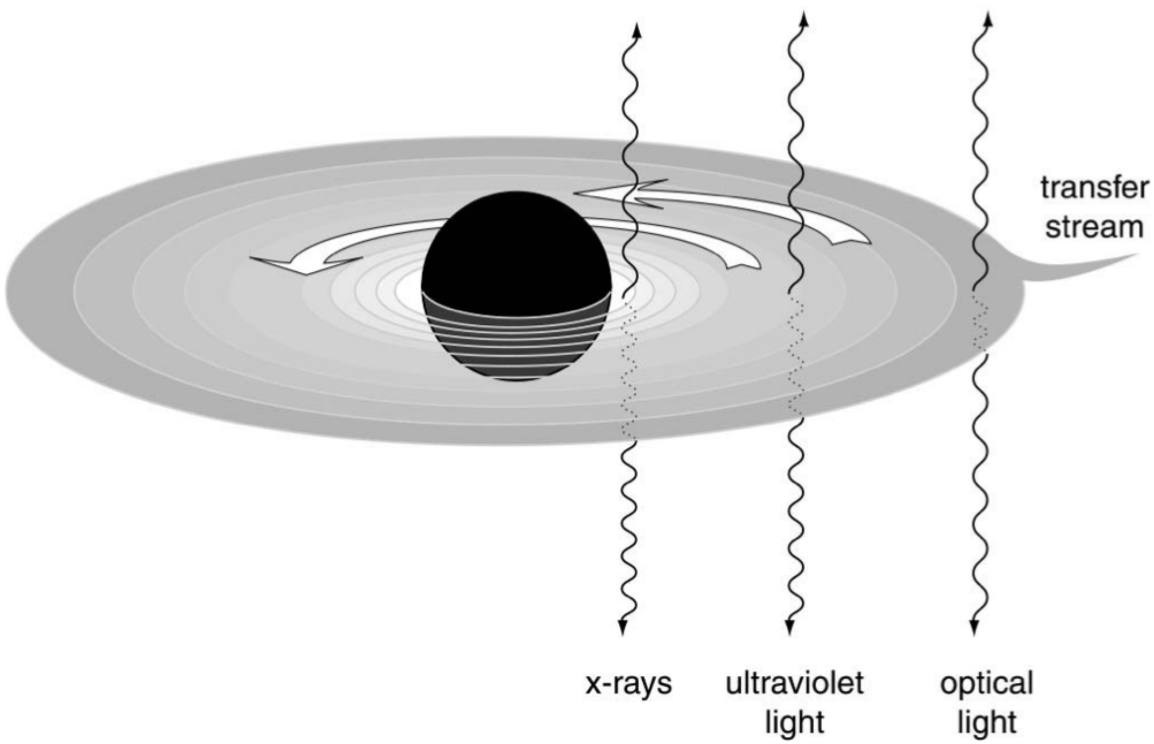
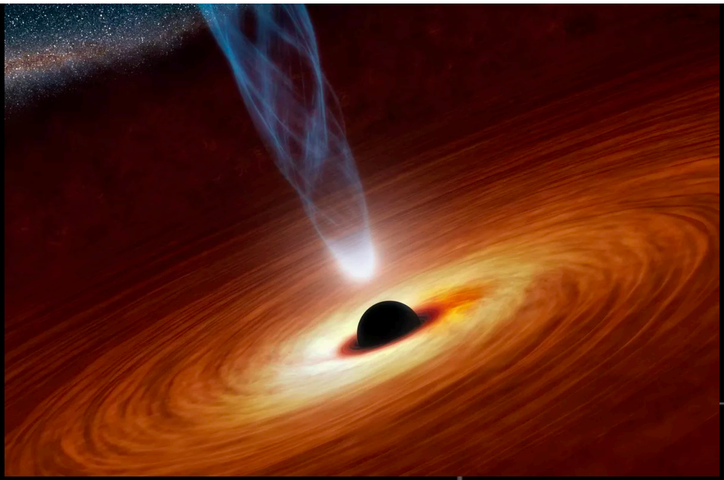
# Black Holes Masses

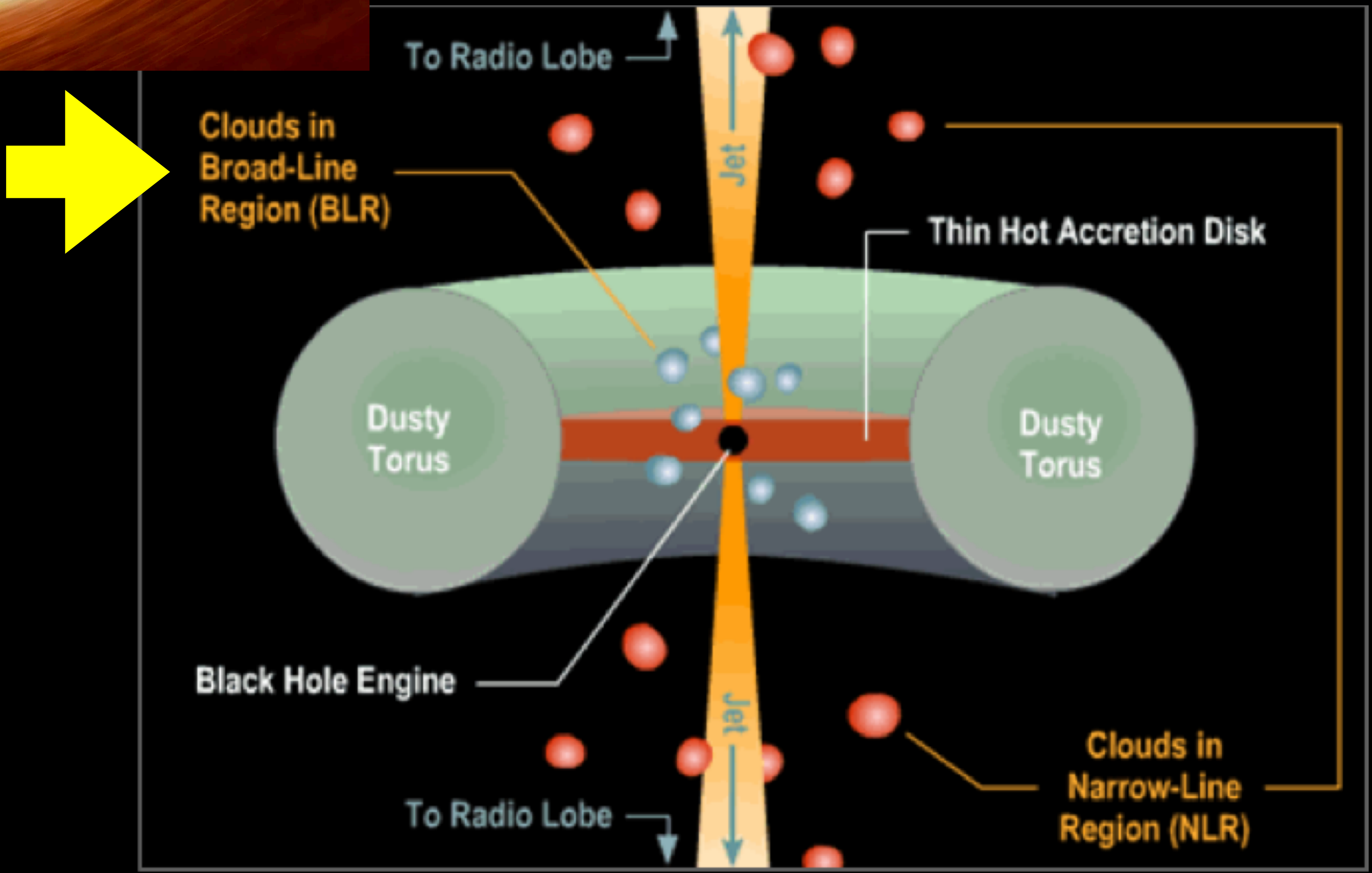
# Energy Release From Central Engines

Some of it will emerge as a mix of ***thermal emission*** from various parts of the accretion disk; some emerges as a ***non-thermal synchrotron emission*** from particles accelerated by the magnetic fields embedded in the accretion disk or the BH itself

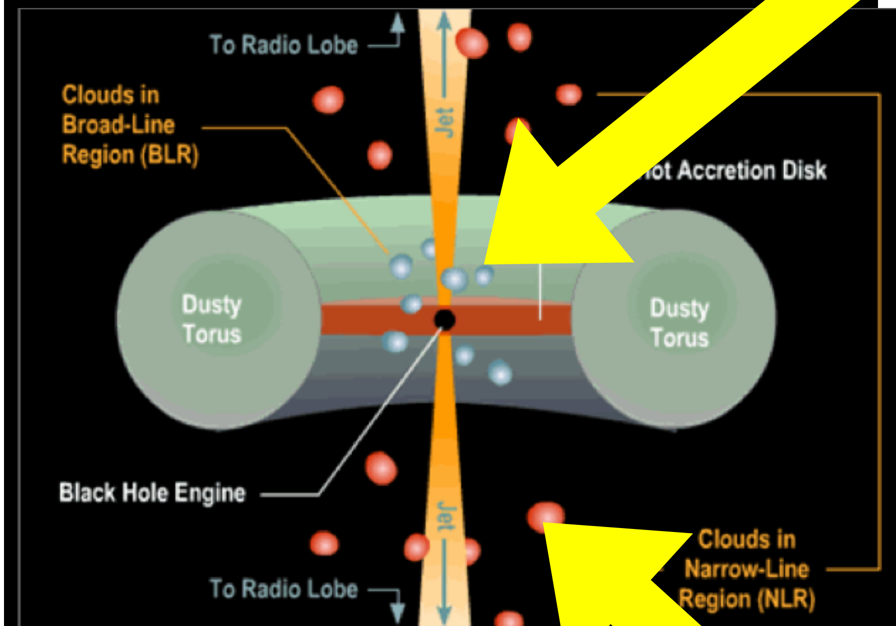


Unified Model for an actively accreting SMBH (Active Galactic Nucleus – AGN)

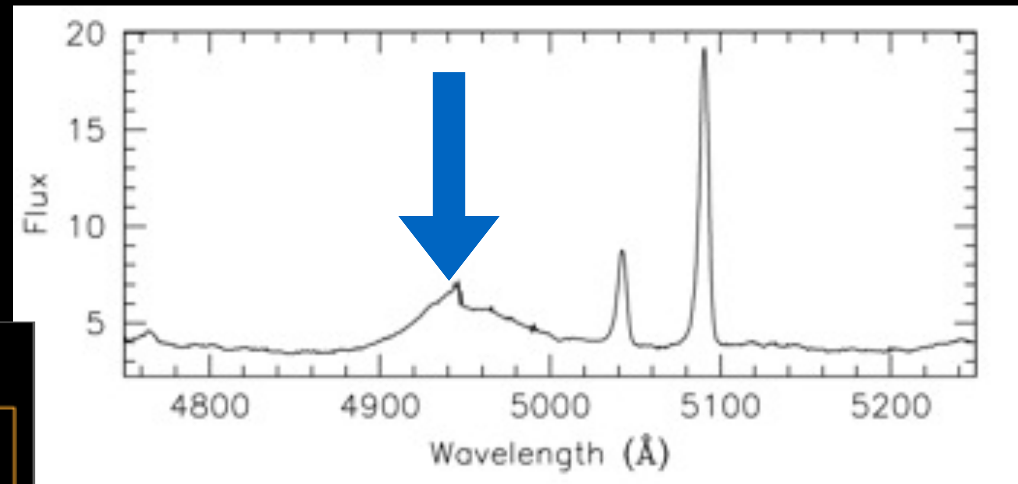




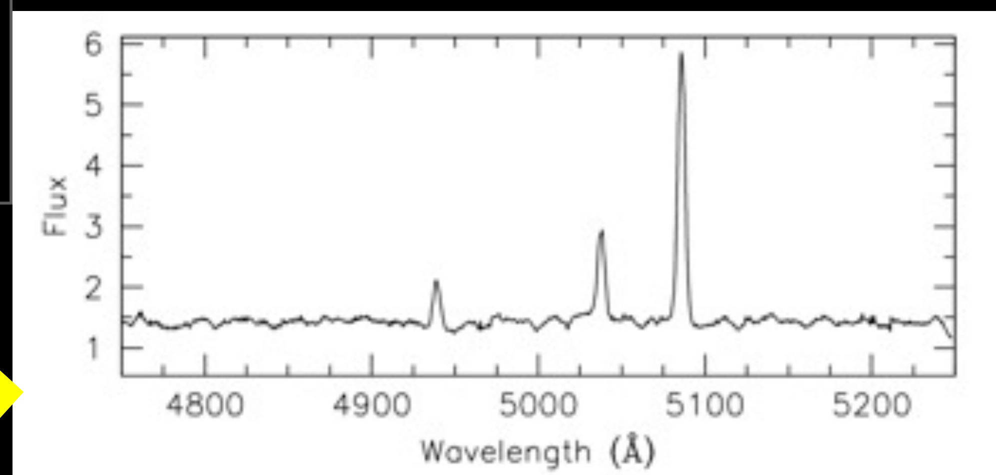

Brooks/Cole Thomson Learning



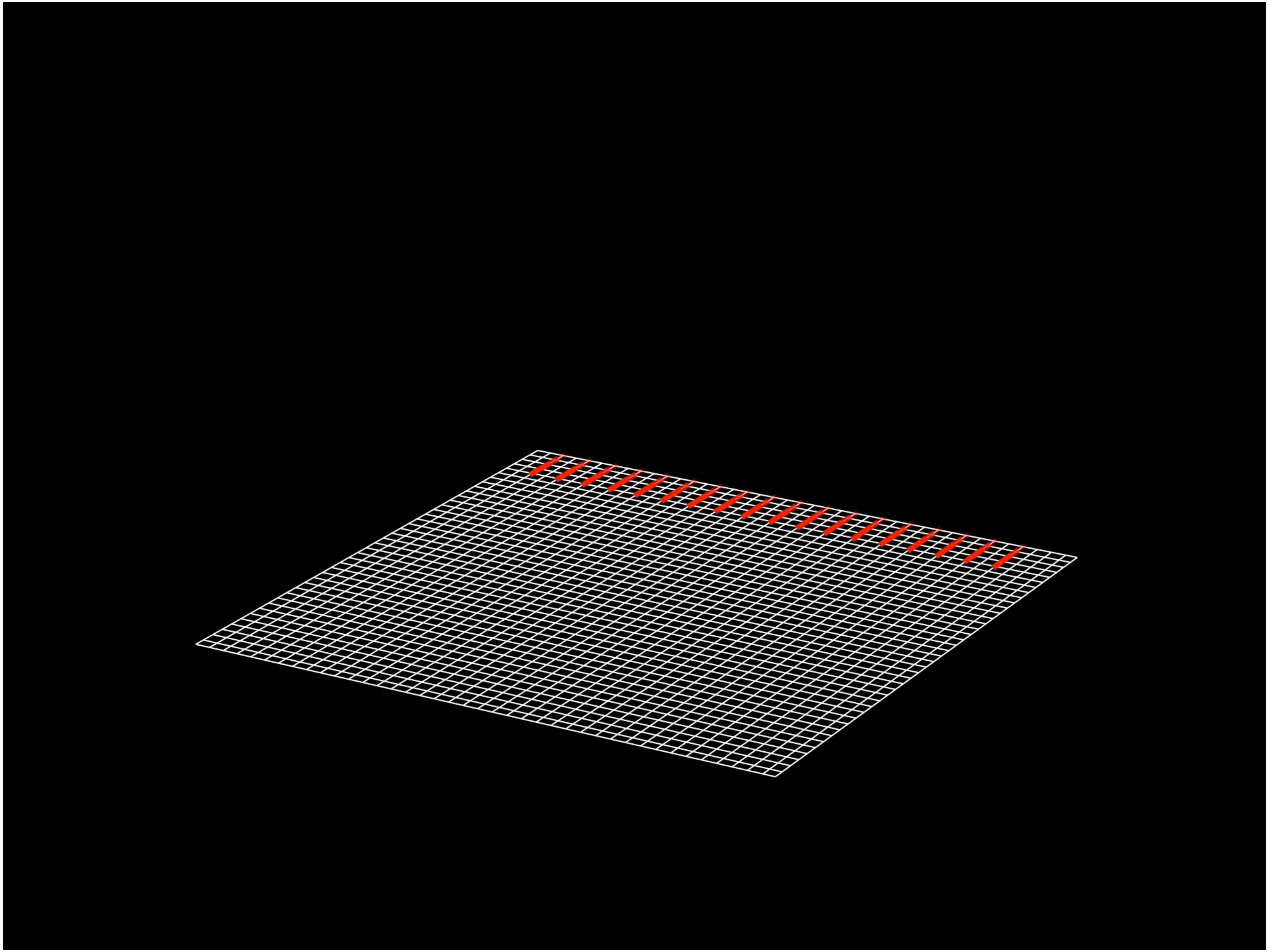

Brooks/Cole Thomson Learning




BLR ~ 0.02 – 0.1 pc
V ~ few $10^3$ km/s

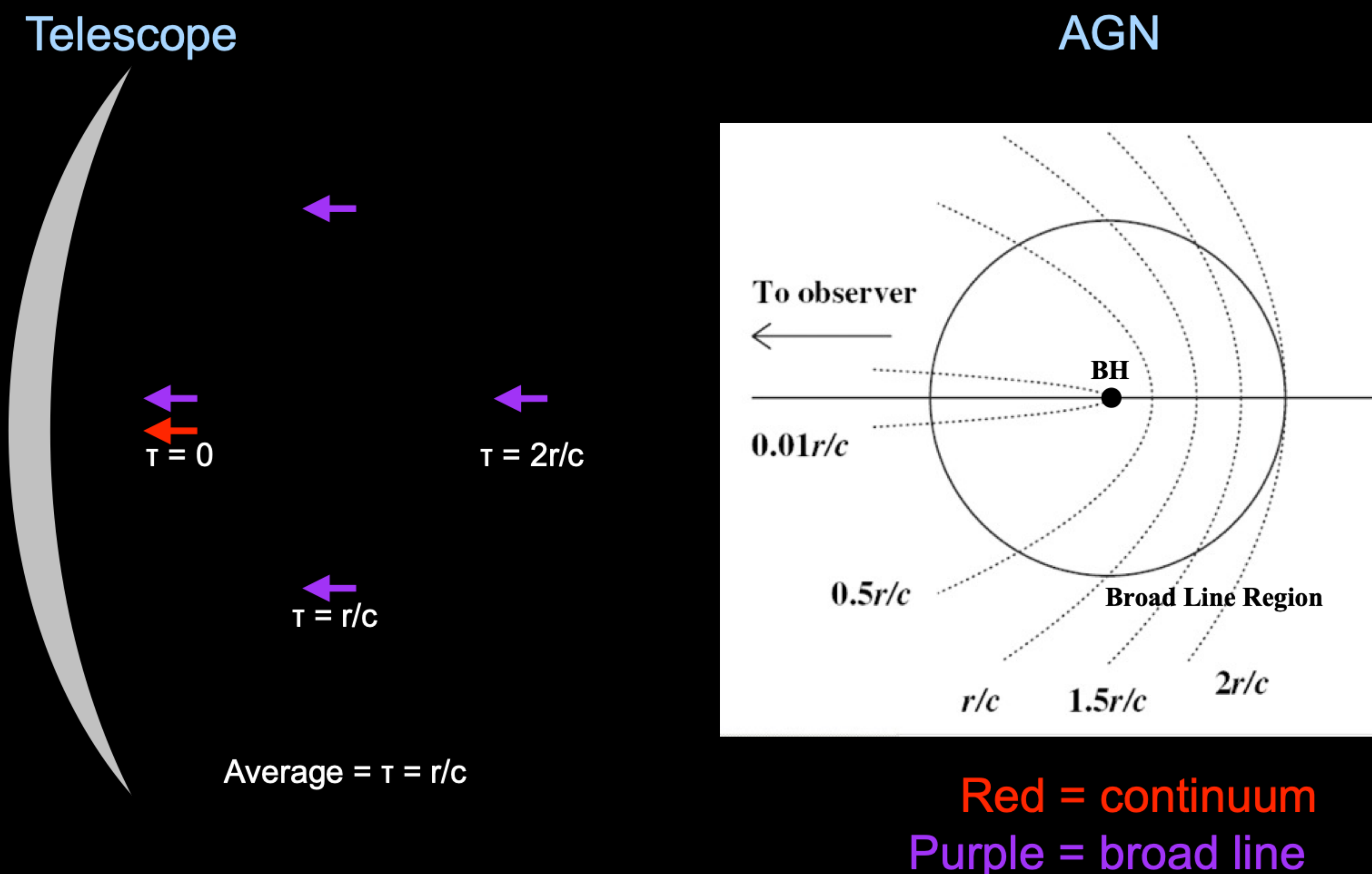


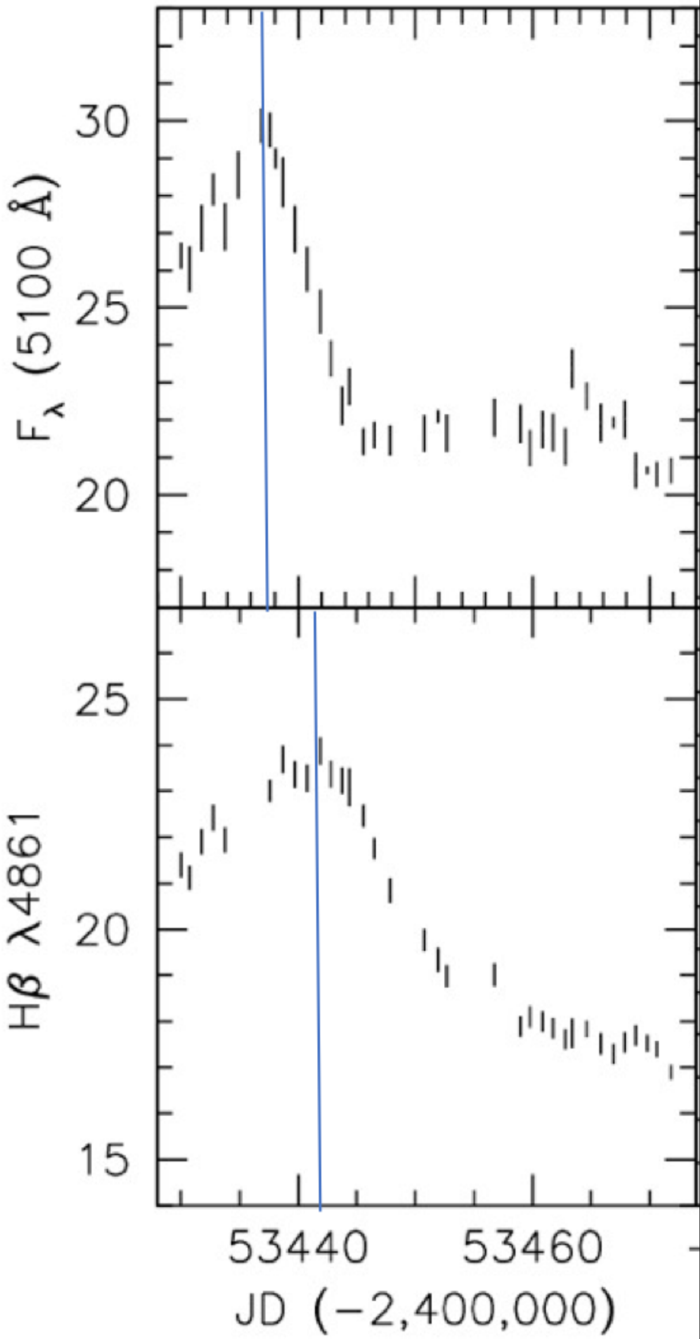

NLR 10 pc – 1 kpc
V ~ few x 100 km/s



# How we measure the mass of SMBHs: Reverberation Mapping

## Measuring the BLR Radius -- RM Cartoon



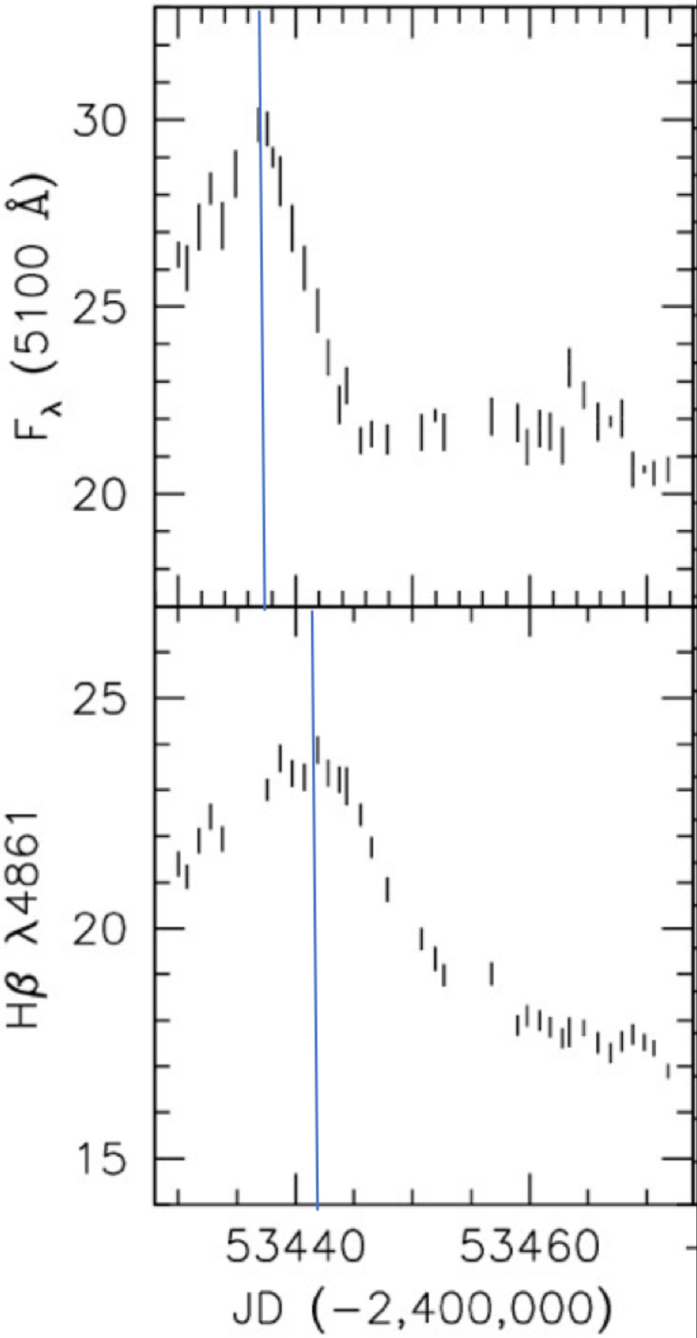



Temporal offsets between continuum and emission-line variability allow one to determine the distance from the BH to the broad emission line region (BLR)

Continuum emission comes from the inner disk and it is variable.

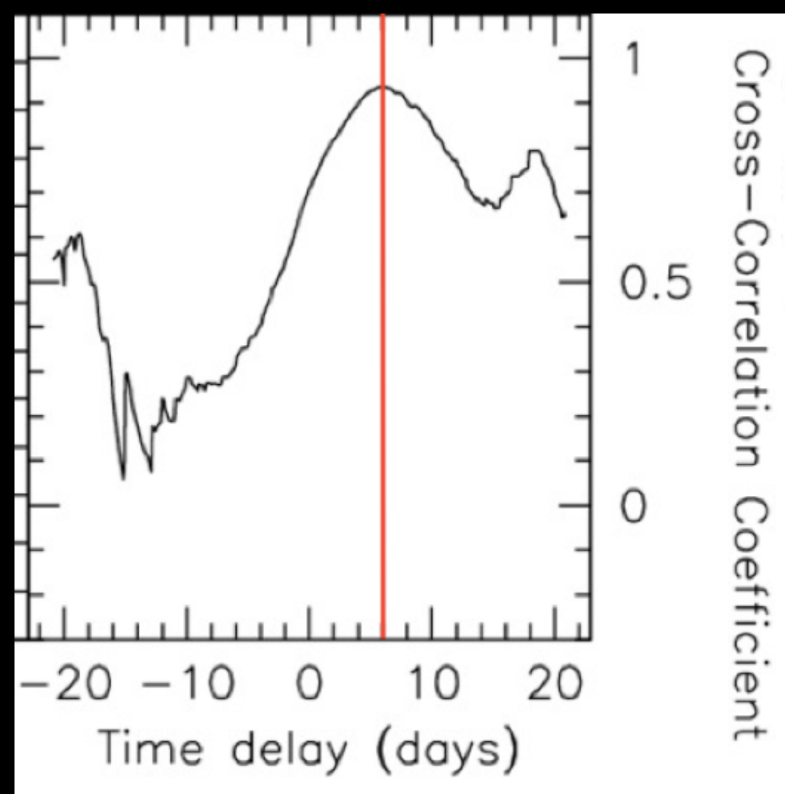
Broad Line Emission (gas clumps orbiting the SMBH) responds to this variability, but it is delayed.

The time delay tells us the size of the BLR




NGC 4151
The observable UV/optical continuum and ionizing continuum vary in phase.
(~ 6 days = r/c)

Bentz+2006



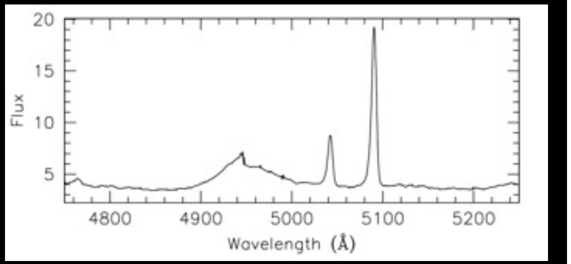
Then, assuming the gas clouds in the BLR are in virial equilibrium, the width of the emission line tells you the circular speed.

$$2K = -U \qquad V^2 = \frac{GM_{BH}}{fR} \qquad M_{BH} = fRV^2/G$$

Fudge factor for geometry of BLR $f = \sqrt{3/2}$

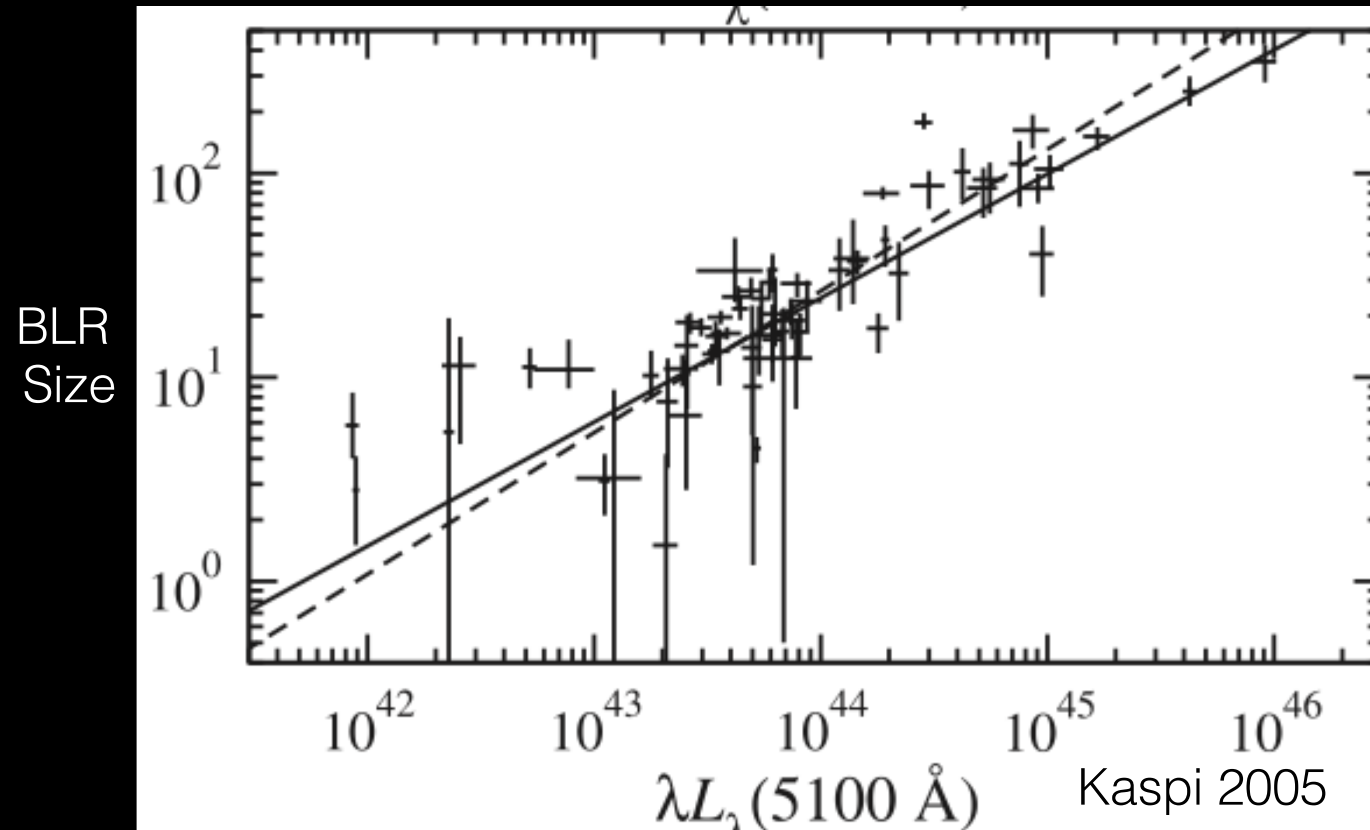
Radius of BLR from reverberation mapping

V from FWHM of emission lines (Hbeta, Mg II)



Correlation between BLR size, R, and luminosity of continuum

$R_{BLR} \;\alpha\; L^{0.5}$




$$\log\left(\frac{M_{\mathrm{BH,vir}}}{M_\odot}\right) = a + b\log\left(\frac{L_{5100}}{10^{44}\,\mathrm{erg\,s^{-1}}}\right) + c\log\left(\frac{\mathrm{FWHM}}{\mathrm{km\,s^{-1}}}\right)$$

a =0.91, b = 0.5, c = 2

Vestergaard & Peterson 2006, Feng + 2014, Shen + 2015

So can use this relation when can’t use reverberation mapping

# Kormendy & Ho 2013 Equations 6 and 7

## Magorrian Relation

$$\frac{M_\bullet}{10^9\ M_\odot} = \left(0.542^{+0.069}_{-0.061}\right)\left(\frac{L_{K,\mathrm{bulge}}}{10^{11}\ L_{K\odot}}\right)^{1.21\pm0.09}$$

## $M_{bh}$-σ Relation

$$\frac{M_\bullet}{10^9\ M_\odot} = \left(0.309^{+0.037}_{-0.033}\right)\left(\frac{\sigma}{200\ \mathrm{km\ s^{-1}}}\right)^{4.38\pm0.29}$$

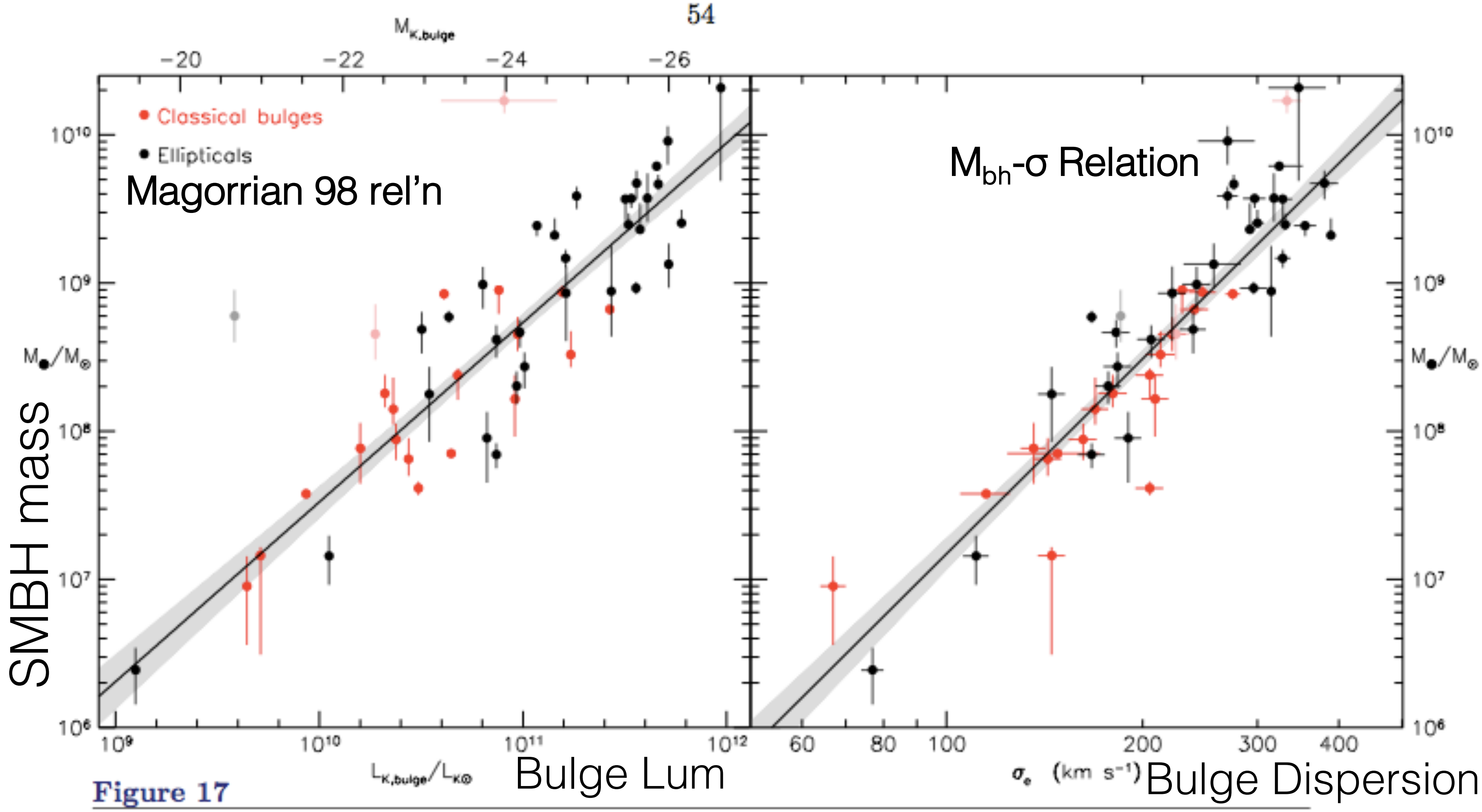
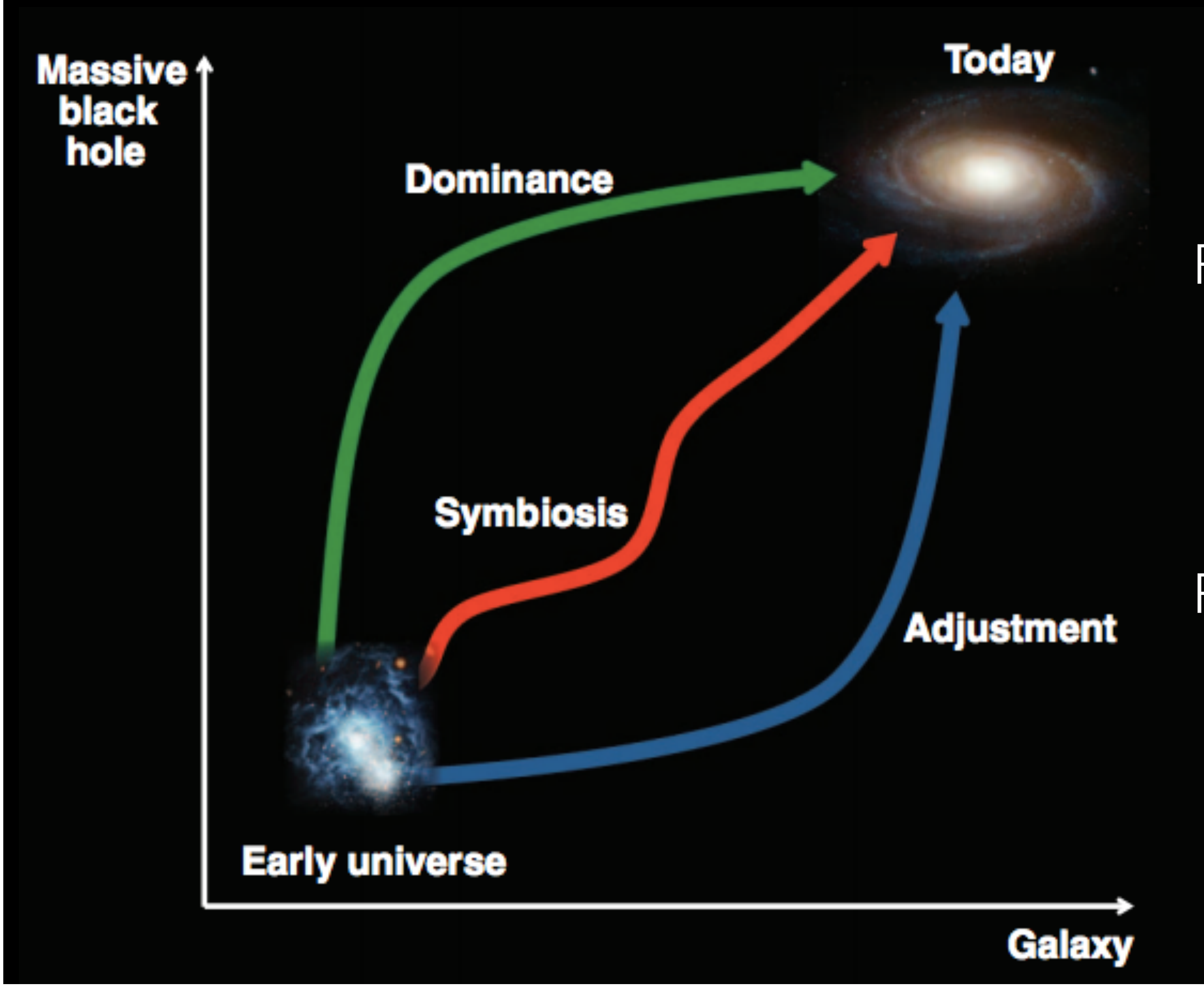


Figure 17

M-sigma / Magorrian relations indicate that the growth of SMBHs and their galaxy hosts are related



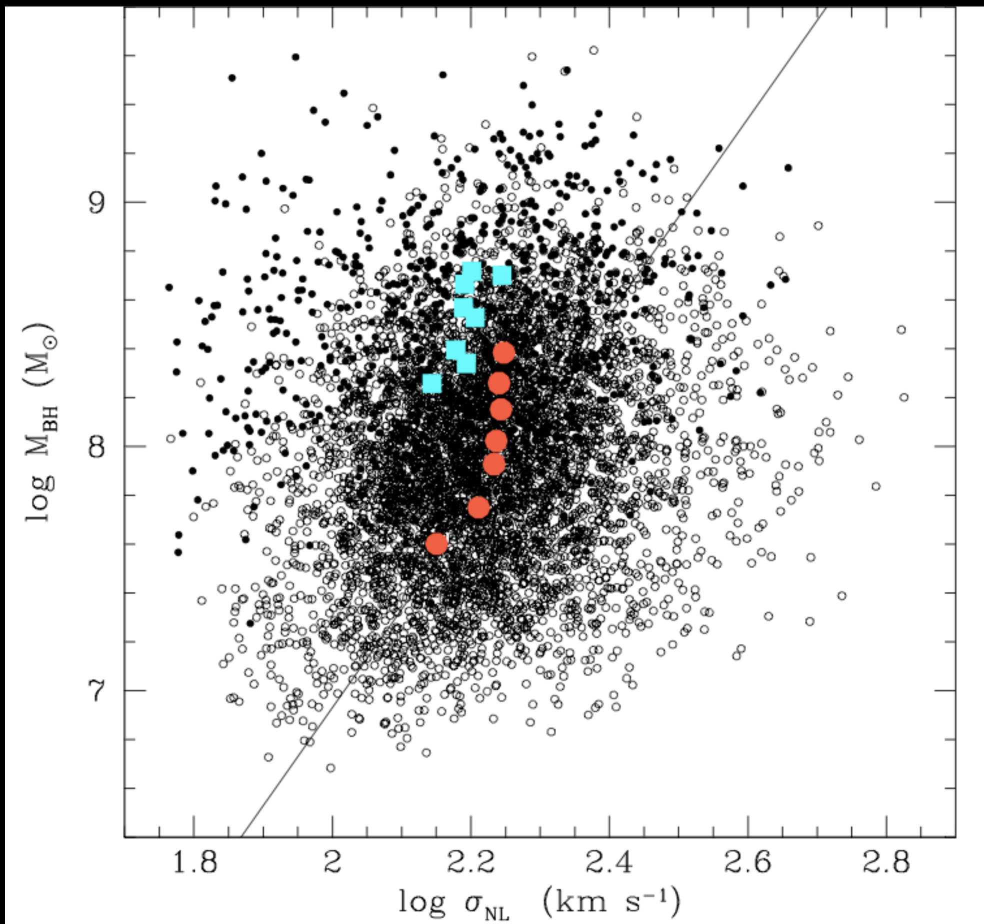

Halo Regulated?

And/Or

Black Hole Regulated?

# Dominance?

Salviander 2013 SDSS DR7




Line is the local relation from Tremaine 2002

Colored points are average $M_{BH}$ and σ per redshift bin

Blue : 0.1 < z < 0.8
Hβ for $M_{BH}$, OIII for σ
open circles

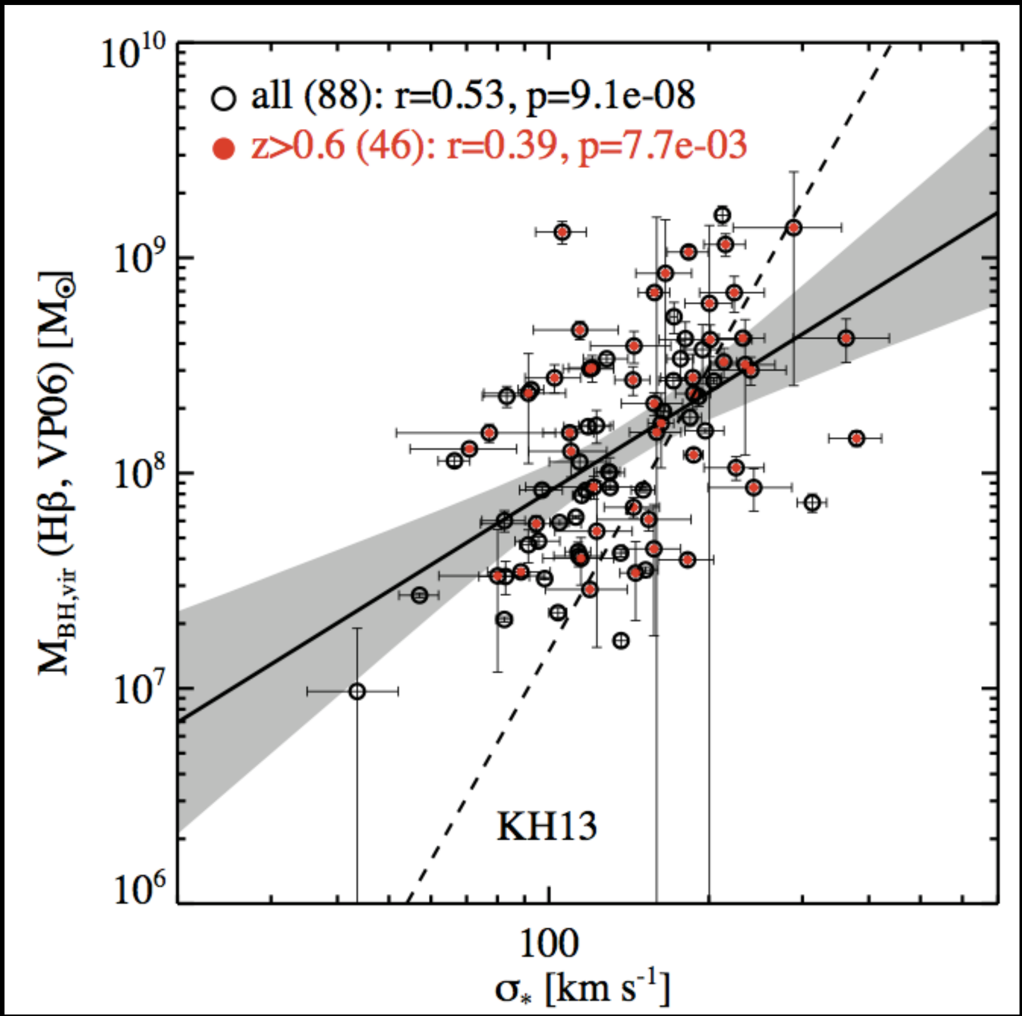
Red : 0.4 < z < 1.35
Mg II for $M_{BH}$ , OII for σ
closed circles

Suggest positive evolution (BH growth precedes that of bulge)

Bulge dispersion from the narrow line emission width

# Adjustment? SDSS Reverberation Mapping project

- $0.1 < z < 1.09$
- Spectroscopically monitor 88 QSOs with the SDSSIII BOSS spectrograph
- New $\sigma_*$ measurements – decomposed spectra into host and QSO
- Relation *does* exist at z~1
- Slope is much shallower than local relation - bias
- No strong evolution with redshift, but the relation may get flatter at higher z




Shen + 2015

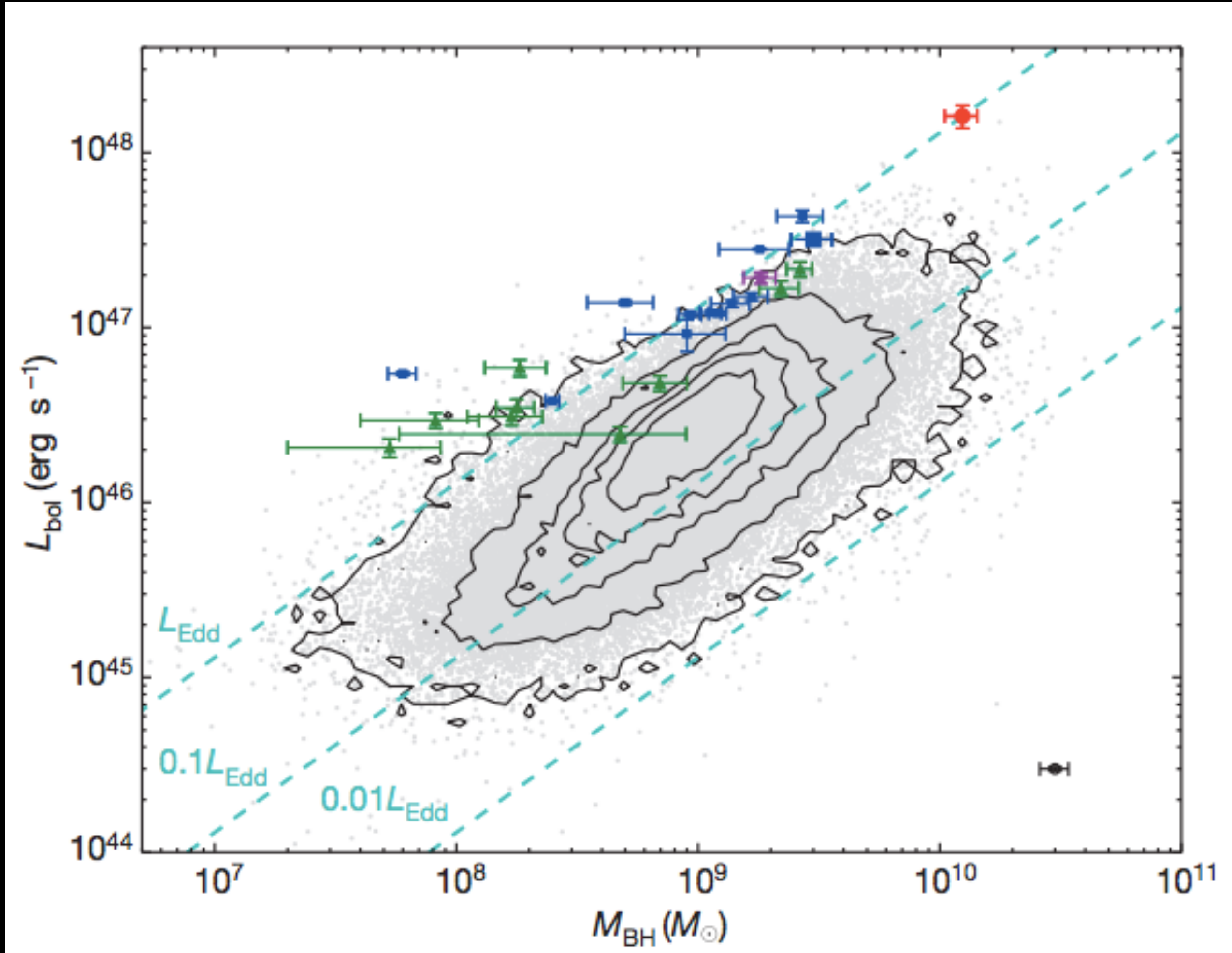
# Most massive SMBH at z ~ 6.3

$M_{bh}$ = (1.24 +/- 0.19) x $10^{10}$ M⊙    Wu + 2015

Isn't super high z, but *much more massive* than other high z SMBHs.

Most massive SMBH we know of at any redshift is ~ 7e10 Msun

(TON 618 z~2)



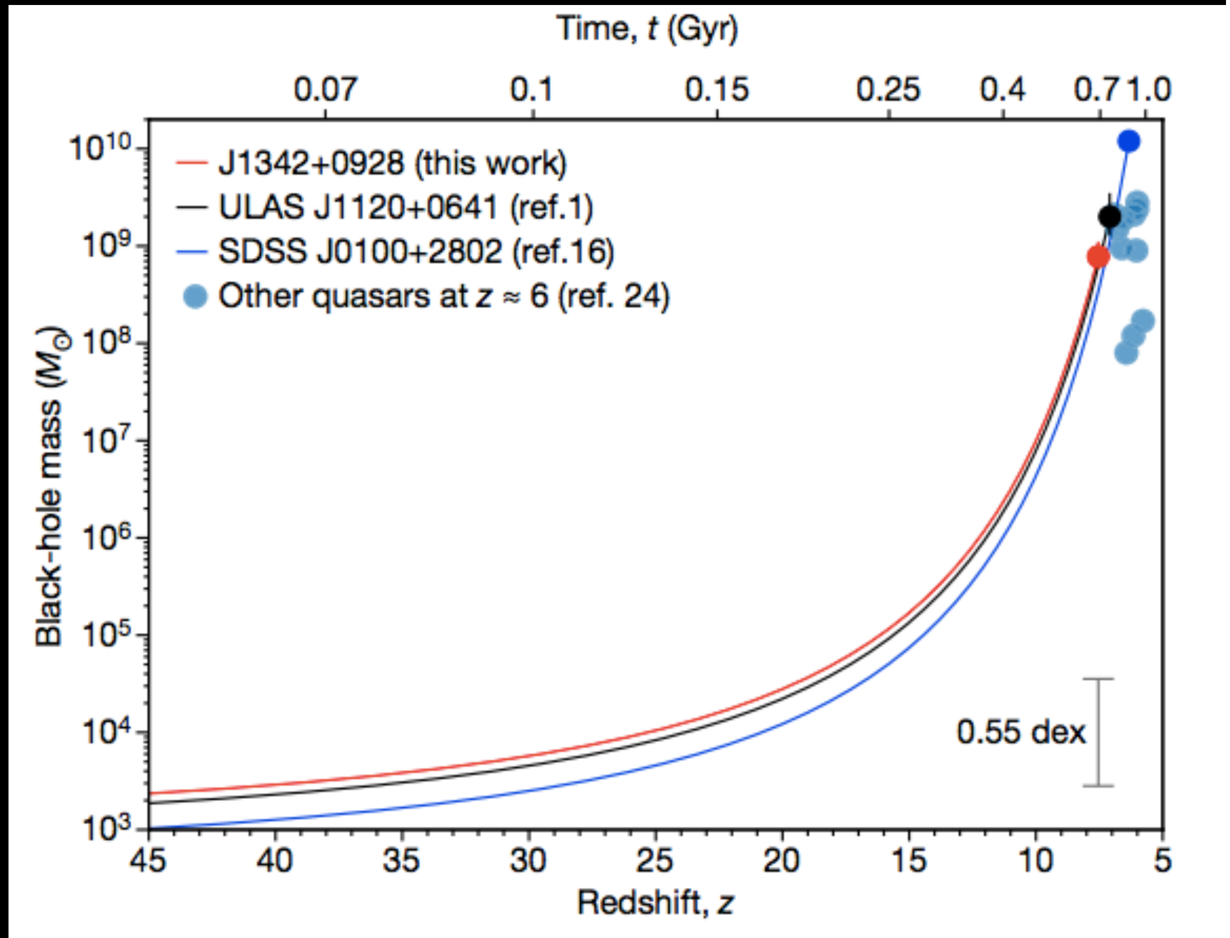
# Highest redshift SMBHs

The black-hole growth is modelled as

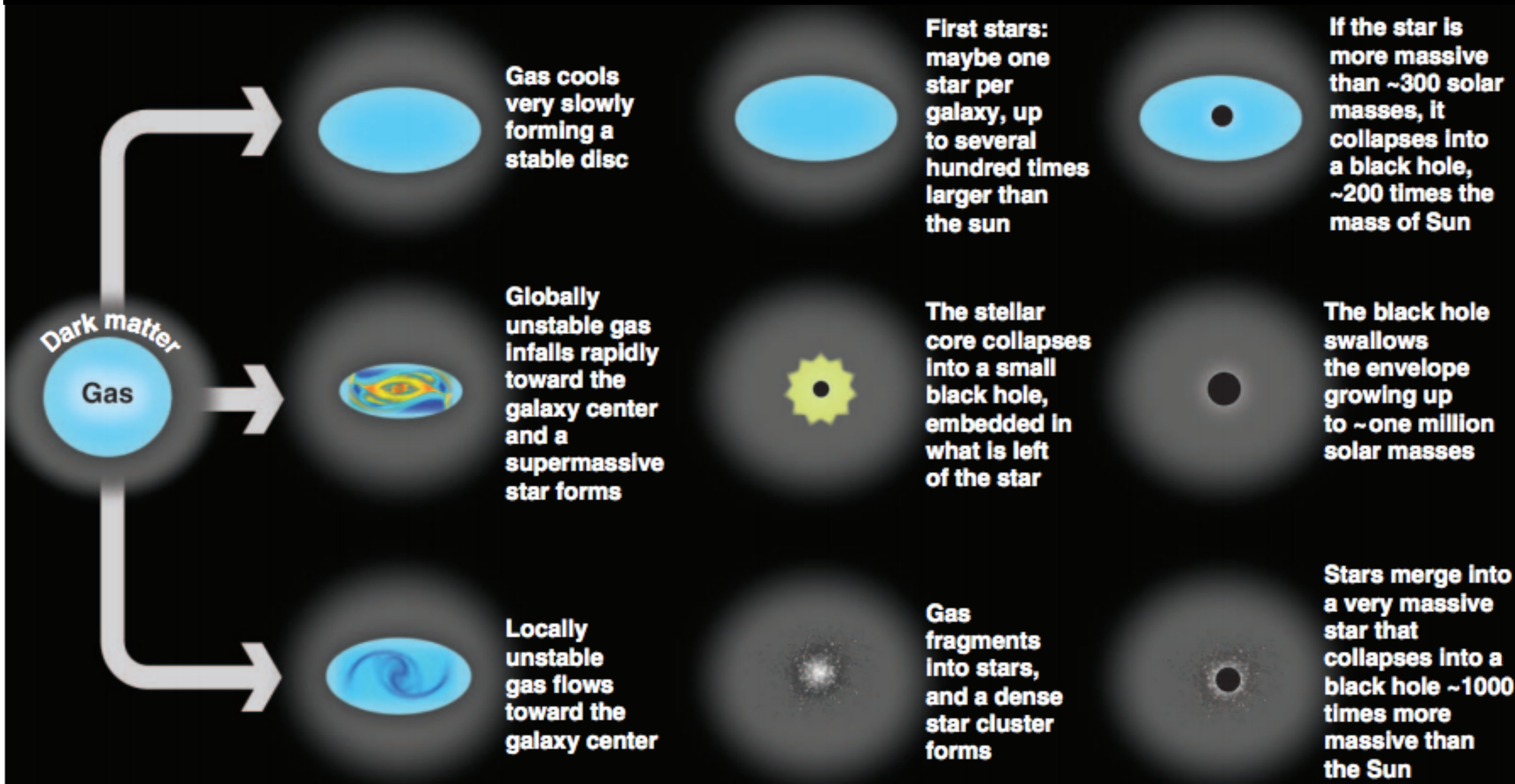
$M_{BH}=M_{BH,seed} \exp[t/(50\mathrm{Myr})]$,

where t is time and the black holes are accreting at the **Eddington limit** with a radiative efficiency of 10%.

Blackhole seeds more massive than 1,000M⊙ by z=40 are necessary to grow the observed supermassive black holes in all three cases.



# Origin of SMBH Seeds



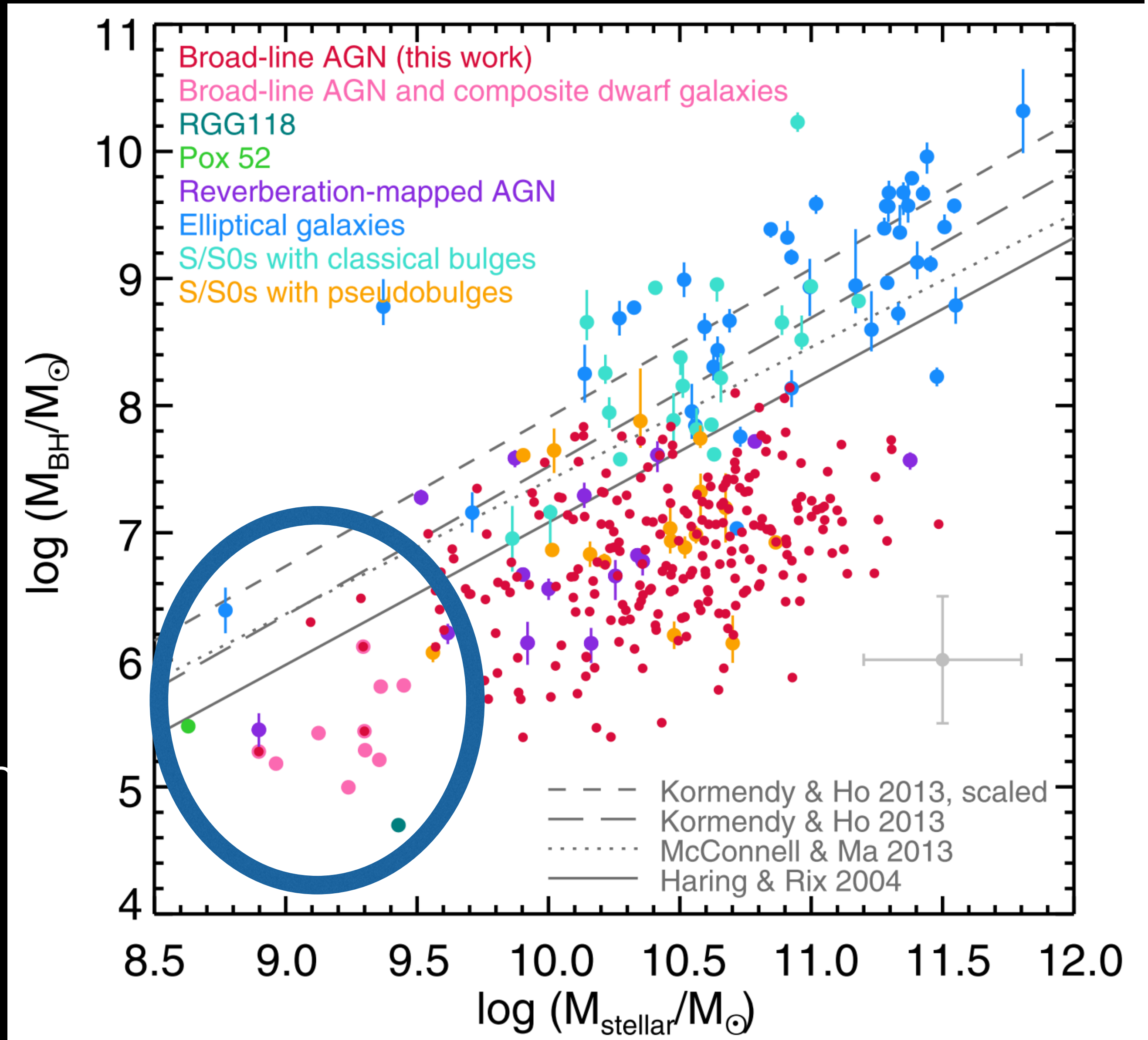

Volonteri+2012

Reines & Volonteri 2015

Intermediate Mass Black Holes

Lowest masses:
RGG 118: 5e4 Msun
Baldassare+15

N205: 7e3 Msun
Nguyen+19




TOTAL galaxy stellar mass

# Reines+2020



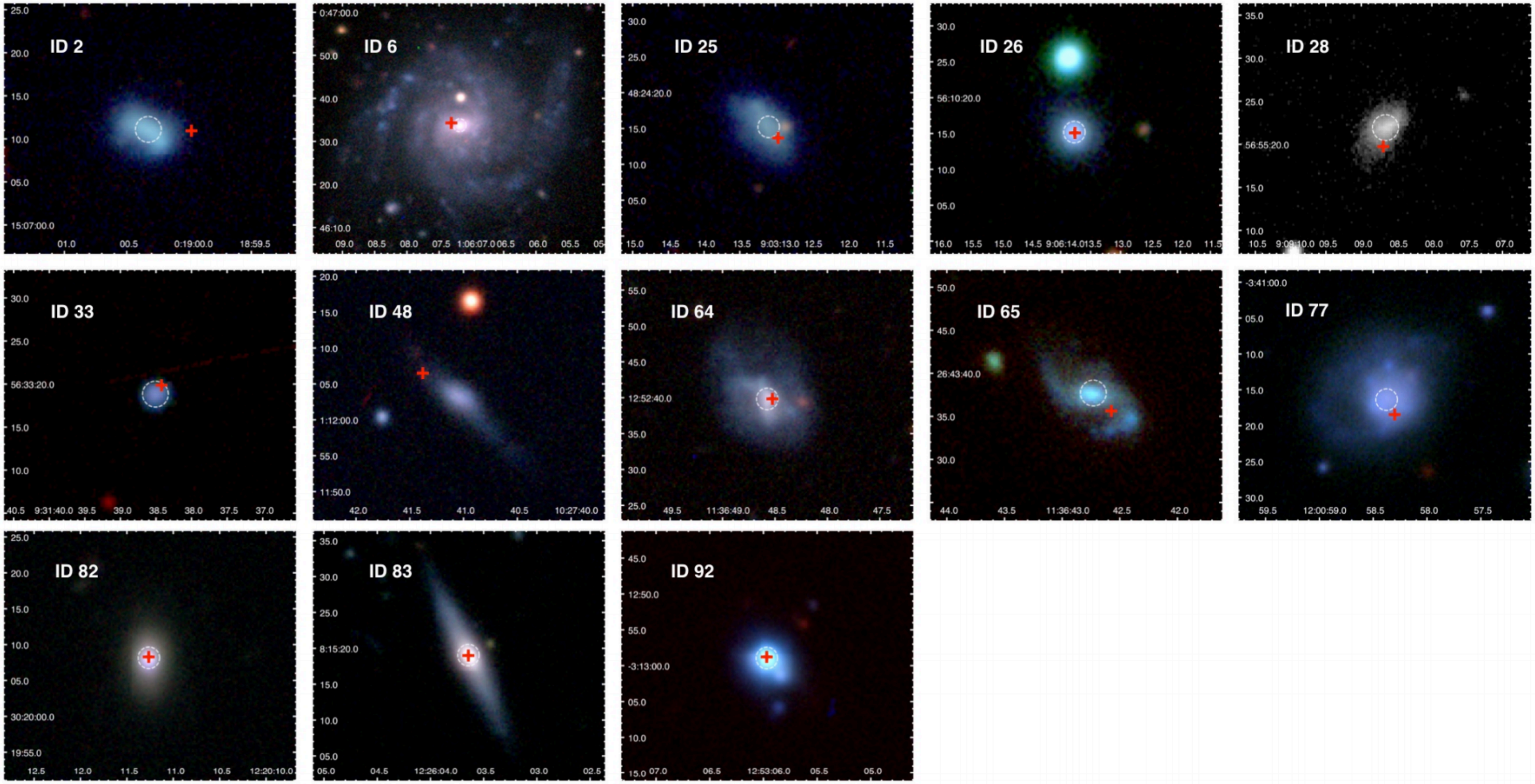



**Figure 7.** DECaLS $grz$-band images of dwarf galaxies (in Sample A) with the strongest evidence for accreting massive BHs (see §5.4). ID 28 only has a $z$-band image, which is shown here in grayscale. Red crosses indicate the positions of the compact radio sources and the white dashed circles indicate the positions of the SDSS spectroscopic fibers (with diameters of $3''$). ID 48 does not have an SDSS spectrum. Absolute astrometry for the optical and radio images is accurate to $\lesssim 0.''1$ and uncertainties in the radio source centroids are also $\lesssim 0.''1$.