the timescales, $\tau_{\text{dyn}} \propto \text{size} \propto M$:
  
  - $\tau_{\text{XRB}} \sim \text{week} @ 10 \ M_\odot$
  - $\tau_{\text{AGN}} \sim 10^6 \text{ years} @ 10^8 \ M_\odot$ !!

- If such scaling exists, consequences are grand: some AGN classes could be “unified” in a HID of their own

We can test this idea, by searching for trends discovered from XRB monitoring in AGN populations
Evidence that HIDs (or equiv. evolution) are universal to accreting sources

There’s certainly reason to think AGN would also have an equivalent evolution/states. NS’s and WD’s do!

(Körding et al. 2008)
Evidence that HIDs (or equiv.) are universal to accreting sources — AGN

For (cyclic)AGN, hardness is not the best diagnostic. Körding et al. 2006 suggest “Disk fraction/luminosity diagrams” (DFLG)
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For (cyclic)AGN, hardness is not the best diagnostic. Körding et al. 2006 suggest “Disk fraction/luminosity diagrams” (DFLG)
Characteristic timescales scale with black hole mass and inversely with $\dot{M}$ — PSDs

\[ \tau_B \propto \frac{M_{BH}^2}{L_{bol}} \]

(Uttley, McHardy, et al.)
Hard XRB state $\Leftrightarrow$ LLAGN, FR Is

Strong case on both empirical and theoretical grounds

- “Fundamental plane of black hole accretion” linking radio and X-ray luminosities with black hole mass
- Same physical models fit broadband data across the mass scale with the same physical parameters
XRB hard state — Radio/Xray correlation

Prediction of jet synchrotron model

(Corbel et al., 2003; Markoff et al., 2003, Gallo et al. 2003)
Mass scaling of jet break frequency

\[ \nu_{\text{break}} \propto Q_{\text{jet}}^{2/3} M^{-1} \]

AGN: radio
XRBs: IR/opt

Expect same radio/X-ray correlation slope but AGN will have lower “normalization” in X-ray luminosity, comparatively!
Fundamental plane of black hole accretion

Observed

Mass “corrected”

Modeling hard state XRBs

keV Photons s$^{-1}$ cm$^{-2}$ keV$^{-1}$

Energy (keV)

Radio NIR OPT UV X-rays

Stellar Companion

Markoff et al. 04-07
Modeling simultaneous data: hard state

(Markoff et al. 03, Markoff, Nowak & Wilms 05, Migliari et al. 07, Gallo et al. 07, Maitra et al. 08)
M81: Hard state equivalent (LLAGN)?

(Markoff et al. 2008)
### XRB/LLAGN model comparisons

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HS-XRBs</th>
<th>M81</th>
<th>A0620</th>
<th>Sgr A*</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M (M_\odot) )</td>
<td>(~10)</td>
<td>( 7 \times 10^7 )</td>
<td>(~10)</td>
<td>( 4 \times 10^6 )</td>
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<tr>
<td>( R_0 (R_g) )</td>
<td>2–20</td>
<td>2.4</td>
<td>2–7</td>
<td>2.5</td>
</tr>
<tr>
<td>( H_0 (R_0) )</td>
<td>( 1.5^* )</td>
<td>( 1.5^* )</td>
<td>( 1.5^*–2.8 )</td>
<td>( 1.5^* )</td>
</tr>
<tr>
<td>( z_{acc} (R_g) )</td>
<td>10–400</td>
<td>144</td>
<td>3–1250</td>
<td>( &gt;10^4 )</td>
</tr>
<tr>
<td>( \rho_{elec} )</td>
<td>2.4–2.9</td>
<td>2.4</td>
<td>2.2–3.4</td>
<td>( &gt;3.8 )</td>
</tr>
<tr>
<td>PL frac</td>
<td>0.75*</td>
<td>0.75*</td>
<td>(&lt;0.75^* )</td>
<td>(&lt;0.01 )</td>
</tr>
<tr>
<td>( T_e (K) )</td>
<td>2–5( \times 10^{10} )</td>
<td>( 1 \times 10^{11} )</td>
<td>( 2 \times 10^{10} )</td>
<td>( 1 \times 10^{11} )</td>
</tr>
<tr>
<td>equip ( (1/\beta) )</td>
<td>1–5</td>
<td>1.4</td>
<td>1.5</td>
<td>( &gt;10 )</td>
</tr>
</tbody>
</table>

\( L < 10^{-7} L_{\text{Edd}} \)

XRB state ↔ AGN Mapping?

FRIIs, RLQ

LLAGN, FRIs

Seyferts, RQQ

X-ray Luminosity

Soft Intermediate
Hard Intermediate
Jet line
Soft
Hard

Spectral Hardness
(spectral slope, soft=steep, hard=flat)
Summary/Outlook

X-ray binaries seem remarkably like scaled down AGN analogs (despite many reasons they shouldn’t be...)

- Faster timescales valuable for studying evolution that may relate/unify AGN classes, cast light on jet formation and physics
- Need more complete multiwavelength AGN samples to compare with trends found in XRBs
- Need better theoretical understanding of state evolution (disk recessing? What’s the difference between the two kinds of jet ejecta? role of spin?!?)
- Chandra is key (sensitivity/resolution) for both the above points!!
- Big questions: what drives the timescale of the state transitions for XRBs/AGN, and how can we use XRB evolution to understand AGN cycles? How can we know where on its potential cycle a given AGN is and what triggers activity?
What we’re up against: Cyg X-1

(Movie courtesy M. Böck, from monitoring campaign by Markoff, Nowak, Wilms, et al.)
XRB Behavior: The Hardness-Intensity Diagram

**JET LINE AREA:**
- 2 - 50% $L_{\text{Edd}}$
- High-frequency QPOs (after)
- Type A & B QPOs (after)
- See radio ejecta (fast) each "crossing" of jet line
- RMS drop ("The Zone") associated with $\sim 0.2$ Hz lowest frequency Lorentzian, close to ejecta time.

**HIMS:**
- Disk starts near ISCO.
- Transition starts around 2 - 50% $L_{\text{Edd}}$
- Type C QPOs.
- IR drops.
- Radio starts going optically thin and variable (new ejecta?).

**SOFT STATE:**
- Optically nuclear thin jet radio emission observed initially, but quenched by at least 20-50x by full transition.
- Detected radio flux not nuclear?
- Type C QPOs.
- Non-thermal power law extending to $\sim \text{MeV}$
- Thin disk $\sim 0.1-1.0$ $L_{\text{Edd}}$ at ISCO.

**HARD STATE:**
- Disk moves in to $\sim$ few $R_g$ by $10\% L_{\text{Edd}}$
- Lorentzian/broad noise components.
- High RMS variability.
- Flat spectrum jet up to IR/opt.
- Compact jet sometimes resolved.
- Radio/IR/X-ray correlations.
- Reflection "bump".

**Spectral Hardness**
(spectral slope, soft=steep, hard=flat)

**HIMS:**
- Same as upper branch but:
  - No optically thin radio flare.
  - Radio recovers close to hard state.
  - Lower flux level (hysteresis).

**QUIESCECE:**
- Thin disk recessed to $> 10^2 R_g$
- BB component seen in UV/Optical.
- Disk 10-100x more luminous than LX. By $\sim 10^{-4} L_{\text{Edd}}$.
- No iron lines?

**Probing the Accretion/Outflow Connection in X-Ray Binaries and Active Galactic Nuclei**