Inconvenient Tales of Dinosaurs

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And thanks to NASA

Black holes are remarkable and important objects.

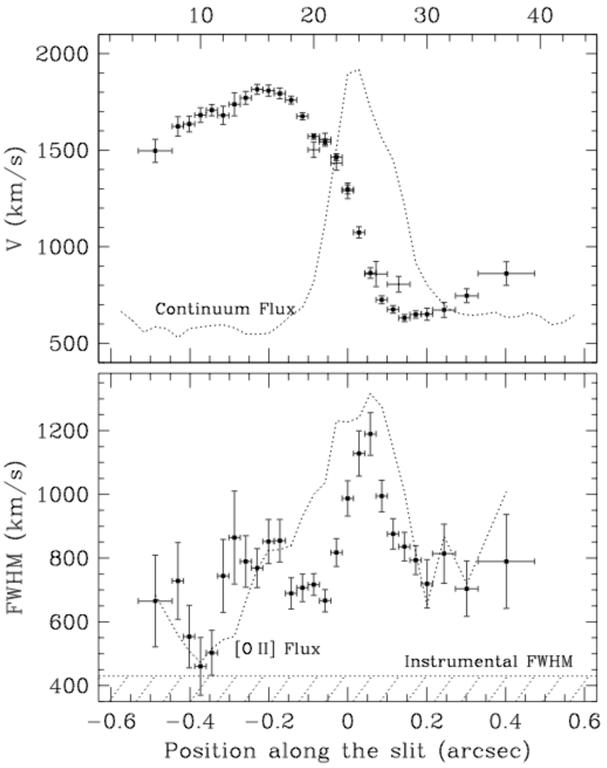
- Fraction of universe: $\Omega_{bh} = 10^{-5}$.
- Fraction of baryonic galaxy mass: 10^{-3}.
- Binding energy compared to baryonic binding energy:

$$E_{bh}/E_{g,grav} = \frac{M_{bh}c^2}{M_g\sigma^2} = 10^{-3} \times 10^6 = 10^3$$

\- and worse in globular clusters if there are BH in globulars. BH dominate the gravitational energy of galaxies. Cannot bind BH by stellar dynamics, gas dynamics. Luminosity in EM or gravitational radiation must dominate the binding energy budget.

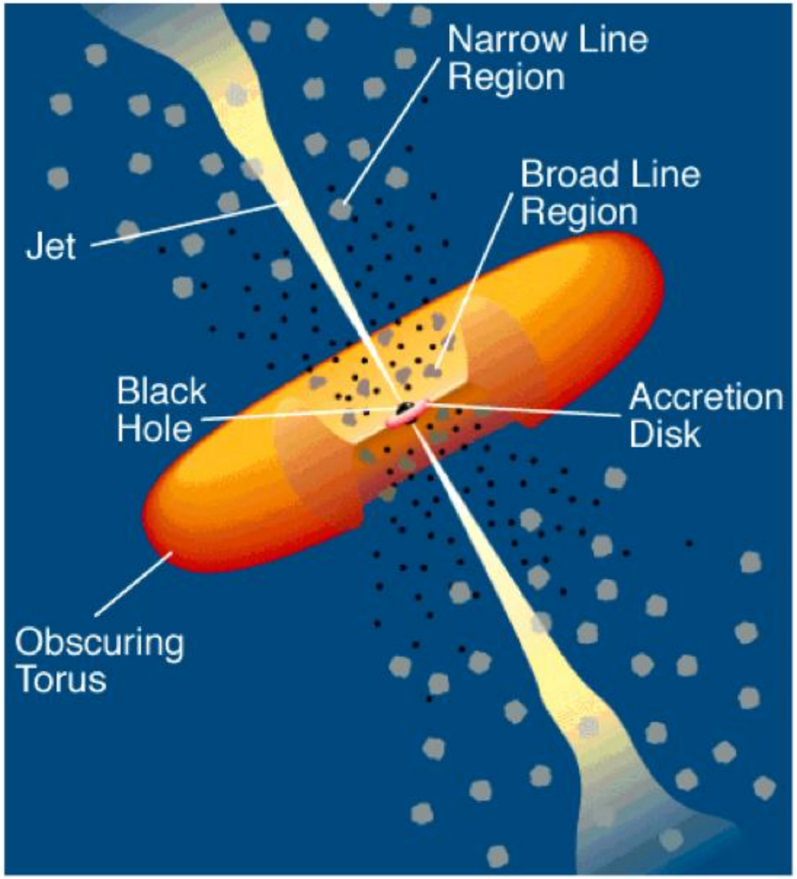
The study of black holes is always paleontology!

Raptor heads



M87 - Macchetto et al.

Relics of observable entities provide extra constraints on theories.



C. M. Urry and P. Padovani

Connection of BH to AGN is Persuasive

- AGN emission requires a relic density of about 3 10^5 solar masses/pc^3 if

  $$E = mc^2(\varepsilon/.1)$$

- Observe comparable density in black holes.

Connection of BH to galaxies is persuasive

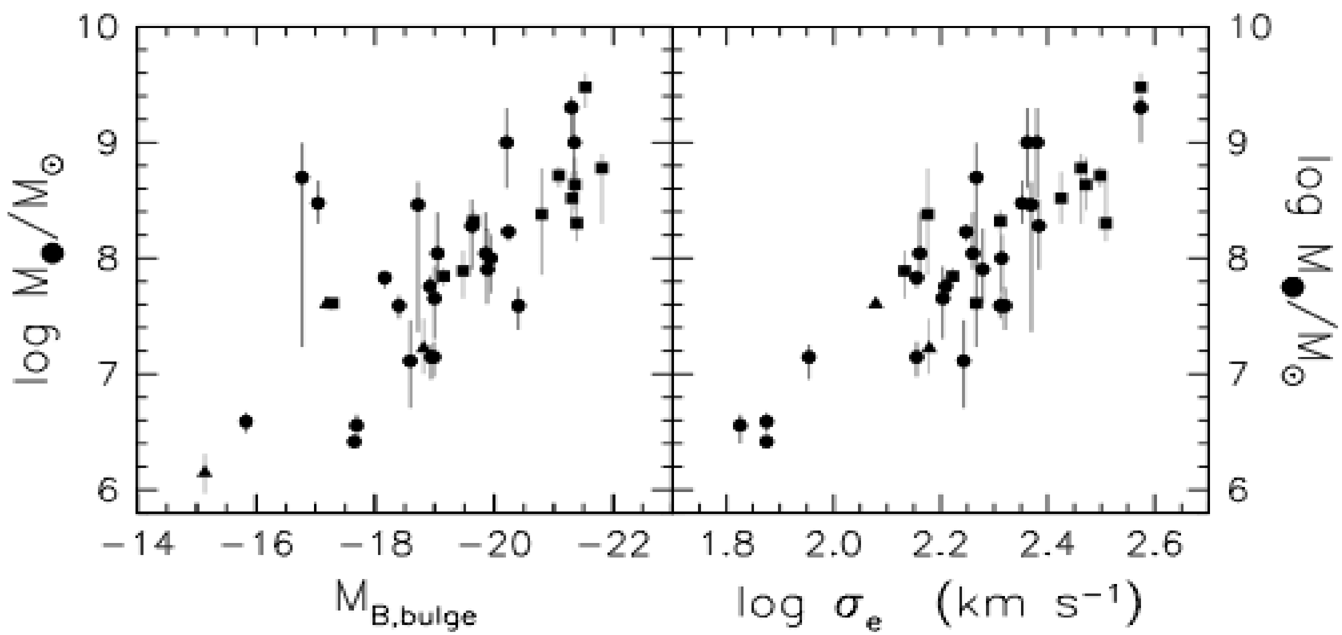


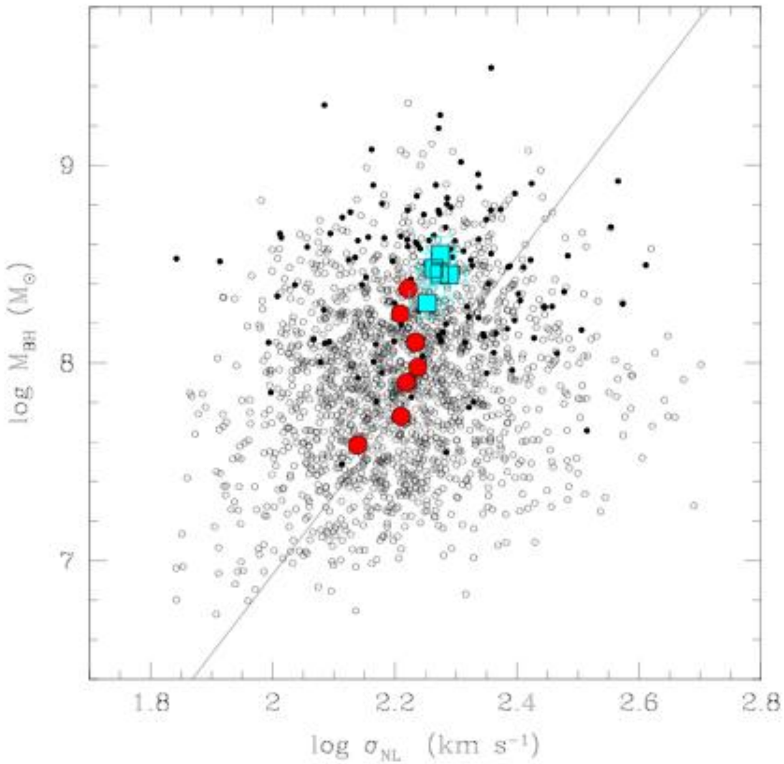
FIGURE 2. Correlation of BH mass with (left) the absolute magnitude of the bulge component of the host galaxy and (right) the luminosity-weighted mean velocity dispersion inside the effective radius of the bulge. In both panels, filled circles indicate $M_\bullet$ measurements based on stellar dynamics, squares are based on ionized gas dynamics, and triangles are based on maser disk dynamics. All three techniques are consistent with the same correlations.

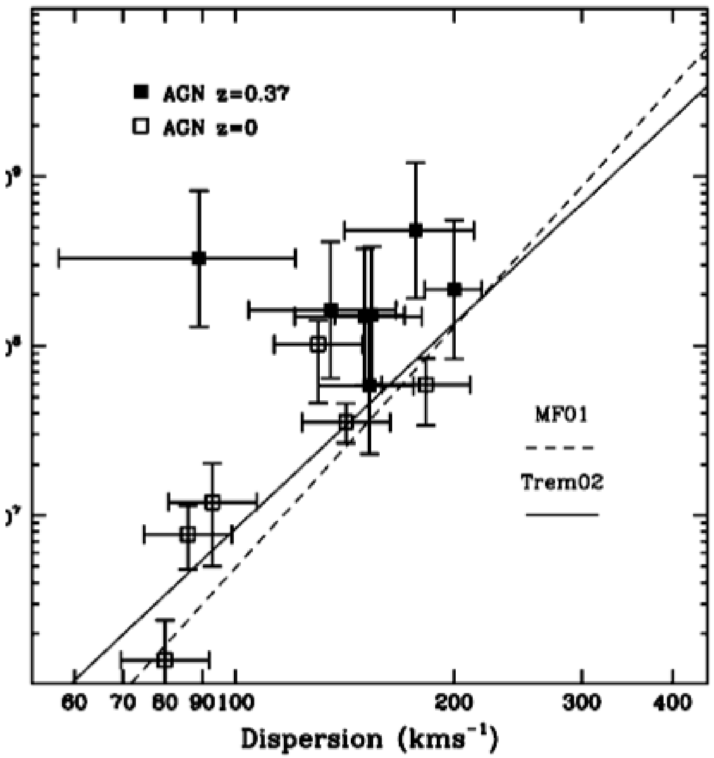
Chicken and Egg questions

1. Which came first, the BH or the galaxy?
2. Do the BH form primarily by merging, or by gaseous accretion –

   monolithic or episodic?

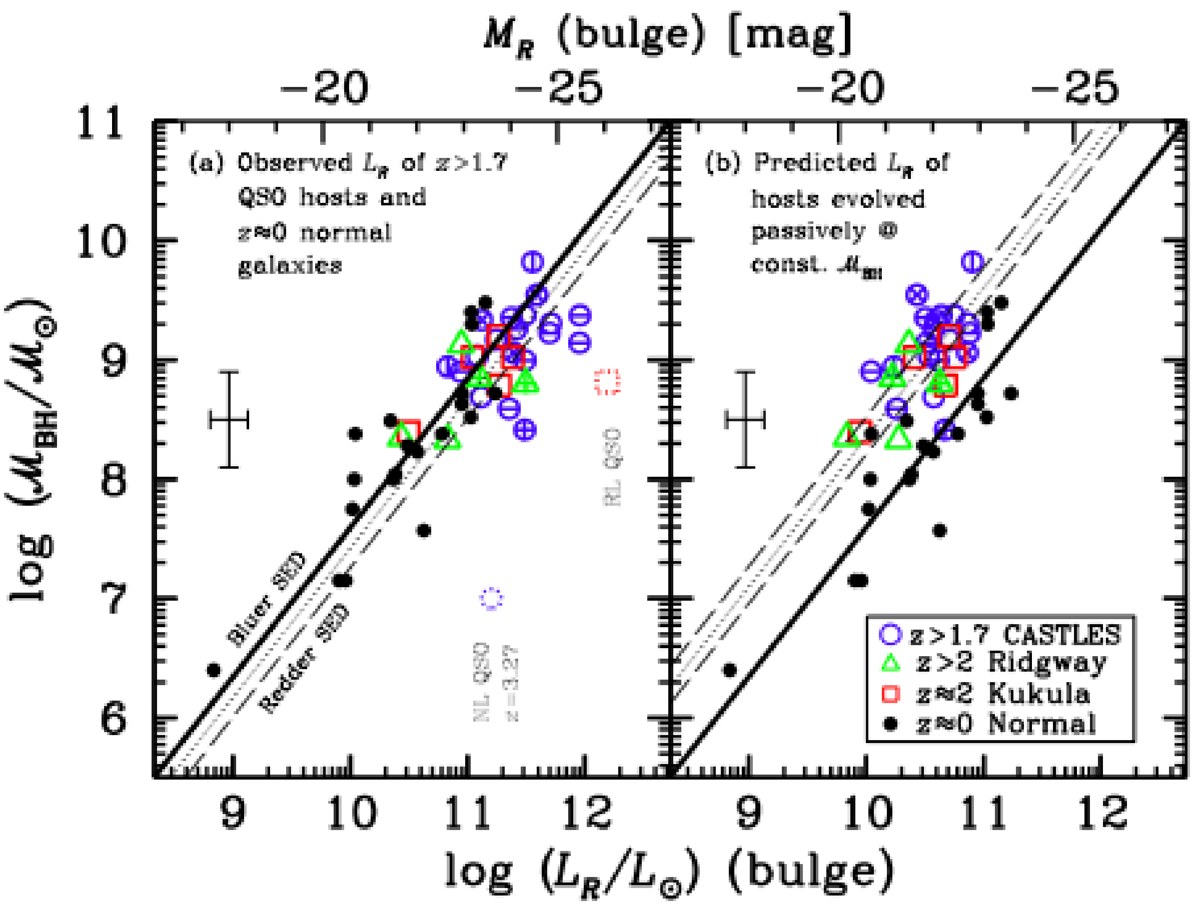
- What are good diagnostics?



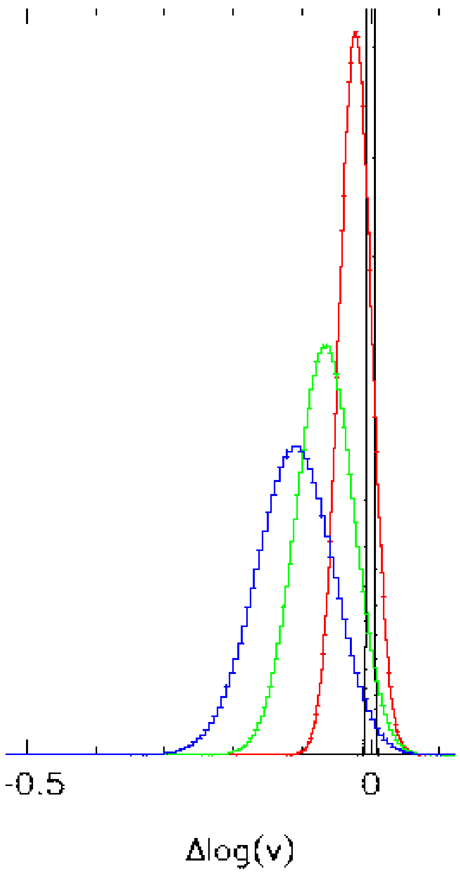


Salviander et al

Treu, Malkan,Blandford

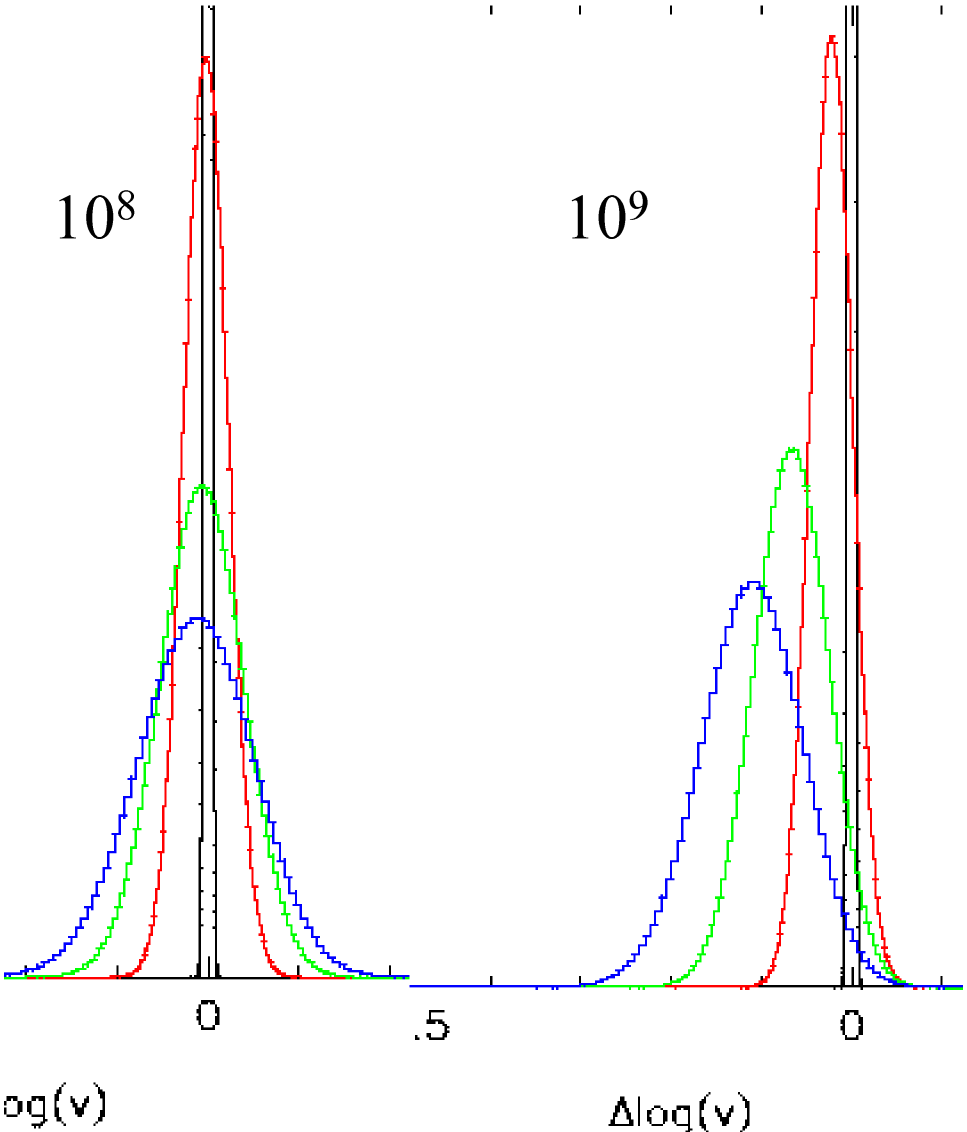


M_R (bulge) [mag]
−20
−25
(a) Observed L_R of z>1.7 QSO hosts and z≈0 normal galaxies
(b) Predicted L_R of hosts evolved passively @ const. $\mathcal{M}_{BH}$
Bluer SED
Redder SED
NL QSO z=3.27
RL QSO
z>1.7 CASTLES
z>2 Ridgway
z≈2 Kukula
z≈0 Normal
log ($\mathcal{M}_{BH}/\mathcal{M}_\odot$)
log ($L_R/L_\odot$) (bulge)



-0.5
0
Δlog(v)

A frightening simple model of sample selection



- P(M|s) is log normal
- dn/ds as observed
- So joint distribution

N(M,s) = P(M|s)*dn/ds

But P(s|M) = N(M,s)/(dn/dm)

Scatter shown is 0, .1, .2, .3.

From Lauer et al. 2007

Modes of Accretion

- BH energy is comparable to stars and fast.

$$E_{bh}/E_* = \frac{0.1 M_{bh} c^2}{.01 M_* c^2} = 10^{-2}$$

- Salpeter (e-folding time) is

$$t_s = M/\dot{M} = 4 \times 10^7 \epsilon_{0.1} yr$$

While stars radiate over 10^{10} yrs, so when they are on, BH dominate the ISM thermodynamics near the galaxy center (feedback).

Star formation competes with BH fueling
Burkert & Silk 2001, Escala

- Mass reservoir is

$$M = \frac{\sigma^2 r}{G}$$

- BH accretion rate is

$$\dot{M} = \frac{M}{t_{viscous}} = A\frac{\sigma^2 r}{G}\frac{\sigma}{r} = A\sigma^3/G$$

- Star formation rate is $t_{sf}^{-1} = Br/\sigma$

- BH growth proceds until stars suck up all the gas:

$$M \sim \Delta M = \dot{M} t_{sf} = AB\sigma^2 r/G \sim ABM_{bulge}$$

- Fundamental plane gives M ~ σ^4 so, also have

  M ~ σ^4

What are the modes of accretion?

- Eddington timescale/rate
- Bondi accretion rate applied where?
- Free-fall timescale
- Viscous accretion timescale
  - (TH for BH)
- Merger rate
- Gas fraction/dynamical time.

What sets the accretion rate?

??Are they Black?

Are the masses reliable?

– 45 –

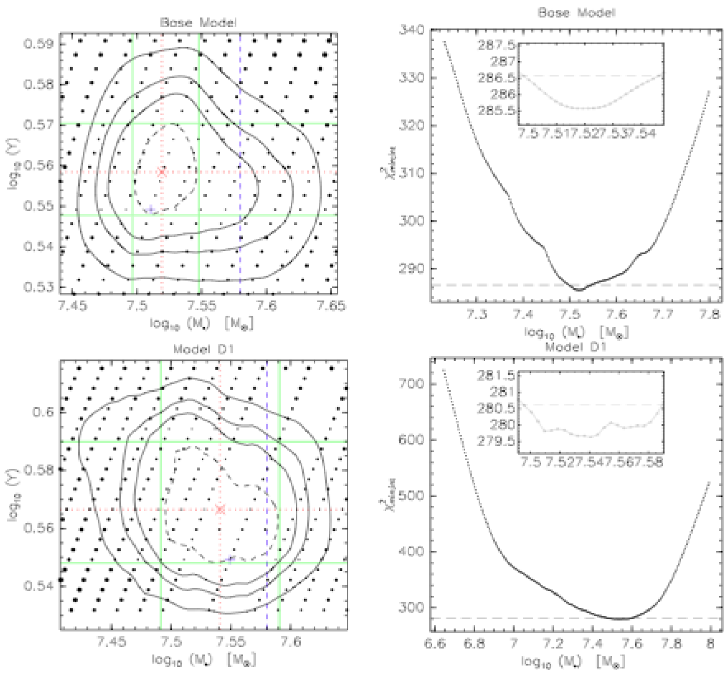


Fig. 14.— *Left:* Contour maps of $\chi^2(M_\bullet, \Upsilon)$ for the dynamical models bearing the parameters listed in Table 4. Model names are as in Table 4. The stellar M/L ratio (Υ) refers to the V band. Each dot represents a model, and dot size is proportional to the value of

NGC 4258

Stellar Dynamics (Siopis et al. 2007):

$$M_\bullet = 3.31^{+0.22}_{-0.17} \times 10^7 M_{sun}$$

Gas Kinematics (Pastorini et al. 2007):

$$M_\bullet = 7.9^{+6.2}_{-3.5} \times 10^7 M_{sun} \ (i = 60^\circ)$$

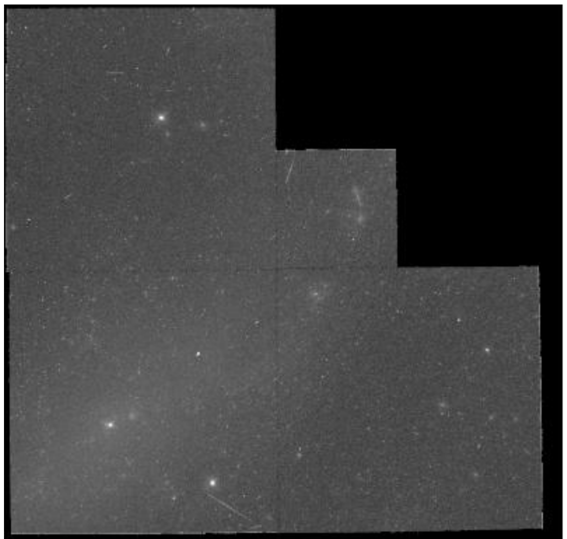
$$2.7 \times 10^7 M_{sun} - 2.6 \times 10^8 M_{sun} \ \text{(diff incl)}$$

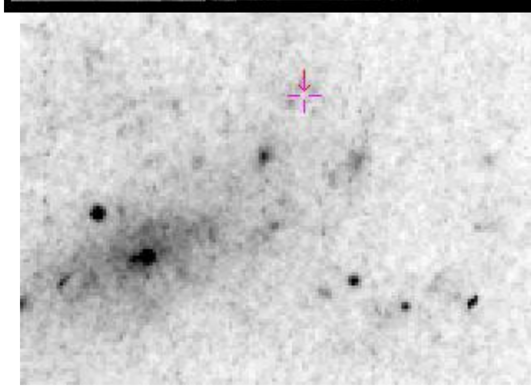
Water Maser Kinematics (Herrnstein et al. 2005):

$$M_\bullet = 3.78 \pm 0.01 \times 10^7 M_{sun}$$

$$3.56 \times 10^7 M_{sun} - 3.85 \times 10^8 M_{sun} \ \text{(diff mode}$$

But is it really L Bulge?





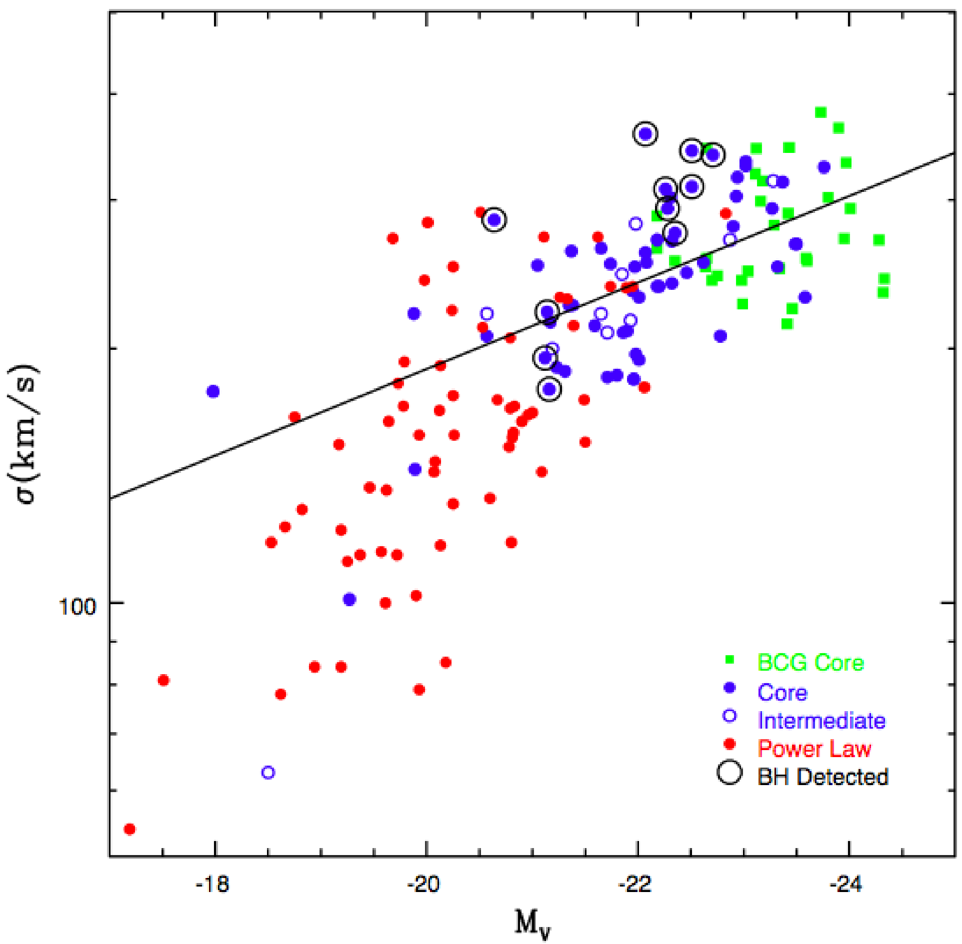
- At low L, M33 has little or no hole, but NGC 4395 and NGC 1042 (see Joe Shields' poster) have weak AGN's
- NGC 4395 has a reverberation mass measurement of $M=3.6 \times 10^5$.
- Perhaps its just M in inner part of galaxy (or binding energy), but it is stochastic at low M.
- NGC 1052 has no measured mass

(picture overleaf) but does have an AGN.

Are they nuclear?

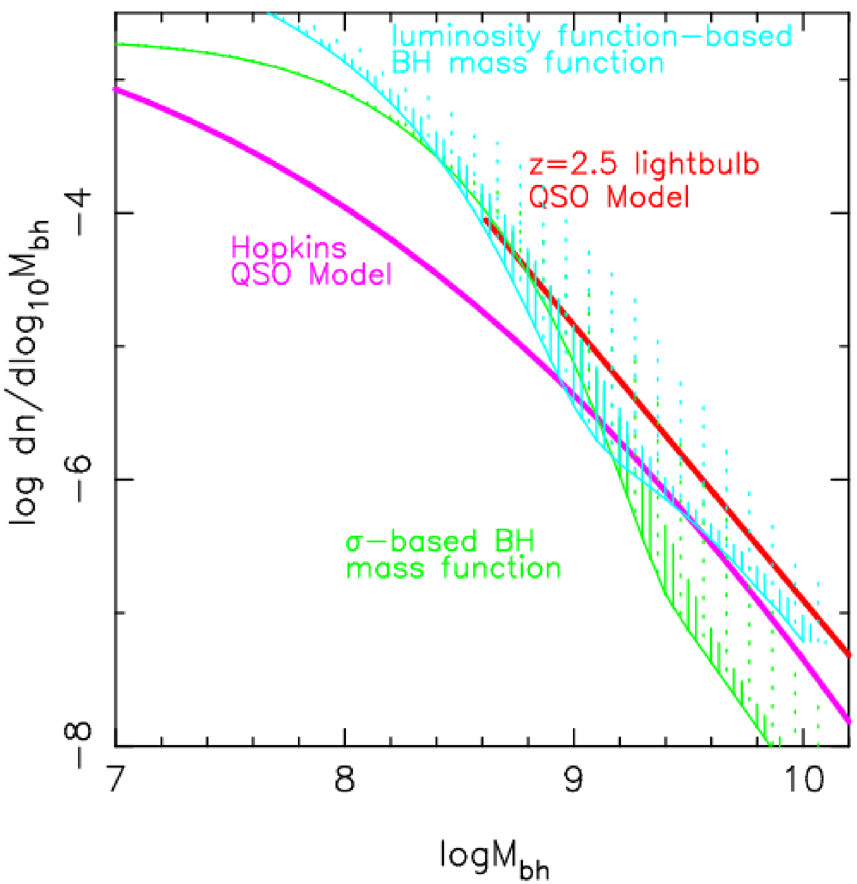
- Do empty nuclei imply rogue black holes?
- What is the rate of ejections from nuclei?
- Connections to XRB, ULX, Globular clusters? Runaway stars?

M vs L and σ^4 is not consistent



- Implies L-M and σ-M relations are not consistent at high mass.
- Can we guess which is correct?
- Measurements of BH M in BCGs would settle it. Maybe.

Compare inferred demographics to quasars.



- Dispersion-based demographics predict fewer high mass bh than luminosity-based demographics.
- Dispersion-based estimates of the numbers of the most massive BH are barely consistent with high redshift quasars.

Can we learn anything by comparing with quasar demographics?

- Recall Soltan argument: (local BH have $\rho \sim (2.5 - 5) * 10^5$ Msun, quasars are similar. Is a factor of 2 a problem?). Either BH grow by visible accretion of normal matter or this is a coincidence.
- Extend argument to compare to quasar LFs (continuity - Blandford and Small).
- Must assume, or calculate, a relationship between quasar luminosity and BH mass *at the end of accretion process (or at z=0)*.
- What are the modes of accretion as a function of dm/dt? What is the distribution of L/L_E?

The really big question

- Are they holes?
  - Can we measure spin distribution now?
  - Are they Kerr?
  - Is GR correct?

Comments:

- There is a conflict between the predicted densities of the highest mass BH derived using dispersion- or luminosity-based predictors of the BH mass in galaxies.
- There is a dangerous bias in selecting high luminosity objects at high-z and comparing to low z surveys. We need to better understand the scatter about M-x relations, and samples need to be carefully defined.

questions

1. Which came first, the BH or the galaxy?
2. Do the BH form primarily by merging or by accretion? - monolithic or episodic?
3. What are the modes of accretion?
4. What sets the accretion rate? - - - - Are they black
5. How reliable are the masses?
6. Do empty nuclei imply rogue BH?
7. What is the rate of ejections …. Are they all nuclear?
8. Connections to XRB, ULX, Globular clusters, runaway stars?
9. What do we learn from evolution in M-sigma? Scatter?
10. What is the rate of ejections? - - - - Are they (all) nuclear?
11. Is the Kerr metric right?
12. Is GR right? --- Are they holes?