The Fundamental Plane of Black Hole Activity

David Nisbet
DEX Meeting January 2016
Two Types of AGN

Radiative-Mode AGN: Accrete at $> \sim 1\%$ of Eddington Limit

Jet-Mode AGN: Accrete at $< \sim 1\%$ of Eddington Limit
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Accretion Flow: X-ray Luminosity
Black Hole: Mass
Radio Jets: Radio Luminosity

\[ L_R = a L_X^\beta M_{BH}^\gamma \]

or

\[ \log L_R = \alpha + \beta \log L_X + \gamma \log M_{BH} \]
Data Base

Jet-mode AGN: 3XMM + SDSS + FIRST
+ quality controls
+ 5 diagnostic tests
= 576 LINERs

X-ray Binaries: 130 observations from 7 XRBs

Sagittarius A*: Black Hole at the centre of the Milky Way
One Approach ....
One Approach ....

... and Ours
Noisy Radio Data

<table>
<thead>
<tr>
<th>S / N</th>
<th>Number of Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 3</td>
<td>194</td>
</tr>
<tr>
<td>2 - 3</td>
<td>45</td>
</tr>
<tr>
<td>0 - 2</td>
<td>208</td>
</tr>
<tr>
<td>&lt; 0</td>
<td>129</td>
</tr>
</tbody>
</table>
Without $M_{\text{BH}}$ Dependency
Without $M_{\text{BH}}$ Dependency

With $M_{\text{BH}}$ Dependency
$M_{BH} - \sigma$ Relationship

$M_{BH} = \alpha \sigma^\beta$

Tremaine et al (2002): $\beta = 4.02 \pm 0.32$

Novak et al (2006): $\beta = 4.59 \pm 0.34$


McConnell & Ma (2013): $\beta = 5.64 \pm 0.32$
Other Results

1. Fraction of galaxies hosting a LINER is a strong function of both stellar mass and black hole mass.

2. A significant proportion (> 50% on average) of the LINERs’ energy is released in the jets.

3. That proportion rises with increasing black hole mass.

4. The Eddington ratio is inversely correlated with black hole mass.

5. Mechanical luminosity becomes progressively more dominant at lower Eddington ratios.

6. Hints that the properties of a black hole (or of its accretion flow) change at a mass of around $10^8$ solar masses.
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Problem 2: Unknown Scatter

Radio Flux
X-ray Flux
Black Hole Mass
Timing Differences, beaming effects, absorption etc
Intrinsic Scatter

Known

Unknown

Procedure to find the Best Fit

1. Make: initial estimates of $\alpha$, $\beta$, $\gamma$, and $\sigma$.

2. Calculate: $\log L_R = \alpha + \beta \log L_X + \gamma \log M_{BH} + N_1 \sigma$.

3. Allow: $N_1$ to vary in small steps from -10 to +10.

4. Convert: each radio luminosity to the equivalent radio flux density.

5. Calculate: how many standard deviations, $N_2$, between each predicted radio flux density and the observed radio flux density.

6. Calculate: $N_{\text{min},i} = (N_1^2 + N_2^2)^{1/2}$, the minimum value for each source, $i$.

7. Calculate: $\ln L = -0.5 \sum_i (N_{\text{min},i}^2 + \ln (2\pi\sigma^2))$.

8. Determine: the values of $\alpha$, $\beta$, $\gamma$, and $\sigma$ that maximise the log likelihood function.