The smallest massive black holes in nearby galaxy nuclei

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The census of massive black holes is mainly being carried out for masses of $10^{6.5} - 10^{9.5} \, M_\odot$.

What can we learn about black hole demographics below $10^6 \, M_\odot$?
Black holes below $10^6 \, M_\odot$: Open questions

- How massive are the initial seeds of SMBH?
- Can black holes form and grow in bulgeless galaxies?
- Event rates for LISA?
- Event rates for stellar tidal disruptions?
- Role of gravity-wave recoil kicks in BH evolution?
Nuclear star clusters in dwarf ellipticals

- Correlation of nuclear star cluster mass with host galaxy mass for dE galaxies follows the $M_{\text{BH}}-M_{\text{bulge}}$ relation

(Wehner & Harris 2006) (Ferrarese et al. 2006)
Are there BHs in late-type spirals and dEs?
Upper limits in Local Group galaxies from HST

**M33:** $M_{\text{BH}} < 1500 \, M_\odot$
(Gebhardt et al. 2001, Merritt et al. 2001)

**NGC 205:** $M_{\text{BH}} < 3.8 \times 10^4 \, M_\odot$
(Valluri et al. 2005)
The smallest Seyfert 1 galaxies

- **NGC 4395** (Sd, $D = 4.2$ Mpc)  
  (Filippenko & Sargent 1989; Filippenko & Ho 2003; Peterson et al. 2005)
  - Host $M_V = -18.0$ mag
  - central $\sigma < 30$ km/s
  - $M_{BH} = (3.6 \pm 1.1) \times 10^5 \, M_\odot$
  - $L/L_{Edd} \sim 10^{-3}$

- **POX 52** (dE, $D = 90$ Mpc)  
  (Kunth et al. 1987; Barth et al. 2004)
  - Host $M_V = -17.6$ mag
  - $\sigma = 36 \pm 5$ km/s
  - $M_{BH} \sim 3 \times 10^5 \, M_\odot$
  - $L/L_{Edd} \sim 0.5$
NGC 4395 and POX 52 are AGNs with subsolar metallicity.

(SDSS data points from Kauffmann et al. 2003)
X-ray variability

(Vaughan et al. 2005)

POX 52
Chandra light curve

Thornton, Barth, et al, in progress...
Finding more:
Search strategies for SDSS

- What are the smallest black holes that can be identified from spectra of broad-lined AGNs?

- What are the smallest host galaxies that can be identified for objects with unambiguous AGN spectra?
Strategy #1: The smallest black holes in Seyfert 1 galaxies

- Work by Greene & Ho (2004)
- Single-epoch virial method (Kaspi et al. 2000) used to derive $M_{BH}$ for all broad-lined AGNs in Sloan DR1 out to $z = 0.3$
- 19 Seyfert 1 galaxies with $M_{BH} < 10^6 \, M_{\odot}$
SDSS Seyfert 1s on the $M-\sigma$ relation

(Barth, Greene, & Ho 2005)

Note: BH masses have been reevaluated based on the Keck spectra, and the updated AGN mass calibration from Onken et al. (2004) has been applied
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Is this the upper envelope of a wide distribution of BH masses in low-$\sigma$ galaxies?
New HST ACS/WFC Images

Greene, Ho, & Barth, in progress...
Strategy #2: The smallest AGN host galaxies

Fraction of galaxies hosting "Type 2" AGNs, as a function of host galaxy stellar mass

(Compiled from the Kauffmann et al. SDSS DR4 catalog)
Strategy #2: The smallest AGN host galaxies

- From SDSS DR2 AGN catalog of Kauffmann et al. (2003), select a sample of the faintest Seyfert 2 host galaxies with unresolved velocity dispersions
  - $M_g > -19.5$ mag
- New Keck observations of 29 galaxies so far
- 13 Seyfert 2s now identified with $\sigma < 60$ km/s
Are these really AGNs?

Coronal lines detected in Keck spectra

SDSS 1440+0247
\((\sigma = 47 \pm 3 \text{ km/s})\)
The smallest Seyfert host galaxy?

- $M_g = -16.8$ mag
- Stellar mass $10^{8.1} M_\odot$ (Kauffmann et al. 2003)
- $\sigma([O III]) = 28$ km/s

XMM & Spitzer observations coming soon...
Conclusions

- AGNs do occur in host galaxies with velocity dispersions down to ~25-30 km/s, but:
  - SDSS selection finds very few black holes below \( \sim 3 \times 10^5 \text{ M}_\odot \)
  - *unambiguous* AGNs are extremely rare in galaxies with stellar mass below \( 10^9 \text{ M}_\odot \)

- There is *tentative* evidence for a flattening in the M-\( \sigma \) slope below \( \sigma = 100 \text{ km/s} \)

- Next steps: Reverberation mapping to better constrain the black hole masses in the smallest AGNs