The Co-Evolution of Massive Galaxies and their Supermassive Black Holes over the past 12 Gyrs

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AGN: Populations, Parameters and Power
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The University of Nottingham

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OUTLINE

1. Introduction to SMBH and Galaxy Co-Evolution

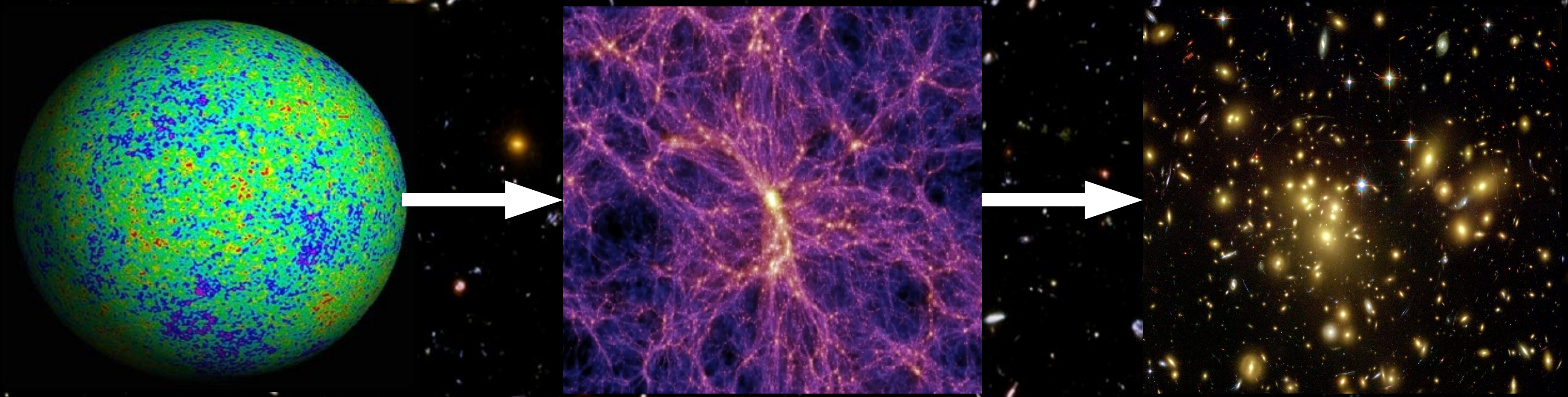
2. The Data: IR – X-ray studies

3. Results: - M_{BH} – M_{*} Evolution
   - The Lifetimes of AGN
   - The Active Fraction
   - Feedback Energy

4. Summary and Conclusions

1. Introduction to SMBH and Galaxy Co-Evolution

Galaxy Formation Paradigm



1. Density fluctuations form during Inflation
2. These grow due to the attractive potential of gravity
3. Dark Matter halos merge and increase their mass
4. Baryonic matter forms galaxies which grow within Dark Matter halos, via hierarchical assembly
5. At late times feedback from Supernovae and AGN shut off star formation and galaxies grow quiescent.

Spheres of Influence

Massive Galaxy sizes vary from 1 – 10 Kpc in size, with masses in the range $10^{10} - 10^{13}\ M_{sol}$

The Schwarzschild Radius of a Black Hole is Given by:

$$R_s = 2GM / c^2 \sim 1\ \text{AU}$$

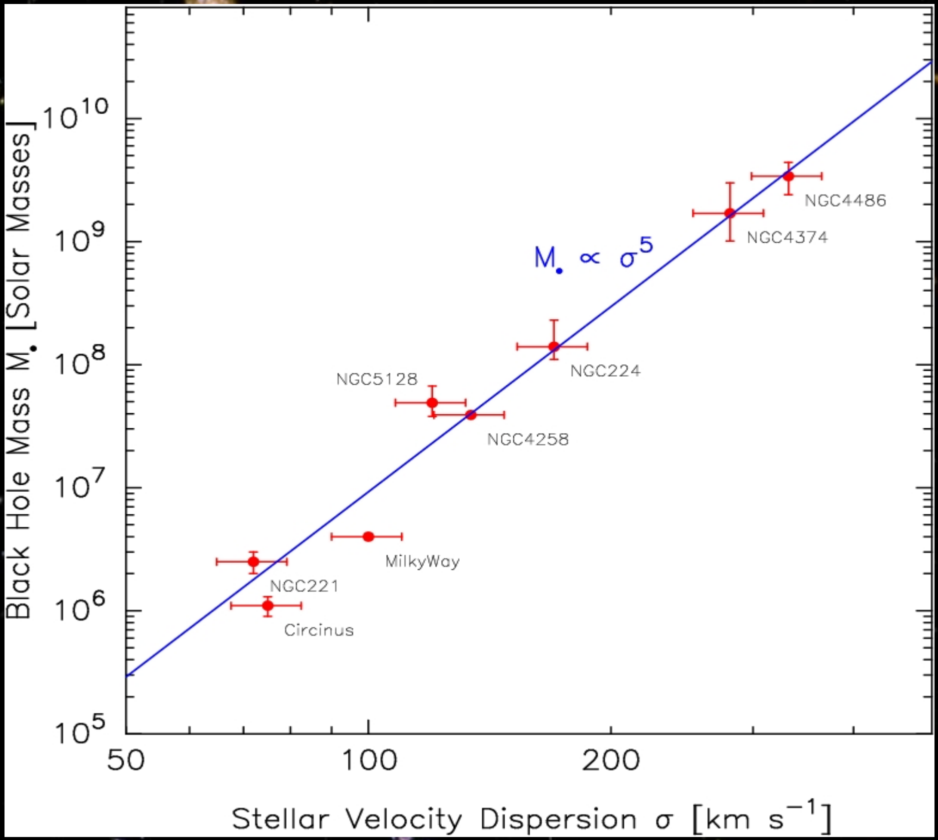
For the most massive SMBHs with $M_{BH} \sim 10^9\ M_{sol}$

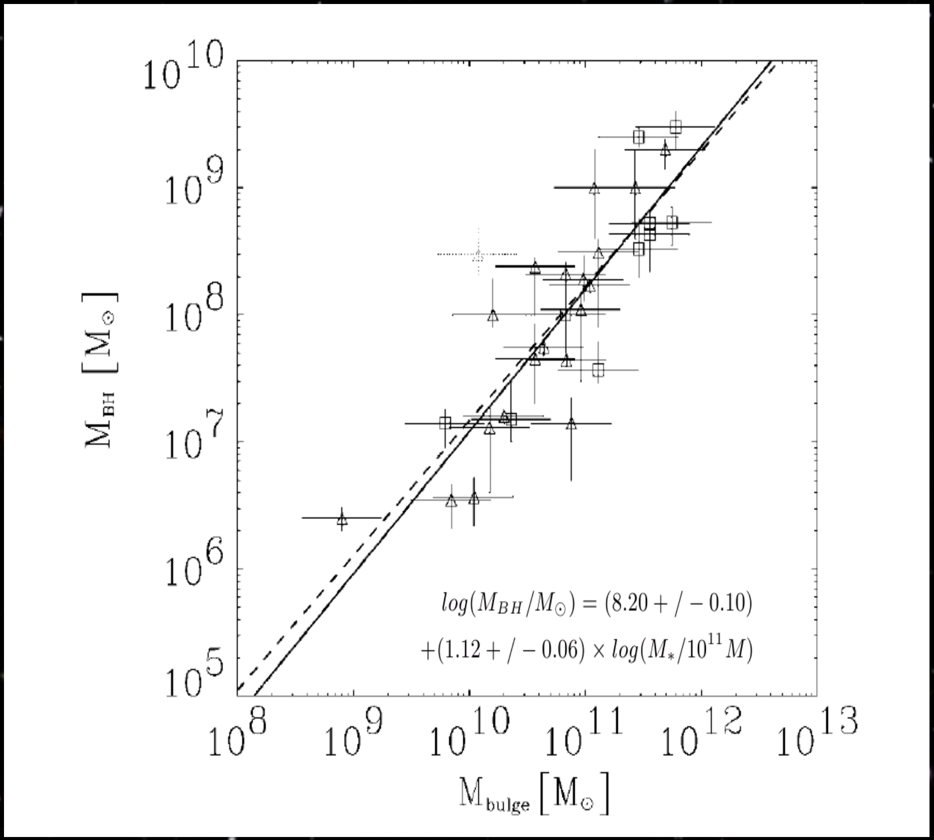
With accretion discs extending to at most a pc or so

Yet often $L_{AGN} >> L_{Gal}$

The Gebhardt-Magorrian Relation

The Local M_{BH} – M_* Relation





Magorrian et al. 1998

Haring & Rix 2004

2. The Data

The Fields

Wavelength	GOODS	EGS
Optical Photometry	HST ACS	CFHT Imaging
NIR Photometry	HST NICMOS	POWIR Survey
X-ray Data	CDF-N/S	AEGIS-X
Spectroscopy	VLT, Keck	VLT, Keck

Completeness

Mass : $M_* > 10^{10.5}\ M_{sol}$ to $z = 3$

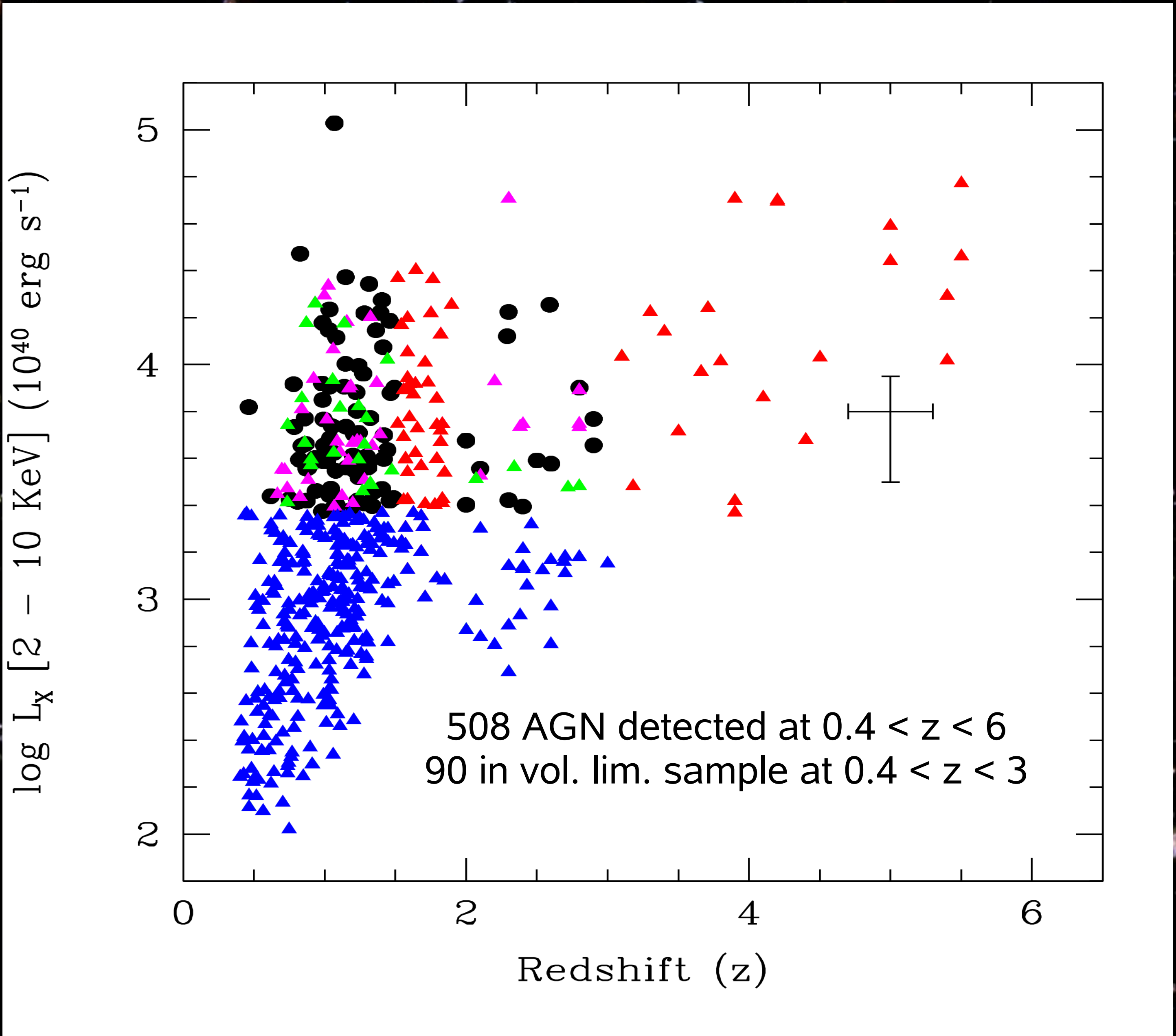
X-ray Luminosity: $L_X > 10^{43}$ erg s^{-1} to $z = 3$

For reduced GOODS and AEGIS areas:

~ 1/9 GOODS area covered

~ 1/4 EGS covered

AGN Volume Limited Sample

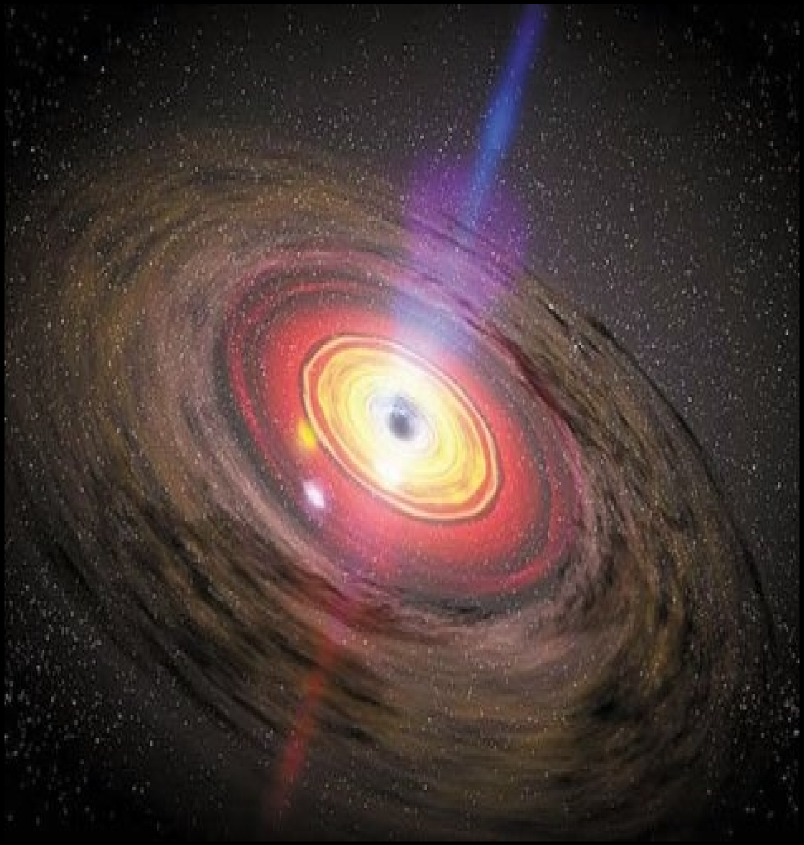


Bluck et al. (2010a, in prep.)

Calculating Minimum SMBH Masses

We adopt an Eddington Limit method.
This equates the inward force of gravity to the outward radiative force to obtain an expression linking the maximum luminosity of accretion to the BH mass, thus:

$$L_E = \frac{4\pi c G M \mu_e}{\sigma_T} = 1.51 \times 10^{38} \frac{M}{M_\odot} \mathrm{ergs}^{-1}$$



Which can be rearranged to give an expression for the minimum mass of a SMBH:

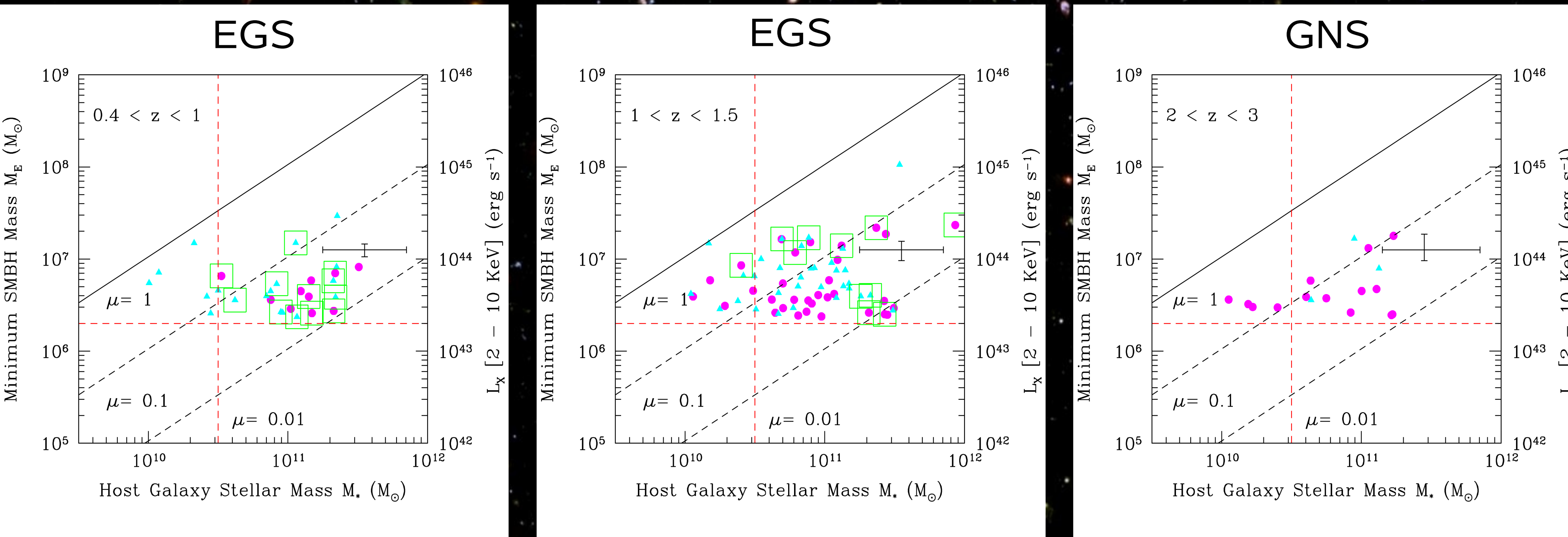
$$\frac{M_E}{M_\odot} = \frac{L_{Bol}(\mathrm{ergs}^{-1})}{1.51 \times 10^{38}}.$$

So the actual mass: $M_{BH} = M_E/\mu$

Where μ is the Eddington ratio of the SMBH.

3. RESULTS:
The Co-Evolution of SMBHs and Massive Galaxies

Evolution in the $M_{BH} - M_{*}$ Relation?

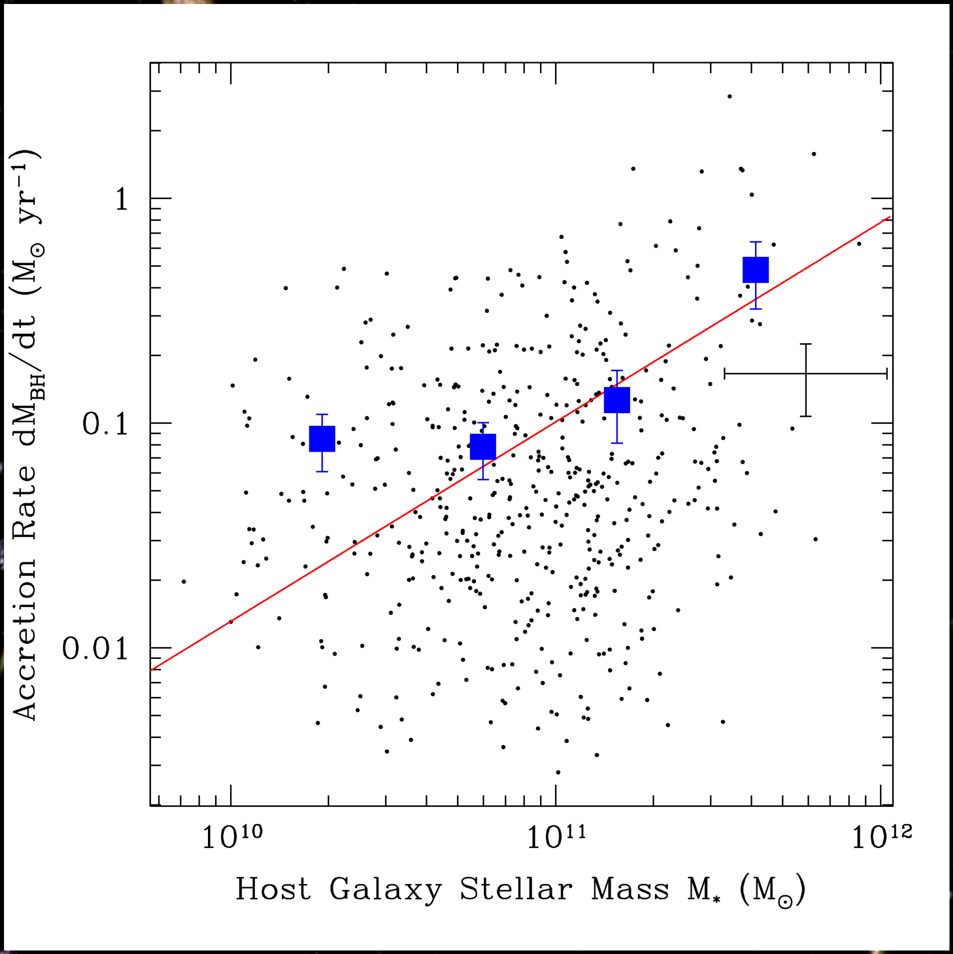


The fraction of SMBHs with $\eta > 0.1$ rises from ~ 10% at z = 0.4 to ~30 % at z = 2.5

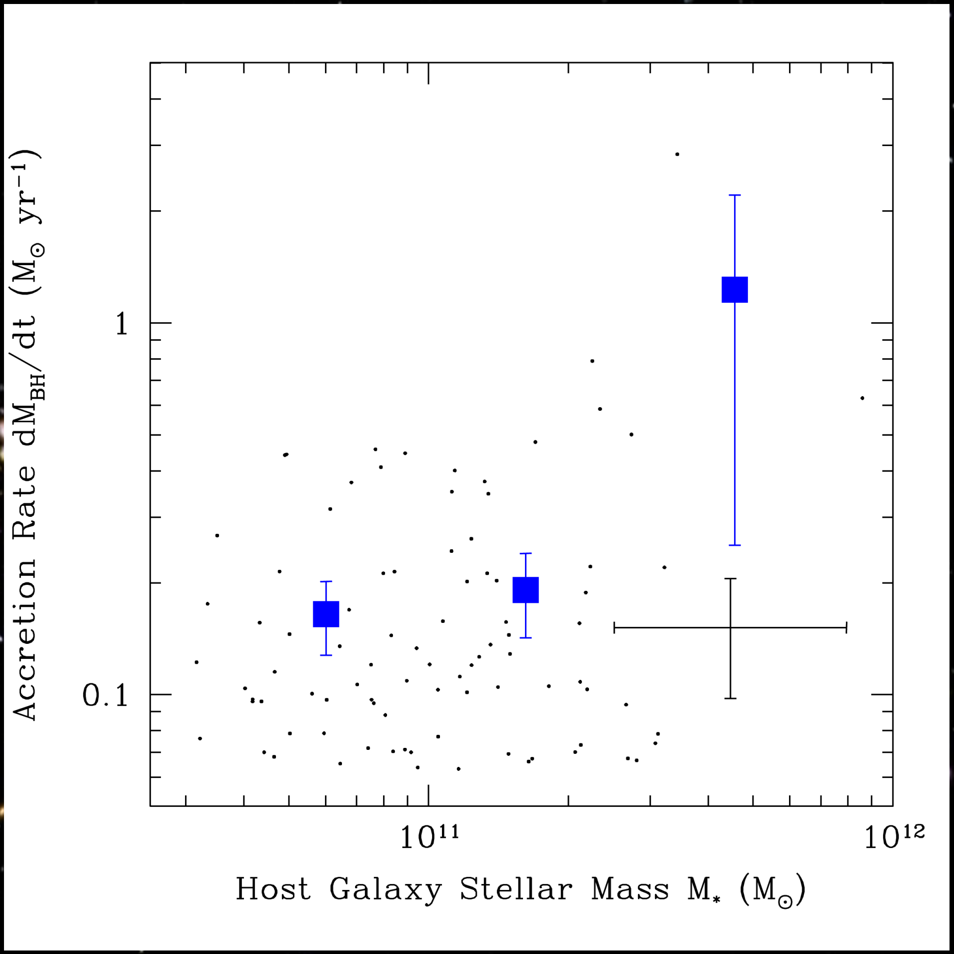
Conversely, if we assume no increase in η this leads to evolution in $M_{BH} - M_{*}$ of < a factor of 2, with M_{*} / M_{BH} ~ 700 at z ~ 2.5

Bluck et al. (2010)

Accretion Rate Dependence on Stellar Mass



All 508 Detected AGN



Volume Limited Sample

Bluck et al. (2010)

Lifetimes of AGN

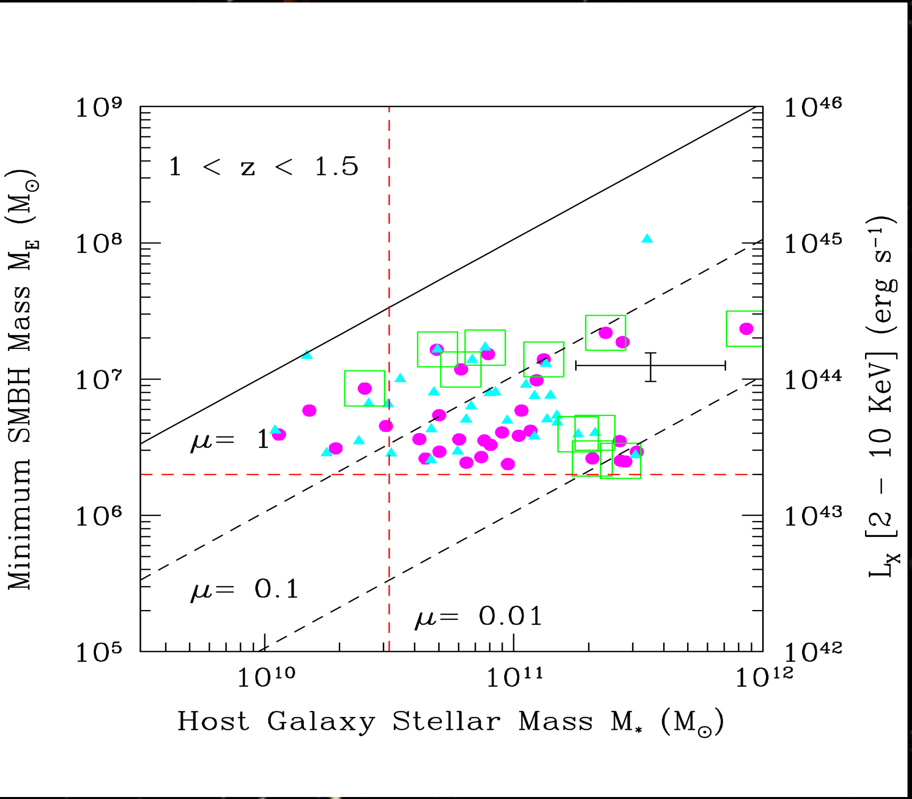
$$log(M_{BH}/M_{\odot}) = (8.20 + / - 0.10)$$
$$+(1.12 + / - 0.06) \times log(M_*/10^{11} M)$$

$\rightarrow M_* / M_{BH} \sim 1000$

Haring & Rix 2004

Lifetimes of AGN

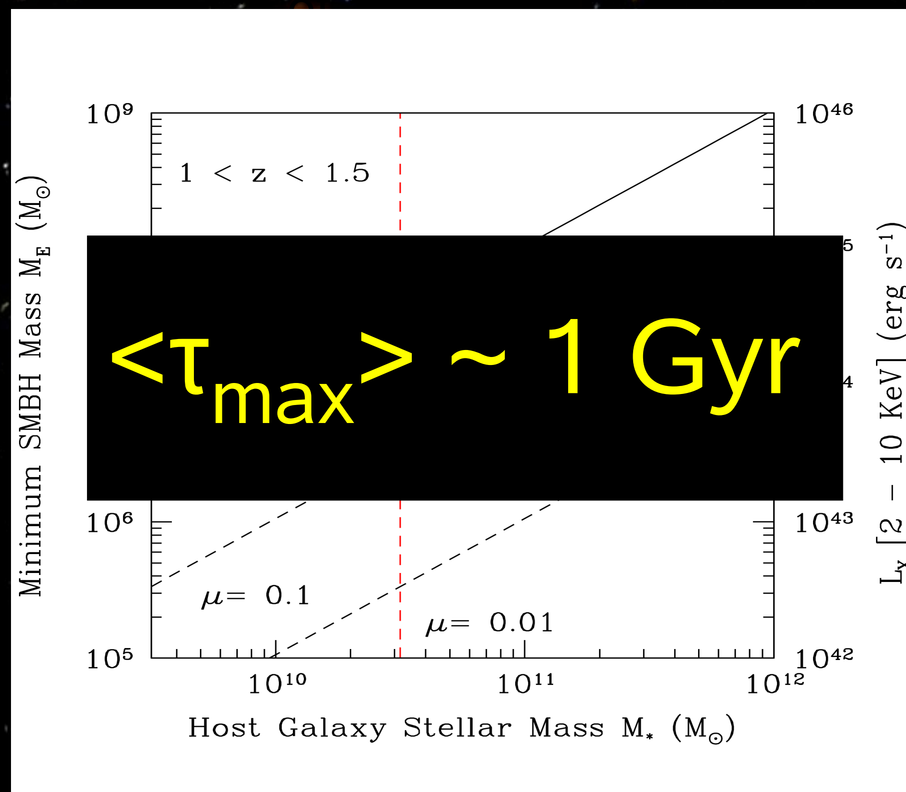
$$\log(M_{BH}/M_\odot) = (8.20 +/- 0.10) + (1.12 +/- 0.06) \times \log(M_*/10^{11} M)$$



$$\tau_{max} = \frac{M_{BH}(z=0) - M_{BH}(z=z')}{\dot{M}} \approx \frac{M_*/1000 - M_E}{\dot{M}}$$

Lifetimes of AGN

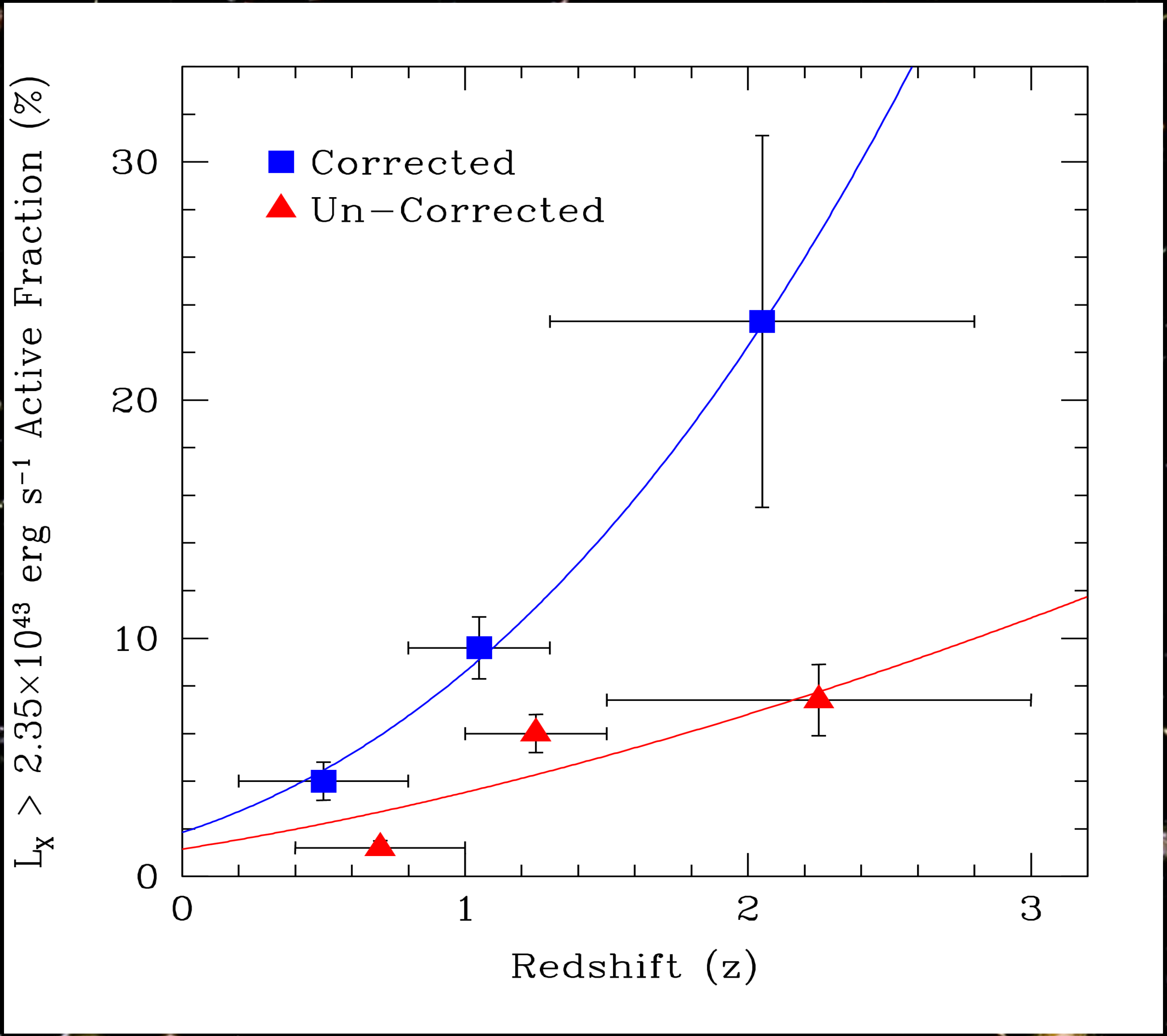
$$\log(M_{BH}/M_{\odot}) = (8.20 +/- 0.10) + (1.12 +/- 0.06) \times \log(M_*/10^{11} M)$$



$\langle \tau_{max} \rangle \sim 1$ Gyr

$$\tau_{max} = \frac{M_{BH}(z=0) - M_{BH}(z=z')}{\dot{M}} \approx \frac{M_*/1000 - M_E}{\dot{M}}$$

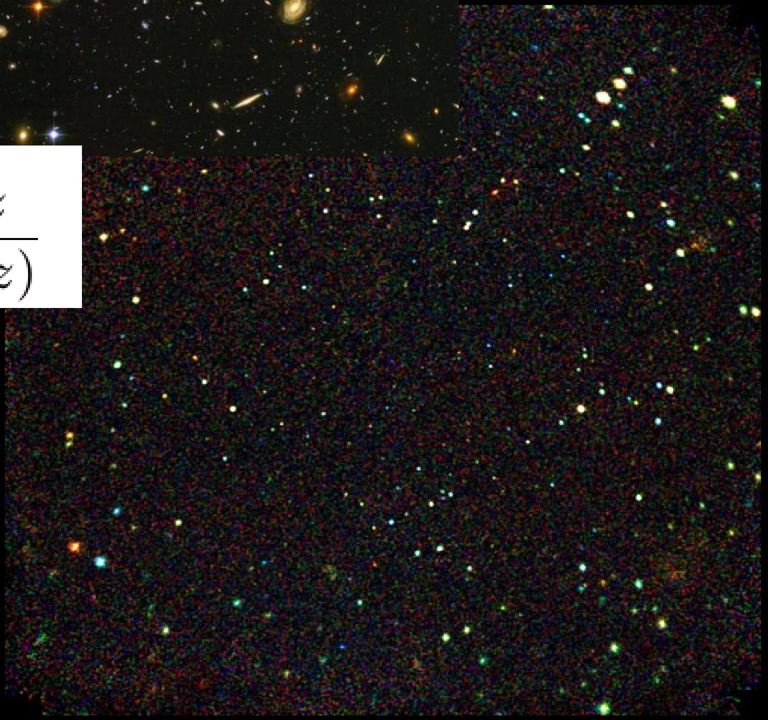
The Active Fraction



Bluck et al. (2010)

The Total Active Fraction Since z = 3

Using the parametrization of the evolution in $f_{AGN}(z)$, and the maximum lifetimes calculated we can compute a minimum value to the total fraction of Massive Galaxies that will be Seyferts or QSO's in the last 11.5Gyrs



$$F_{AGN} = \int_{t1}^{t2} \Gamma_{AGN}^{-1}(z)dt = \int_{z1}^{z2} \Gamma_{AGN}^{-1}(z)\frac{t_H}{(1+z)}\frac{dz}{E(z)}$$

$$\Gamma_{AGN}(z) = \frac{< \tau_{Max} >}{f_{AGN}(z)}$$

The Total Active Fraction Since z = 3

Using the parametrization of the evolution

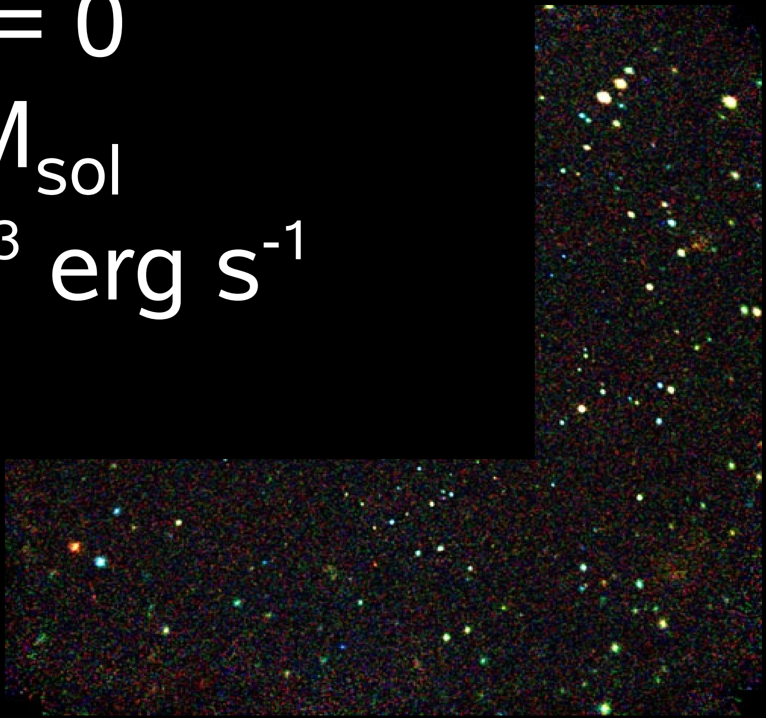
lifetimes
a minimu
of Massi
Seyferts

$F_{AGN} \geq 40$ +/- 10 %

from z = 3 to z = 0
for $M_* > 10^{10.5}$ M_{sol}
and $L_X > 2.35 \times 10^{43}$ erg s^{-1}

$$F_{AGN} =$$

$$\Gamma_{AGN}(z) = \frac{<\tau_{Max}>}{f_{AGN}(z)}$$



The Energy Output of AGN - Feedback

$$E_{AGN} = F_{AGN} \times < L_{Bol} > \times < \tau_{max} >$$

$$E_{AGN} = 1.4 \text{ +/- } 0.25 \times 10^{61} \text{ erg}$$

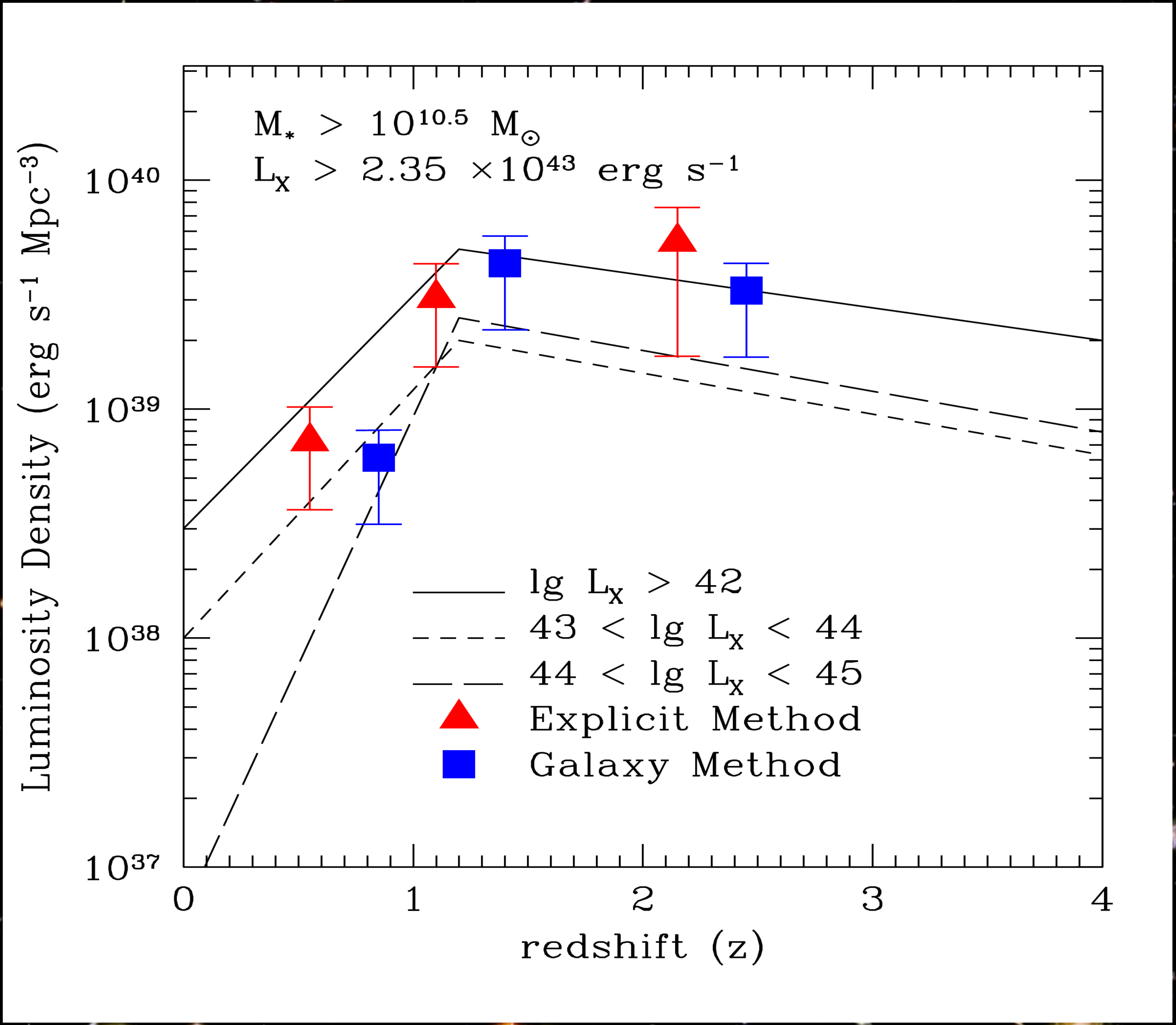
$$r = \frac{E_{AGN}}{V_{Gal}} \sim 35$$

$$V_{Gal} \sim M_{Gal} \times \sigma^2$$

The Energy Output of AGN - Luminosity Density

$$\rho_{AGN}(z_1 - z_2) = \frac{1}{V_S} \sum_{j=0}^{j=A_S} \sum_{i=z1}^{i=z2} L_X(i,j)$$

Massive Galaxy contribution to the XLF



Bluck et al. (2010)

4. Conclusions

1st statistically significant study of massive galaxies and their AGN at high redshifts

1. The Active Fraction of Massive Galaxies rises with redshift
2. Bright AGN lifetimes are typrically < 1 Gyr
3. The total fraction of Massive Galaxies that were active since $z = 3$ at Seyfert luminosities is > 40 %
4. The total energy output per galaxy, available as feedback, is $E_{feedback} > 35\ V_{gal}$
3. The local $M_{BH} - M_*$ relation does not evolve strongly with redshift with a maximum positive evolution of < factor of 2
4. Massive Galaxy Seyferts dominate the X-ray Luminosity Function

More details in:

Bluck et al. (2010), MNRAS in press [arXiv:1008.2162]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Additional Slides

THE GOODS NICMOS SURVEY

180 orbits HST program
NICMOS 3 camera F160W (H) band
Greatest coverage in other bands
60 pointings, 45 arcmin^2, > 8000 galaxies in total
Pixel scale 0.1", PSF ~ 0.3", Limiting mag. H = 26.8 (5σ)

81 galaxies $\geq 10^{11} M_{sol}$ at $1.7 \leq z \leq 3$
BzK galaxies (Daddi et al. 2007)
IRAC-selected Extremely Red Objects, IEROs (Yan et al. 2004)
Distant Red Galaxies, DRGs (Papovich et al. 2006)

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Pieter Van Dokkum
Meg Urry

- The University of Texas Austin

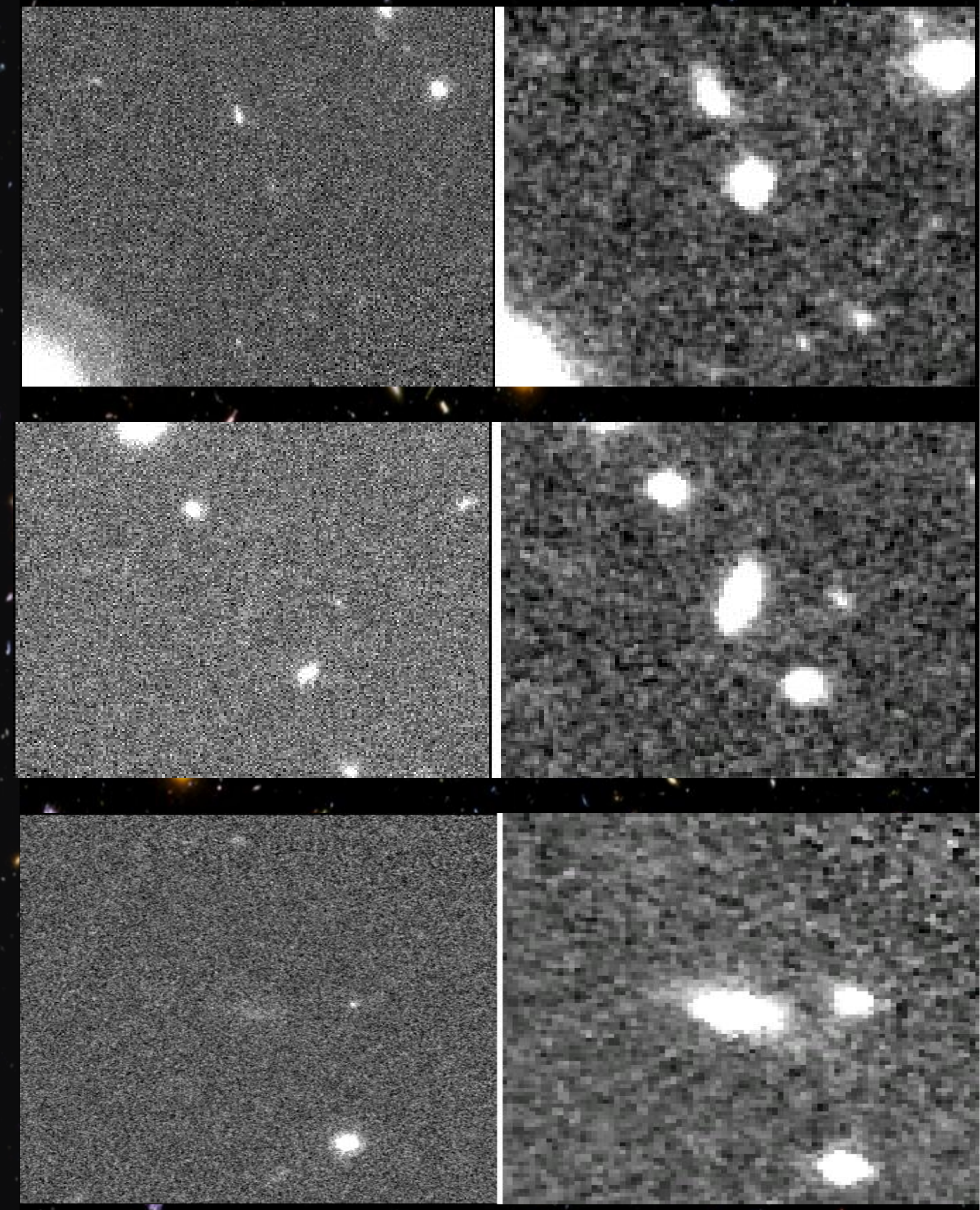
Shardha Jogee

New Light

To the right is an example of three of our sample of massive galaxies viewed on the left in ACS (rest-frame UV) and on the right in NICMOS (rest-frame optical).

It is clear that many galaxies are visible in the infrared which are invisible in the optical at high z.

In fact ~ 30 % of massive galaxies are detected only in GNS



Masses and Photometric Redshifts

Standard multicolor stellar population fitting techniques

Suite of filters: U, B, V, R, I, i, z, J, H, K_s

Uncertainties in mass: 0.2 dex

(Conselice et al. 2007)

SEDs constructed from Bruzual & Charlot (2003) models

Comparison with the observed SEDs

IMF: Chabrier (2003)

7 spectroscopic redshifts:

GOODS / VIMOS DR1 (Popesso et al. 2008) $\frac{\delta z}{1+z} = 0.026$

Compilation GOODS-S (Wuyts et al. 2008) $\frac{\delta z}{1+z} = 0.034$