Observational Signatures of Accretion Disk Evolution

SMBH

Stellar Mass BHs

X-ray binaries

Disk

Jet

Galaxy

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Feedback Changes as the Structure of the Accretion Disk Evolves

L_{bol}/L_{edd} \sim 10^{-1}

L_{bol}/L_{edd} \sim 10^{-3}
Stellar Mass Black Holes: X-ray spectral slope vs. Eddington Ratio

Wu & Gu (2008)

0.5-8 keV

Soft

Low $R_{\text{acc}}$

High $R_{\text{acc}}$

Wu & Gu (2008)
$L_{\text{bol}}/L_{\text{edd}} < 10^{-2} \times 10^{-3}$: (radiatively inefficient flow)

(Dominant cooling mech.: Comptonization of synchotron photons by hot gas)

As accretion rate increases

- optical depth of the flow increases
- number of Compton scatterings increases (increasing $\gamma$-parameter)
- $\Gamma$ hardens (Esin97, Yuan07, Gu08, Wu08).

Low Accretion Rate (ADAF/RIAF)
As accretion rate increases

- Transition radius (between outer thin disk & inner RIAF) decreases
- Outer thin disk radiation becomes stronger
- Compton cooling by outer disk photons becomes more efficient
- Electron temperature decreases
- $\Gamma$ softens/steepeens ($Wu08$).
$L_{bol}/L_{edd} > 10^{-2} (-3)$: (standard optically thick disk)

As accretion rate increases

- fraction of accreting energy released to corona decreases (Merloni02, Liu02, Wang04)
- corona becomes weak and shrinks
- optical depth of the corona decreases, reducing $\gamma$-parameter
- $\Gamma$ softens/steepens (Wu08).

OR

- disk flux irradiating corona increases
- corona cools more efficiently through Compton cooling
- $\Gamma$ softens/steepens (Haardt91, Lu99, Wang04, Gu08).
Stellar Mass Black Holes: X-ray spectral slope vs. Eddington Ratio

Wu & Gu (2008)
High Accretion Rate AGN:

$\frac{L_{\text{bol}}}{L_{\text{Edd}}} > 10^{-2}$: $\Gamma$ softens with accretion rate

\[ \Delta \log \left( \frac{L_{\text{bol}}}{L_{\text{Edd}}} \right) \]

\[ \text{Gamma} \]

Also see Porquet04, Piconcelli05, Saez08, Kelly08

BH by the Black Sea, June 2012, 7/20
Lower Accretion Rate AGN:
$L_{bol}/L_{Edd} < 10^{-3}$: Conflicting Results

Winter09, Trump11, etc. find no correlation for $L_{bol}/L_{Edd} < 10^{-2}$
Lower Accretion Rate AGN: \( \frac{L_{\text{bol}}}{L_{\text{Edd}}} < 10^{-3} \): Conflicting Results

Gu08 & Constantin09,12 see a correlation for \( \frac{L_{\text{bol}}}{L_{\text{Edd}}} < 10^{-3} \)
600 ChaMP (SDSS + *Chandra*) Sources
Constantin et al., in prep.
Chandra Deep Field South, 4Ms

- 740 X-ray sources (Xue11)
- 419 public spec-z

M_{SMBH}:
- 366/419 with L_K,rest-frame
- 48/419 with M_{stellar} (Babic07)

- X-ray spectral fitting of individual sources with > 150 Cts_{0.5-8 keV}
- Stacking and then fitting of sources w/ < 150 Cts_{0.5-8 keV} using STACKFAST (Hickox et al.)
CDFS Subsample: Source Properties

Spectroscopic Redshift

Observed 0.5-8 keV Luminosity

\[ R_{edd} \sim 10^{-1} \]

\[ R_{edd} \sim 10^{-2} \]

\[ R_{edd} \sim 10^{-3} \]

\[ R_{edd} \sim 10^{-4} \]
CDFS: $\Gamma$ vs $L_{\text{bol}}/L_{\text{Edd}}$

Individual Sources ($>150$ counts):

Stacked sources ($<150$ counts):

- Soft
- Hard
- $\text{Low } R_{\text{acc}}$
- $L_{\text{bol}}/L_{\text{Edd}}$
- $\text{High } R_{\text{acc}}$
CDFS: $\Gamma$ vs $L_{\text{bol}}/L_{\text{Edd}}$

- **Low $R_{\text{acc}}$**
- **High $R_{\text{acc}}$**

Energy (keV):
- Data points for different energy bins are plotted with error bars.

Counts/sec/keV:
- Counts are shown for each energy bin with error bars.

Sigma:
- Sigma values are plotted for each energy bin with error bars.

-$10^{-2}$ to $10^{1}$ $L_{\text{bol}}/L_{\text{Edd}}$ range is shown with data points and error bars.
CDFS: $\Gamma$ vs $L_{\text{bol}}/L_{\text{Edd}}$

Individual Sources ($> 150$ counts):

Stacked sources ($< 150$ counts):
CDFS: $\Gamma$ vs $L_{\text{bol}}/L_{\text{Edd}}$

Individual Sources (> 150 counts): □
Stacked sources (<150 counts): ▲

Low $R_{\text{acc}}$

Hard

Soft

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$

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Using Narrow EW(Fe Kα) to Estimate $N_H$
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Fukazawa11

BH by the Black Séa, June 2012, 15/20
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Fe64 Equivalent width (eV)

Counts/keV

Energy (keV)

Sigma

Counts/keV

Energy (keV)

3x10^{-4} < L_{bol}/L_{Edd} < 3x10^{-3}

EW(Fe) \sim 400 \text{ eV}
CDFS: $\Gamma$ vs $L_{\text{bol}}/L_{\text{Edd}}$
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$3 \times 10^{-3} < L_{\text{bol}}/L_{\text{Edd}} < 3 \times 10^{-2}$
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Counts/sec/keV

Energy (keV)

Sigma

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $10^{0}$

$L_{\text{bol}}/L_{\text{Edd}}$
CDFS: $\Gamma$ vs $L_{\text{bol}}/L_{\text{Edd}}$

$L_{\text{bol}}/L_{\text{Edd}} < 3 \times 10^{-4}$
Comparison with AGN & XRB Results

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AGN

- Constantin12
- Gu08
- Shemmer08
- Risaliti09

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$\Gamma$ vs $L_{\text{bol}}/L_{\text{edd}}$

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• Larger sample, better statistics (OPTX, Trouille09,10,11)

• Test reflionx -- better modeling of impact of NH (Brenneman talk)

• Jet contribution
  • For sources where jet dominates in X-ray, what is the expected slope and keV range?
QUESTIONS

• Is there a theoretically predicted lower limit to the X-ray spectral slope for XRBs?
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Wu & Gu (2008)
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• Are there models for why, in XRBs, at the low \( \text{Lbol}/\text{Ledd} \) end, the rate of change in \( \Gamma \) differs from one source to another?

• For either XRBs or AGN, is there consensus on where in \( \text{Lbol}/\text{Ledd} \) the inflection point occurs?
FIN