Black Hole Masses Across the Universe with GMT

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The M87 Jet
New School Results:

- Power law slope of 4 (+-0.3)
- Intrinsic scatter of 0.39 dex
- Scatter for ellipticals is 0.25
- Evolution of BH correlations are biased by the scatter
- Not clear what determines the scatter, but the scatter with sigma contains important information (e.g. Volonteri et al.)
- Lots of on-going work
- The upper end is very not well understood, but is important for many reasons
Number density of black holes depends critically on understanding the intrinsic scatter (Lauer et al 07).

Lauer et al. 2007, Faber et al. 1997, Ebizusaki et al. 1991 suggest the galaxy core is due to BH merging.
Two Important Observational Goals

1. **Upper end of the black hole correlations:**
   - Want largest leverage for feedback models
   - Provides leverage for correlation studies
   - Quasar masses are around $10^{10}$
   - Good targets for massive binaries
   - Scatter in correlations versus BH mass signifies underlying physical model

2. **Stellar orbital structure near the black hole:**
   - Determines mass growth of the black hole
   - Our best measure for binary black hole mergers

Black hole correlations exist due to:

1. BH feedback effects (Silk & Rees, Fabian)
2. By-product of galaxy evolution (Hopkins)
3. Central Limit Theorem (Peng 07)
Black Hole Masses with GMT

Sphere of influence for black holes of various masses versus redshift

GMT can measure $5 \times 10^9$ Msun black holes anywhere in the Universe.

(if you can make it there, you can make it anywhere)
An Unpublished Black Hole Correlation

BH data from pre-2000

Present BH data
An Unpublished Black Hole Correlation

BH data from pre-2000

Present BH data

Black Hole Mass (M_{sun})

Log scale

NGC #

Log scale

NGC #
Gemini/NIFS laser AO for M87

- 24 10-minute exposures
- laser AO using AGN as TT

Outer Radii data from VIRUS-P on the McDonald 2.7m, out to 250” (Murphy, kg and Adams 11)
Once dispersions get this fat, it is hard to measure them robustly.
BH mass from NIFS+VIRUS-P data is $6.6 \times 10^9$, with almost no dependence on dark halo.

BH mass from published and SAURON data is $6.4 \times 10^9$, with strong dependence on dark halo.

Sargent et al. (1978) reported $6 \times 10^9$!

Gas mass (Macchetto et al.) can be made consistent with a small inclination change of disk.
Do 1e10 black holes exist? I think so....

- Nicholas McConnell, with Graham, Ma, kg, Lauer, have been using Gemini and Keck AO on BCGs to measure the black hole mass.
- N6086 is at 3.5e9. Initial, preliminary results on N3842 show a larger mass.
- We are pushing the limits of what the current AO systems and telescope can deliver.
- We are almost out of good targets
- van den Bosch, Gultekin, kg have a major campaign to get dispersions of high-mass, nearby galaxies, using HET, Magellan, VLT; excellent targets for AO
Wavelength range for distant black holes

- 2.3μm CO bandheads best for z<0.1
- 1.6μm CO bandheads best for 0.1>z>0.6
- CaT at 0.85μm for 0.6<z<1.9
- for z>2, probably too hard for stars, but should be fine with gas disks (Halpha)

McConnell et al. data for N6086; H-band spectra is ideal but OH lines are problematic
Requirements and Exposure Times

- We are fairly well calibrated in terms of what we need for S/N, spatial resolution, spatial coverage.
- We need to get close to the radius where the BH mass equals the enclosed stellar mass. For core galaxies, we can add within radial annuli to increase S/N.
- Scale from current AO data to $z=1$.
  - Need 3 hrs currently for $z=0.25$ at 50mas to get accurate BH mass (to 20%).
  - GMT at $z=0.5$, require about 8 hrs for 12 mas.
  - GMT for $z=1$ need to average over angles to get S/N (resolution is not the issue), and require about 8 hrs.
  - A good program would have 20 object at $z<0.5$, and around 10 at $z=1$ (for any evolution). This is about at 400 hr program.
Strong tangential bias in the central region (seen in other galaxies) suggest black hole growth from stellar accretion – consistent with black hole scouring models.
Infalling BH(s) leaves a mark on the orbital structure (Quinlan & Hernquist 97, Quinlan et al. 95)

Tangential orbit bias is commonly seen in central regions: kg et al. 03, 07, Cappellari & McDermid 05, Shapiro et al. 06, Cappellari et al. 07

GMT will allow us to probe 3-4x in radius
GMT’s Role in Black Hole Studies

- In 10 years, we will probably have about 10 dynamically measured black hole masses at >3e9; but we are running out of targets and these are all nearby (z<0.1).
- GMT can go out to z=1 (maybe more distant with select objects)
- A 400 hour program on GMT should produce about 40 black hole masses at >3e9. This will find the most massive BH and determine the scatter.
- We’ve reached the radial limit for understanding the stellar orbital structure. GMT will go about 4x deeper. This should show strong evidence for binary black hole models – although we need better theoretical models to predict what we would find.