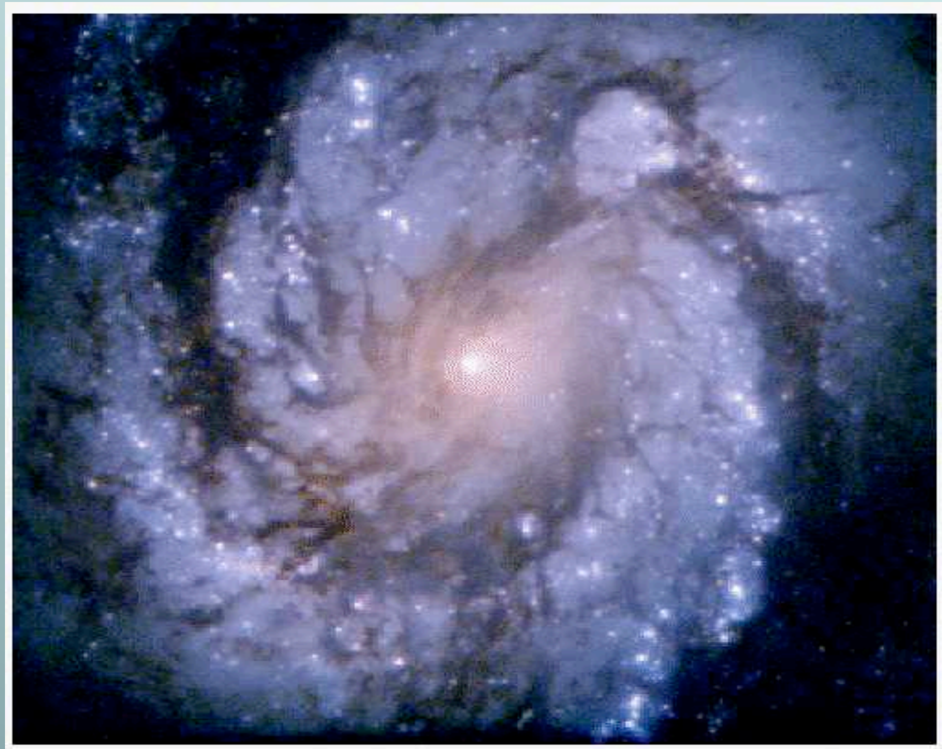
Black Hole – host relationship and NLS1 galaxies



NLS1 Milano 2011

Amri Wandel
Hebrew University of Jerusalem

Black Hole vs. bulge in Active Galaxies

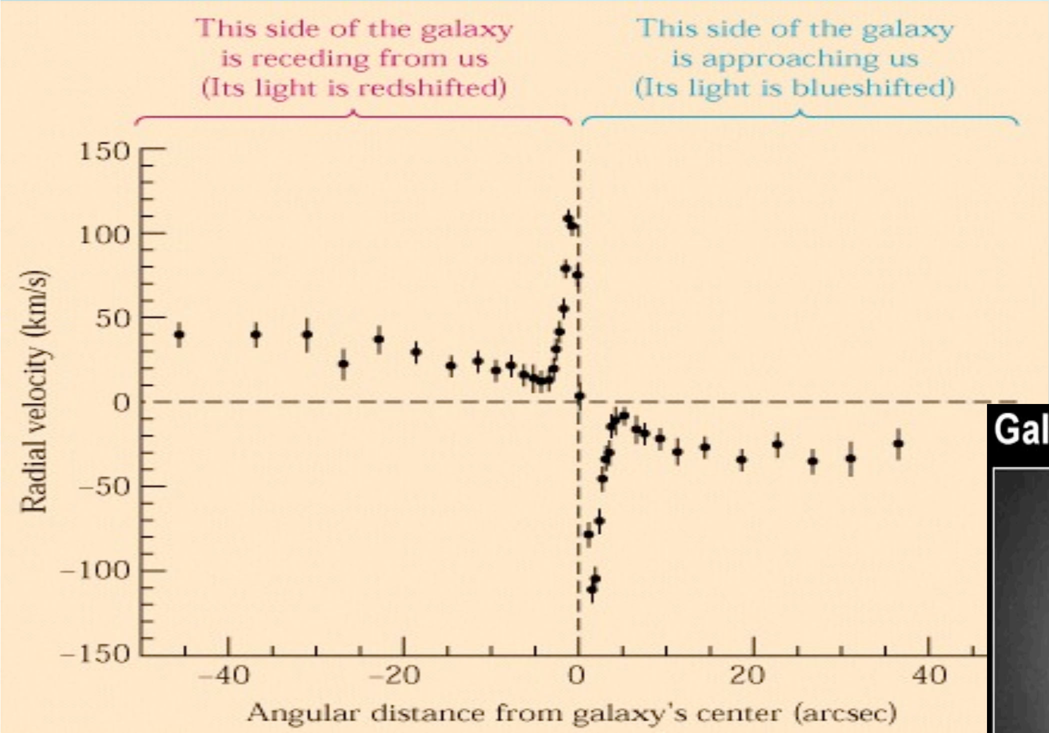
- **BH/bulge relationship -quiescent & active galaxies**
- **M_{BH} from gas dynamics vs. stellar dynamics**
- **Do NLS1 have lower BH/bulge ratios?**
- **Where are they in M_{BH}-σ^* plane?**

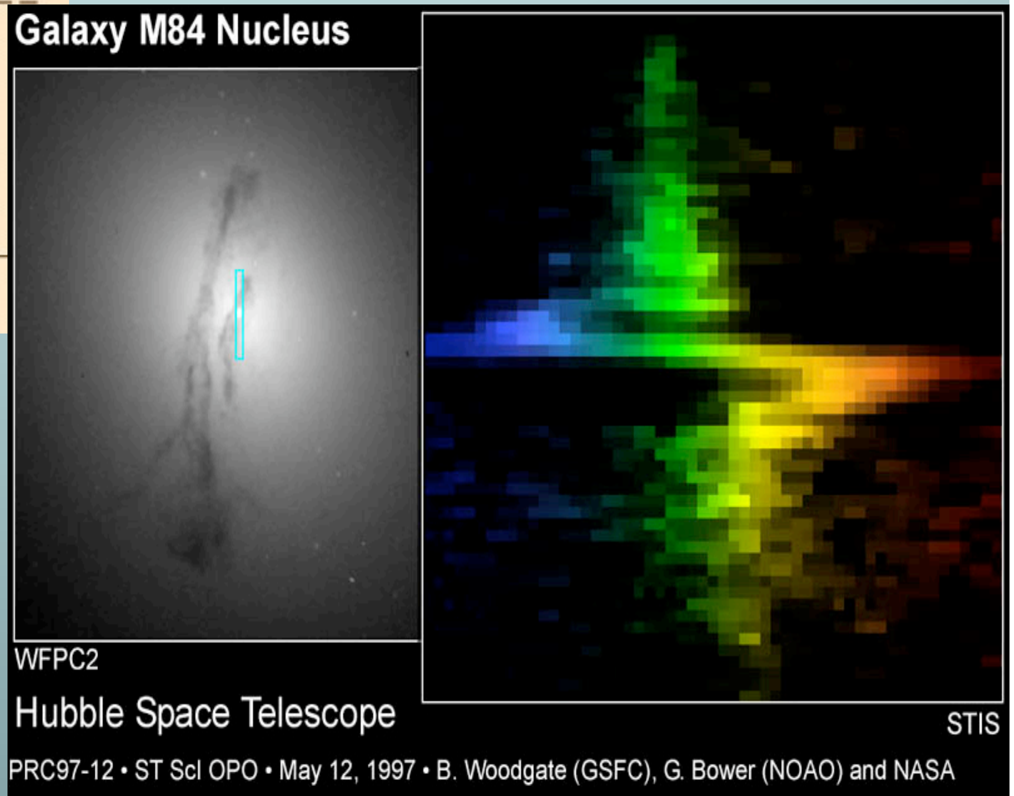
History of M_{BH}/bulge ratio of NLS1

- Steep soft X-ray excess of NLS1 => accretion disk spectrum of **lower BH mass** (Wandel & Boller 1997)
- M_{BH}-L_{BLG} relation in quiescent galaxies (Maggorian+1997)
- **Compare with AGN - Seyfert 1s** have a **lower M_{BH}/L_{BLG}** ratio than quasars and quiescent galaxies (Wandel 1999)
- **AGN – same** M_{BH}-L_{BLG} as quiescent galaxies
  (Wandel 2002, McLure & Dunlop 2002)
- **NLS1**s and NLQ have M_{BH}/bulge by **factor 10 lower** than BL AGN & quiescent galaxies, (Mathur+2001, Wandel 2002)
- **New M_{BH}/bulge relationships** in AGN:

  $L_{AGN} \sim L_{blg}^2$, $M_{bh}/M_{blg} \sim FWHM(H_\beta)^2$… (Wandel 2002, 2009)

MBH in quiescent galaxies

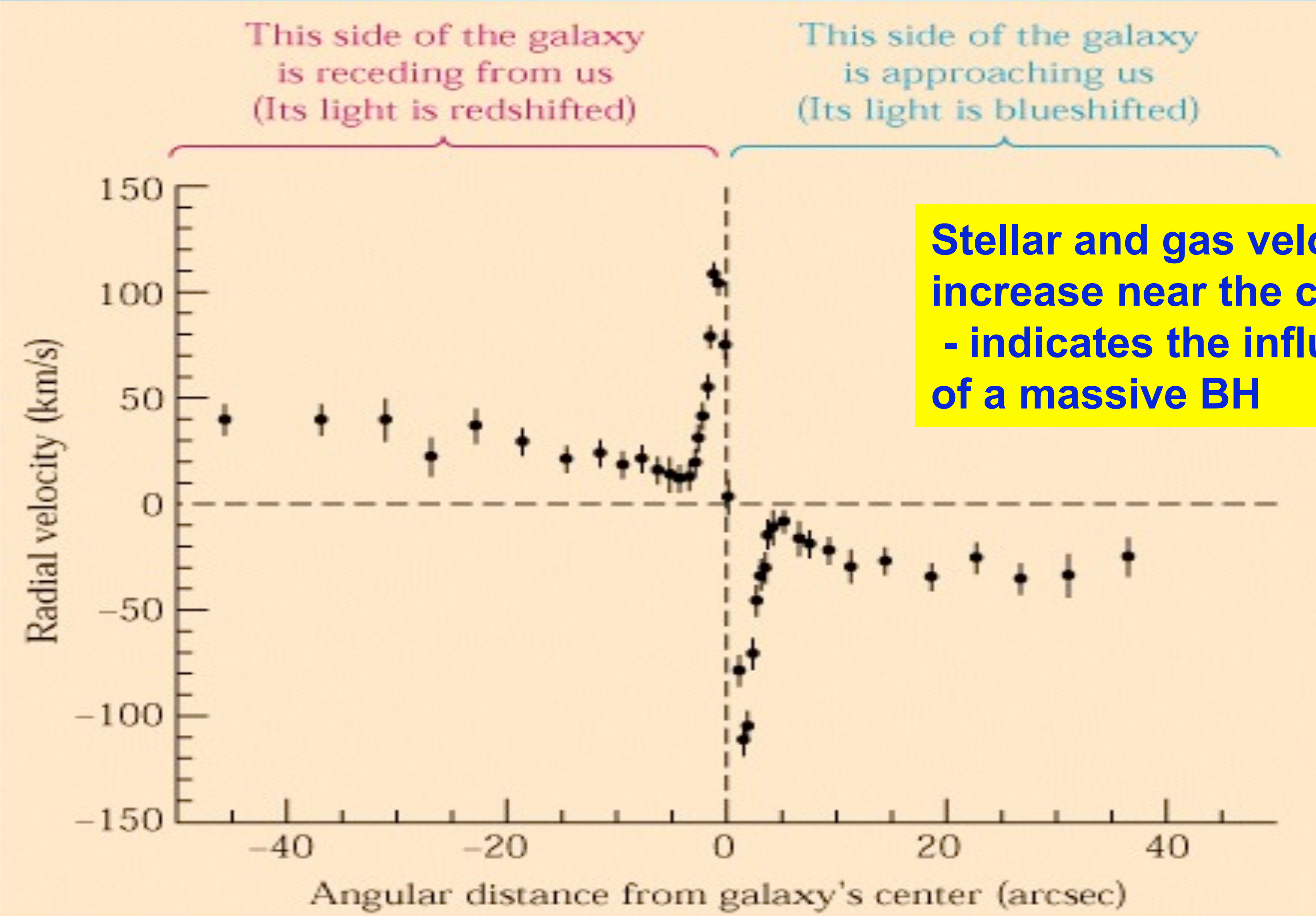




Stellar and gas velocity increase near the center

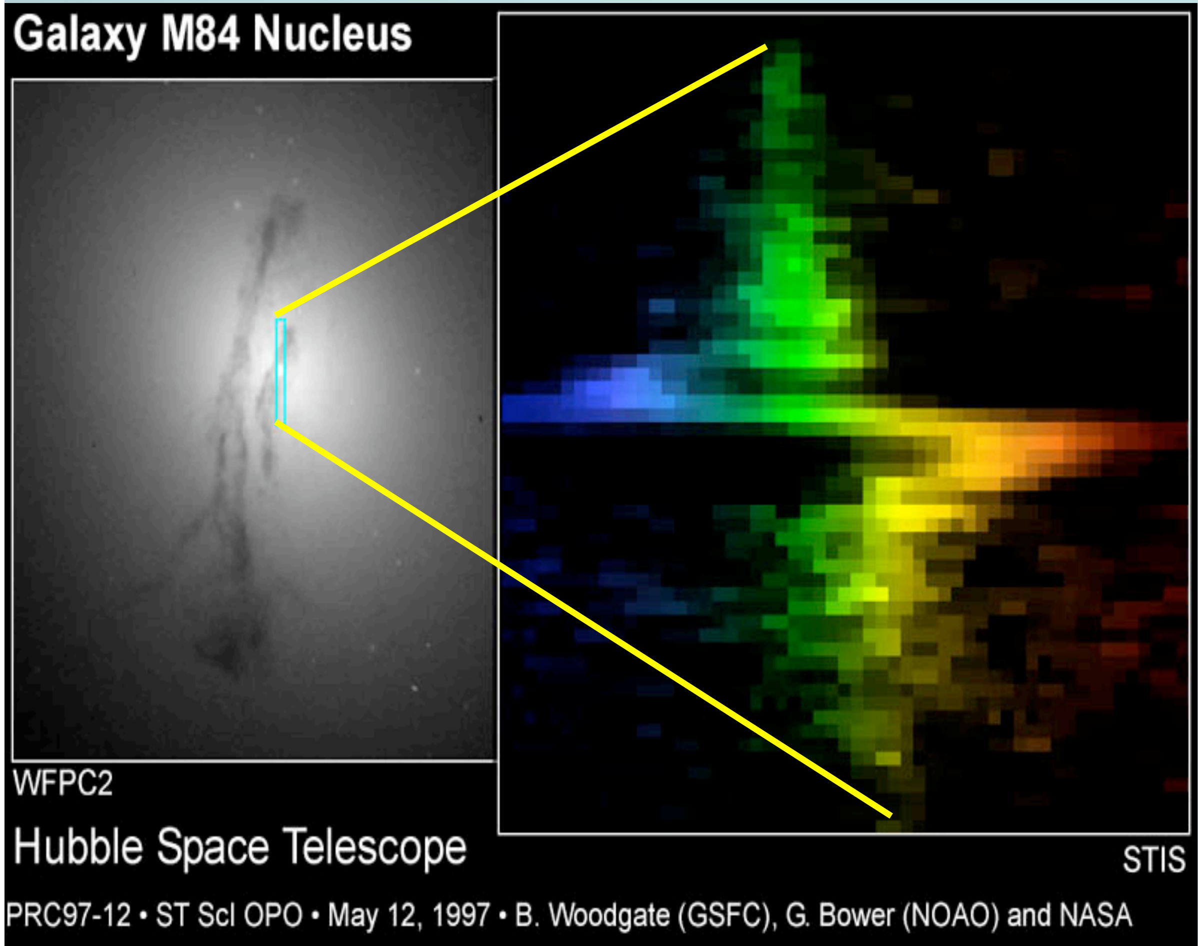
- indicates the influence of a massive BH

Massive BHs in quiescent galaxies



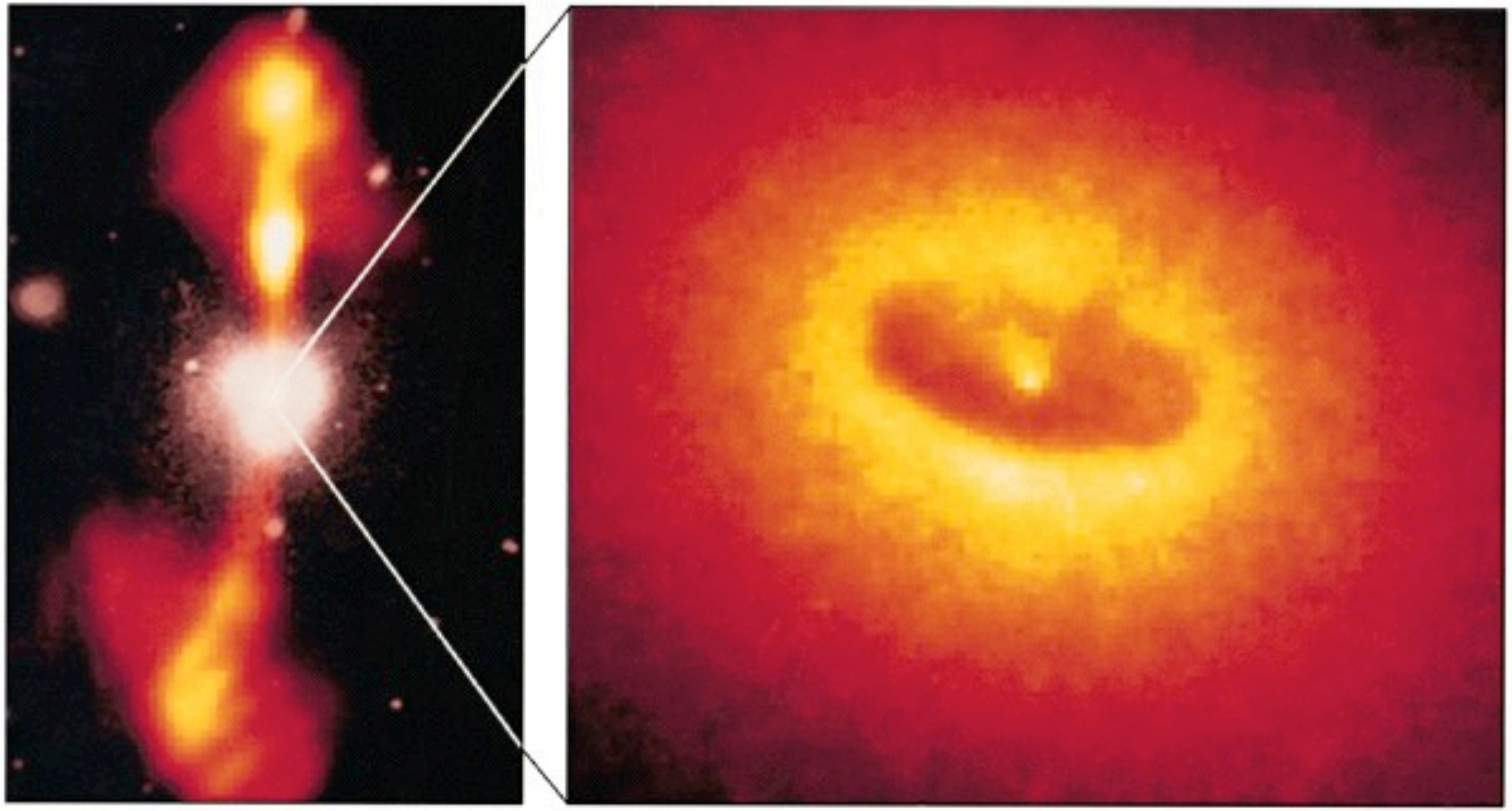
Stellar and gas velocity increase near the center - indicates the influence of a massive BH

A Massive Black Hole in the center of M84

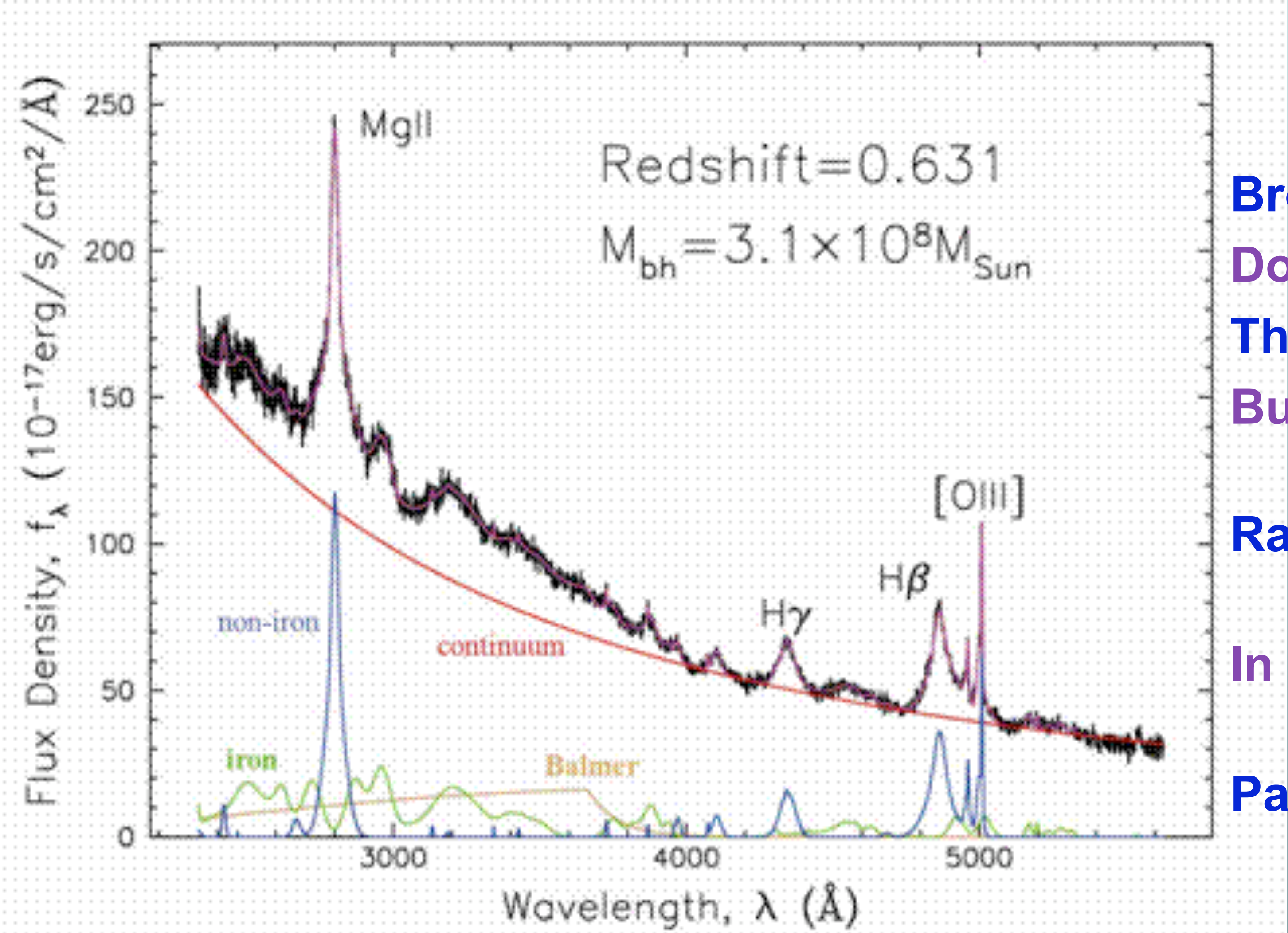


- ***Material flowing into a black hole forms a gas disk***
- ***Doppler effect measures gas moving in a disk at nearly 400 km/s within 26 light years of the center of M84***
- ***The central velocity increase provides a "signature" of the black hole's presence.***

Jets and disks in active galaxies

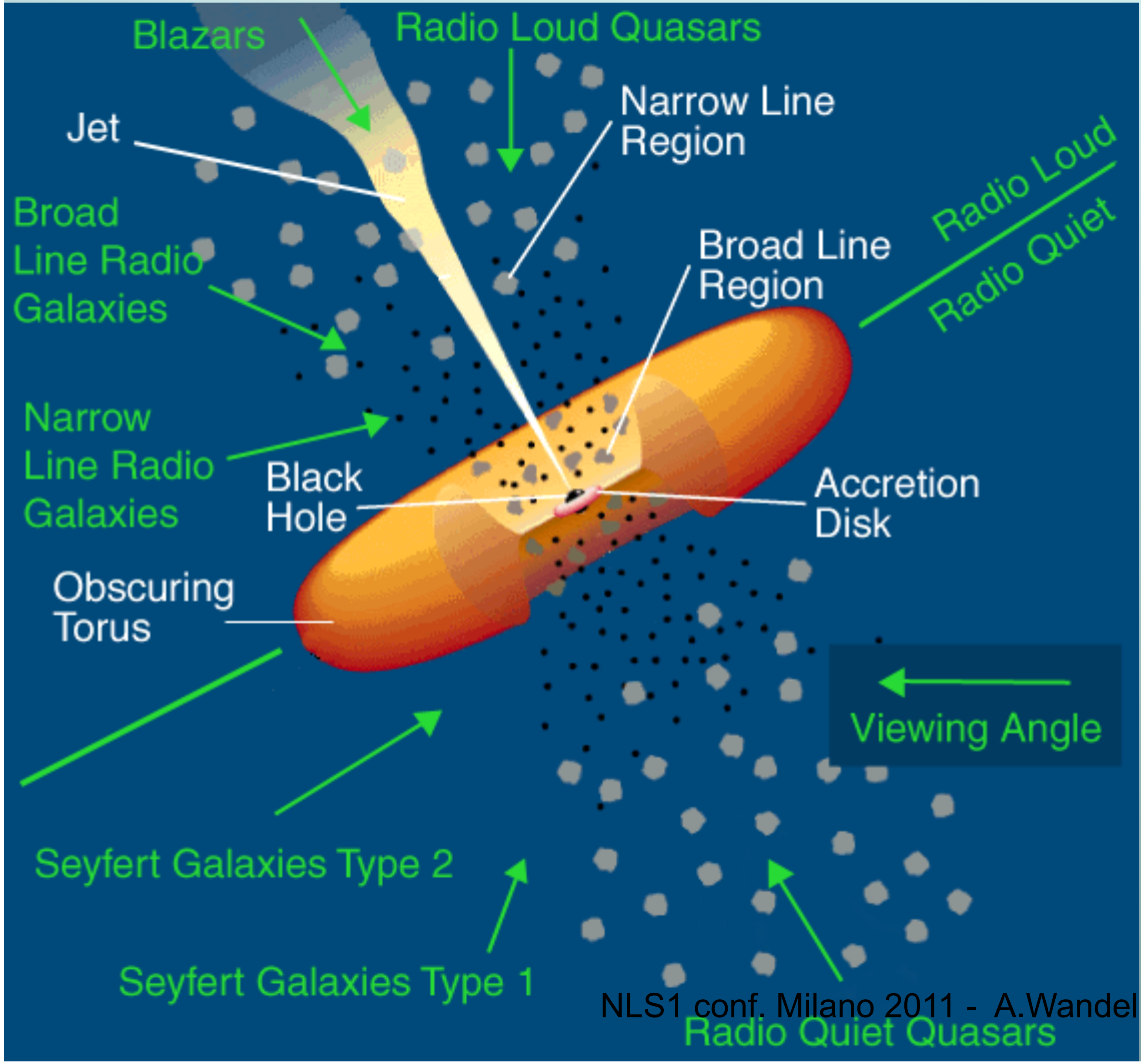


Emission line spectrum of AGN



- Broad emission-lines
- Doppler broadened
- Thousands of km/s
- Bulk motion (cannot be thermal)
- Random motions of many clouds
- In the gravitational well of central BH
- Partially ionized by central continuum

Broad emission-line clouds



Massive central BH

Accretion disk

Broad Line Region

BLR size ~ 0.01-0.3pc

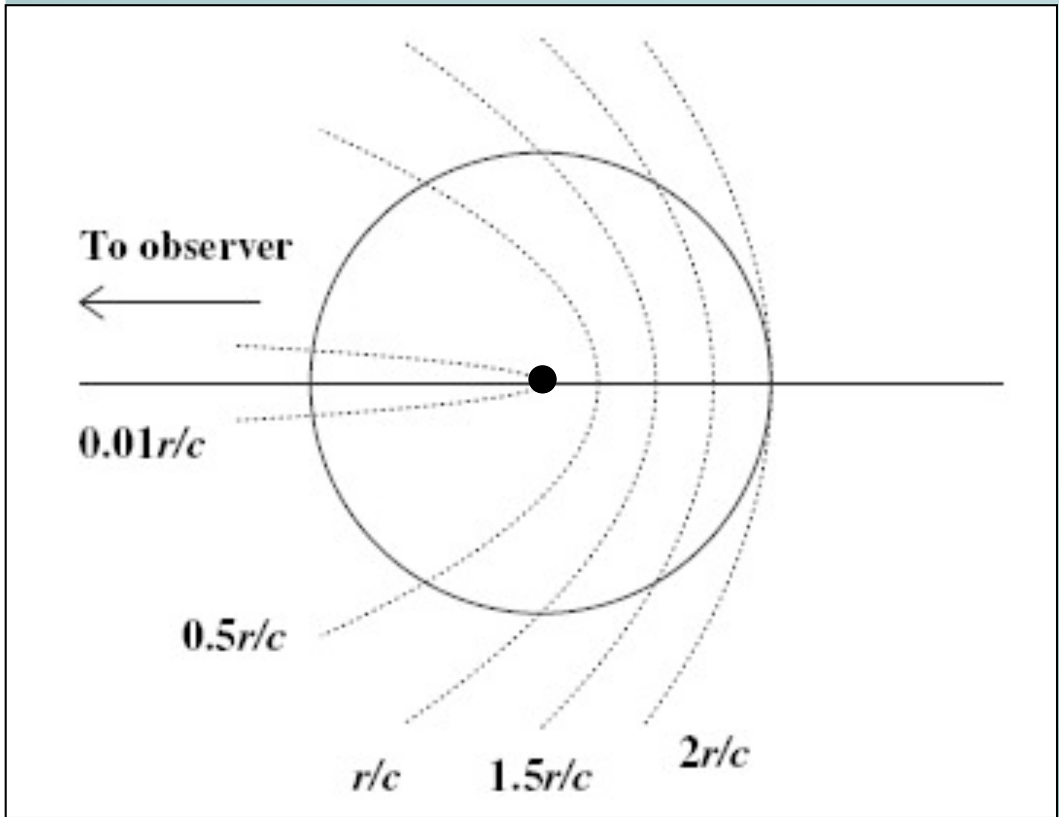
Obscuring torus

Narrow Line Region

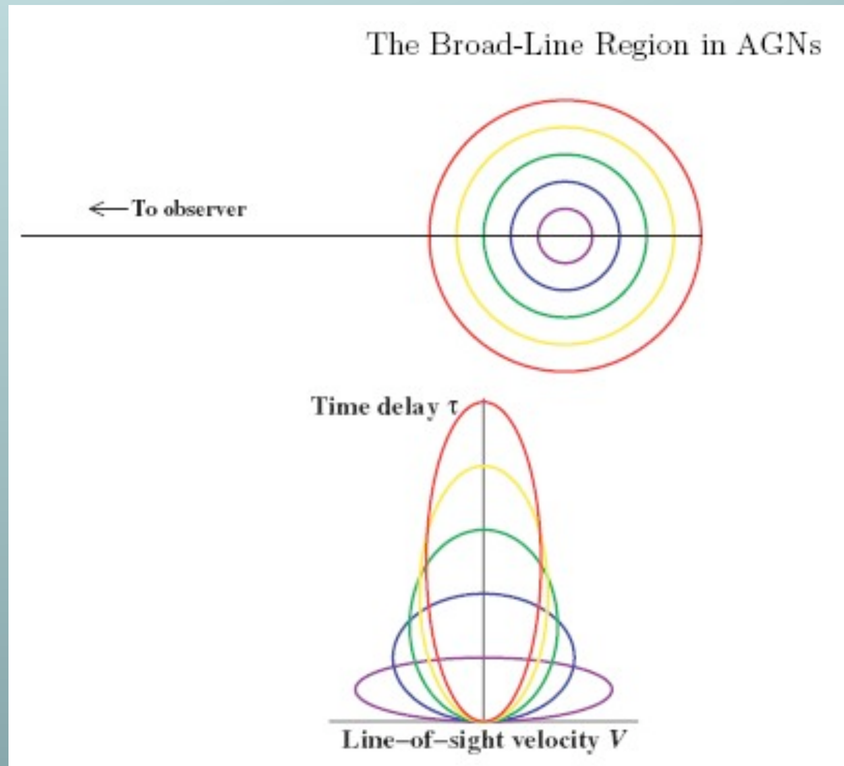
NLR size ~ 3-100pc

Reverberation Mapping geometry

Equal time-delay surfaces



Delay vs. v for spherical shells



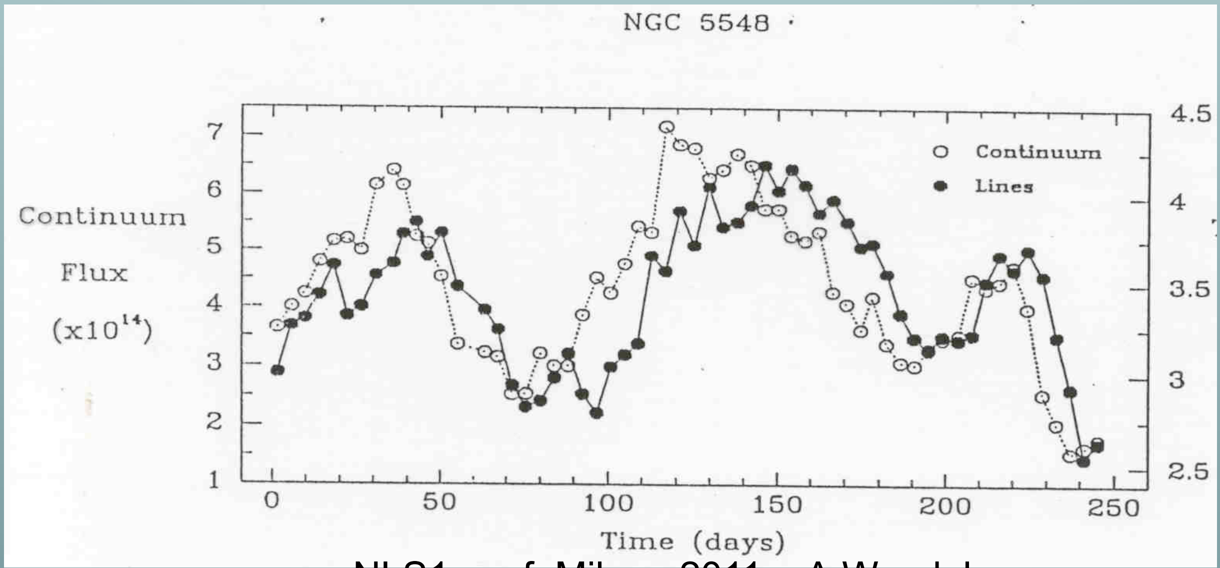
Reverberation Mapping: estimating Black Hole masses in AGN

Light-echo from gas in Broad emission Line Region

Time delay of line variations easures the distance of emitting gas from the central source

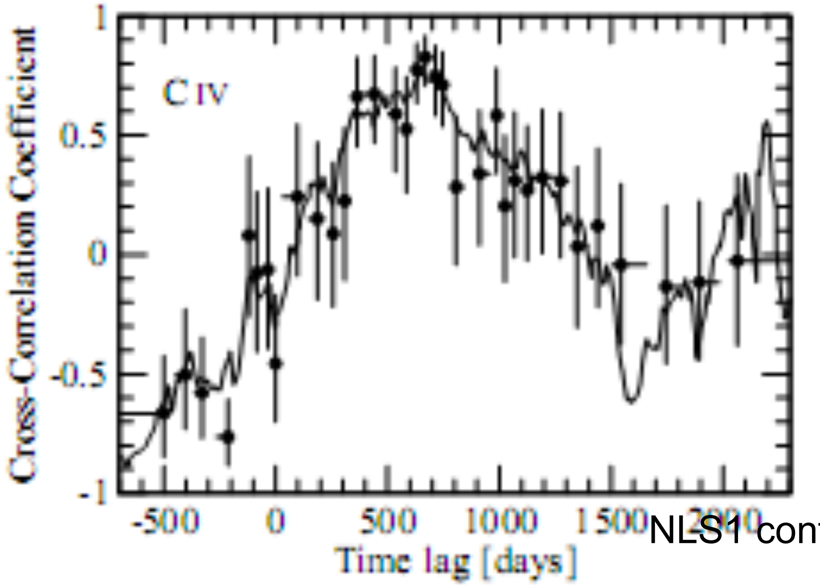
Doppler line broadening measures velocity

Is the gas gravitationally bound? If so $v^2 \sim fGM/r$



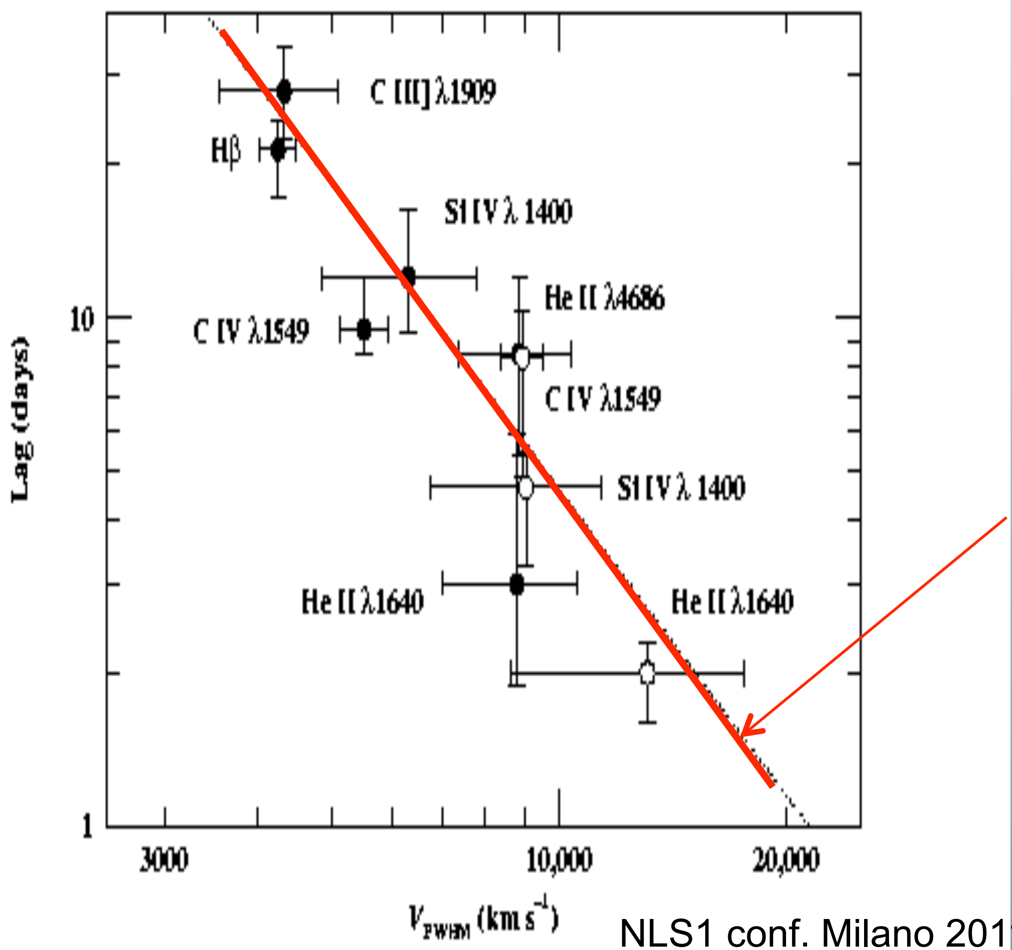
Reverberation Mapping: mathematical formalism

- Line –continuum light curve relation (McKee &Blandford 1982)
- $L(v,t)= \int \Psi(v,t-\tau)\, C(\tau)\, d\tau$, Ψ is the transfer function
- Time delay deined as the centroid of the cross-correlation function $CCF(\tau)=\Sigma\, C(t)(L(t+\tau)$
- BH mass estimated from the virial relation : $M=fG^{-1}v^2R_{blr}$



Kepplerian signature of a Black Hole in AGN

Peterson & Wandel ApJL1999



Reverberation mapping of broad emission-line region in **NGC 5548.**

Different lines show different time lags (r) and different widths (v)

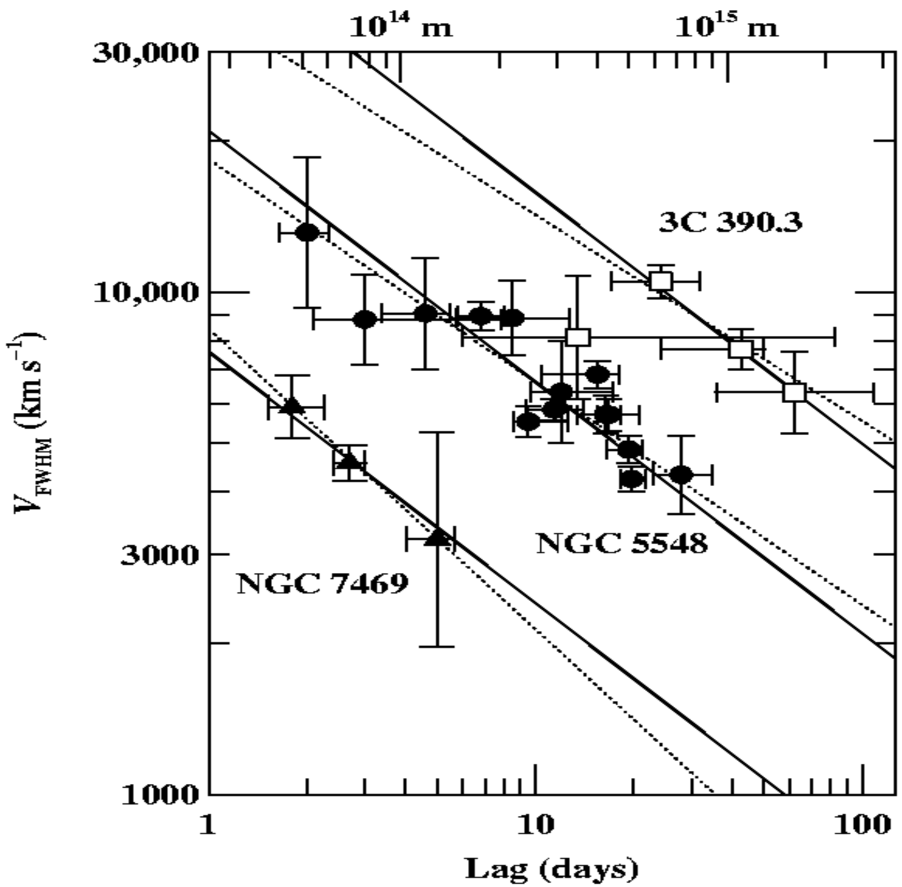
Radius-velocity relation for different lines : $\boldsymbol{v \sim r^{-1/2}}$

Radial range: 2-30 light days (250-4000 Rs)

Strongest case for central BH in AGN

Black Hole Signatures in AGN

Peterson & Wandel ApJL 2000



- **Multiple line mapping in three Seyfert galaxies**

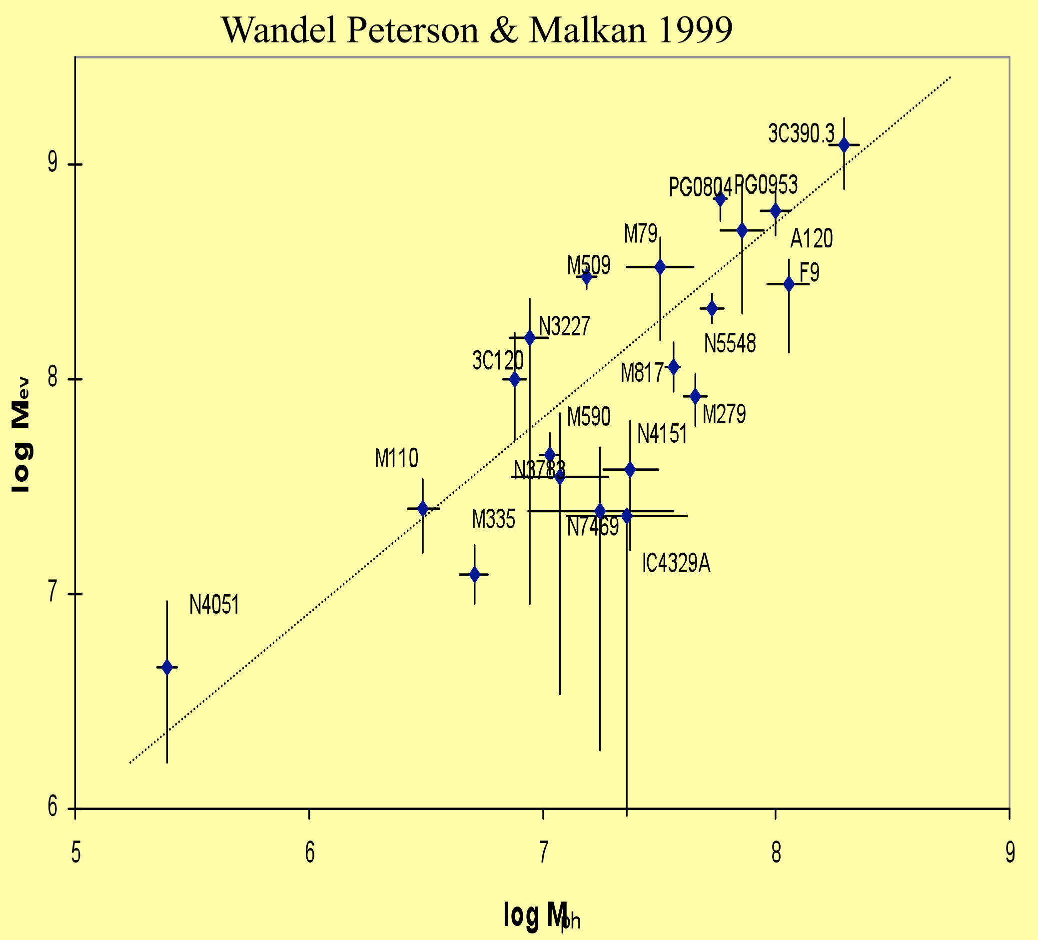
BH mass range:

NGC 7469: $8x10^6$ Mo

NGC 5548: $7x10^7$ Mo

3C 390.3: $3x10^8$ Mo

The Photoionization vs. reverberation Black Hole mass in AGN



Reverb. mapping from multi-year campaigns for 17 Seyfert galaxies (Wandel Peterson & Malkan 1999)

calibrate an *empirical photoionization vs. reverberation Mass* relationship

Added 18 quasars (Kaspi et al. 2000;2005)

calibrate an *empirical delay-luminosity* relation $\tau \sim L^{0.5}$

Then estimate BH mass

$M \sim FWHM^2 L^{0.5}$

The empirical BLR size vs. continuum Luminosity relation in AGN

- The Hβ BLR radius in AGN scales as the $L^{0.5\text{-}0.7}$ (Kaspi et al. 2001;2005)
- Similar scaling CIV BLR radius (Vestergaard &Peterson 2006)
- The ionization-parameter theory (Wandel 1987;1999;2009)

$$\xi = L / 4\pi R^2 n \varepsilon c$$

- Optimally local emission: line emissivity peaks sharply at definite values of the ionization parameter and density (Korista et al 1998) $\xi \sim n^{-1}$ contours giving
- $R_{blr} \sim L^{0.5}$

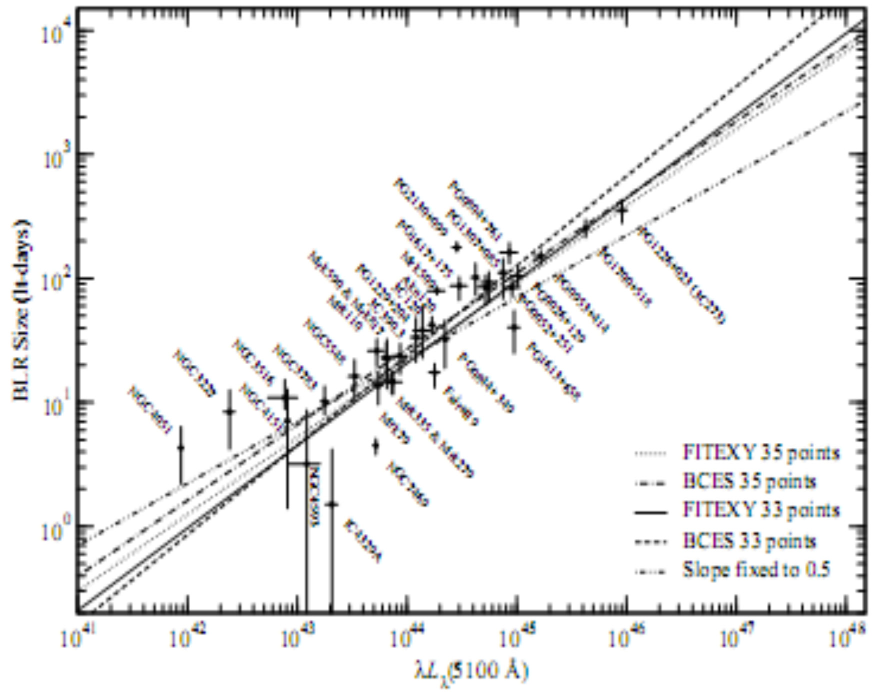
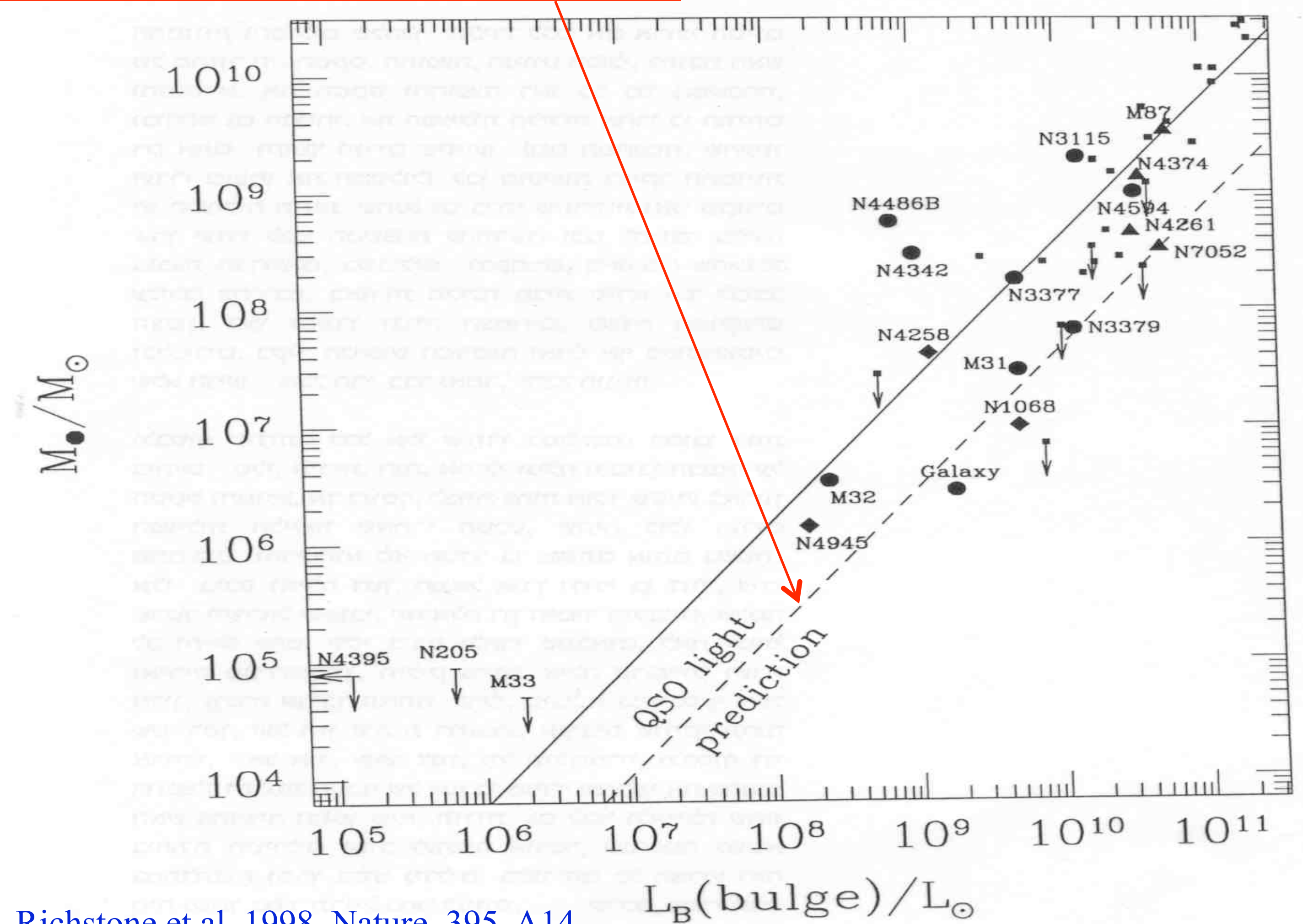


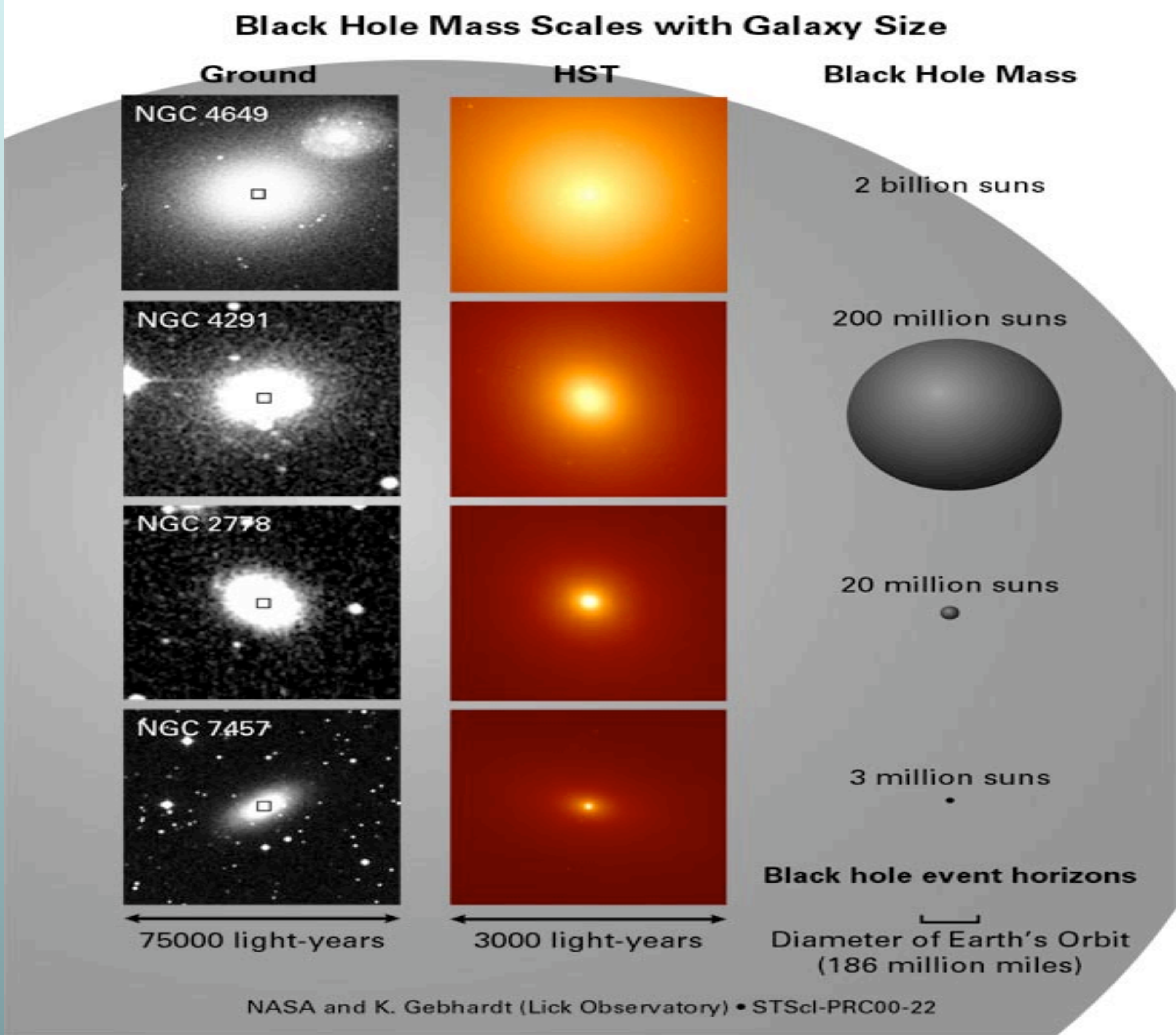
Figure 1. Balmer-line BLR size plotted versus the λL_λ(5100 Å) luminosity (in units of ergs^{-1}). The BLR size of each data set is determined from the averaged Balmer-line time lags. Objects with multiple data sets have been averaged to one point per object. See Kaspi et al. (2005) for further details.

BH Mass -bulge relationship for quiescent galaxies

$$\rho = \varepsilon^{-1} \int \int \Phi(L,z) L dL dt = 2\text{x}10^5 \text{ MoMpc}^{-3}$$



Richstone et al. 1998, Nature 395, A14

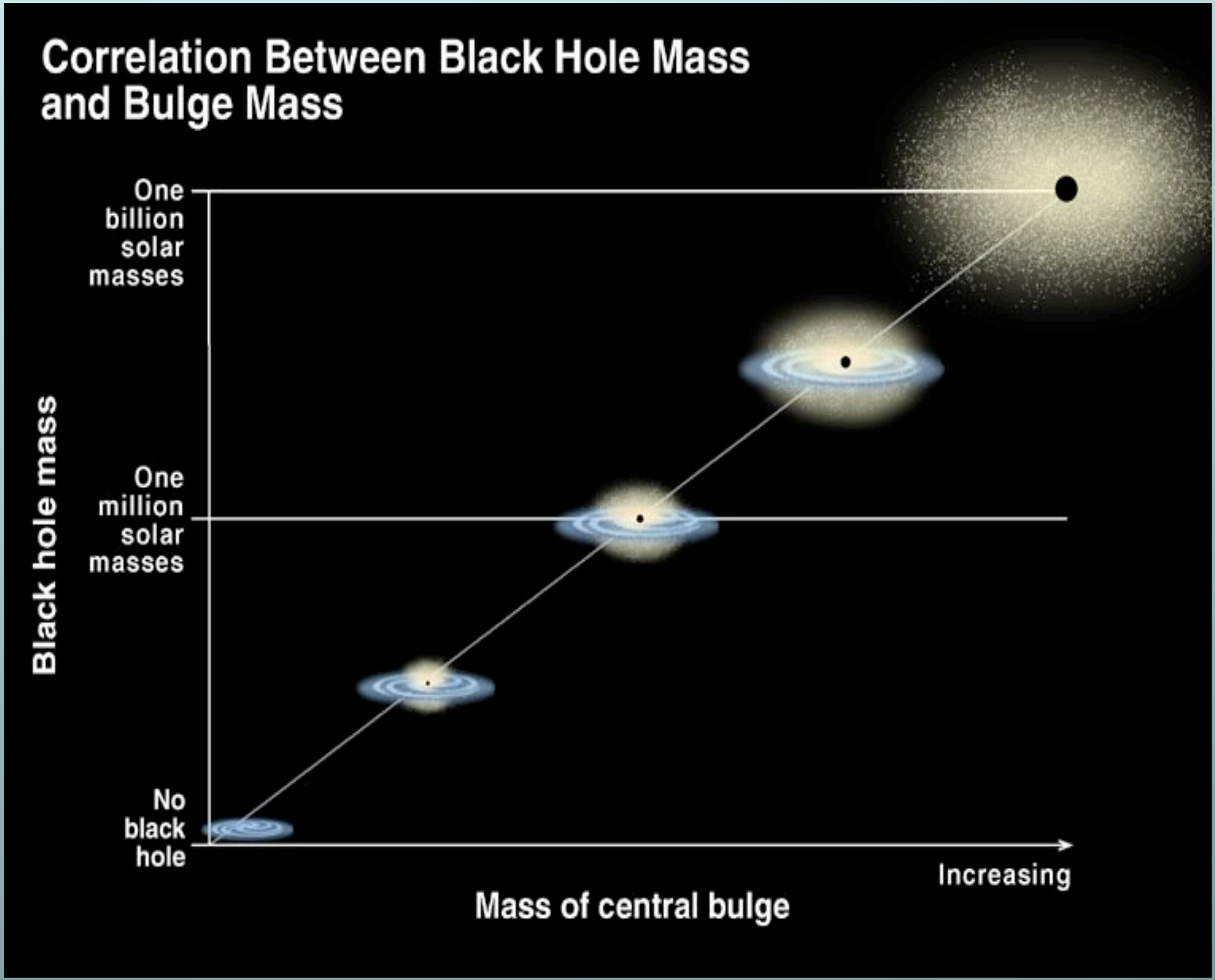

Black Hole Mass Scales with Galaxy Size
Ground
HST
Black Hole Mass
NGC 4649
2 billion suns
NGC 4291
200 million suns
NGC 2778
20 million suns
NGC 7457
3 million suns
Black hole event horizons
75000 light-years
3000 light-years
Diameter of Earth's Orbit
(186 million miles)
NASA and K. Gebhardt (Lick Observatory) • STScI-PRC00-22

The Black Hole - Host Galaxy Relation

The mass of central black holes is approximately proportional to the luminosity (and mass) of the host galaxy:

M_{bh}~(0.001-0.002) M_{bulge}

Do massive Black Holes in AGN show a similar relation?



Quasar Light estimate of BH mass

- Integrated quasar light gives density of dead BHs:

$$\rho = \varepsilon^{-1} \int\int \Phi(L,z) L dL dt = 2\text{x}10^5 \text{ MoMpc}^{-3}$$

- Comparing to light density of galaxies (10^8 Lo Mpc^{-3}) gives $M_{bh}/L_{gal} \sim 0.002$ Mo/Lo
- => average bright galaxy (5 10^{10} Lo) has a ~10^8 Mo BH

- "Eddington limit" M> 10^8 (L/ 10^{46} erg/s) Mo => the brightest quasars (L=10^{47} erg/s) have Mbh>10^9Mo

M_{BH}-bulge relationship in AGN

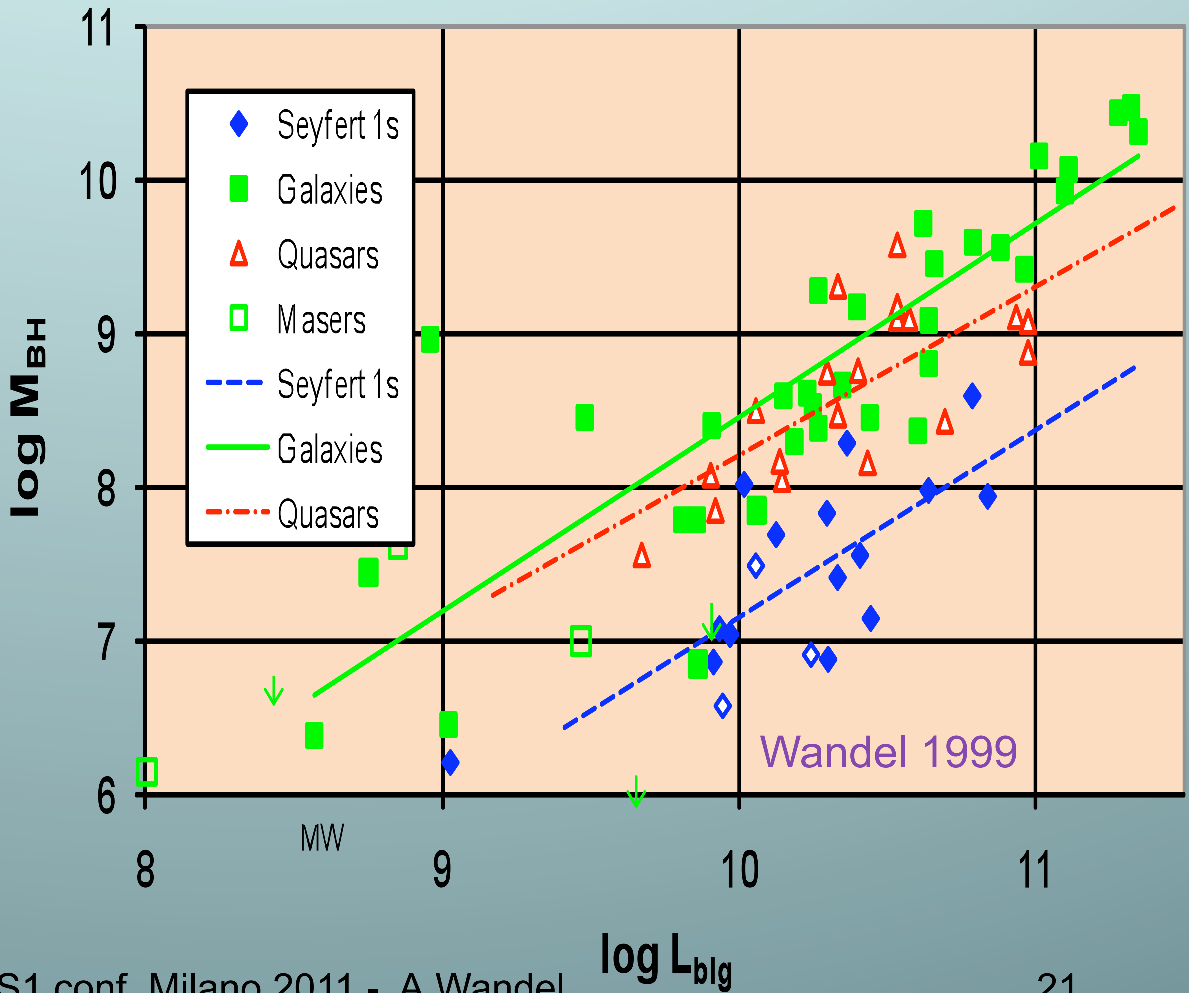
Quiescent galaxies:

M_{BH}~ 0.006 M_{bulge}
(Magorrian et al. 1997)

Quasars BH/blg similar to galaxies (Laor 1998)

Seyfert galaxies – often smaller M_{BH}/ M_{bulge} than quiescent galaxies and quasars (Wandel 1999) :

M_{BH}~ 0.0003 M_{bulge}



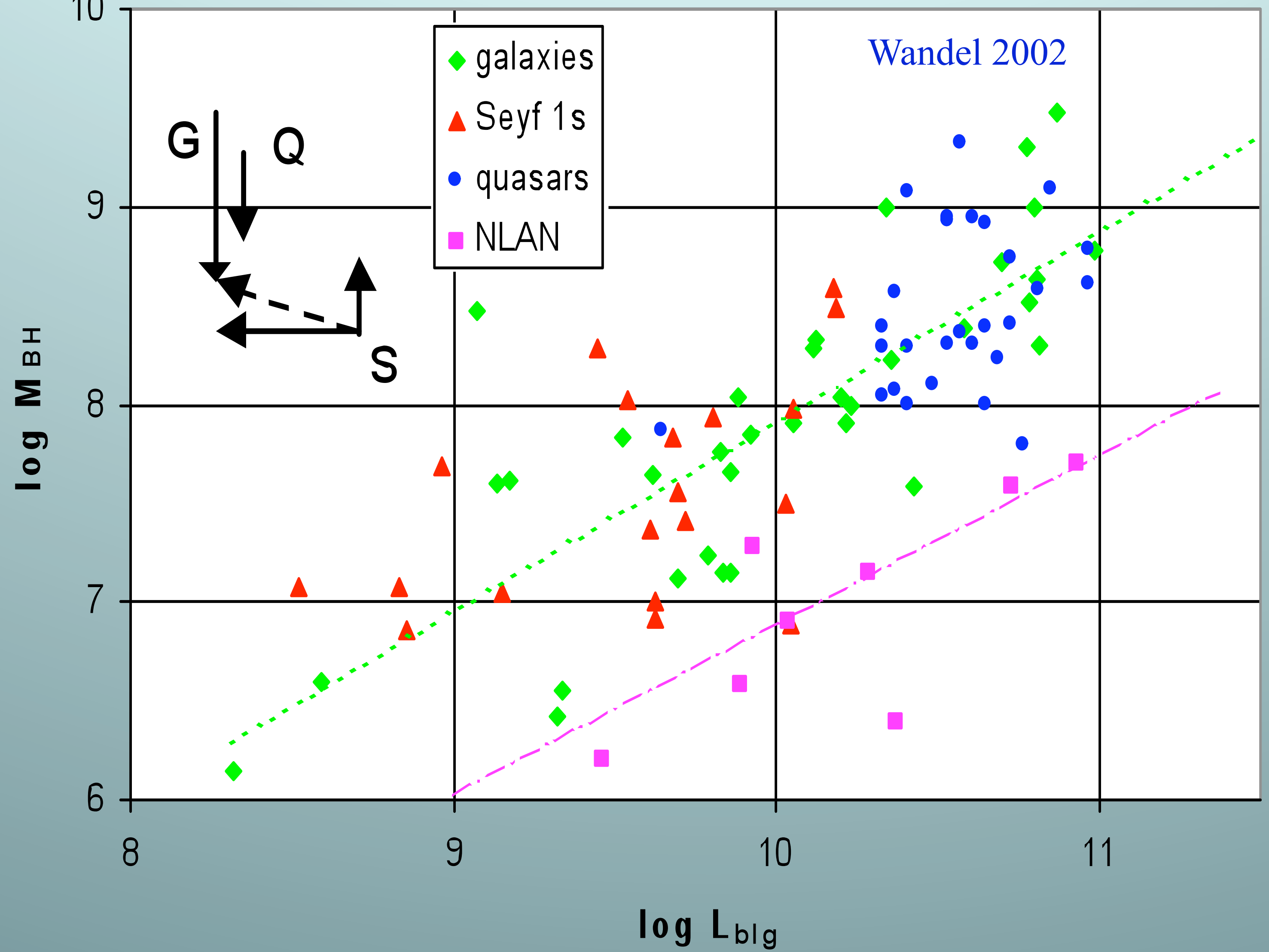
Improved data & modeling

- **Corrected BH masses for quiescent galaxies from HST data + improved modeles**
  (Kormendy & Gebhardt 2001, Merrit & Ferarrese 2001)
- **Corrected L_{bulge} for Seyfert galaxies & quasars**
  (McLure & Dunlop 2001)
- **Reverberation M_{BH} for quasars** (Kaspi et al. 2000)

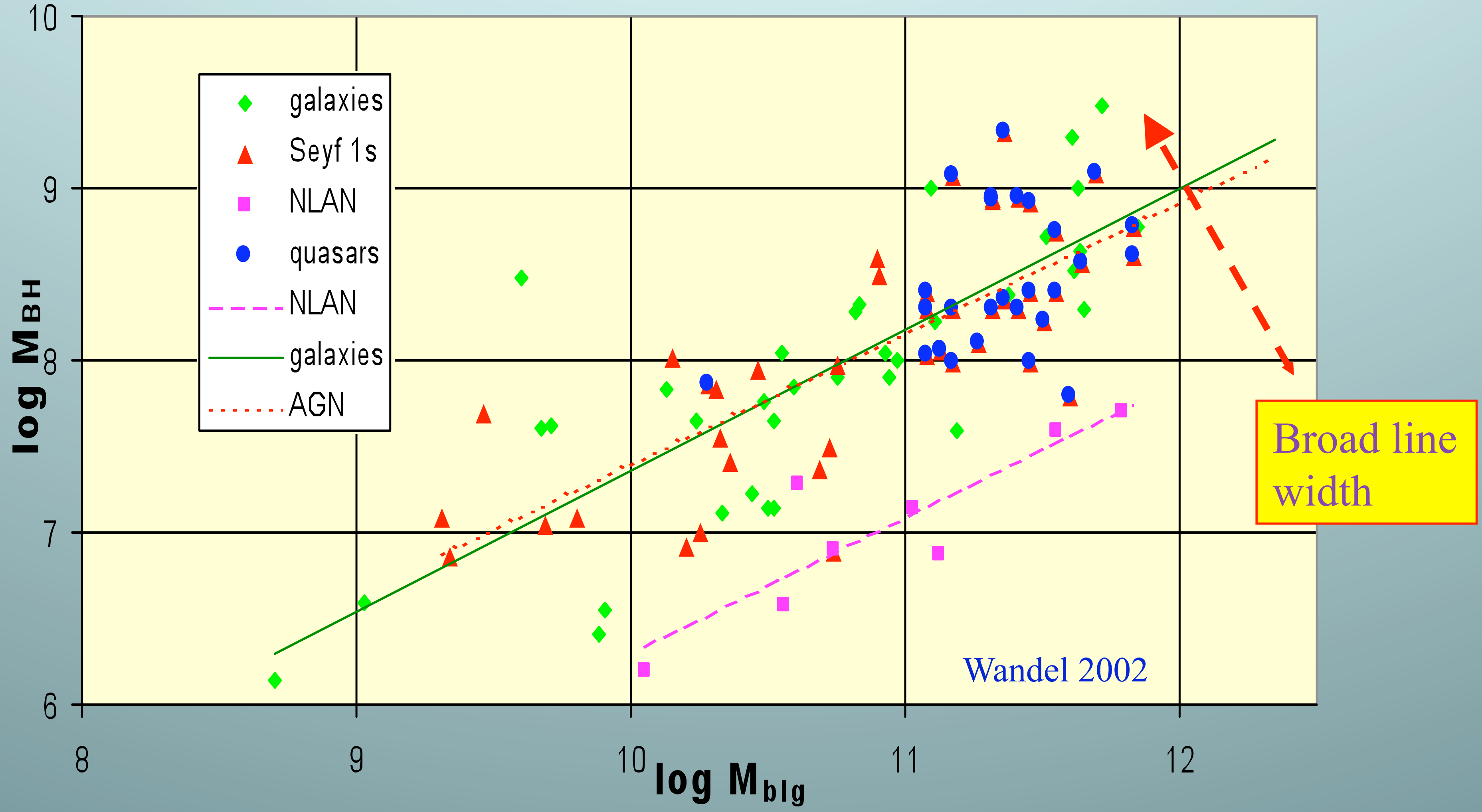
➢ **Most AGN have same BH/bulge relationship as inactive galaxies** M_{BH}/M_{blg}~0.002 (Wandel 2002)

➢ **NLSy1 galaxies have smaller M_{BH}/ M_{bulge}**
(Mathur et al. 2001, Wandel 2002)

Improved data: BLS1s & Quasars have same M_{BH}-L_{bulge} relationship as quiescent galaxies NLS1 & NLQ (NLAN) M_{BH}/L_{blg} values are ~10 lower



Mass fraction: M_{BH}/ M_{bulge} ~0.002
*Narrow Line AGN (NLAN) have **lower** M_{BH}/M_{blg} values*

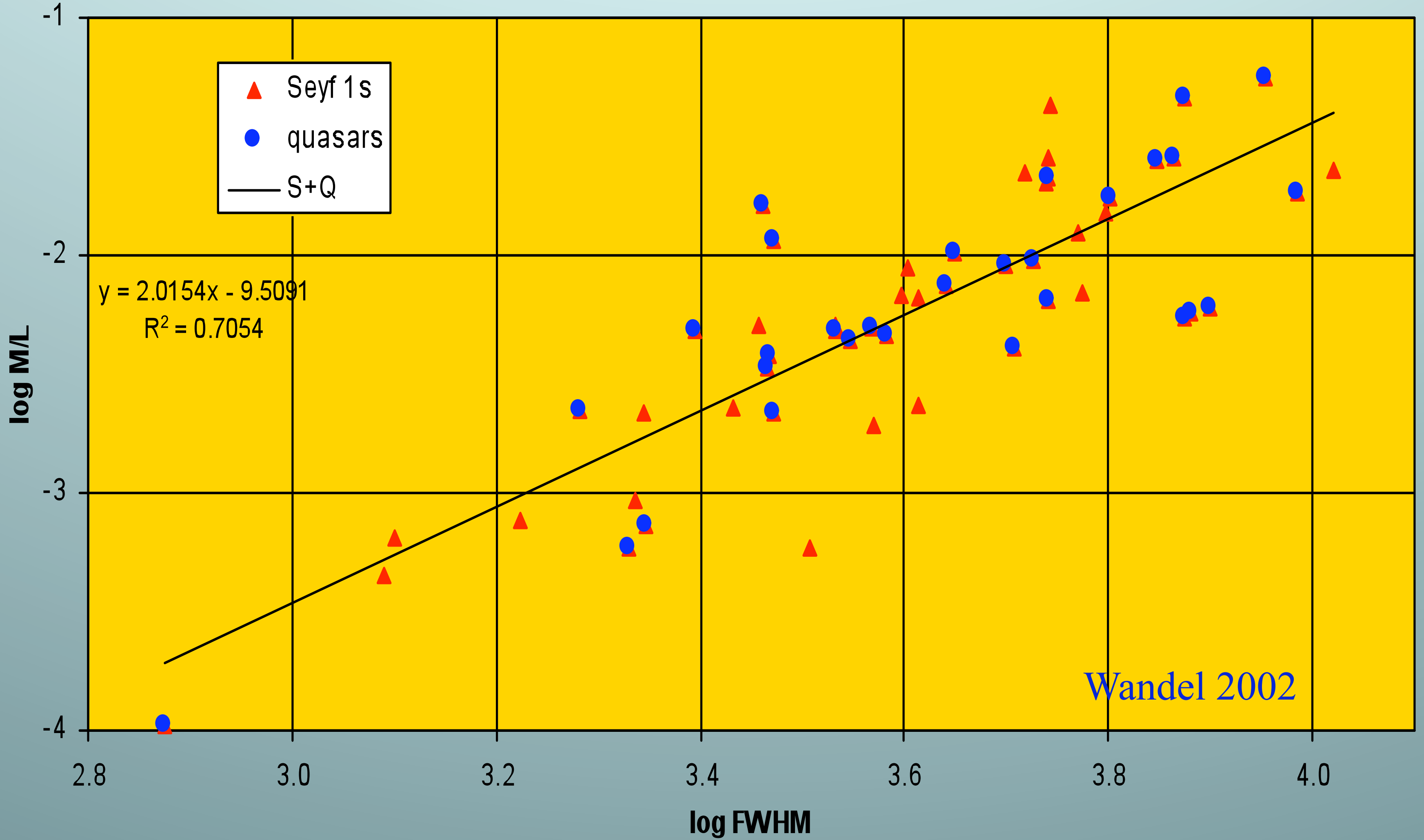


More BH-bulge relationships in AGN

- **BH/bulge ratio – broad emission line width - $M_{BH}/L_{blg} \sim v^2$`**
- **Size of Broad Emission-line Region -host bulge luminosity $R_{BLR} \sim L_{blg}$**
- **AGN luminosity - bulge luminosity $L_{AGN} \sim L_{blg}^2$**

- **These relations do not show a difference between ordinary and Narrow-line AGNs.**

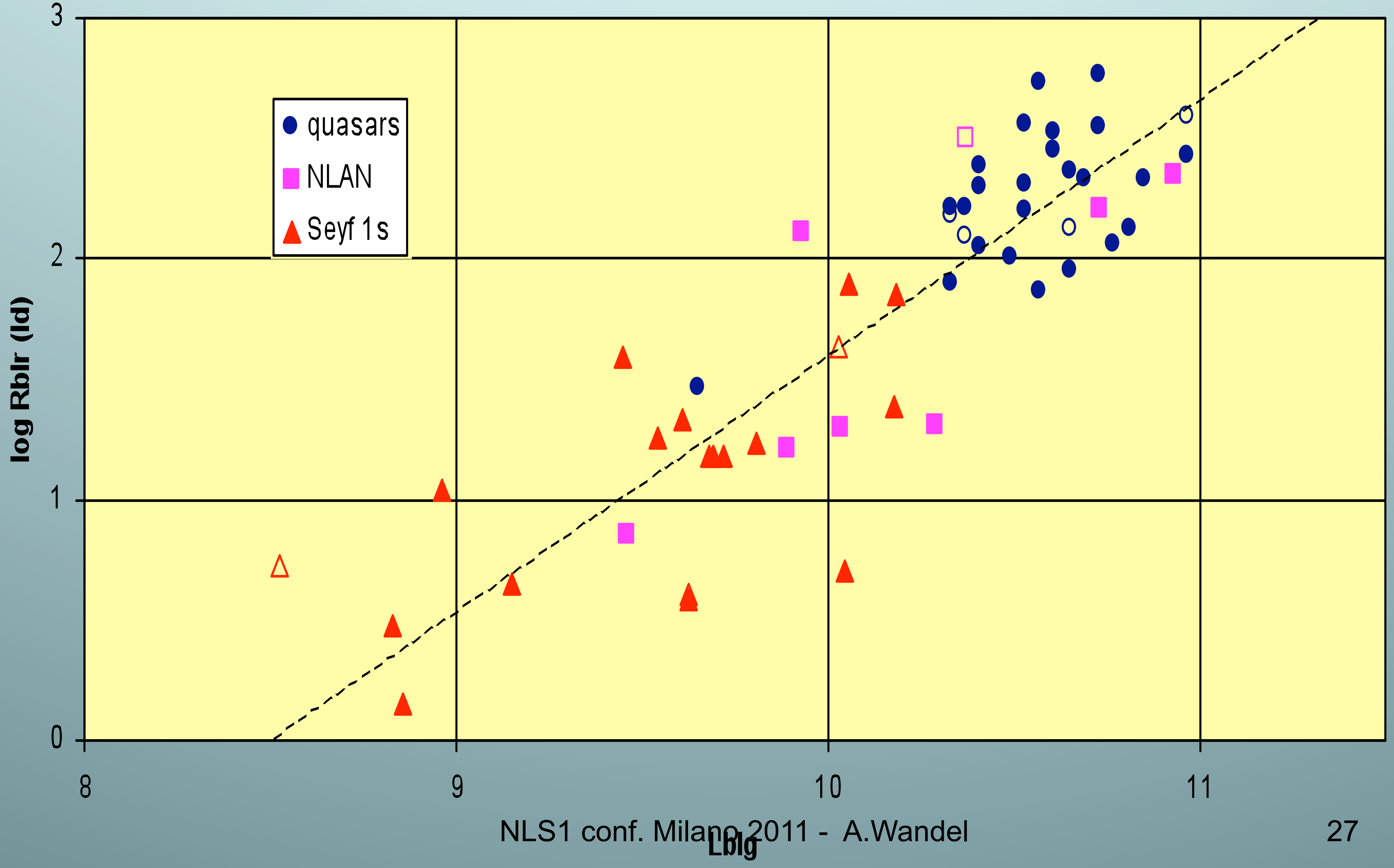
The M_{BH}/L_{bulge} ratio in AGN is correlated with the broad emission line width – indep. correlation: $M_{bh}/L_{blg} \sim v^2$



Elliminating v gives a strong independent relation:

the size of the Broad Emission-line Region in AGN scales with the host bulge R(BLR)~L_{bulge}

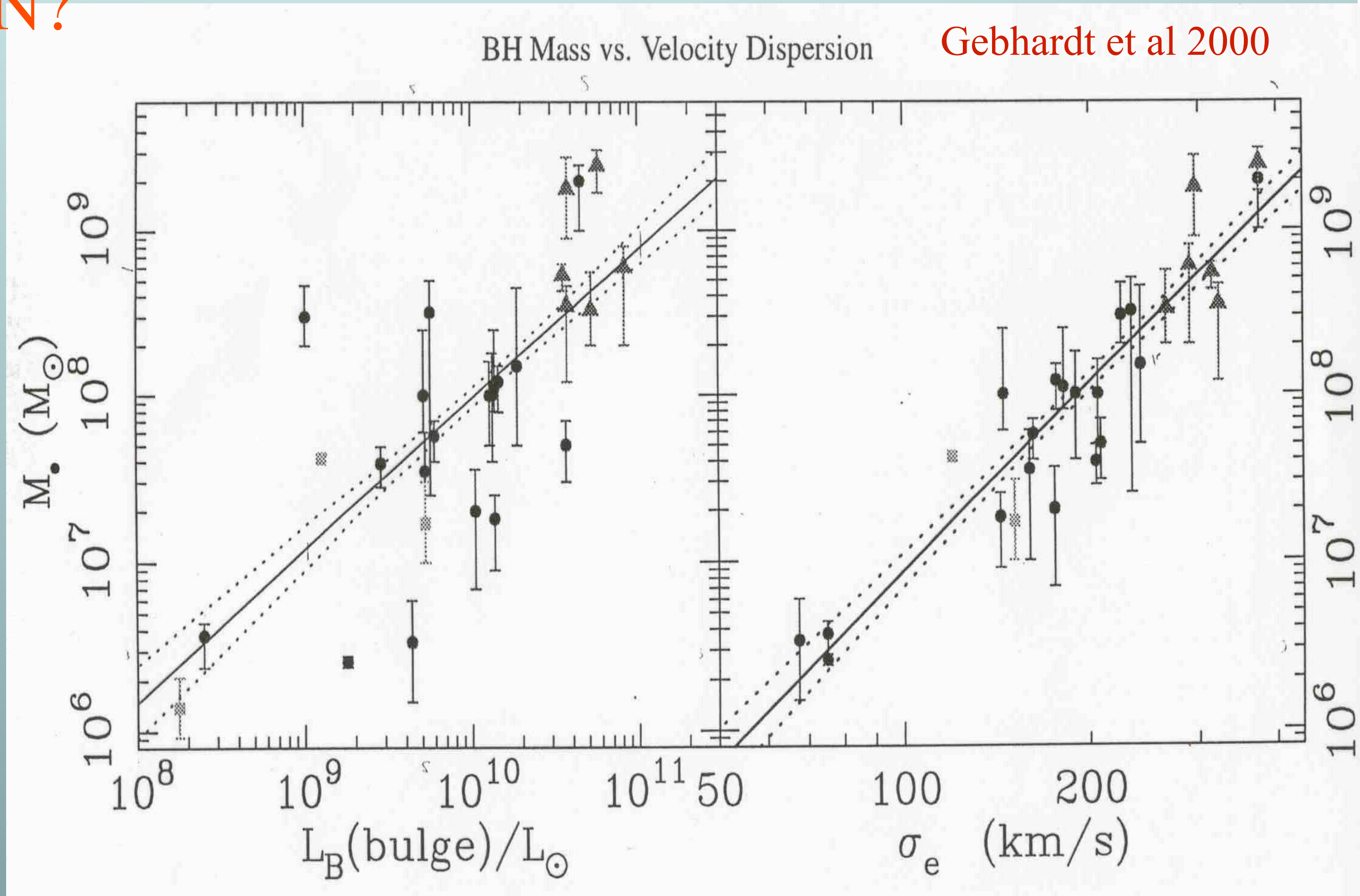
Wandel 2002



The M-σ relation:

in quiescent galaxies the BH mass is better correlated with bulge stellar velocity dispersion than with bulge luminosity

Is it also in AGN?

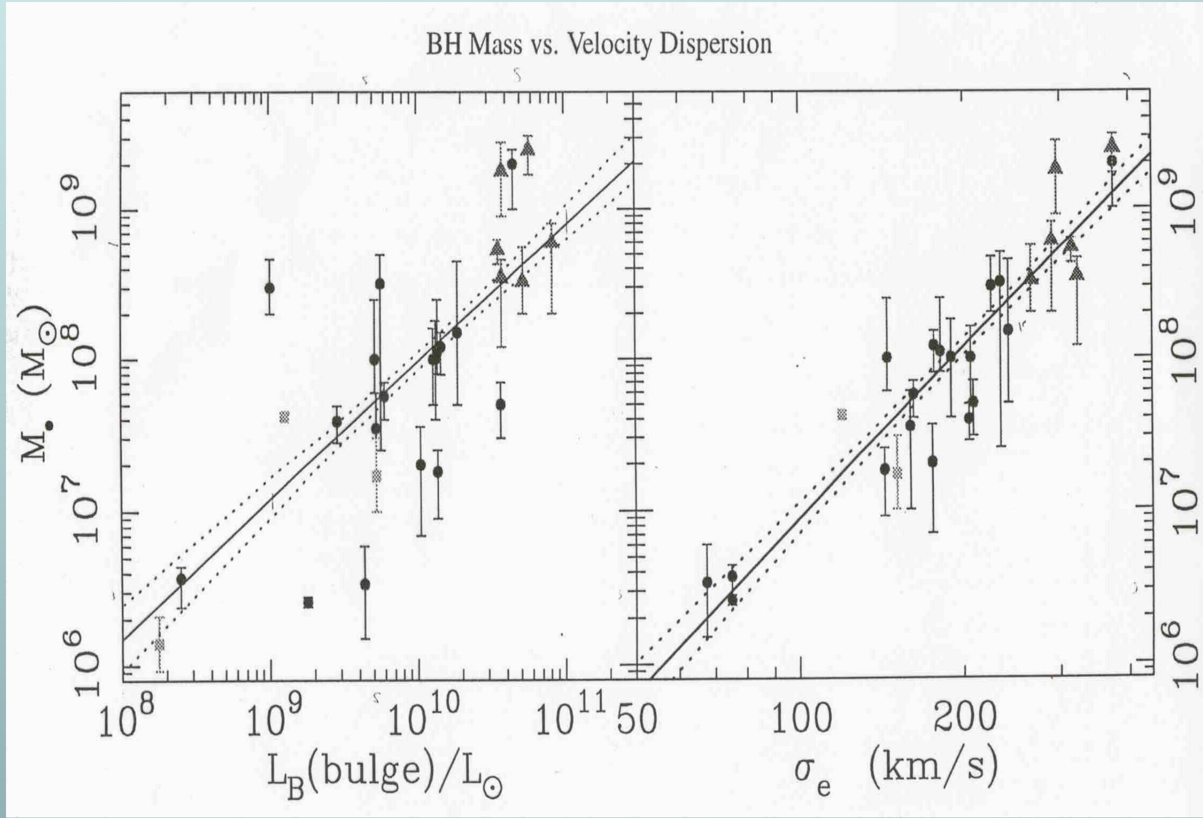


The M-σ Relation:*
BH mass – stellar velocity dispersion

A stronger relation?

M_{bh} is tightly correlated with stellar velocity dispersion in central bulge

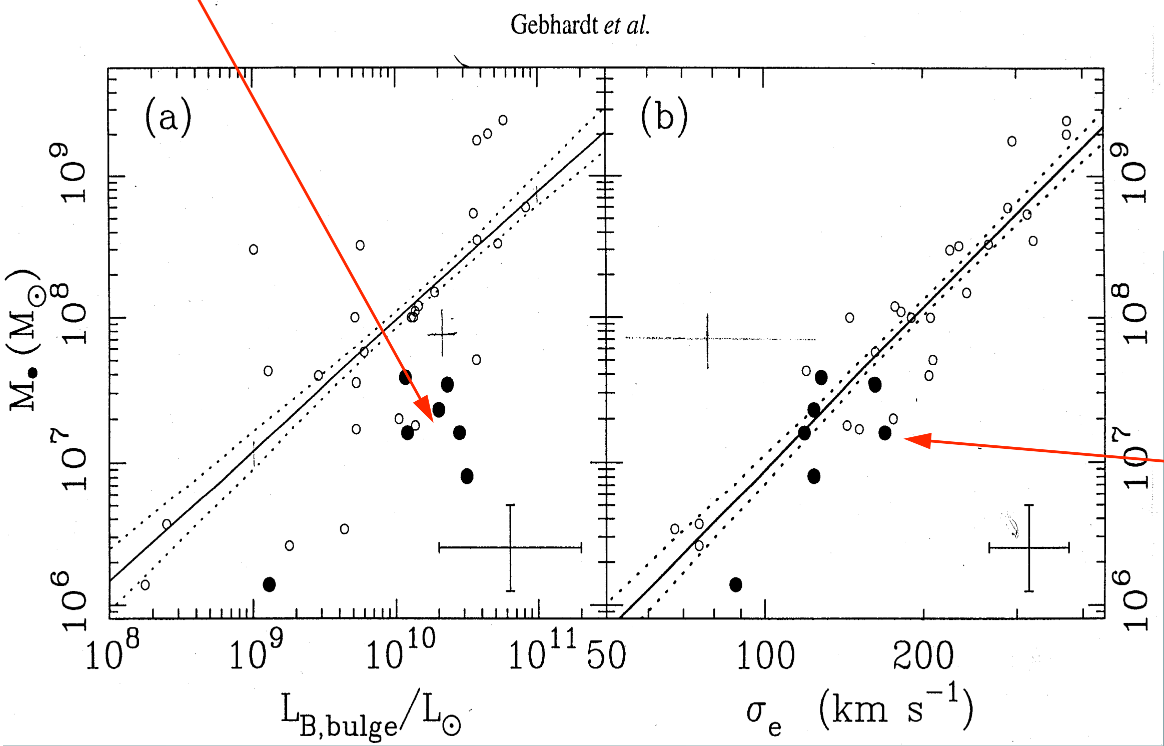
(Gebhardt et al. 2000; Ferrarese & Merrirtt 2000)

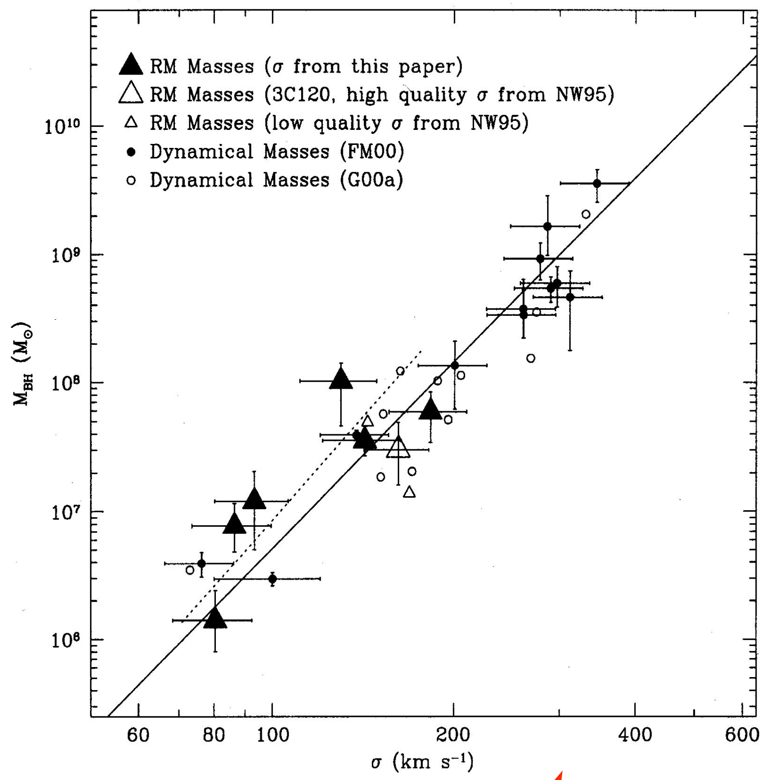


$$M_{BH} \sim \sigma*_{bulge}{}^{4-5}$$

M_{BH}-σ* relation in AGN

Narrow Line Seyferts galaxies (solid circles) seem to have a lower M_{BH}-L_{bulge} ratio than inactive galaxies



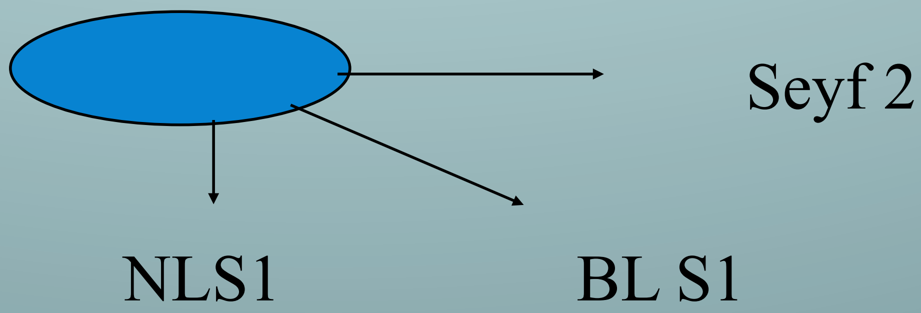


Ferrarese et al 2001

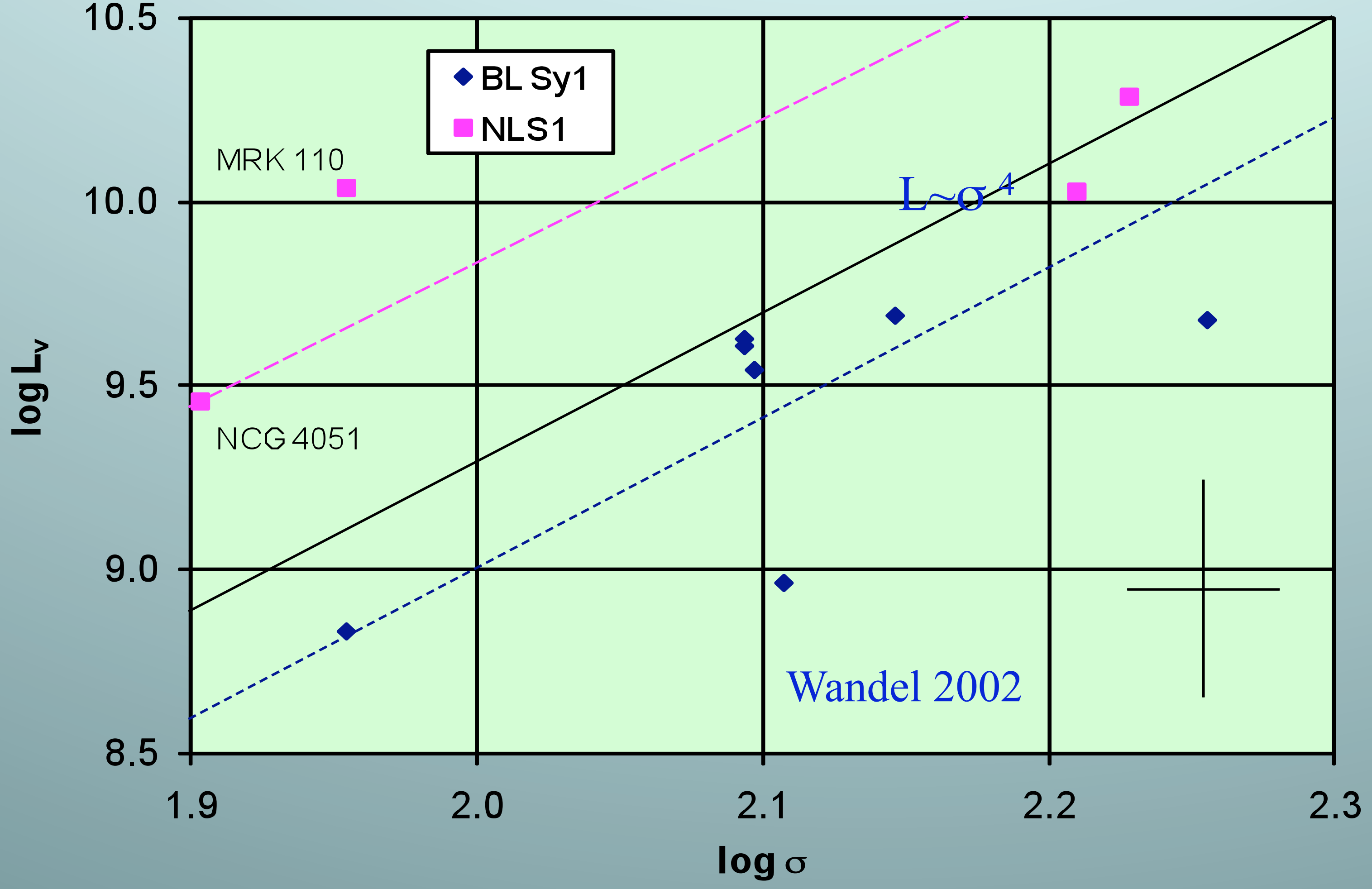
yet a similar M_{BH} –σ relation as quiescent galaxies and BLS1?*

Geometrical aspects

- If the BLR has a **flattened** geometry,
- the lower M_{BH}/L_{blg} of NLS1 could be an **inclination** effect (flattened+ near face on)
- BH mass of NLS1measured by assuming isotropic geometry would be **under-estimated**
- If so, NLS1 should fall low also in the M_{BH}-σ* relationship
- Unless the bulge is deformed as well (pseudo-bulge?)

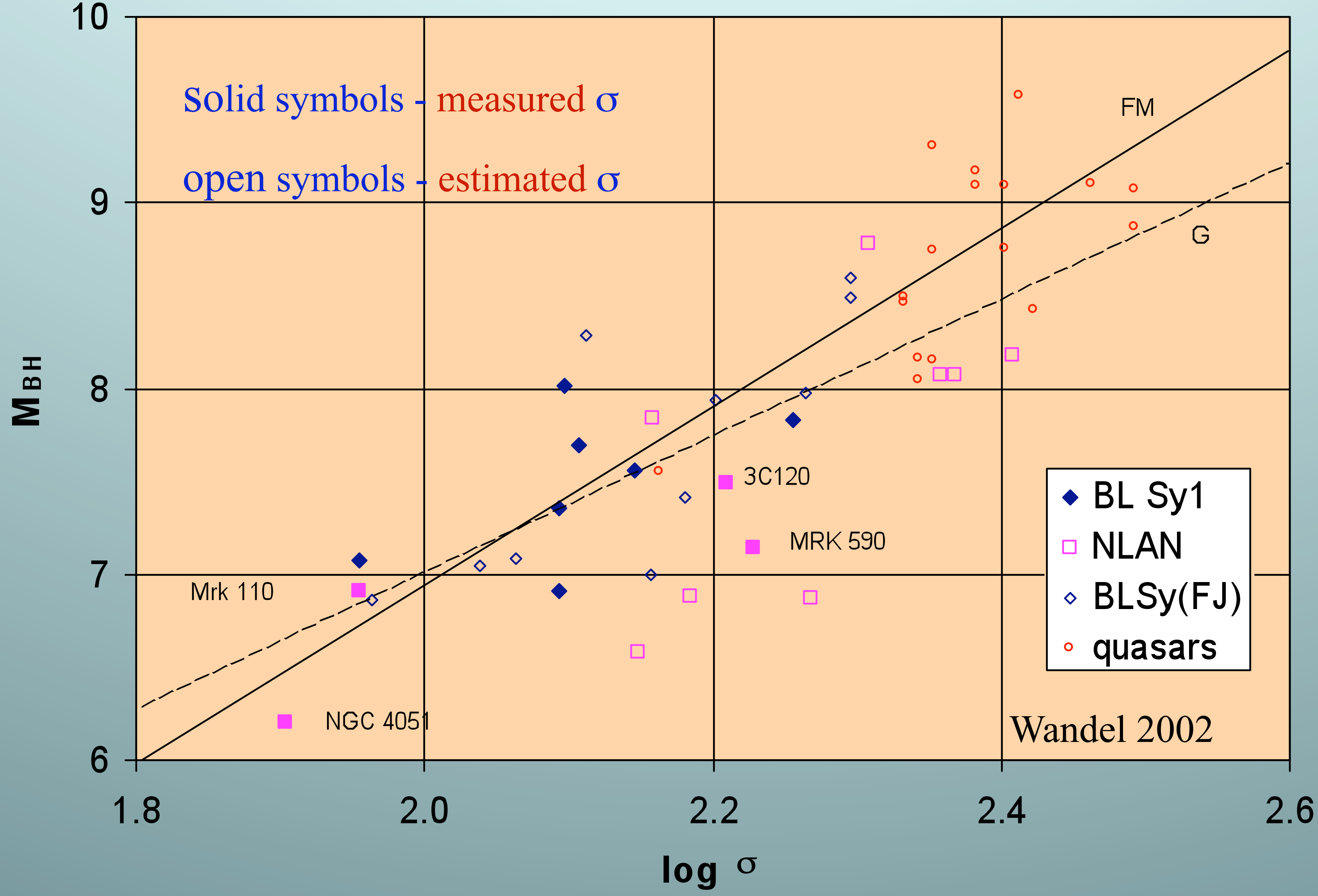


The Faber-Jackson relation as a proxi for σ* in AGN
Do NLS1s have a different FJ relation than broad line AGN? Brighter bulge or lower σ*??

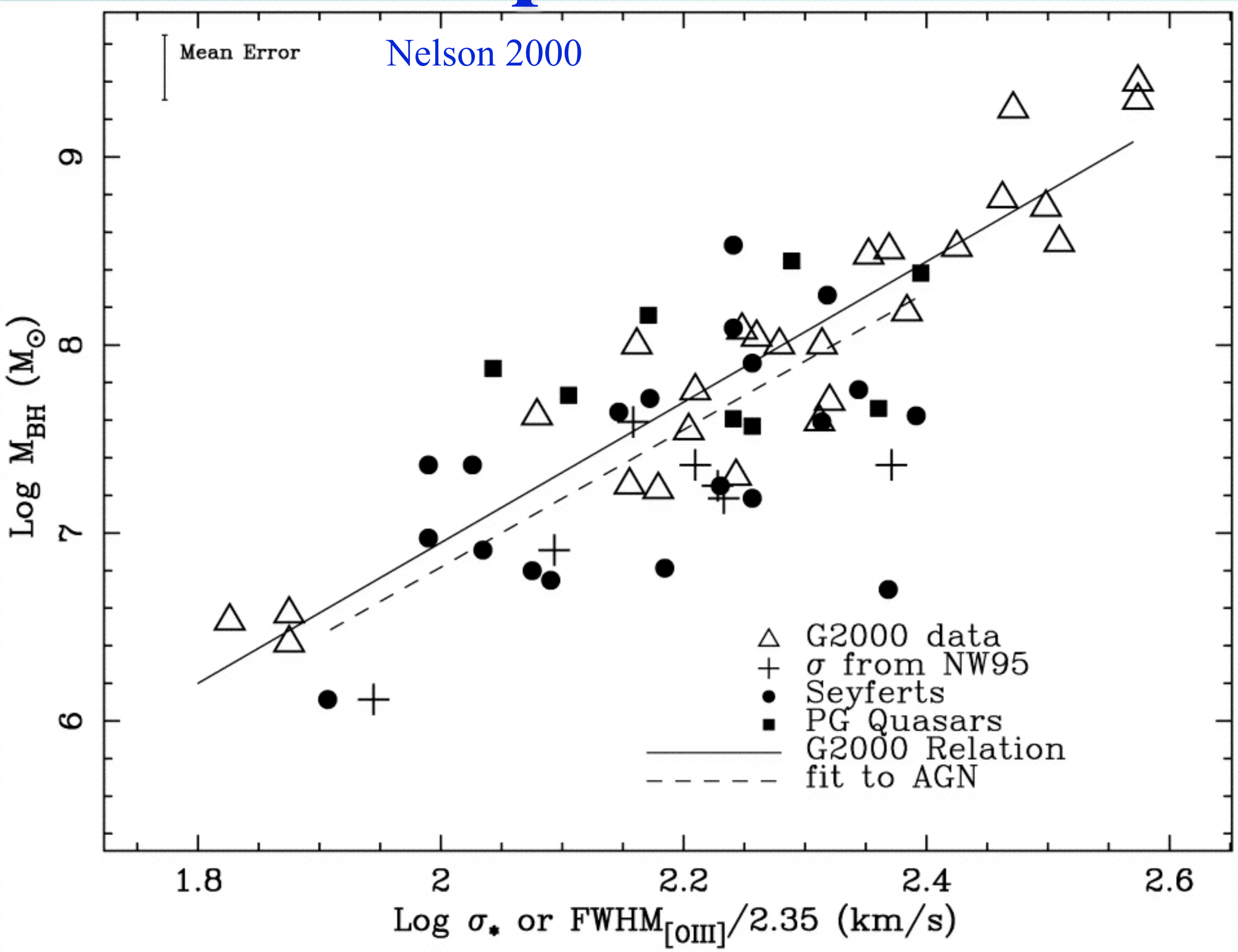


The BH-velocity dispersion relation of AGN: $M_{BH} \sim \sigma^{4-5}$

σ measured or estimated using the F-J relation



NLR OIII proxi for σ* in AGN



The relation between Mbh and the gas velocity dispersion in the Narrow Emission Line Region in AGN agrees with the Mbh-stellar velocity relation in normal galaxies (Nelson 2000)

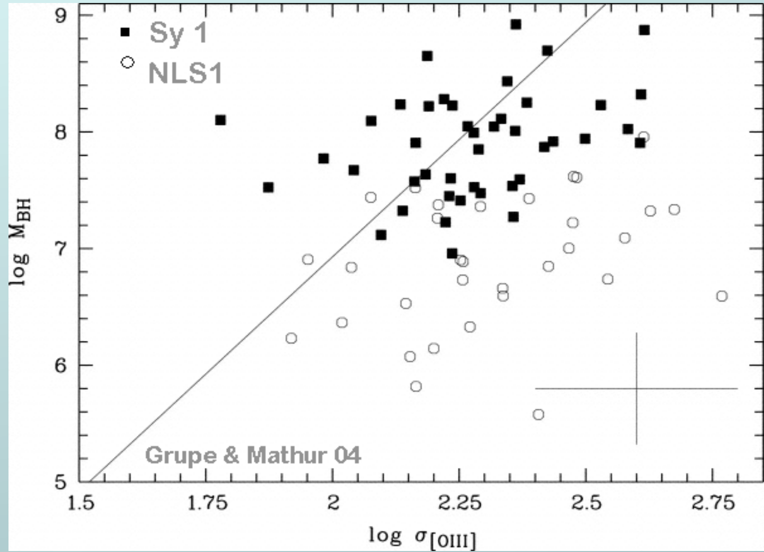
The size of the NLR (1-100 pc) is comparable to the central bulge region where the stellar velocity dispersion is measured
=> both velocities measure the potential of the central bulge

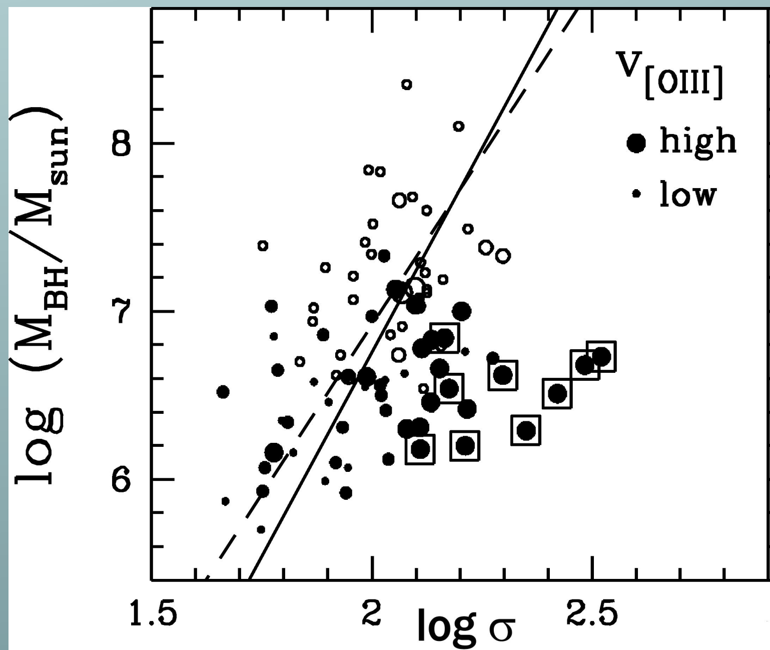
Are NLS1s on or off the $M_{BH} - \sigma_{[OIII]}$ relation?

- **Off** the BLS1 $M_{BH} - \sigma_{[OIII]}$ relation (Mathur+ 01),
- "on" Wang & Lu (2001)
- Few real σ_* measurements
  (Botte+ 05: "on"; Zhou+ 06: "off"; Bian+ 08 "on" or "off")
- few L_{bulge} measurements
  (Botte+ 04: "on"; Ryan+ 07, Mathur+ 11,Orban Xivry+11: "off")

❑ how reliable is [OIII] as substitute for stellar velocity dispersion ?

❑**on** the $M_{BH} - \sigma_{[OIII]}$ relation when corrected for outflow (Dawei+ 2007 & this conf.)





[Mathur & 01, Wang & Lu 01, Wandel 02, Grupe & Mathur 04, Bian & Zhao 04,06, Botte & 04, 05, Barth & 05,

Conclusions

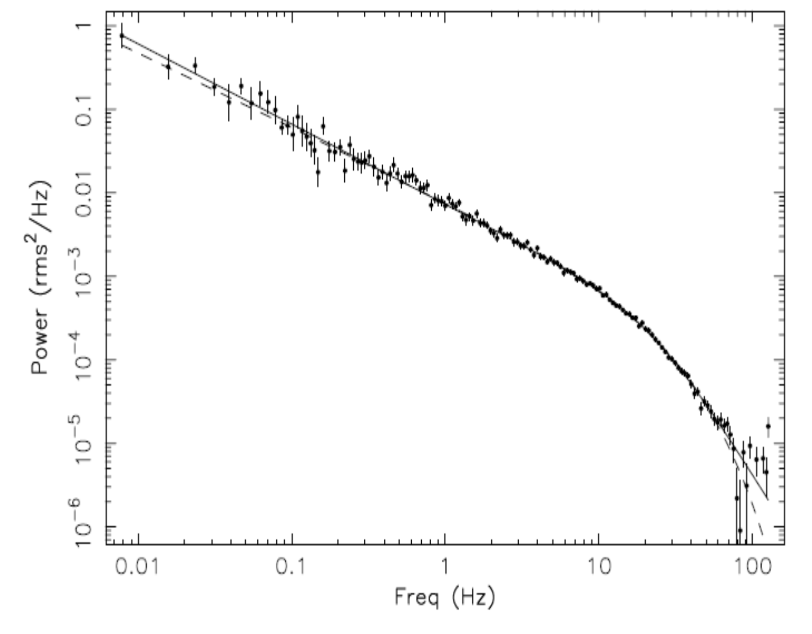
- BLR Reverberation in AGN probably gives similar BH masses to M_{BH} from stellar dynamics
- AGN have the same BH-bulge relation's as inactive galaxies
- Narrow Line AGN have a lower M_{BH}/L_{blg} ratio
- New BH-bulge relations:
- $R_{BLR} \sim L_{blg}$, $M_{BH}/L \sim v^2$, $L_{AGN} \sim L_{blg}^2$
- M-σ* relation: are NLS1 similar to BLS1 & quiescent galaxies?
- Good measurement of true σ* for AGN problematic, surrogates (gas) uncertain (possibly outflow).

X-ray fluctuation analyses of accreting Black Holes

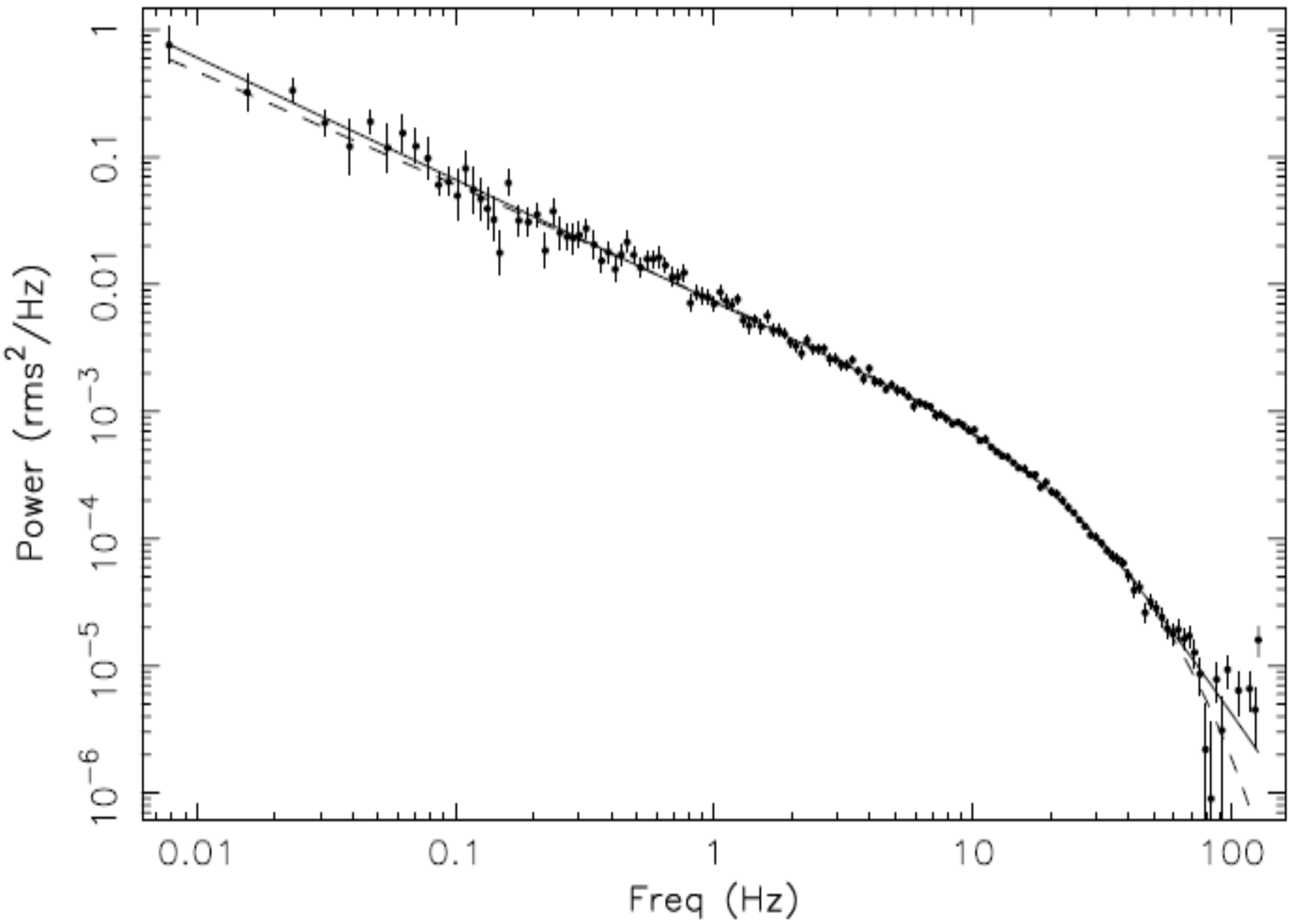
- Power spectral density (PSD) and structure-function analyses of X-ray fluctuations
- XTE and XMM data of ~ 20 Seyfert nuclei
- Linear correlation: break-timescale in the fluctuation spectrum (Tb) and BH mass (Mbh)
- SF- similar to Tb-Mbh correlation found with PSD
- Extends to lower mass BHs (Cyg X-1 and others)
- Common physical mechanism – scaled by BH mass

X-ray fluctuation analyses of accreting Black Holes

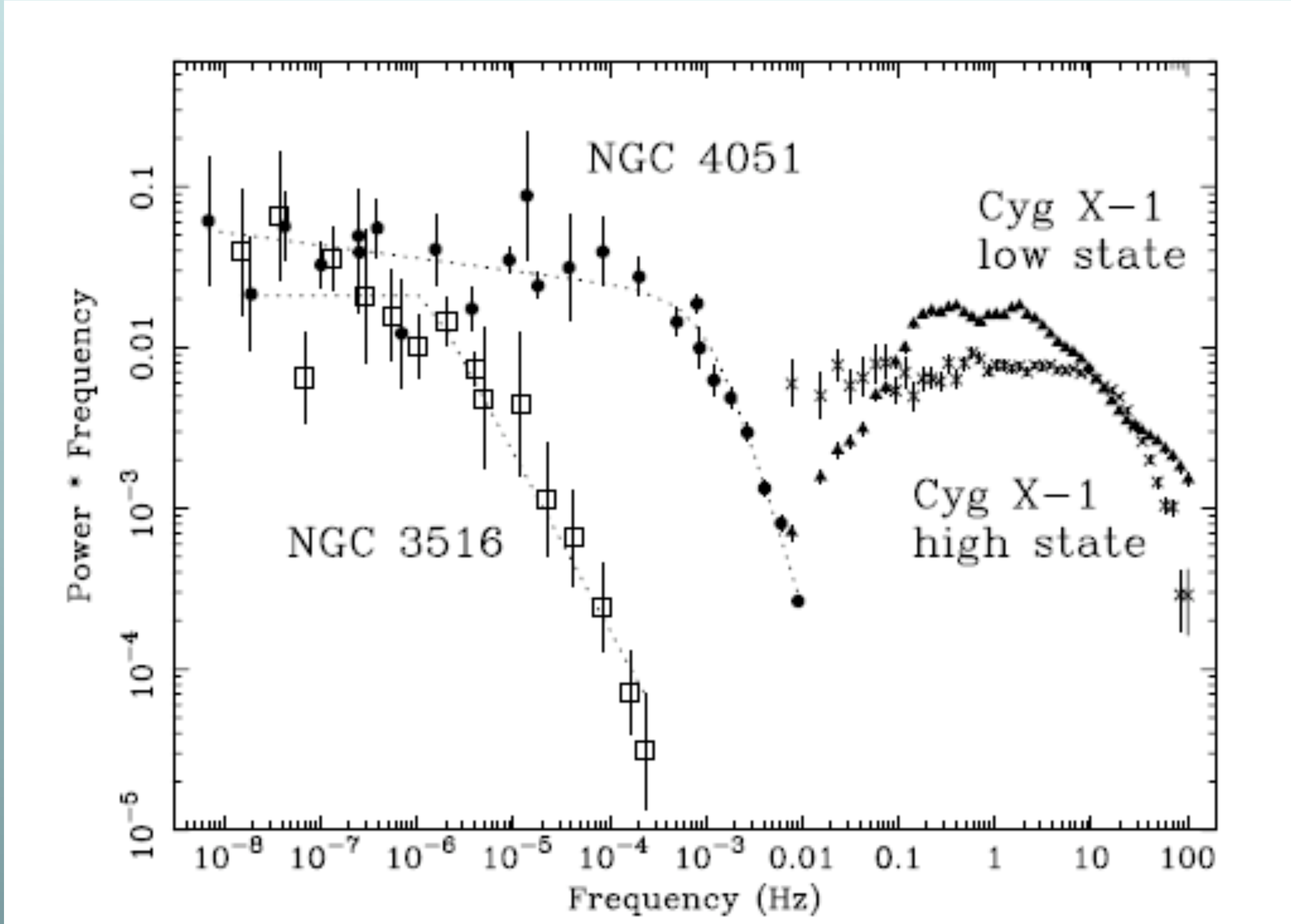
- Power spectral density (PSD) – Fourier-like analyses of time variability
- "Break" in the PSD of Cyg X-1 and other stellar BH-systems
- PSD of Seyfert 1 galaxies also show "break"
- Similar to PSD-break of stellar BH but at lower frequency
- ***Common physical mechanism produces X-rays in accreting Black Holes?***



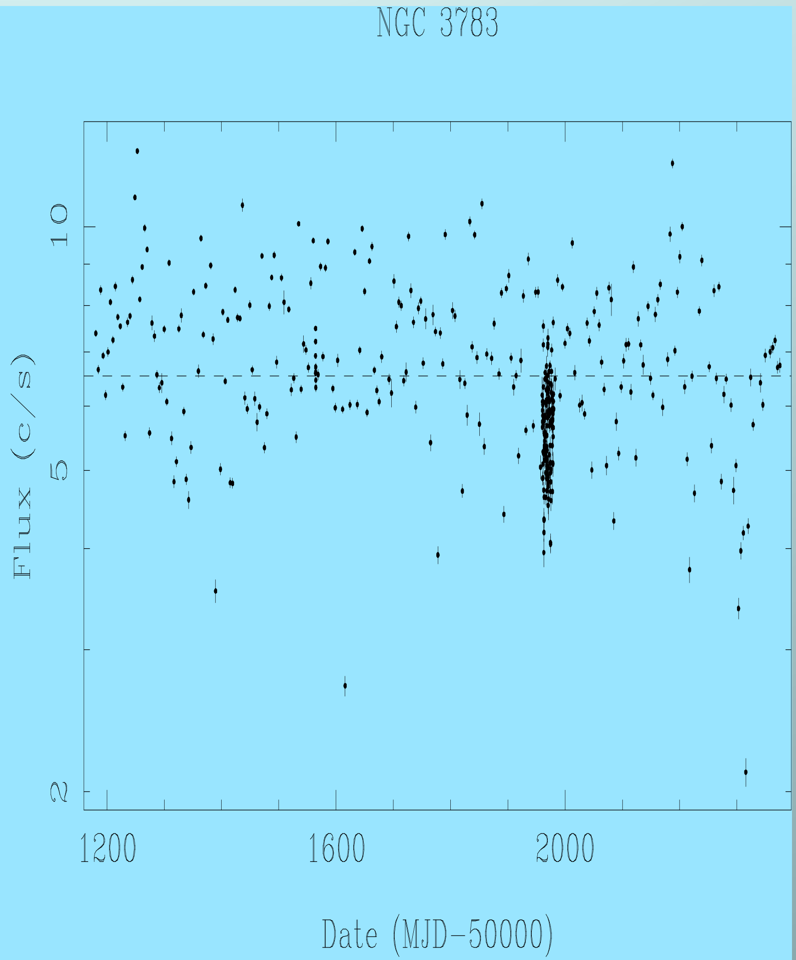
PSD of Cyg X-1 (high/soft state)



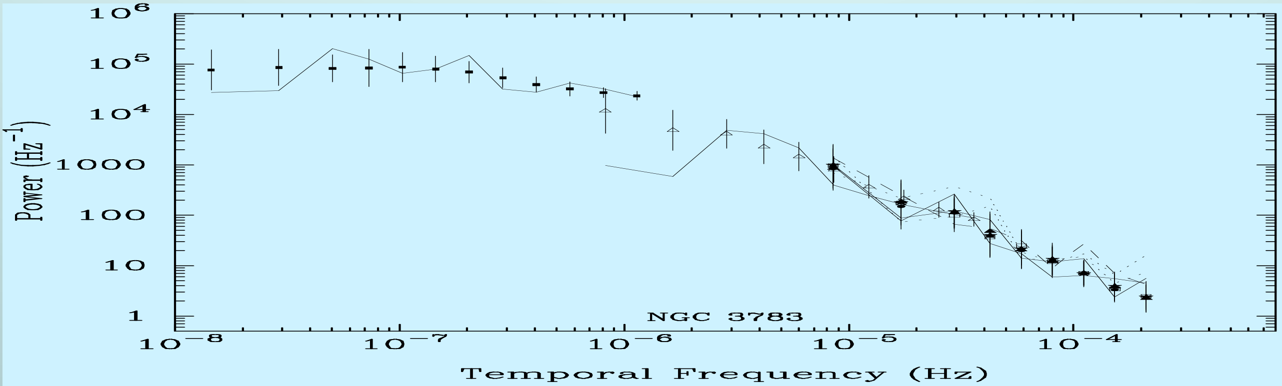
PSDs of Cyg X-1 and AGN



Light Curve of NGC 3783



PSD of NGC 3783



Structure Function analyses of time-series

$$S(\tau) = \frac{1}{N(\tau)} \sum_{i<j} [f(t_i) - f(t_j)]^2$$

Tti- tj=τ

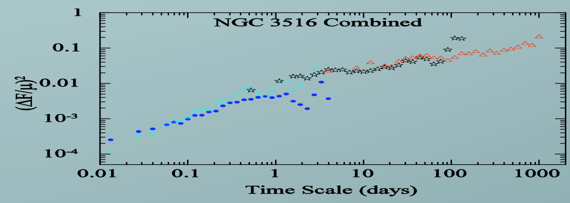
SF: definition

$$S(\tau) = 2[\sigma^2 - \mathrm{ACF}(\tau)]$$

Auto-correlation function

$$S(\tau) = 2\left[\int_0^\infty P(f)df - \int_0^\infty P(f)\cos(2\pi f\tau)df\right]$$

SF - PSD relation

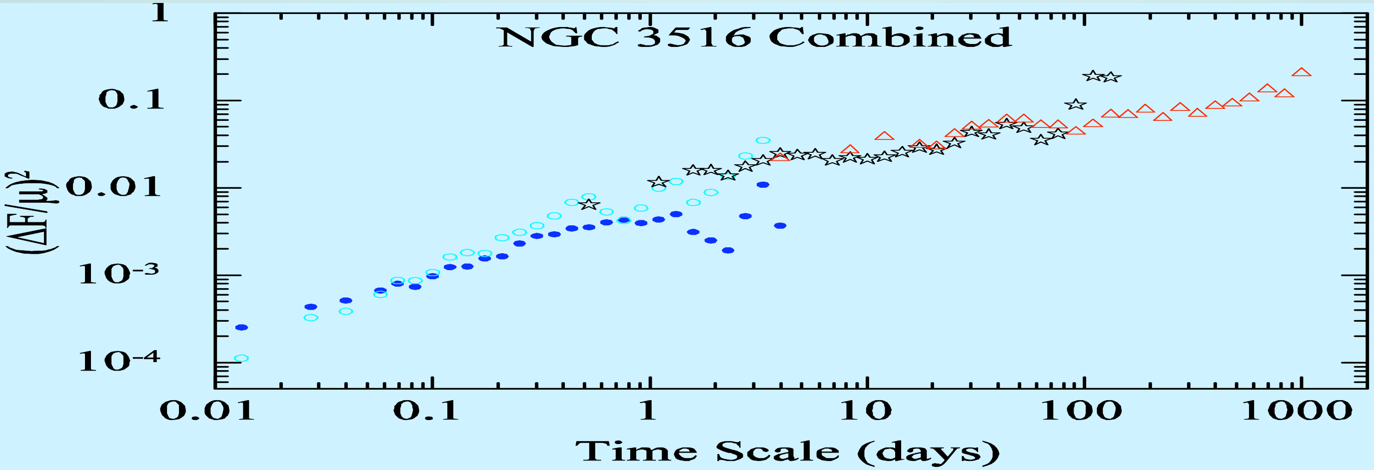


Collier & Peterson 2001

power-law section defines the range of timescales over which the variations are correlated, and its slope depends on the physical mecha- nism responsible for the intrinsic vari

The timescale $\tau_{char} \sim \tau_{max}$ at which the structure function flattens may represent a robust, charac- teristic timescale determined by fundamental source charac- teristics, e.g., mass and size; provid

Structure Function of NGC 3516



Wandel, Markowitz & Malkan 08

XTE & XMM Light Curves of NGC4051

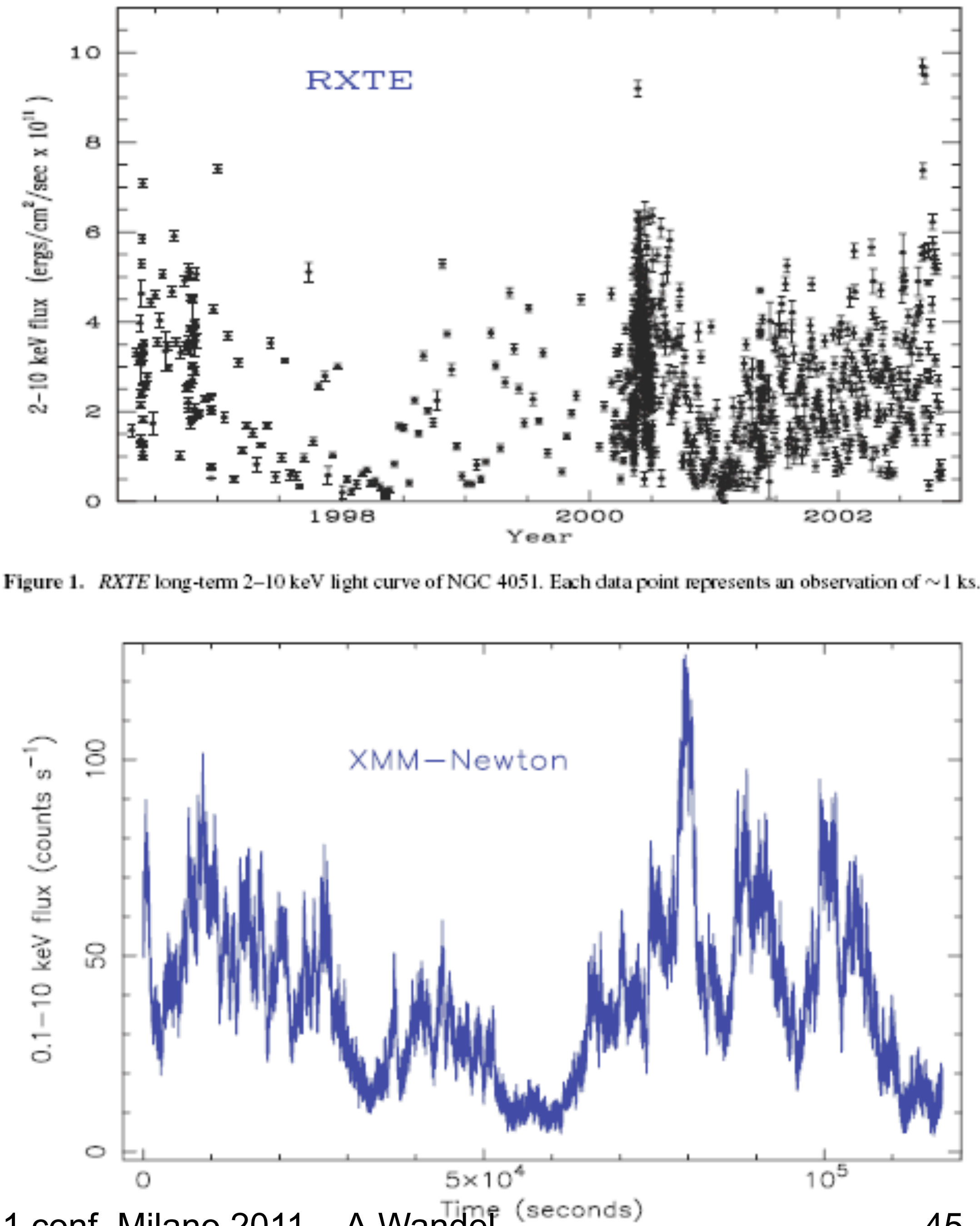
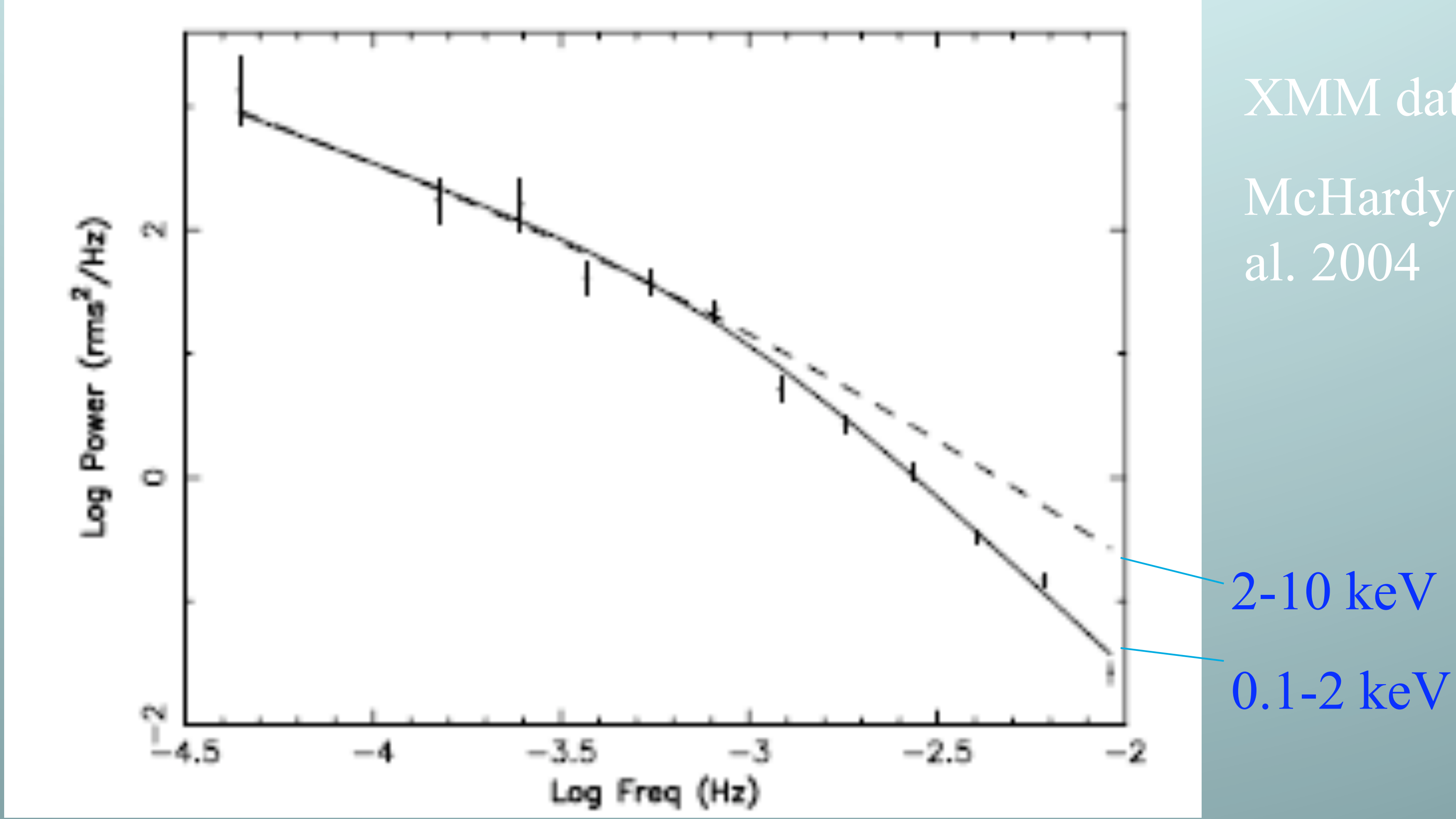


Figure 1. *RXTE* long-term 2–10 keV light curve of NGC 4051. Each data point represents an observation of ~1 ks.

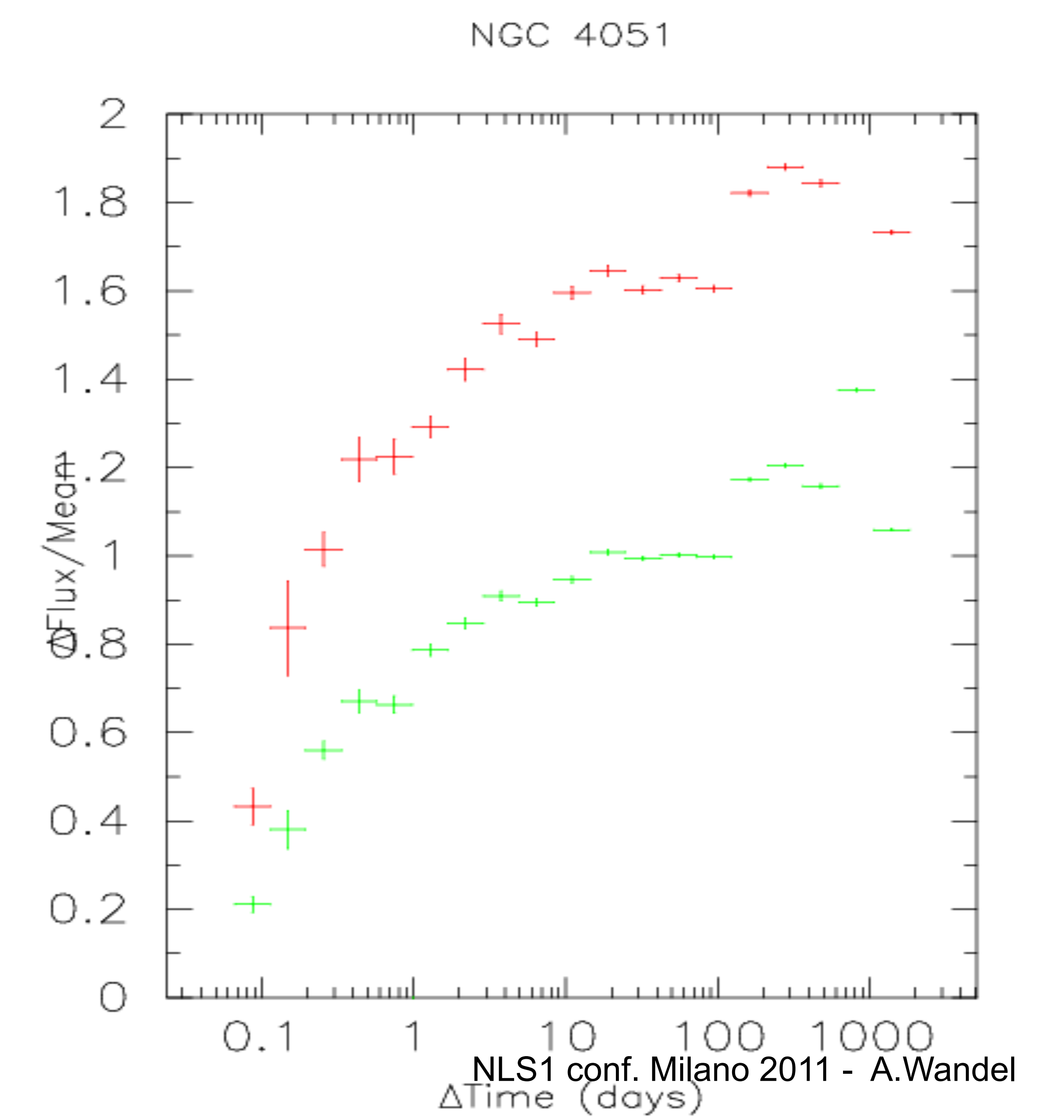
PSD of NGC 4051



XMM data

McHardy et al. 2004

SF of NGC 4051

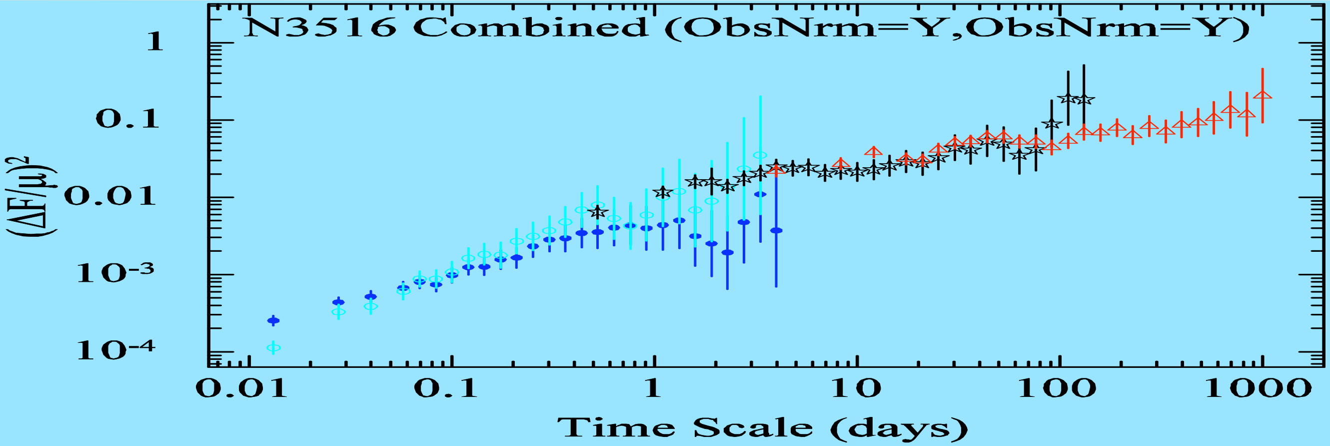


XTE data

Edelson et al. 2002;

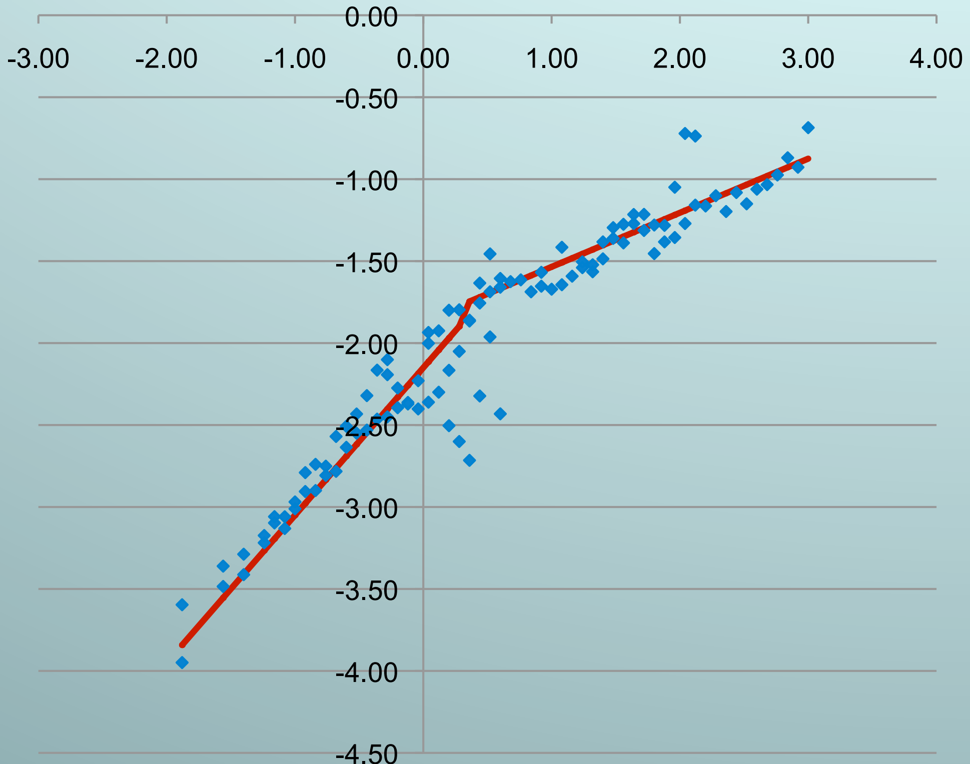
Wandel Markowitz & Malkan

Structure Function of NGC 3516



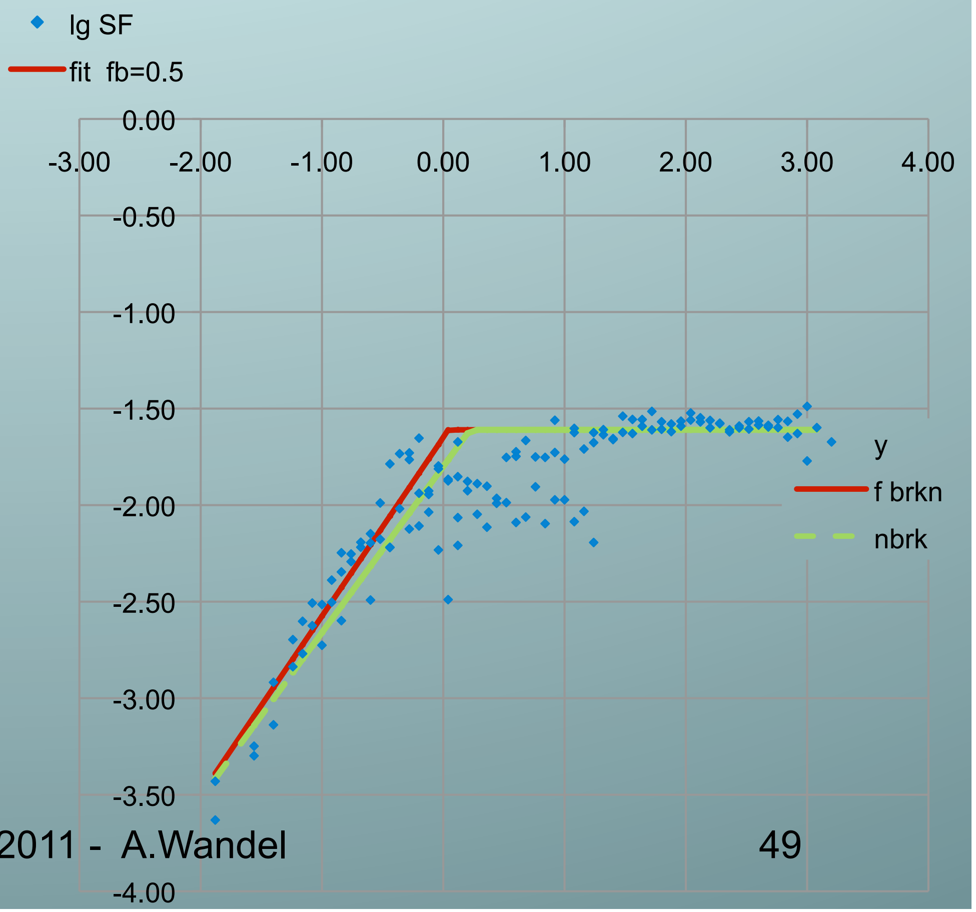
Wandel, Markowitz & Malkan 08

Structure Functions of AGN



NGC 3516

NGC 3783

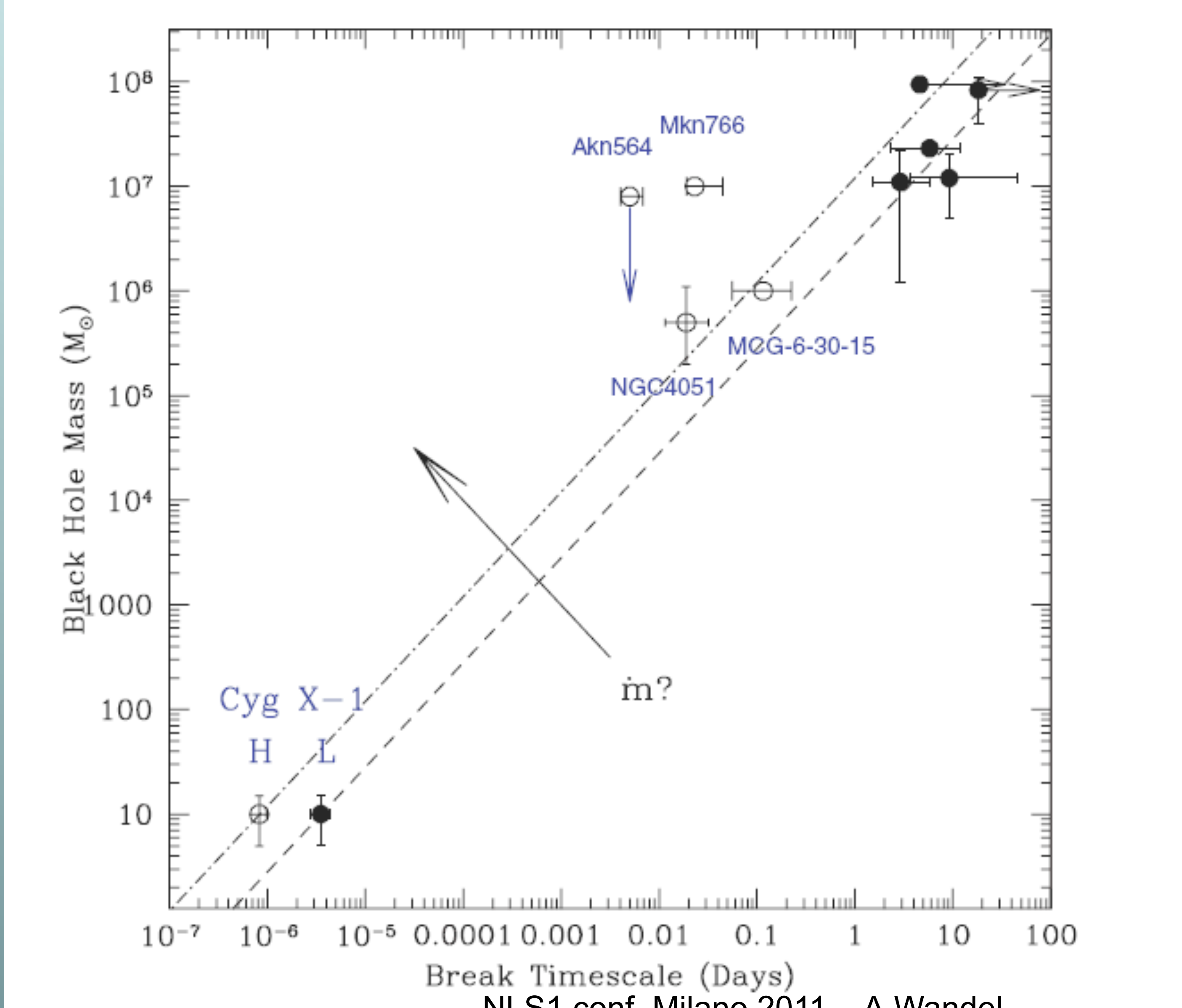


Wandel, Markowitz & Malkan 2010

X-ray fluctuation time scale correlated with BH mass

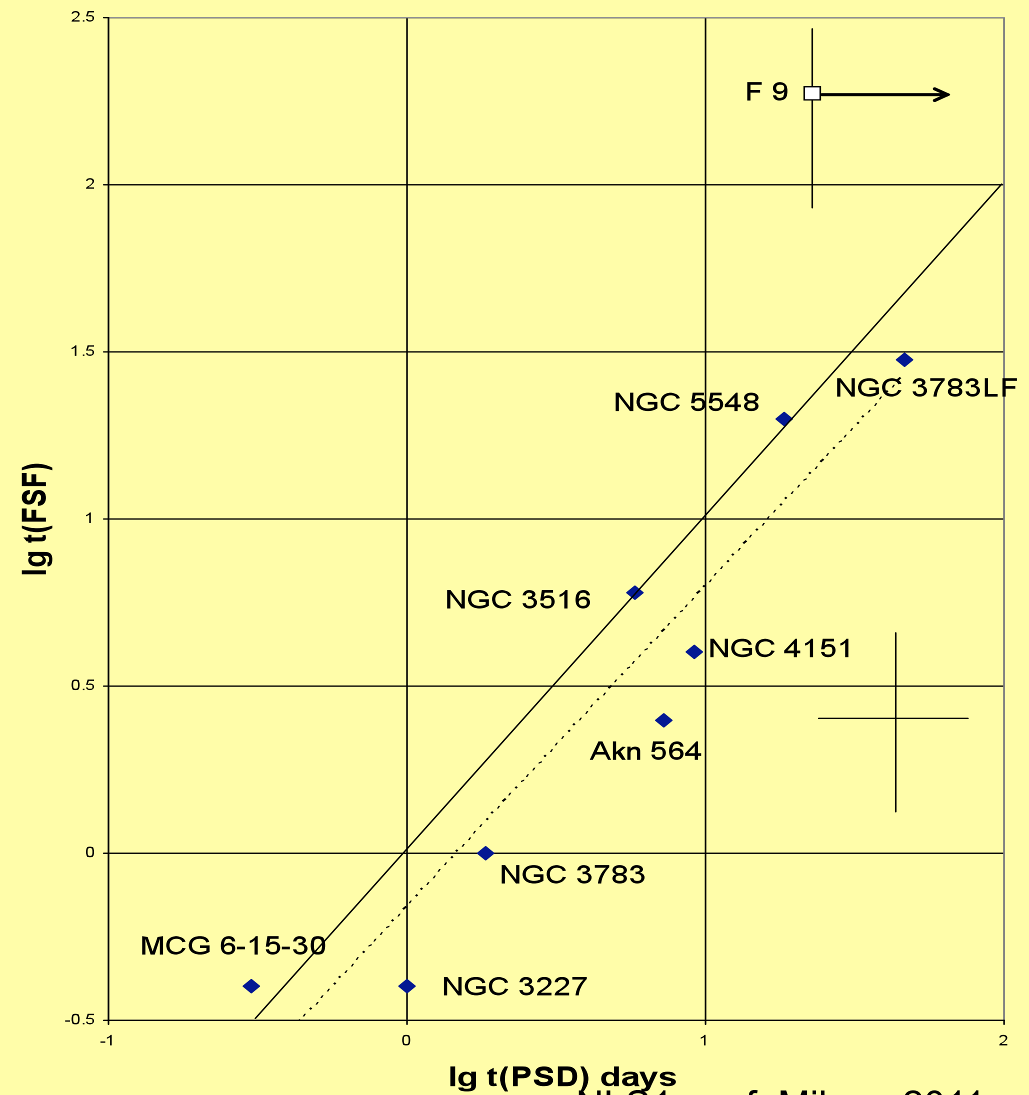
- **1987 - Einstein data: time-scale of variability of X-rays in AGN prop. to BH mass** (Wandel & Mushotzky)
- ***2010 - XTE/XMM data: correlation between break-frequency in the fluctuation spectrum and BH mass*** *(McHardy et al., Wandel, Malkan & Markowitz)*
- ***The same correlation extends to lower mass BHs (Cyg X-1 and others)***
- ***Common physical mechanism – scaled by BH mass***

PSD Mbh-Tb correlation



McHardy et al. 2004

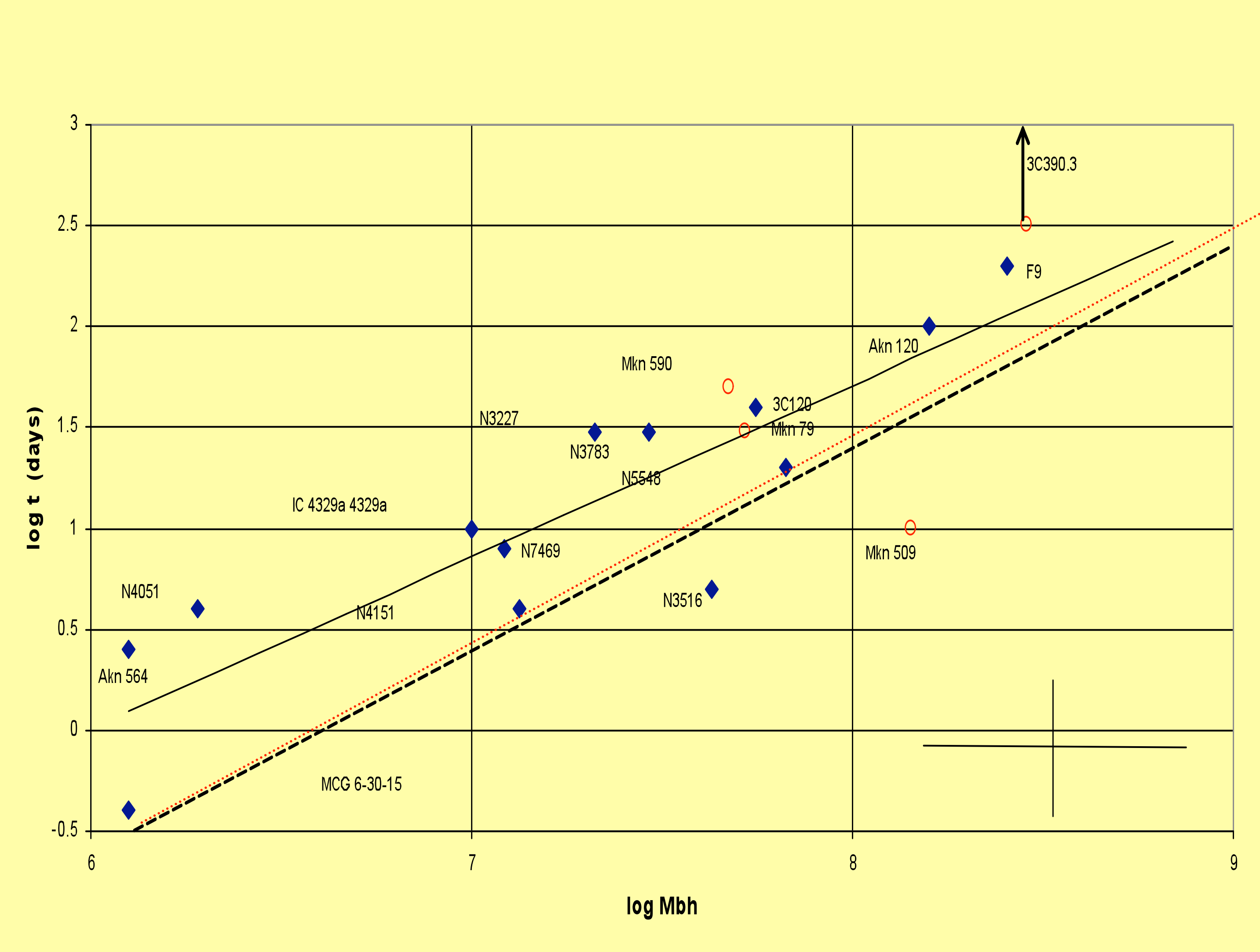
PSD-SF correlation



Timescale of the break or flattening in the X-ray fluctuation power (SF or PSD)

Wandel,Markowitz &Malkan 2010

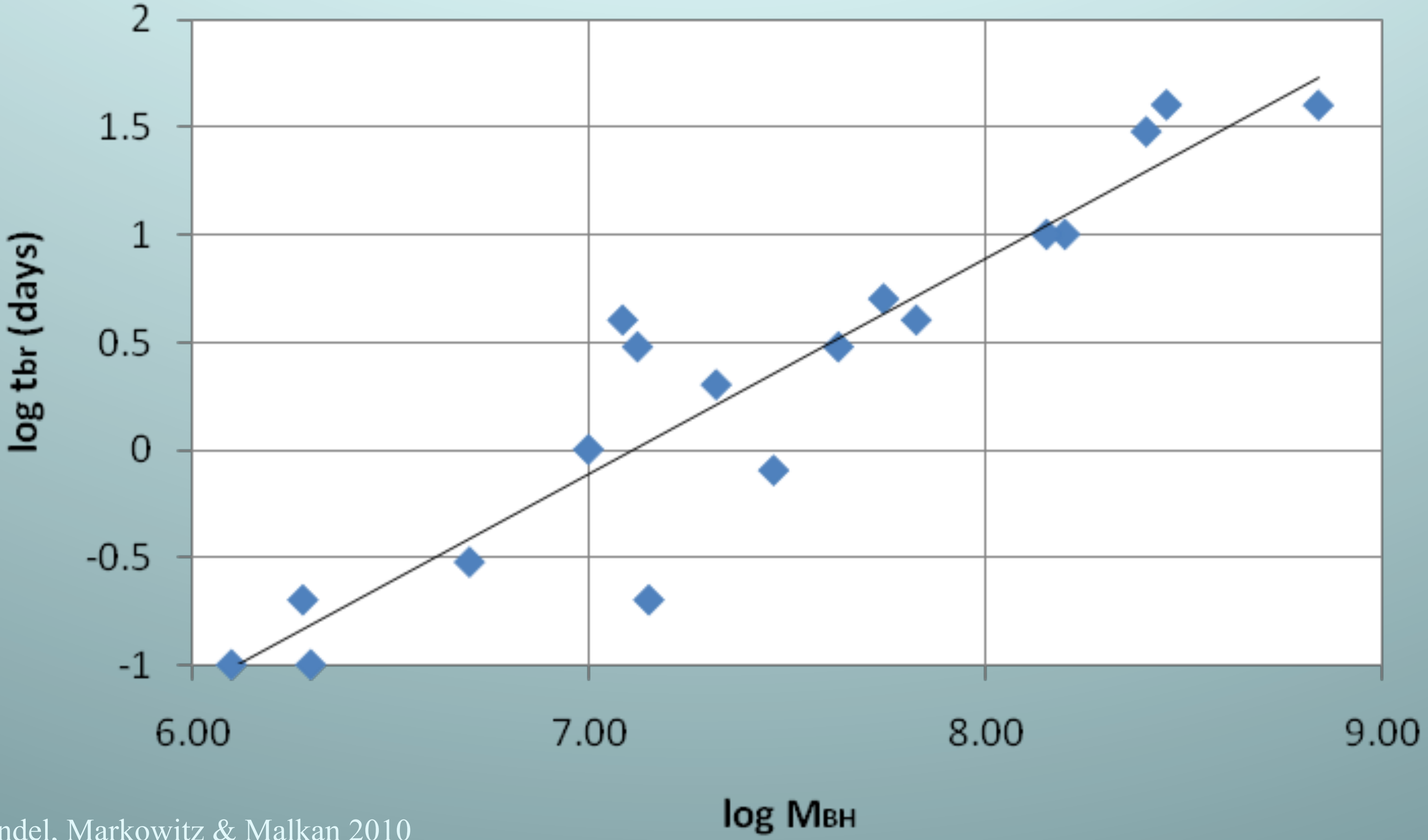
Mbh-SFTb correlation



Cyg X-1 PSD extrapolation

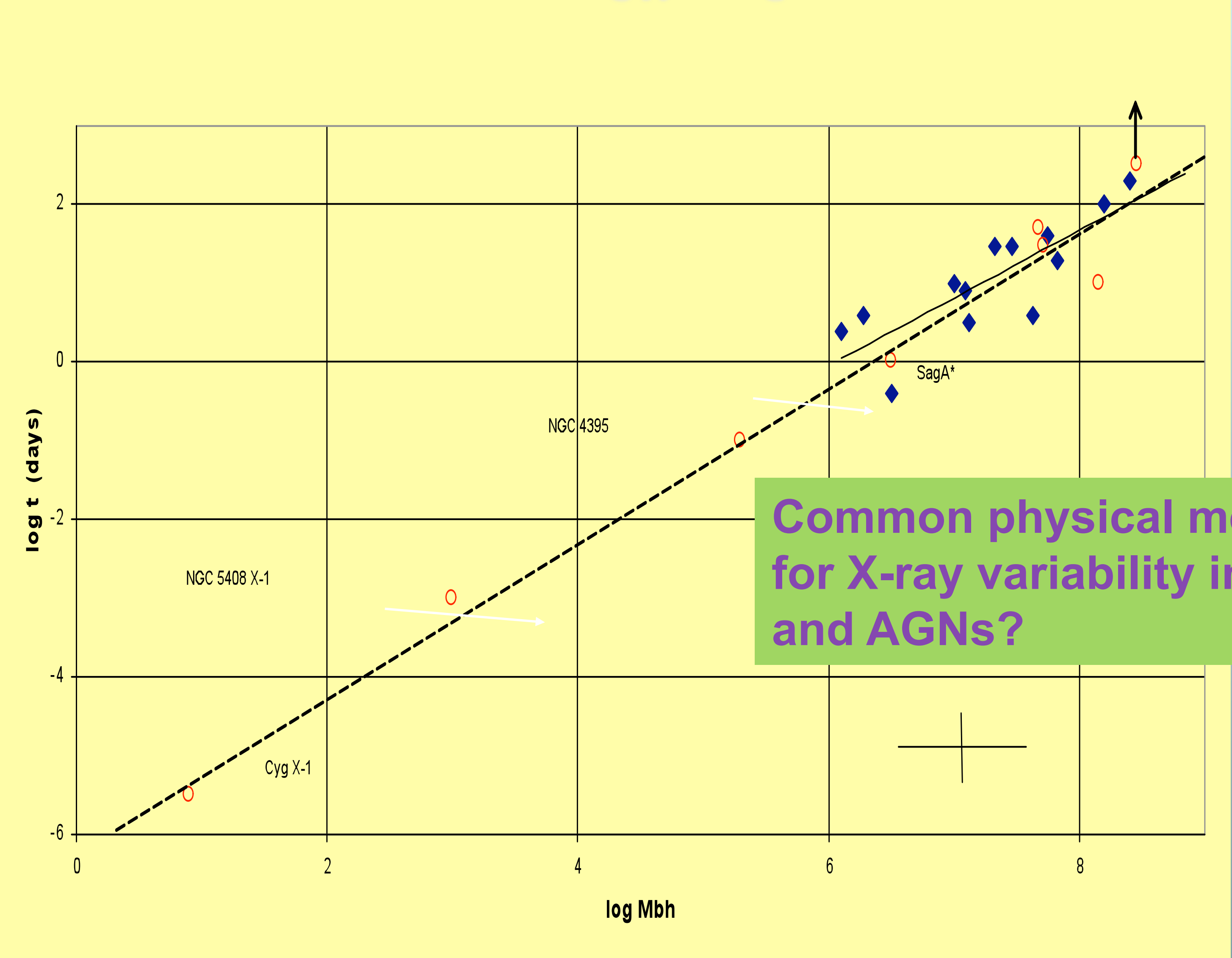
Wandel, Markowitz & Malkan

M_{BH} - T_b correlation (SF)



Wandel, Markowitz & Malkan 2010

Extended M_{bh}-T_b correlation



Common physical mechanism for X-ray variability in BHXRBs and AGNs?

Accretion timescales

- *Light-travel time at R_s: $2GM/c^3 \sim 10^3 M_8$ sec*
- *Orbital time at 5 R_s: $t_{orb} \sim 10^5 M_8$ s $\sim 1 M_8$ days*
- *Viscous time at 5 R_s: $t_{visc} \sim 10 M_8(\alpha/0.1)^{-1}$ days*
- *Most of the energy in a thin α-disk is produced at a few $R_s \sim M$*

Summary

- Structure-function analyses of X-ray fluctuations
- XTE and XMM data of about 20 Seyfert nuclei
- Doubles the number of objects in the database
- Linear correlation between the break-timescale in the fluctuation spectrum (Tb) and the black hole mass Mbh
- Improves the correlation found between Tb and Mbh with power spectral density (e.g. McHardy 2004;06)
- Extrapolation of the Mbh-Tb relation of Cyg X-1 & GBHs
- ULXs (IMBHs?) and low end SMBHs
- Common physical mechanism for X-ray variability in BHXRBs and AGNs?
- Predicted timescale for Sag A* Tb~1day

Conclusions

- Reverberation Mapping +stratified BLR structure >>Kepplerian measurement of BH mass in AGN
- AGN have the same BH-bulge relations as inactive galaxies
- Narrow Line AGN have a lower M_{BH}/M_{blg} ratio
- New relations: $R_{BLR} \sim L_{blg}$, $M_{BH}/L \sim v^2$, $L_{AGN} \sim L_{blg}^2$
- M_{BH} -T_b correlation - between the break-frequency in the fluctuation spectrum and the BH mass
- Extends over 8 orders of magnitude in BH mass
- Common physical mechanism in accreting BHs

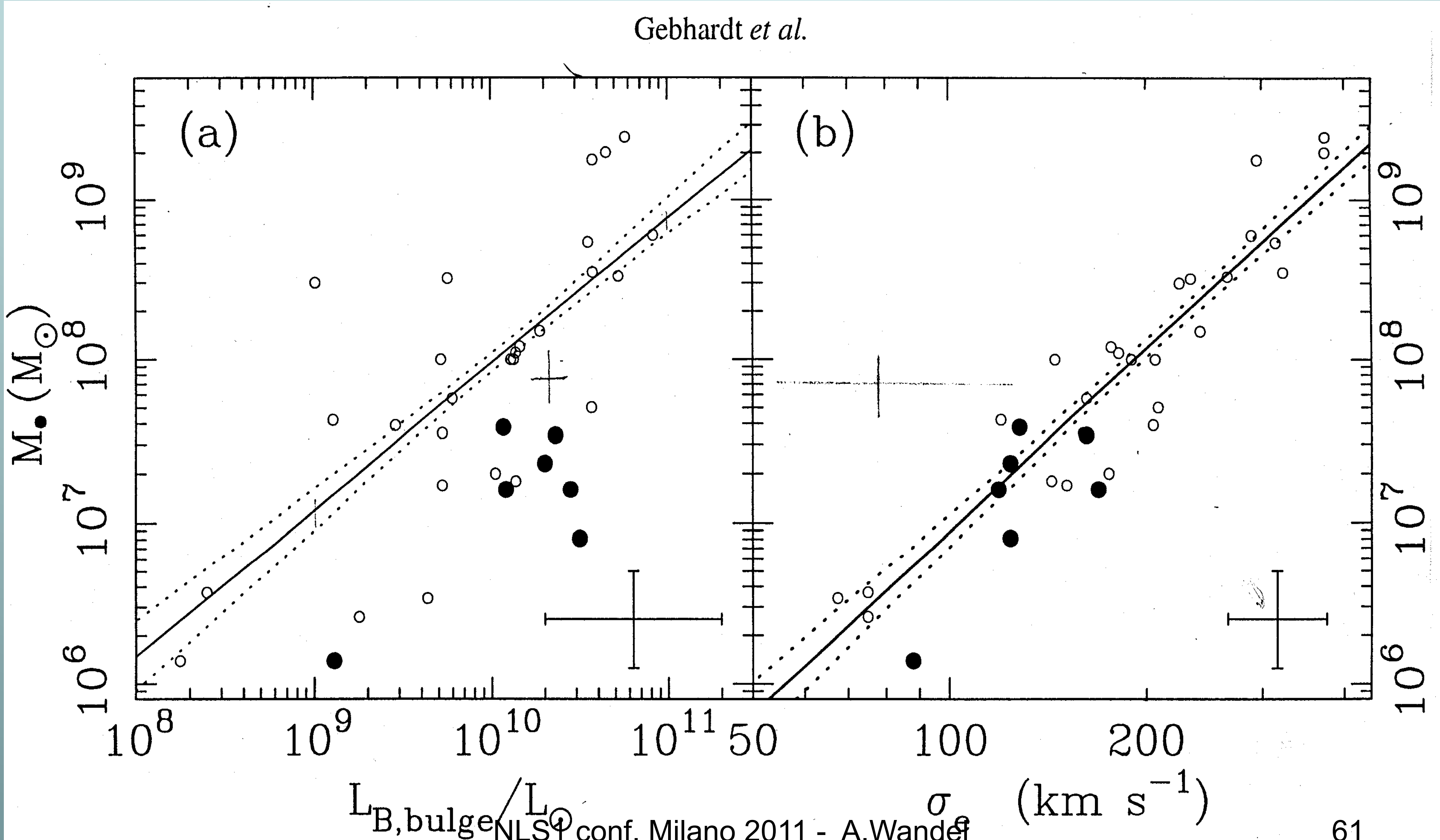
Questions

- Do all galaxies have massive black holes (MBHs) ?
- Did all galaxies with a MBH have an active phase?
- How is the MBH coupled to its host galaxy ?
- Is nuclear activity in AGN related to growing MBHs ?
- How is the BH growth related to the halo

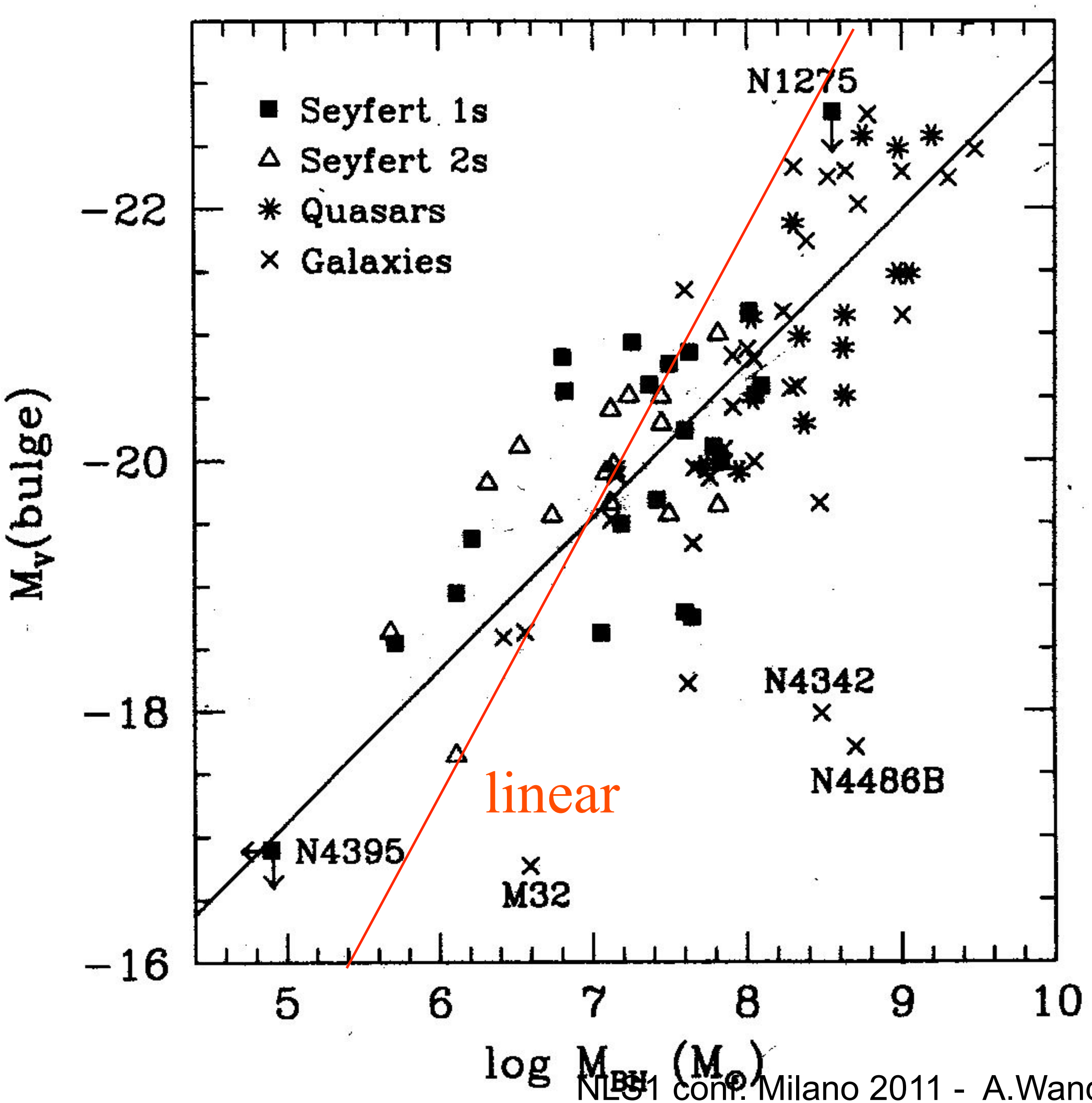
New relation between host bulge and BH mass in AGN ?

- M_{BH}/L_{blg} depends on the gas velocity in the broad emission line regions $M/L \sim v^{2.0}$
- may be caused because the BH mass in AGN is estimated using the virial relation $M_{BH} \sim v^2 r$ (BLR)
- Canceling the v dependence v^2 r (BLR)/L~ $v^{2.0}$ ...
- we expect no correlation to be left, but actually the remaining correlation, r (BLR)~L_{blg} is very strong!

Seyferts galaxies (solid) may have a lower M_{BH}-bulge luminosity relation than normal galaxies (open), (a), -- yet similar M_{BH}-stellar velocity ratios (b)



Non-linear BH-bulge relation?



$-M_{V\ blg} \sim M_{BH}^{\ (1.2\text{-}1.5)}$

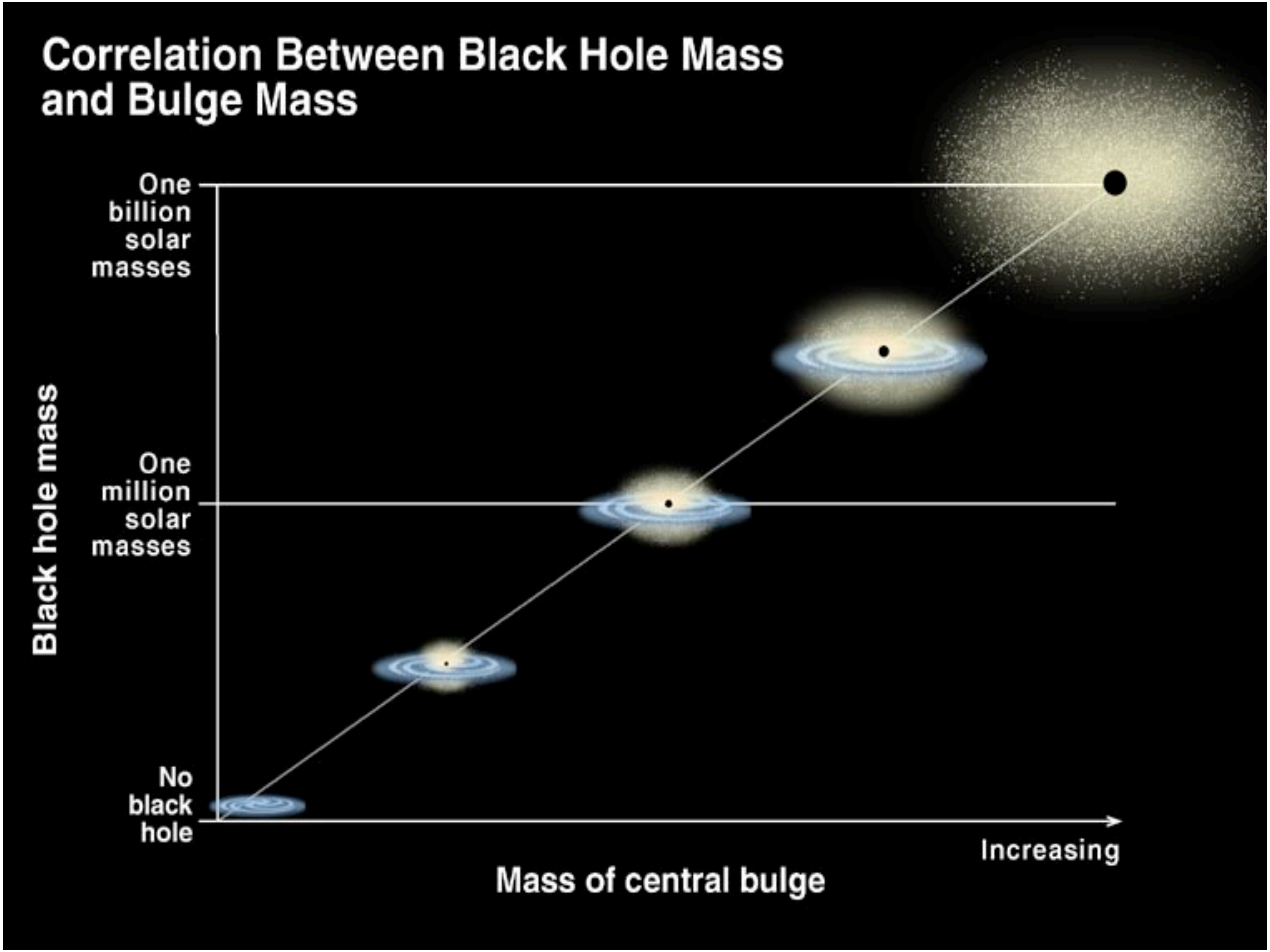
or

$M_{BH} \sim L_{blg}^{\ (1.7\text{-}2)}$

$M_{BH} \sim M_{blg}^{\ (1.4\text{-}1.7)}$

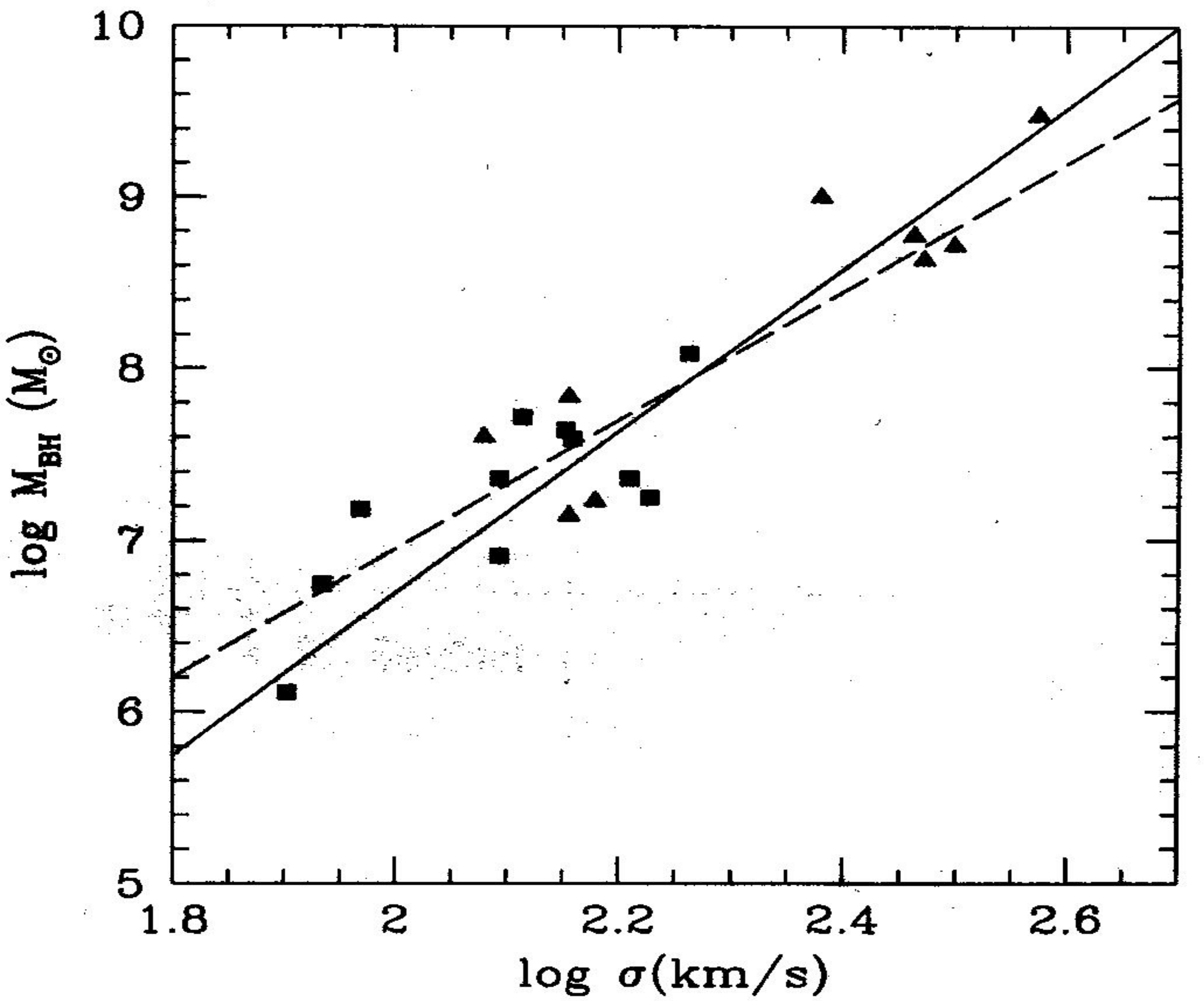
(Laor 2001,

Wu & Han 2002)


Correlation Between Black Hole Mass and Bulge Mass
Black hole mass
One billion solar masses
One million solar masses
No black hole
Increasing
Mass of central bulge

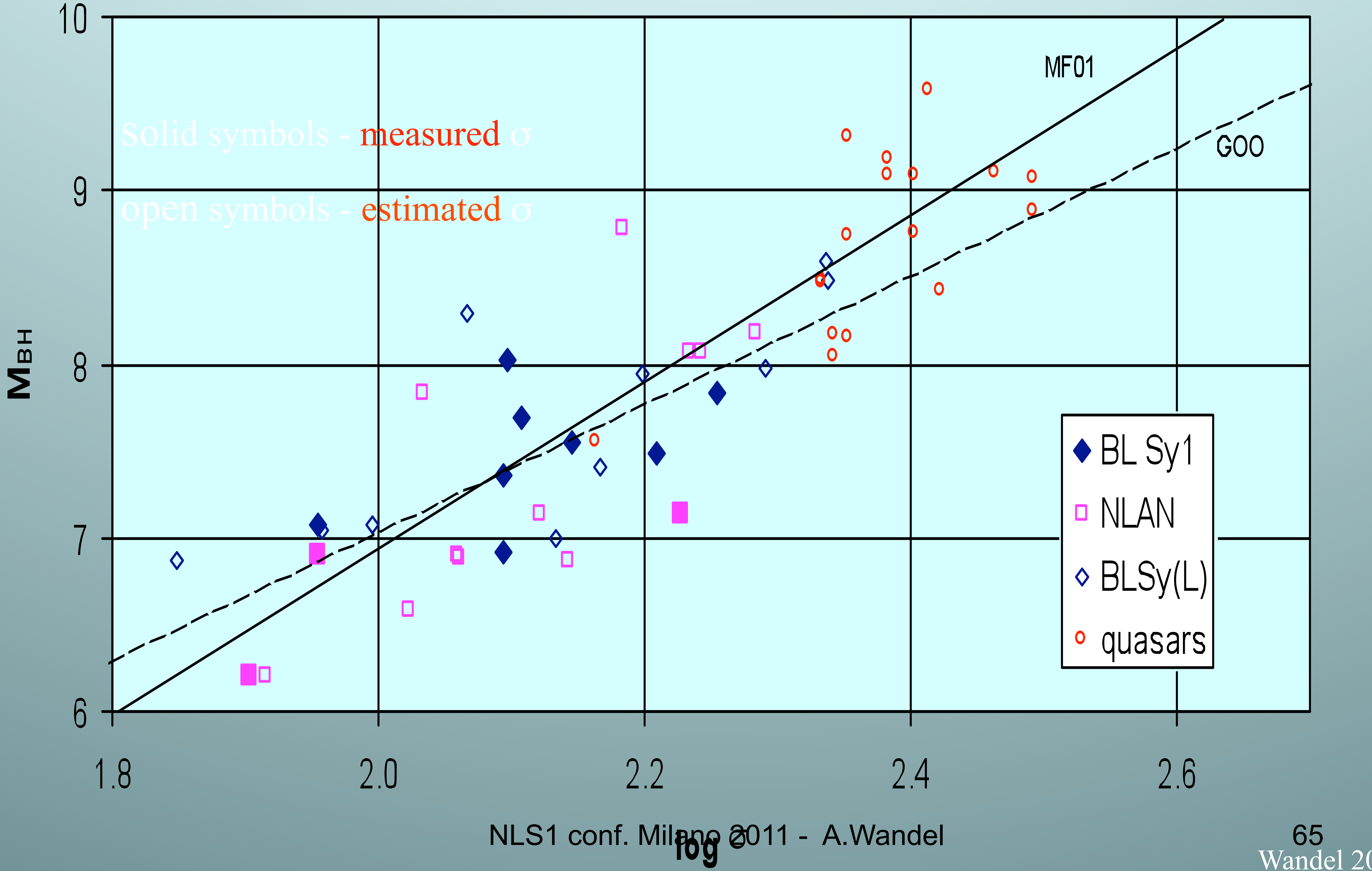
The BH mass - bulge velocity dispersion relation

for Seyfert galaxies (Wu & Han, A&A 2002)



The BH-velocity dispersion relation of AGN: $M_{BH} \sim \sigma^{4-5}$

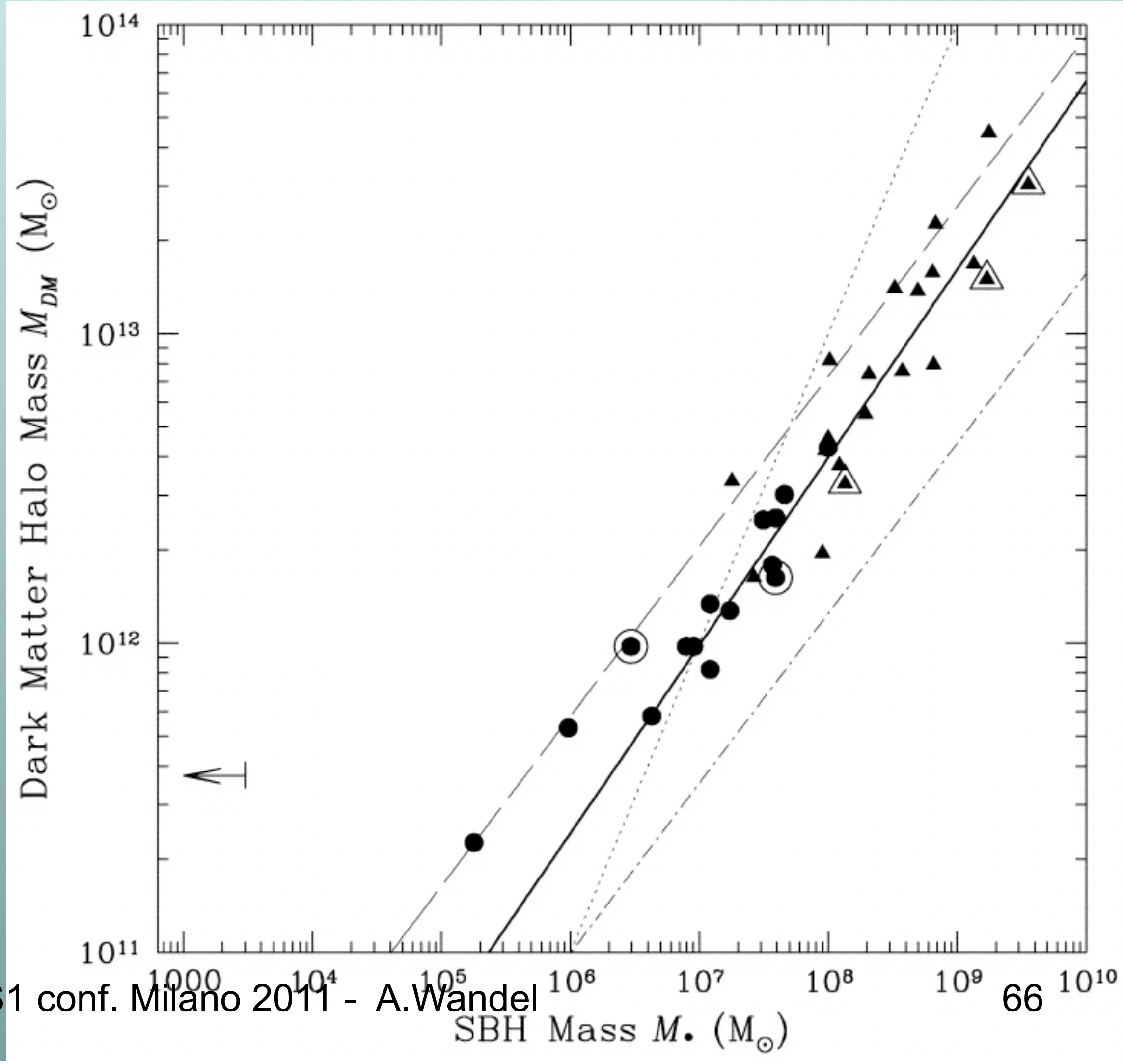
σ measured or estimated using the FJ relation



Wandel 2001

The Black Hole - Halo Relation

- The mass of central black holes is related also to the mass of the host halo (estimated from v_c; Ferrarese 2002)
- $M_{bh} \sim 10^{-5} M_{halo}^{5/3}$
- Does this originate in the formation proccess?



Possible explanation of R-M relation

* Interstellar gas in the core: $M_{gas} \sim L_{bulge}$

* The dynamical friction time scale:

τ_{df}=1.2 $r^2 v/\ln\Lambda$ GM $R_{blr}\sim$ dM/dt ~ M/τ ~ M^2

(assume week dependence on r,v)

* Empirical R-L relation: $R_{blr} \sim L_{agn}^{1/2}$

$\Rightarrow$ $R_{blr} \sim L_{bulge}$

* For a fixed efficiency: $L_{agn} \sim dM/dt \sim M_{blg}^2$