M31*, The Nearest Extra-Galactic SMBH X-ray (and Radio Properties) +BH-XRT

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Fig courtesy: M. Gilfanov, Z. Li
How do Quiescent BH Accrete?

- BH spend the majority of their time at low accretion rates.
- RIAF forms, but what fraction gets blown out?
- Indirect: Spectra, CV/NS comparisons
- Resolve the flow!
- M31* best target. Sgr A*, NGC3115, M87 next (jet).

Chandra PSF 0.6” FWHM

Why is M31* excellent?

Angular Bondi Radius ~ (M/kT)/D

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>kT (keV)</th>
<th>D (kpc)</th>
<th>R(B)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>M31*</td>
<td>1.4e8</td>
<td>0.3</td>
<td>780</td>
<td>5.2”</td>
<td>XRBs all resolved, accurate subtraction possible</td>
</tr>
<tr>
<td>Sgr A*</td>
<td>4e6</td>
<td>1.3</td>
<td>8</td>
<td>1.8”</td>
<td>0.3 keV absorbed</td>
</tr>
<tr>
<td>M87</td>
<td>6.4e9</td>
<td>0.8</td>
<td>17,000</td>
<td>1.7”</td>
<td>Bright Jet!</td>
</tr>
<tr>
<td>NGC3115</td>
<td>1-2e9</td>
<td>0.3-0.6</td>
<td>9,700</td>
<td>2”-4”</td>
<td>XRBs unresolved but subtracted w/ average 2-6keV spectrum</td>
</tr>
</tbody>
</table>
Our Chandra Monitoring Campaign + Intensive CXO/VLA/HST AO13

- ACIS+HRC concentrated in bulge
- AO1 through 13, total is >1Ms. Nucleus w/ ACIS-I only ~300ks. 5ks snapshots
- 50/50 GO/GTO – multi-year program not possible w/o GTO time!
- AO13 (this week!): burn in nucleus with 400ks ACIS-S
Orbital Period Distribution for XRNe
Barnard, Garcia et al 2012

Shorter than in MW (P=8%): evidence for capture (triple) formation, re: Voss & Gilfanov 2007
A Decade Long Light-Curve
(Li, Garcia, et al 2011)

• Imaging
  – Chandra HRC, slightly better PSF
  – 40 obs, 1999 – 2010, 571ks

• Spectra
  – Chandra ACIS, allows spectral determination
  – 58 obs 1999-2010, 305ks

• HST/ACS
  – Register to Local Group Survey (stars, 0.03″)
  – Resister X-ray to LGS Globulars (∼0.1-0.2″)
  – HST – Chandra ∼0.2″
  – VLA – Radio Spectrum
The Murmur from the Hidden Monster

$4 \times 10^{37}$ ergs/sec

$< 10^{36}$ ergs/sec

$5 \times 10^{36}$ ergs/sec
X-ray flares in M31*

10 days ~orbital timescale
at 100 Schwarzschild (Martin’s father) radii
Sgr A* flares x10-100 on timescale of hours
(Baganoff et al. 2001, Marrone et al. 2008)

Scaling to mass of M31* (x35) - M31* flares would be few days long

⇒ M31* variation may be similar to Sgr A* flares (IR, sub-mm also?)
⇒ Are flares in q-SMBH common at lowest luminosities?
The Murmur from the Hidden Monster
Positional Co-Incidence Only

M31* or XRB? Radio / X-ray Correlation would help!
But pre/post 2006 variability unusual for XRB
Most Recent Data - X-ray/Radio correlation?

**EVLA, Sept 2011, <10 uJy**

(50+ typical)

**EVLA, June 2012 ~20 uJy**
Density within $<5''$ - $0.1 \text{ cm}^{-3}$ (X-ray emission measure)

$$R(B) = \frac{2GM(BH)}{c^2}, \text{ } c_s \sim (T)^{1/2}T = 0.34 +/- 0.05 \text{ keV}$$

$$R(B) = 5.2'', \text{ } 18.7 \text{ pc}$$

$$M_{\text{dot}}(B) \sim \frac{\rho}{c^3} = 7 \times 10^{-5} \text{ M}_{\odot}/\text{year}$$

$$L(B) = 4 \times 10^{41} \text{ erg/sec}$$

$$L_x/L(B) \sim 5 \times 10^{-6}$$
From Princeton to Aspen and Back Again: RRIOS, Rotating Radiating In/Out Solutions

Choi and Ostriker 2012
From Princeton to Aspen and Back Again: RRIOS, Rotating Radiating In/Out Solutions

Prediction: Opt+UV ~ 1/5 X-ray. Data: ☑️

M31* Slightly Resolved in UV

Lauer et al. 2012

Choi and Ostriker 2012
From Princeton to Aspen and Back Again: RRIOS, Rotating Radiating In/Out Solutions

Resolve structure in NGC3115, M31*, accretion flows?

Li, Ostriker, Sunyaev 2012

Red lines = Constant density
Blue arrows = Flow
Bremss dominates
## Bondi flows: Structure?

<table>
<thead>
<tr>
<th>Source</th>
<th>M</th>
<th>$M_B/M_{Edd}$</th>
<th>$L/L_{Edd}$</th>
<th>R(B)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>M31* Point / resolved</td>
<td>1.4e8</td>
<td>5x10^{-5}</td>
<td>10^{-9}</td>
<td>5.2”</td>
<td>Variable Point(?) source, diffuse just below detection?</td>
</tr>
<tr>
<td>Sgr A* diffuse</td>
<td>4e6</td>
<td>1x10^{-5}</td>
<td>5x10^{-12}</td>
<td>1.8”</td>
<td>Slightly resolved at $\sim R_B$</td>
</tr>
<tr>
<td>NGC3115 diffuse</td>
<td>2e9</td>
<td>4x10^{-4}</td>
<td>&lt;2e^{-10} p 1.5x10^{-10} d</td>
<td>4”</td>
<td>Resolved at $\sim R_B$</td>
</tr>
</tbody>
</table>
WOULD we see extended Structure?

‘color’ X-ray image

150ks sum

SMOOTHED

No hint of excess
At R(B)
NO extended emission
<6e35 (100 cts)

Narayan and McClintock 2008 New Astr Rev

Assume M31* and Sgr A* accreting at same Fractional Eddington rate, then Lx scales With Mass.

Scale by 35 to Sgr A* extended structure,
⇒Predicts ~4e35 for M31* (close to CURRENT limit)
⇒Large uncertainty due to high absorption
X-ray and Radio Spectrum

Longest single ACIS-S Observation (50ks, 2001 - so faint!)
70 counts at M31*, X-ray energy slope = 0.9 +/- 0.2
Bremms would also fit

Radio SPECTRAL data non-simultaneous, different VLA arrays,
but taking average: Radio energy slope = 0.8 (same as X-ray!)

X-ray far above extrapolation of Radio slope,
Similar slopes - X-ray point source SSC (jet?)
Stellar Wind Feedback (SN heating)

Hot X-ray Outflow

Fig courtesy: M. Gilfanov, Z. Li
Feedback: Nuclear Spiral

5 arc-min, ~1000pc

H-α

X-ray

~\(R_B\)

X-ray gas ablating away cooler, more dense gas
Z. Li 2009, 2010 (\(C_{\text{sound}} \sim V_{\text{rotation}}\))