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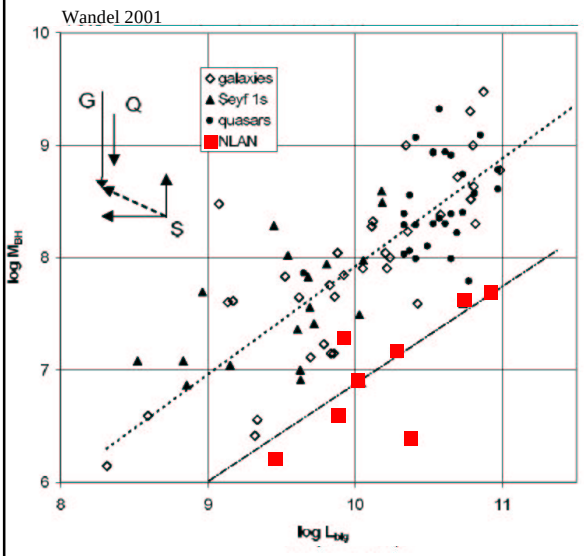
Supermassive Black Holes in AGNs

Santa Barbara – February 25, 2002

Motivation

Wandel 2001

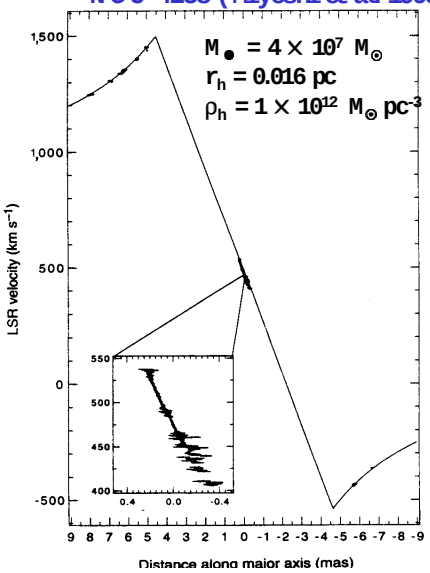


1. Knowing SBH masses is essential if we are to understand the mechanisms that drive the evolution of different types of AGNs.

2. At the resolution capabilities of current instrumentation, spatially resolved gas/stellar kinematics can target (almost) exclusively the $>10^7$ $M_\odot$ range.

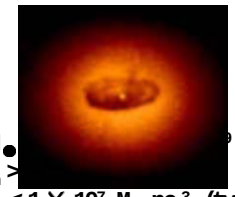
"Classical" SBH Masses in AGNs

NGC 4258 (Miyoshi et al. 1995)



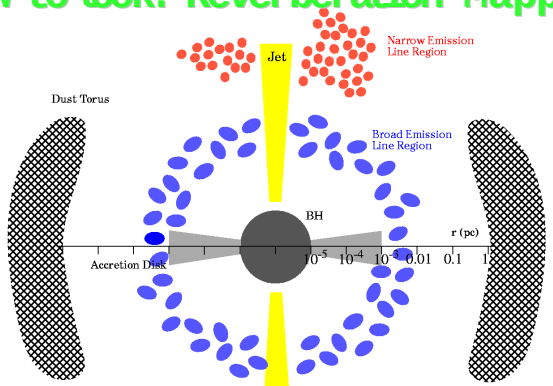
Dynamics of Gas Disks:

- ✓NGC 4261 (Ferrarese et al. 1994)
- ✓M 87 (Macchetto et al. 1997)
- ✓NGC 4374 (Bower et al. 1998)
- ✓NGC 7052 (van der Marel & van den Bosch98)
- ✓NGC 6251 (Ferrarese & Ford 1999)
- ✓IC 1459 (Verdoes Kleijn et al. 2000)
- ✓NGC 5128 (Marconi et al. 2001)
- ✓NGC 3245 (Barth et al. 2001)
- ✓NGC 2787 (Sarzi et al. 2001)



$M_\bullet$ $M_\odot$
r_h >
$\rho_h < 1 \times 10^7\ M_\odot\ pc^{-3}$ (typically 10^4)

How to look: Reverberation Mapping

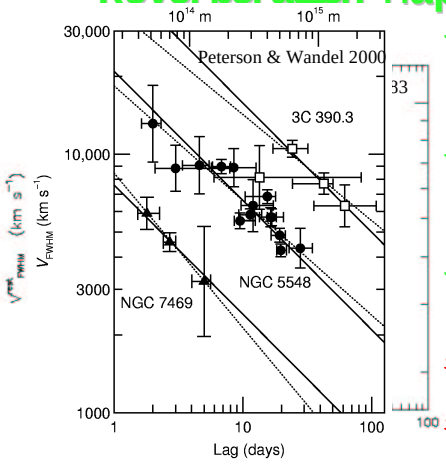


SBH masses are derived in a two step process:

1) Reverberation Mapping allows the measurement of the size r of the BLR through monitoring of the light-travel time delayed response of the emission lines to continuum variations (Blandford & McKee 1982, Peterson & Netzer 1998)

2) $M_\bullet$ is derived from the virial theorem as $r\sigma^2/G$ where σ is measured from the width of the broad lines (generally Hβ).

Reverberation Mapping : Pros and Cons

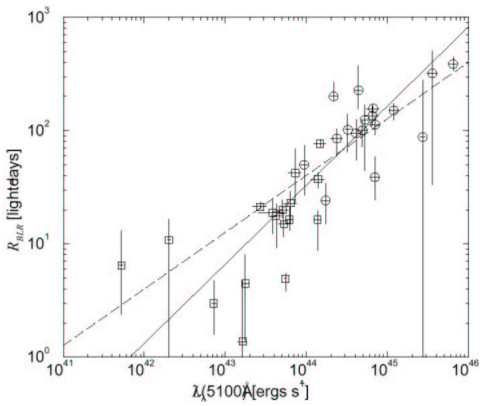


- ✓ RM is intrinsically unbiased with respect to the SBH mass and the distance to the host galaxy.
- ✓ RM targets gas which is very close to the BH, therefore it is very unlikely to be influenced by the stellar gravitational potential.
- ✓ RM is the only method applicable to bright AGNs (Seyfert 1s and QSOs)
- × Can only be applied to Seyfert 1s and QSOs
- × The kinematics of the BLR are complex and the risk of systematic errors is large (Krolik 2001; Peterson 2001)
- × The method is observationally intensive, requiring frequent AGN monitoring over long periods

$M_{BH} = 1 \times 10^6$ to 5×10^8 $M_\odot$
$r_h = 1$ to 400 light days
$\rho_h > 10^{14}$ $M_\odot$ pc^{-3}

(Wandel, Peterson & Malkan 1999, Kaspi et al. 2000)

"Secondary" Mass Estimators: L(5100 A)

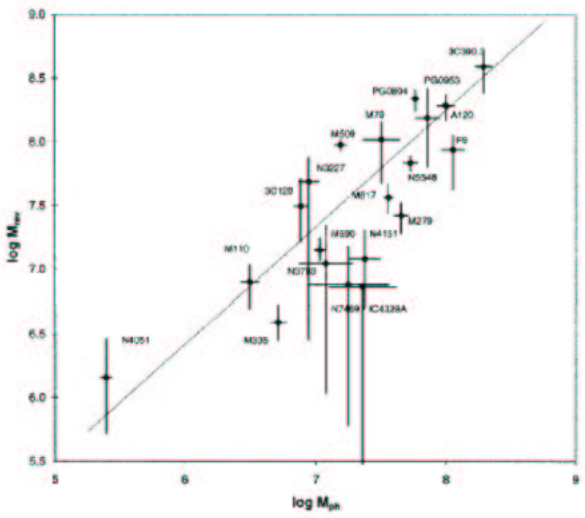


Koratkar & Gaskell (1991); Wandel, Peterson & Malkan (1999); Kaspi et al. (2000):

In reverberation mapped galaxies, R_{BLR} correlates loosely with the AGN monocromatic luminosity at 5100 A.

$$R_{BLR} = (32.9^{+2.0}_{-1.9}) \left(\frac{\lambda L_\lambda (5100\,\text{Å})}{10^{44}\,\text{erg s}^{-1}} \right)^{0.700 \pm 0.033}$$

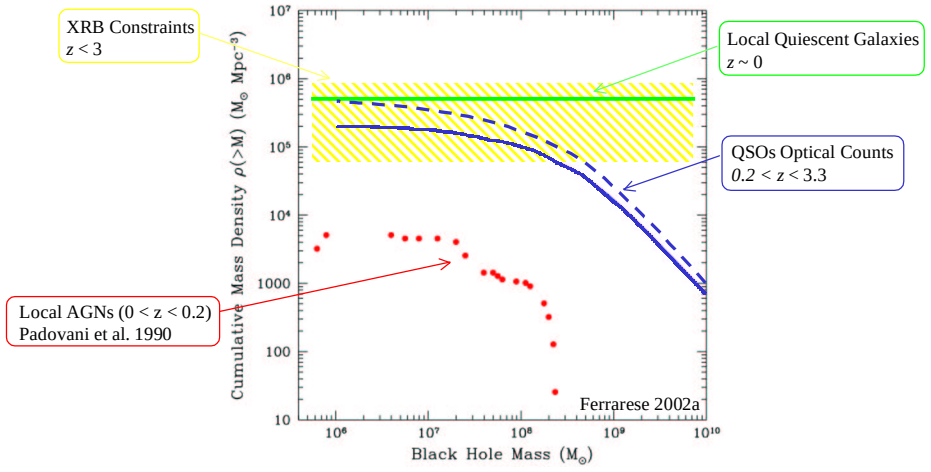
"Secondary" Mass Estimators: Photoionization Method



$$U = \frac{L_{ion}}{4\pi r^2 \overline{E} n_e c}$$

Padovani, Burg & Edelson 1990, Wandel, Peterson & Malkan 1999, Netzer 1990

Comparing SBHs Mass Functions

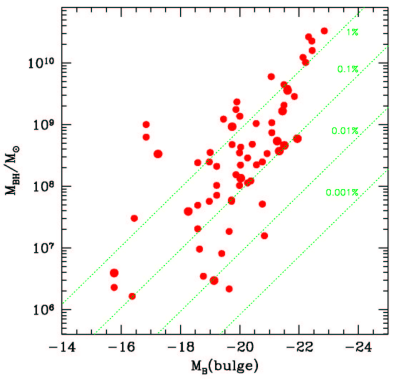


The integrated mass density in Local AGNs is lower than the value inferred from the energetics associated with QSO counts: the bulk of the mass connected with the accretion of high z QSOs does not reside in local AGNs. Remnants of past activity must be present in a large number of quiescent galaxies

Problems in the Local Universe

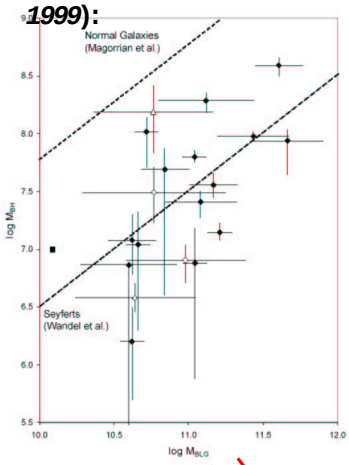
Seyfert galaxies seem to harbor "lighter" SBHs, compared to their bulges, than quie

Local quiescent galaxies (e.g. *Kormendy & Richstone 1995; Magorrian et al. 1998*):



$M_\bullet / M_{bulge} \sim$ ~~0.6%~~ 0.15%

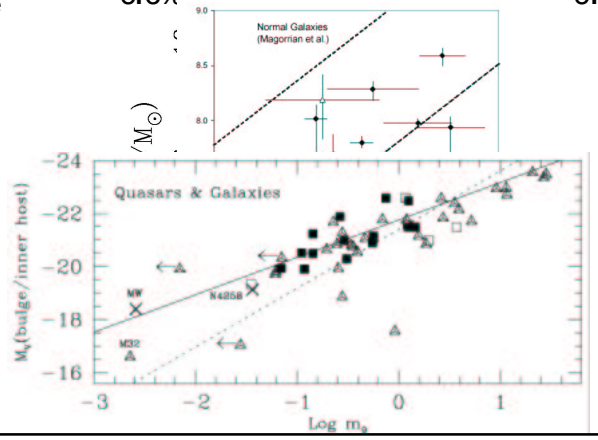
Seyfert 1 galaxies (*Wandel 1999*):



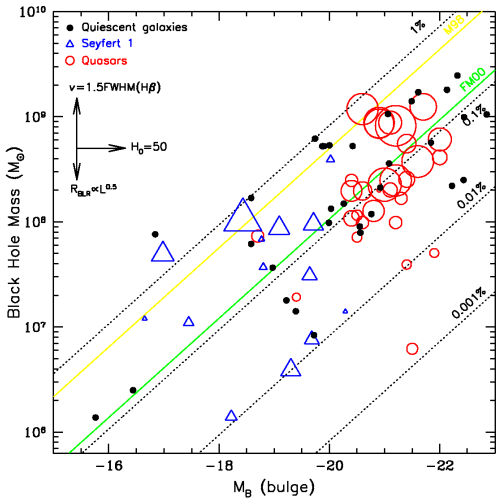
$M_\bullet / M_{bulge} \sim$ ~~0.03%~~ 0.2%

SBH Demographics in Local AGNs: the $M_{BH}-M_B$ Relation

	Laor (1998)	Wandel (1999)	McLure & Dunlop (2000)
BLR Size	$R \propto L^{0.5}$	Rev.Map.	$R \propto L^{0.7}$
Virial velocity	v = 0.87 FWHM(Hβ)	v = 0.87 FWHM(Hβ)	v = 1.55 FWHM(Hβ)
Bulge Magnitude	*V*-band	*B*-band	*I*-band
	Bulge/Disk decomp.	(Simien & de Vaucouleurs)	Bulge/disk decomp.
Distances	H_0=80	H_0=75	H_0=50
$M_\bullet / M_{bulge}$	0.6%	0.03%	0.25%



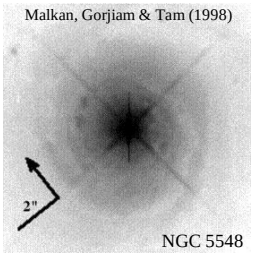
BH Demographics in Local AGNs (cont'd)



$M_{BH}/M_{bulge} \sim 0.2\%$

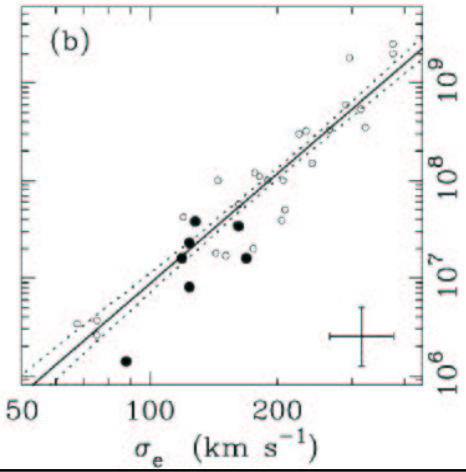
in agreement with the value determined for local quiescent galaxies (Merritt & Ferrarese 2001a, Merritt & Ferrarese (2001b, astro-ph/0107134)

Testing Reverberation Mapping Masses



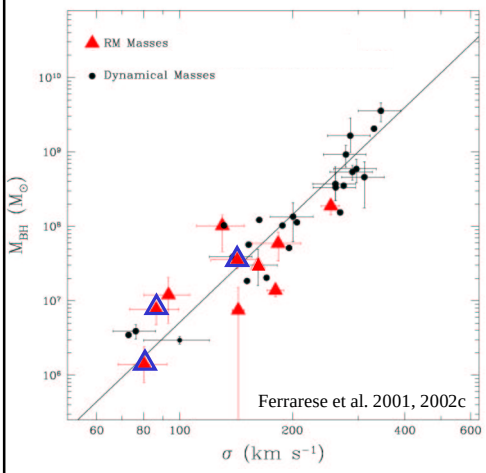
Challenge: The stellar continuum will be severely diluted by the non-thermal nuclear emission: only one reverberation mapped galaxy has a measurement of σ accurate to 30% (*Nelson & Whittle, 1995*)

Gebhardt et al. 2000

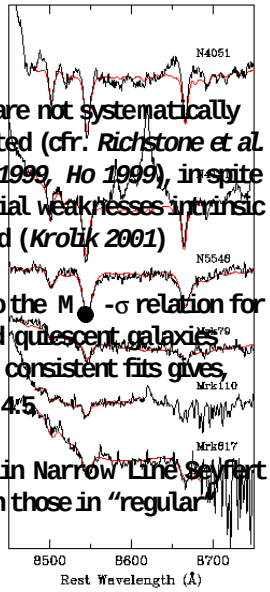


SBH Demographics in Local AGNs

KPNO/4m + Gemini: On-going program to measure σ for all reverberation mapped galaxies (*Ferrarese, Pogge, Peterson, Merritt, Wandel & Joseph 2001*)



- RM masses are not systematically underestimated (cfr. *Richstone et al. 1998, Faber 1999, Ho 1999*), in spite of the potential weaknesses intrinsic to the method (*Krolik 2001*)
- Linear fits to the $M_\bullet$-σ relation for the AGN and quiescent galaxies samples give consistent fits gives, with slope ≈ 4.5
- SBH masses in Narrow Line Seyfert 1s agree with those in "regular" Seyferts.



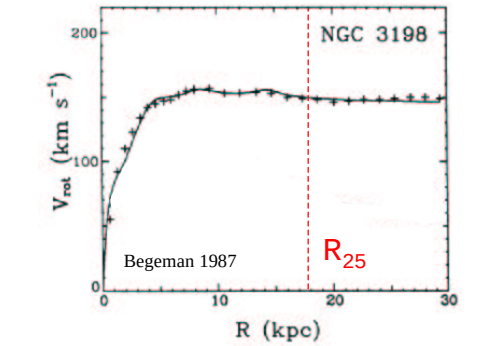
Wish list: move to larger redshifts, very small or very large $M_\bullet$

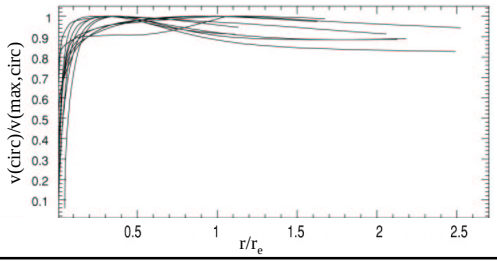
Beyond the Bulge: the Dark Side of Galaxies

Most self-regulating models of SBH formation link $M_\bullet$ to the total gravitational mass of the host galaxy or to the mass of the dark matter halo, rather than to the mass of the bulge (e.g. Loeb & Rasio 1994, Haehenlt, Natarajan & Rees 1998, Silk & Rees 1998, Haehnelt & Kauffmann 2000, Adamns, Graff & Richstone 2000).

Is the $M_\bullet$-σ relation the fundamental reflection of the processes that lead to the formation of SBHs? Could $M_\bullet$ be controlled by the total gravitation mass of the host galaxy?

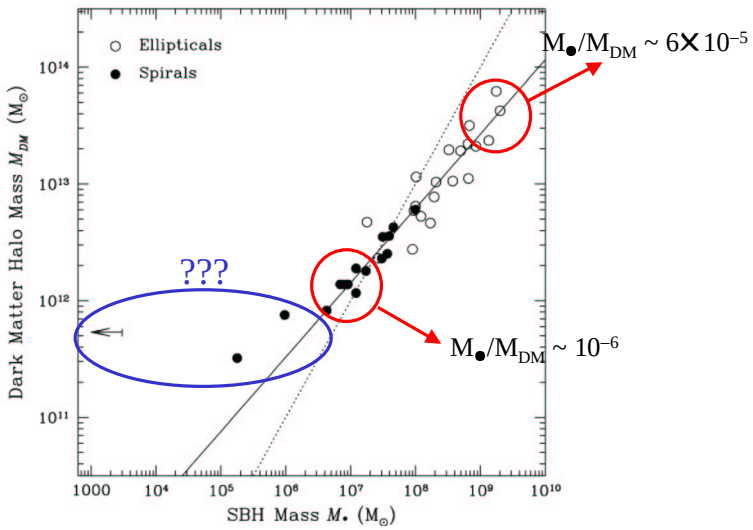
Mass Tracers





- Spiral Galaxies: circular velocity of the cold disk component: 15 objects with HI or optical rotation curves extending beyond R_{25} (e.g. Begeman 1987, Broeils 1992,...)
- Elliptical Galaxies: circular velocity derived from dynamical modeling: 20 objects (Kronawitter et al. 2000)

The v_c - σ Relation



$$\frac{M_\bullet}{10^8 M_\S} \sim 0.046 \left(\frac{M_{DM}}{10^{12} M_\S} \right)^{1.57}$$

Conclusions

1. Measuring SBHs masses in AGNs is important to 1) constrain models of formation and evolution for different classes of active nuclei and 2) better characterize the demography of SBHs both in the local universe and at high redshifts.

2. Precise estimates of the bulge velocity dispersions in 10 reverberation mapped Seyfert 1 galaxies show their SBHs have masses consistent with those found in local quiescent galaxies.

3. Preliminary results indicate that narrow line Seyfert 1s do not seem to contain undemassive SBHs compared to regular Seyfert 1s.

4. A new, non-linear relation is found between the masses of SBHs and the total mass of the dark matter halos in which they have likely formed. Halos become increasingly less efficient in forming SBHs as their mass decreases. Indeed halos $< 10^{12}$ $M_{\odot}$ might loose their ability to form SBH. The relation might provide a good fit to the QSO luminsoity function for a QSO lifetime ~ t_{Salp}