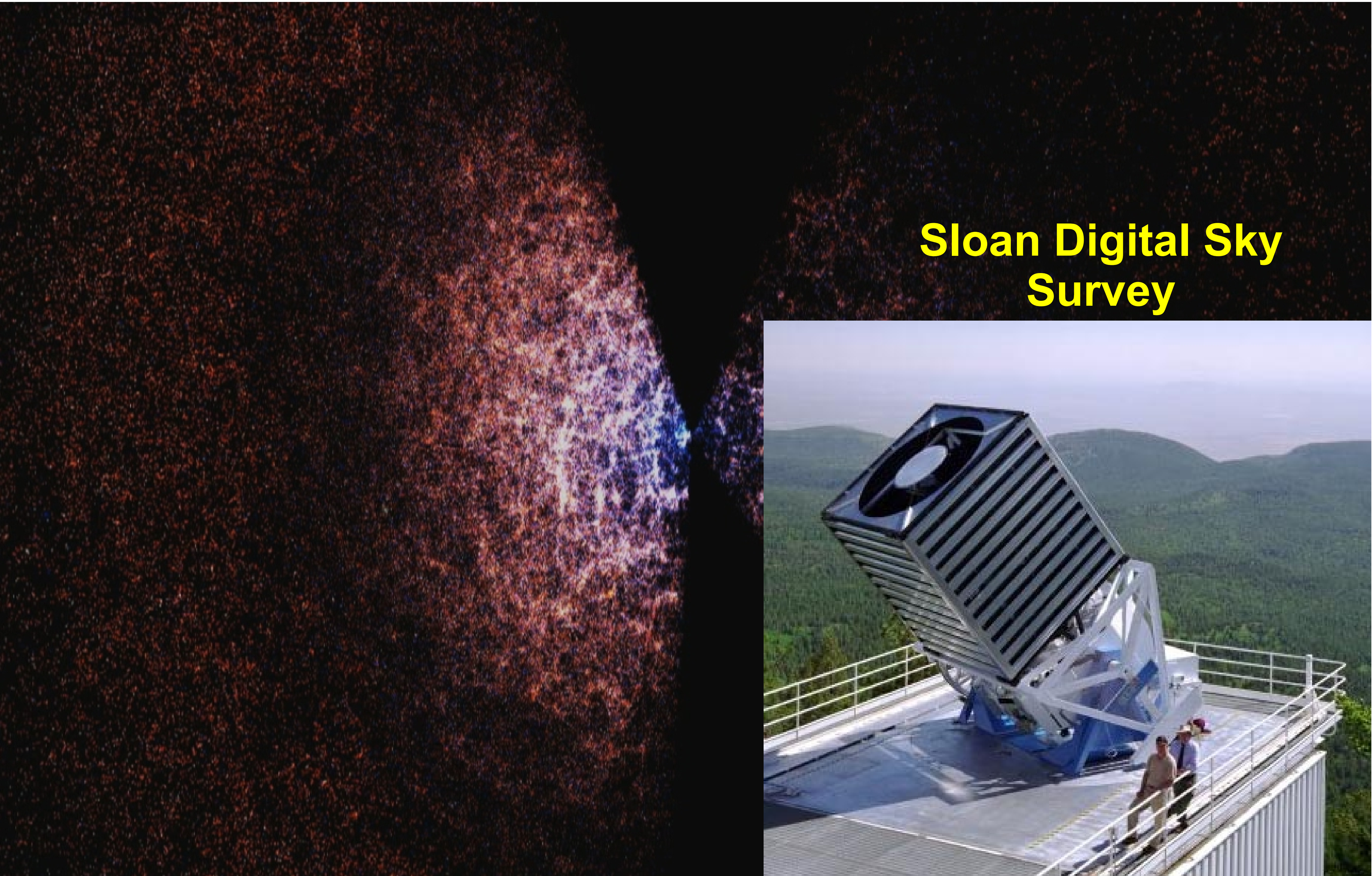
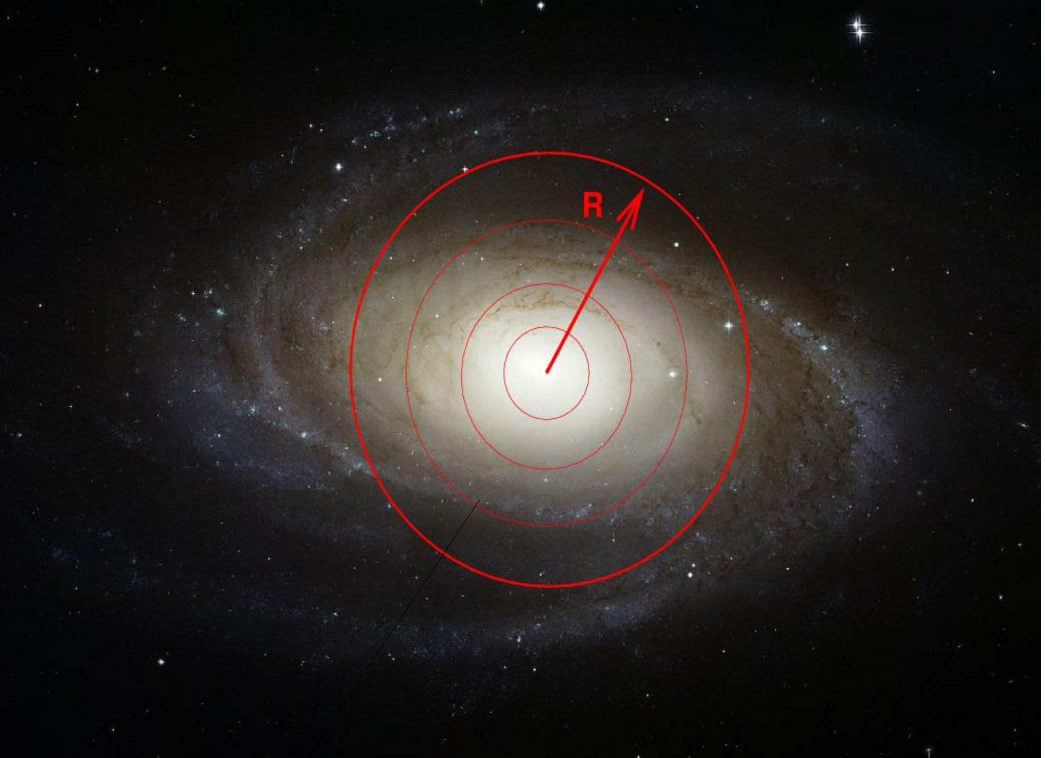
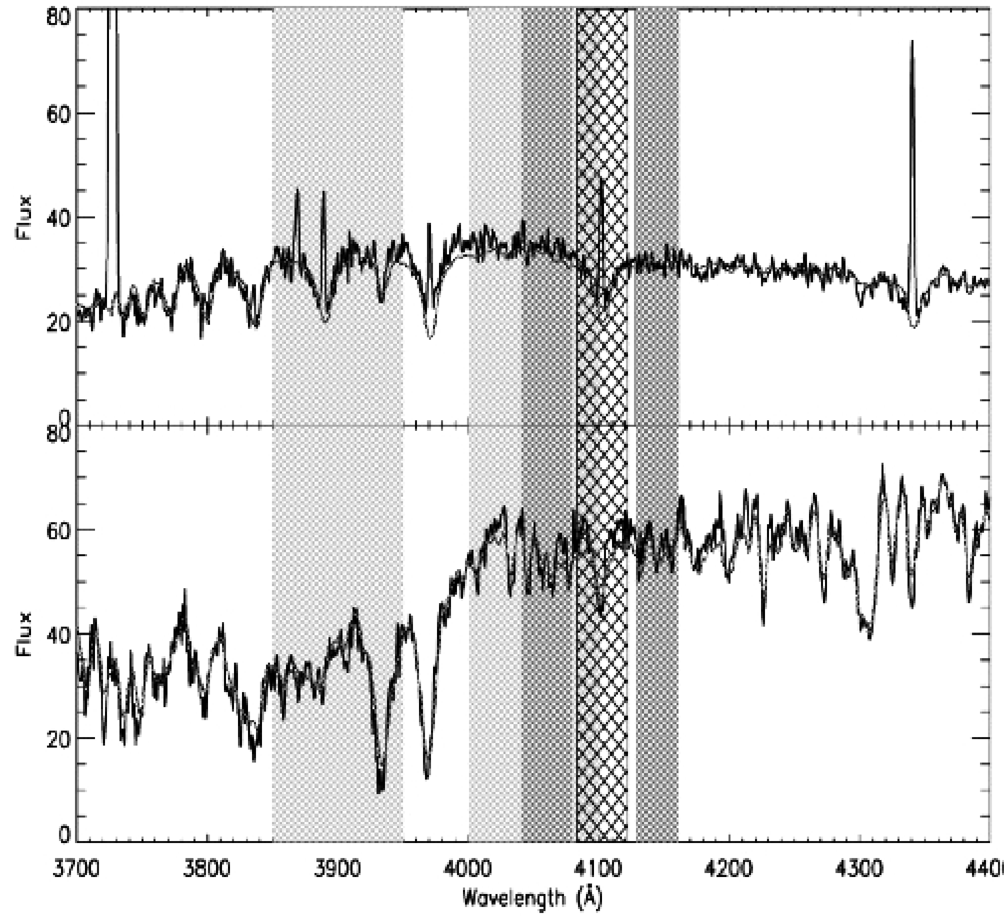
The link between black hole growth and galaxy formation: clues from large spectroscopic surveys





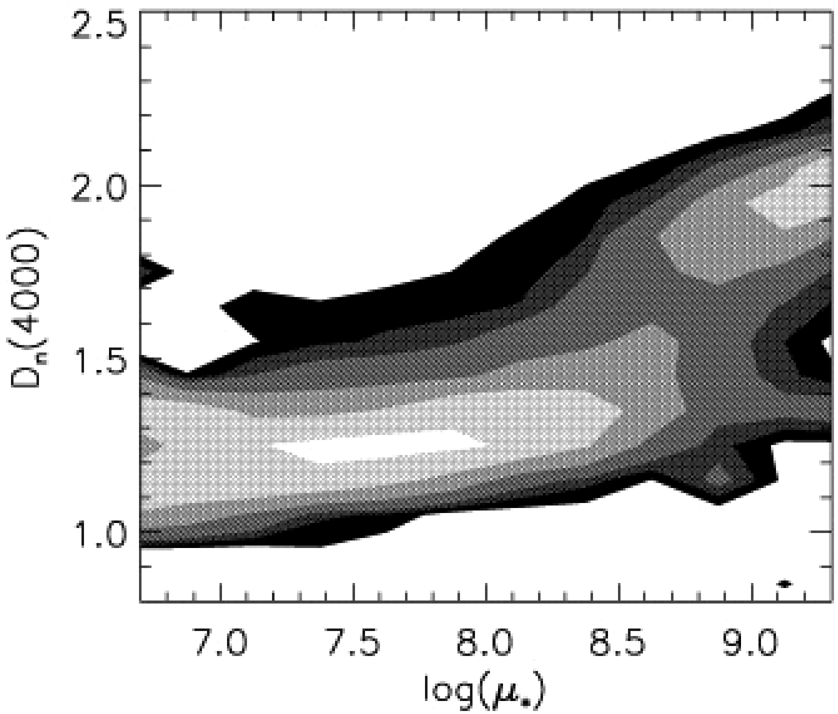
R50—radius enclosing half the light

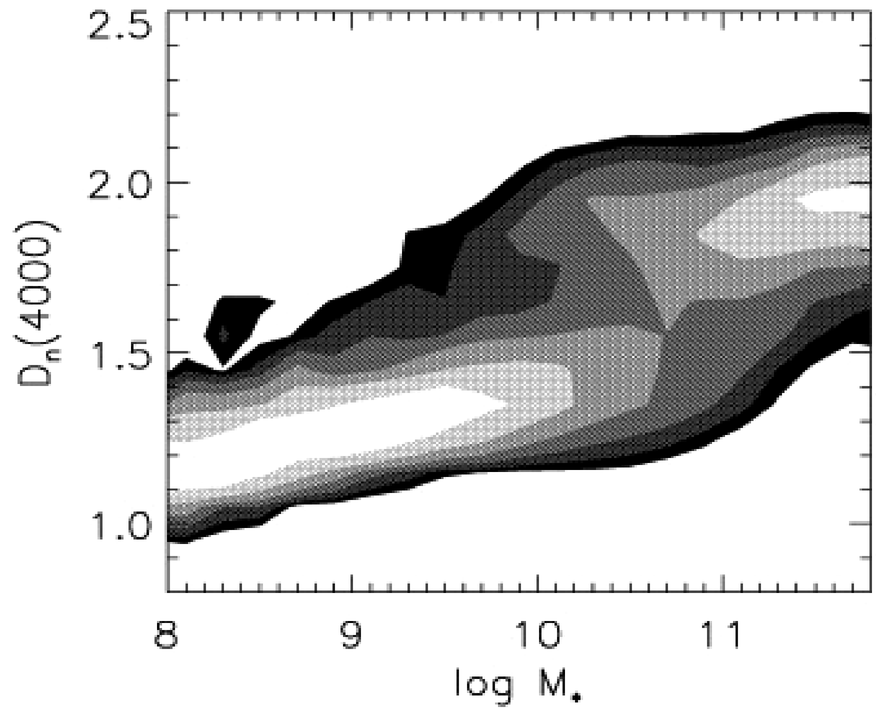


Concentration index (C) = R90/R50

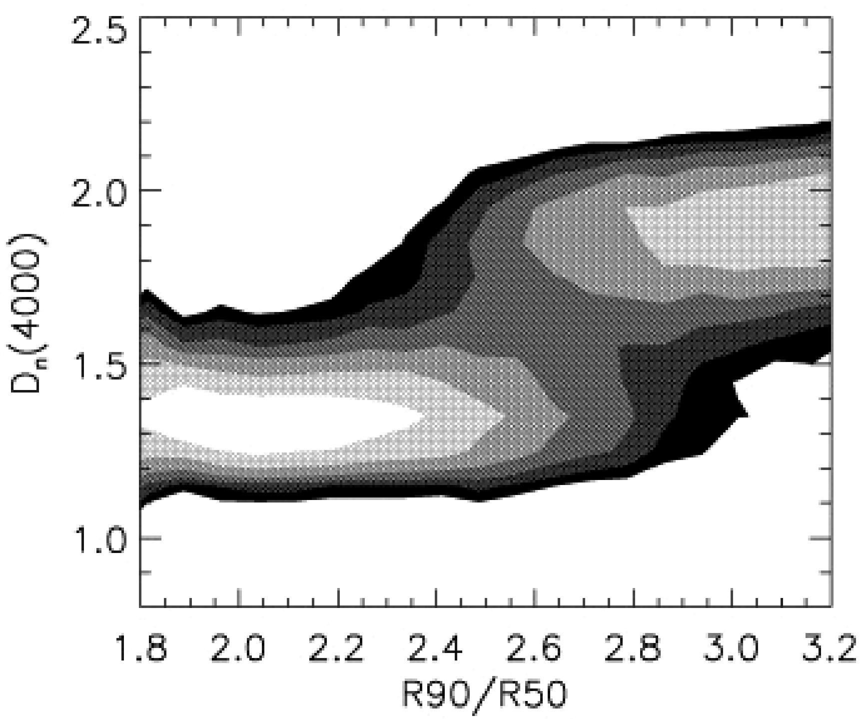
Stellar age parametrized by the 4000 Ā break: ratio of flux bluewards and redwards of the break in the spectrum

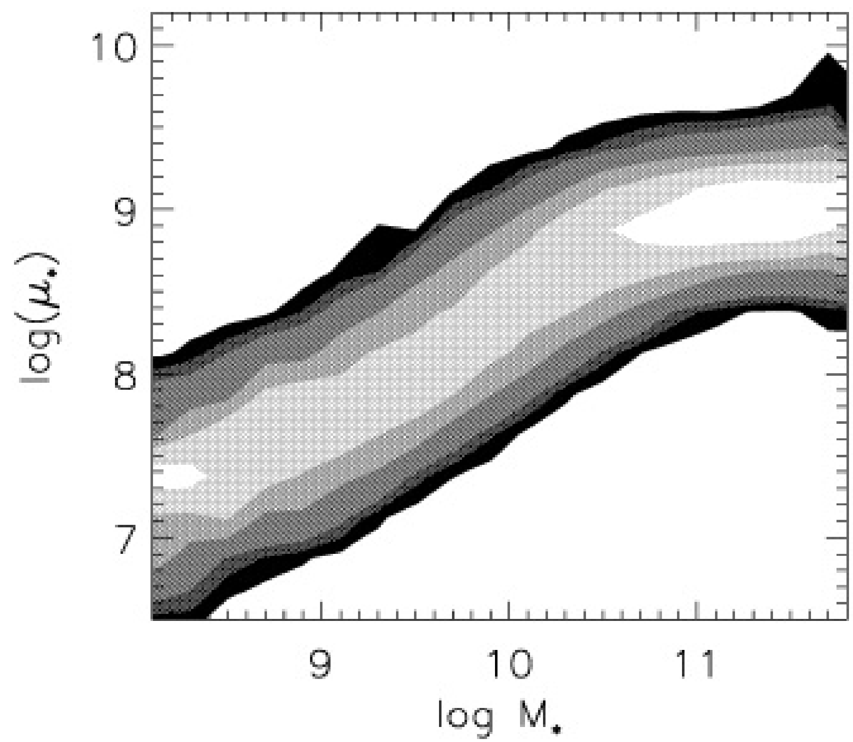
Stellar surface mass density ($\mu^* = 0.5\ M_*/R50^2$)



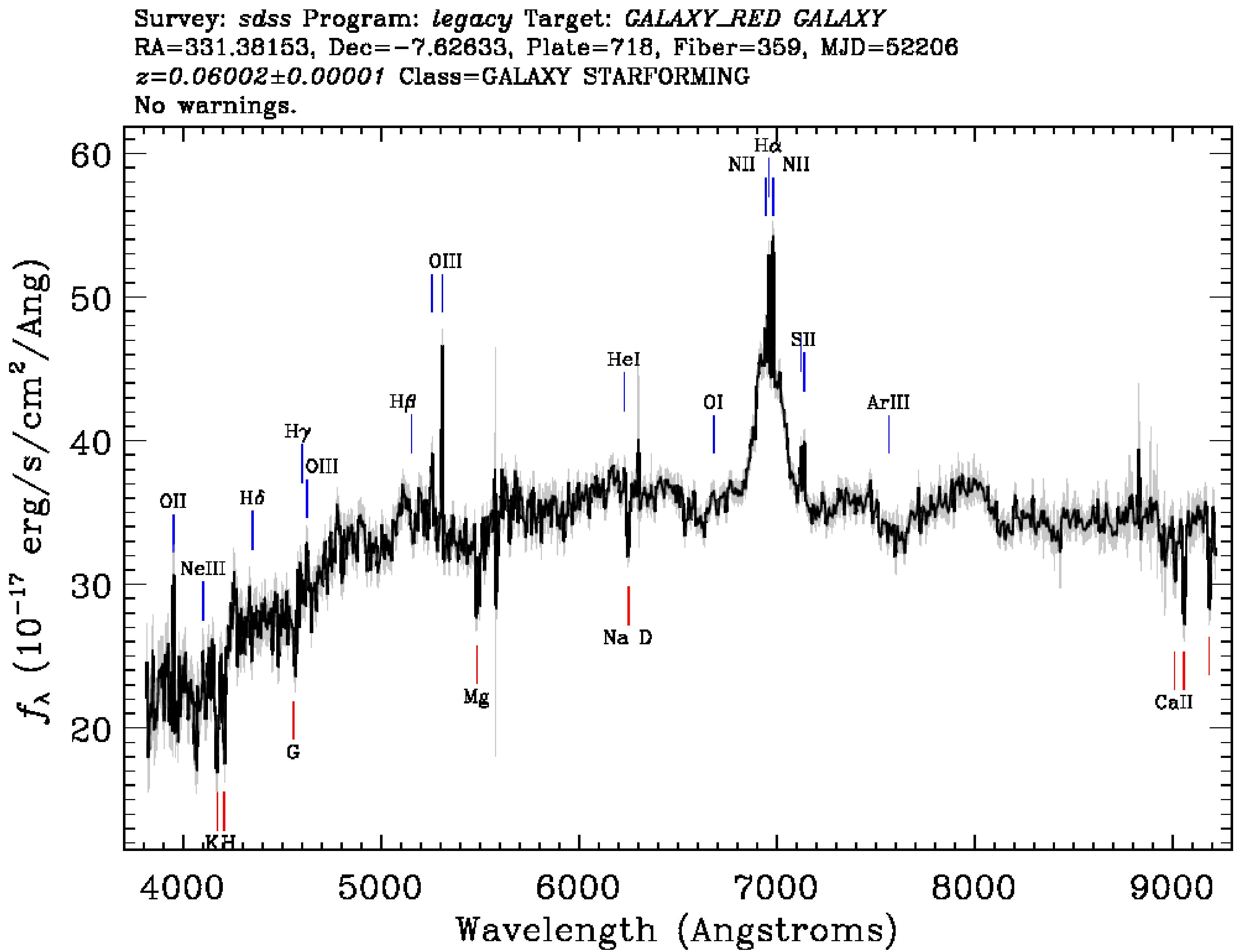


Scaling relations for normal galaxies

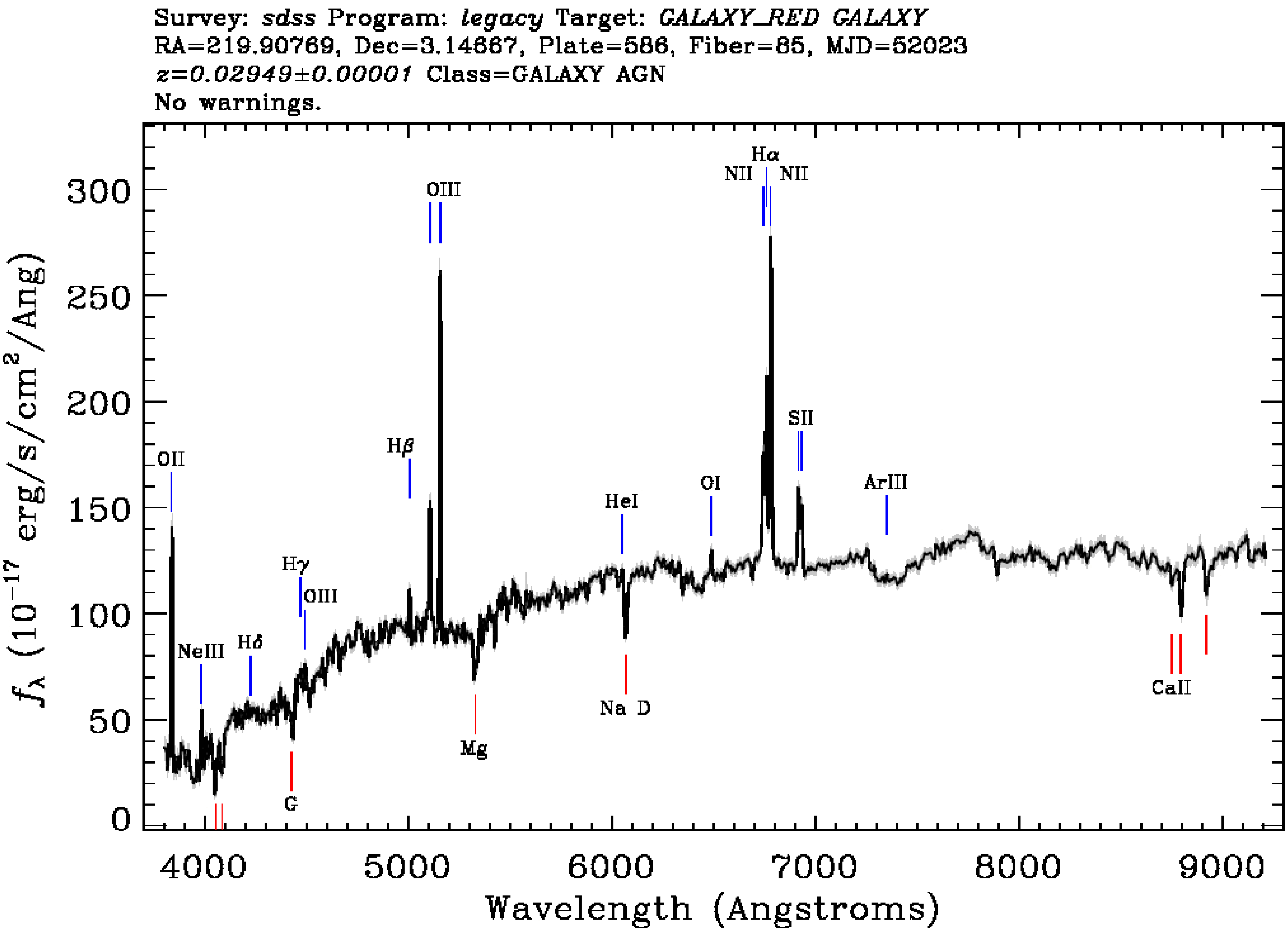




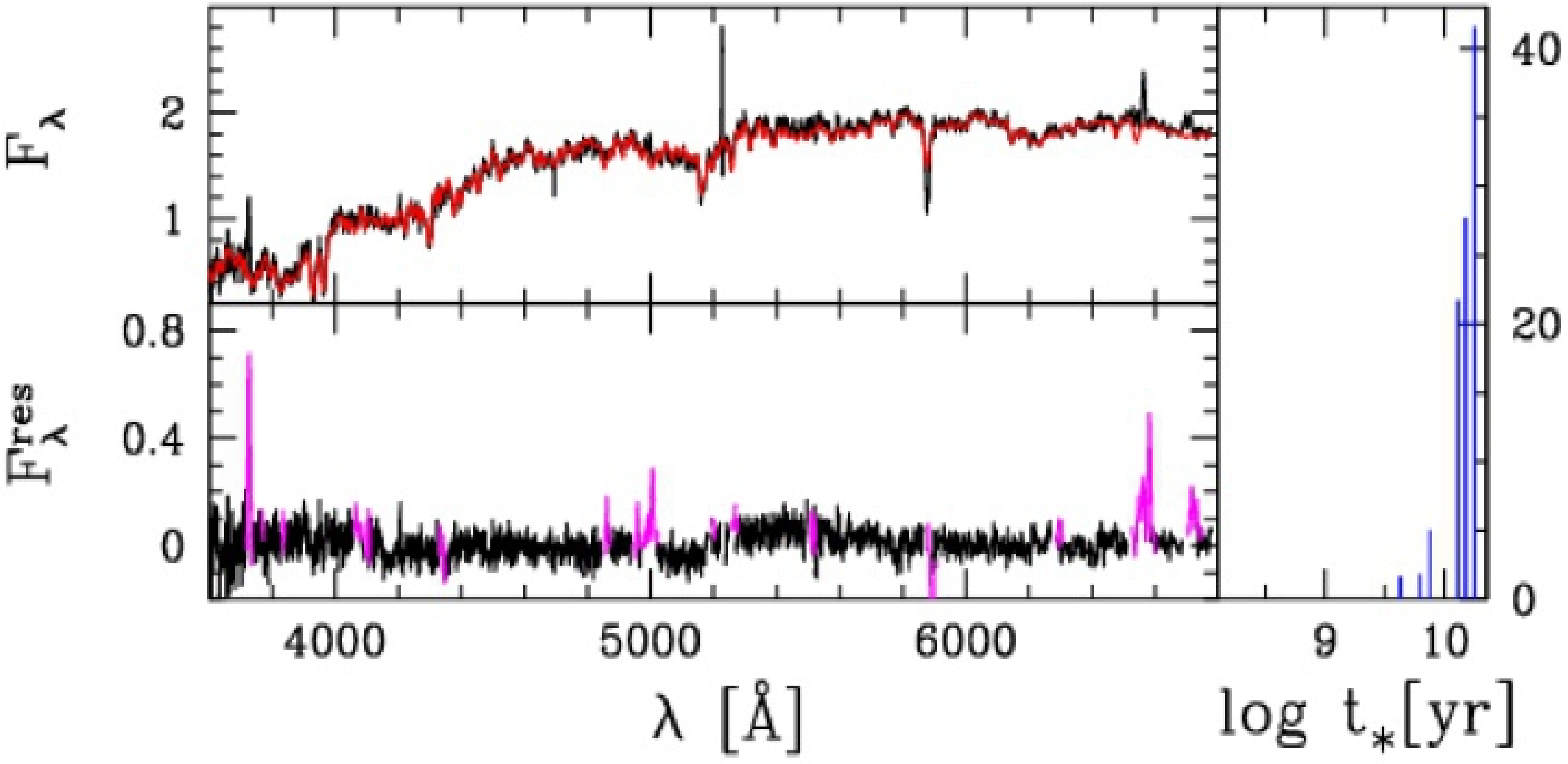
Type I Seyfert Galaxy



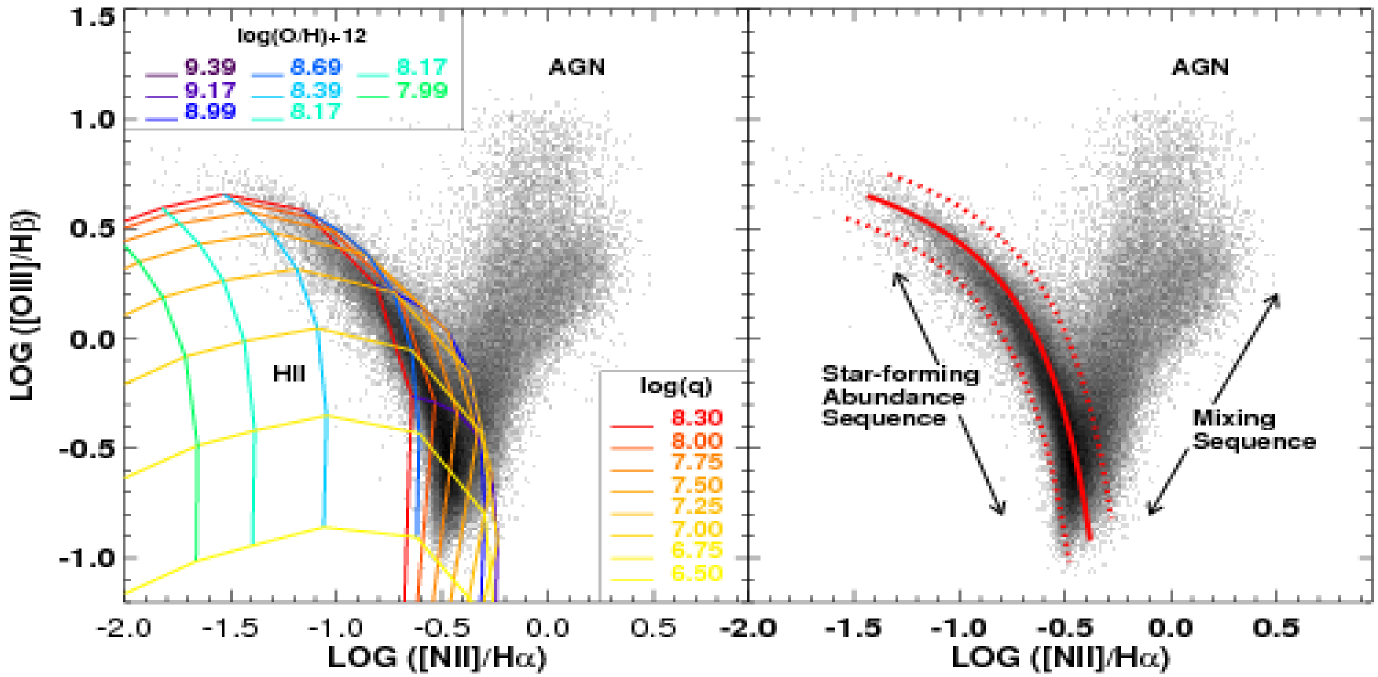
Type II Seyfert Galaxy

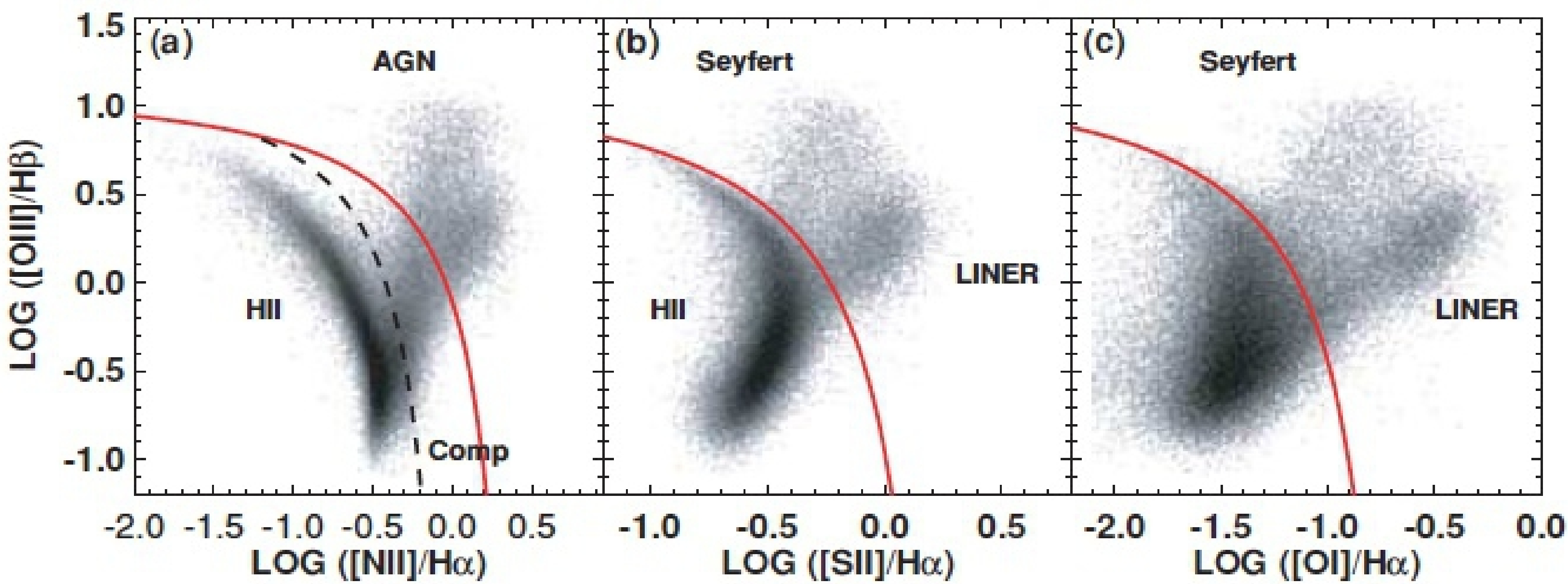


Fit the stellar absorption line spectrum with a superposition of stellar templates of different ages/metallicities, subtract, then measure emission lines from the residual spectrum.

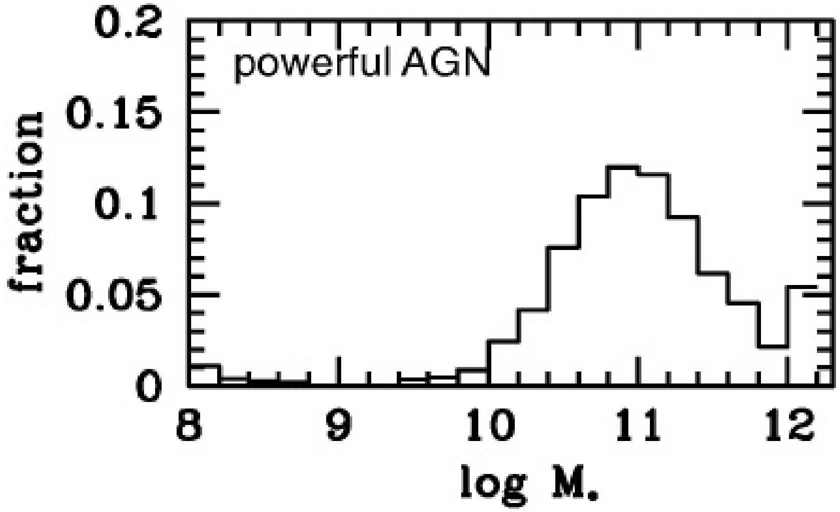


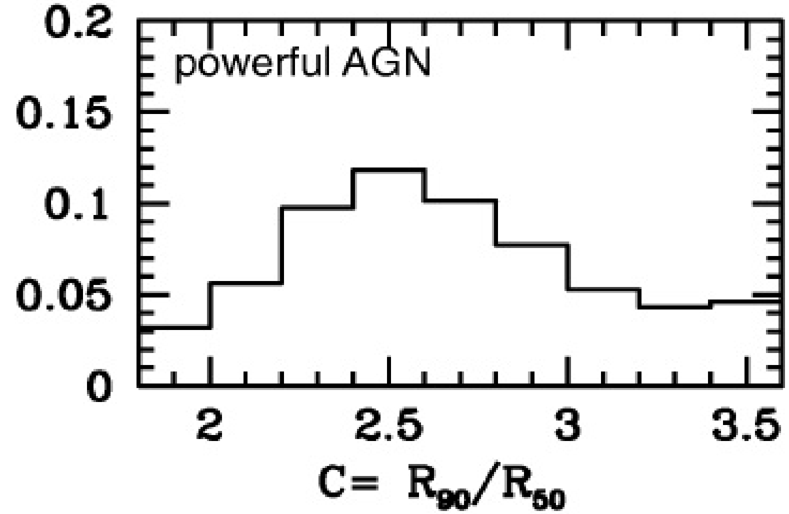
Emission line diagnostic diagrams for identification of AGN through emission-line ratios



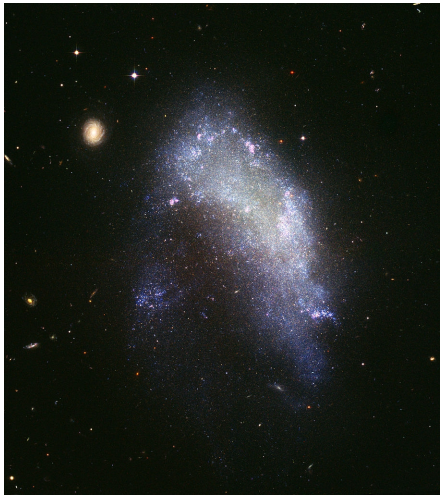


Fraction of AGN as a function of Mass/Concentration



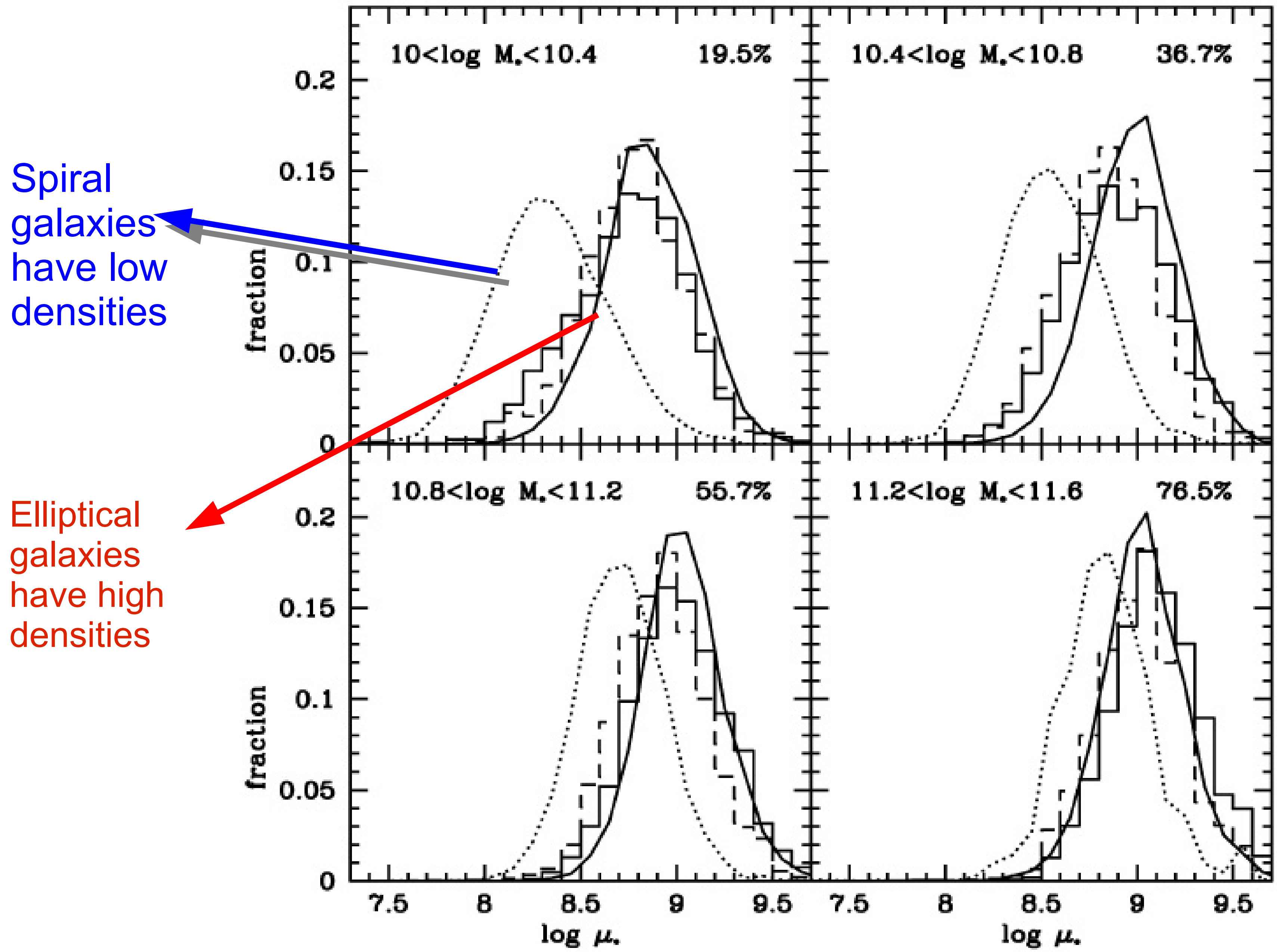


AGN are found only in massive galaxies with significant bulge component

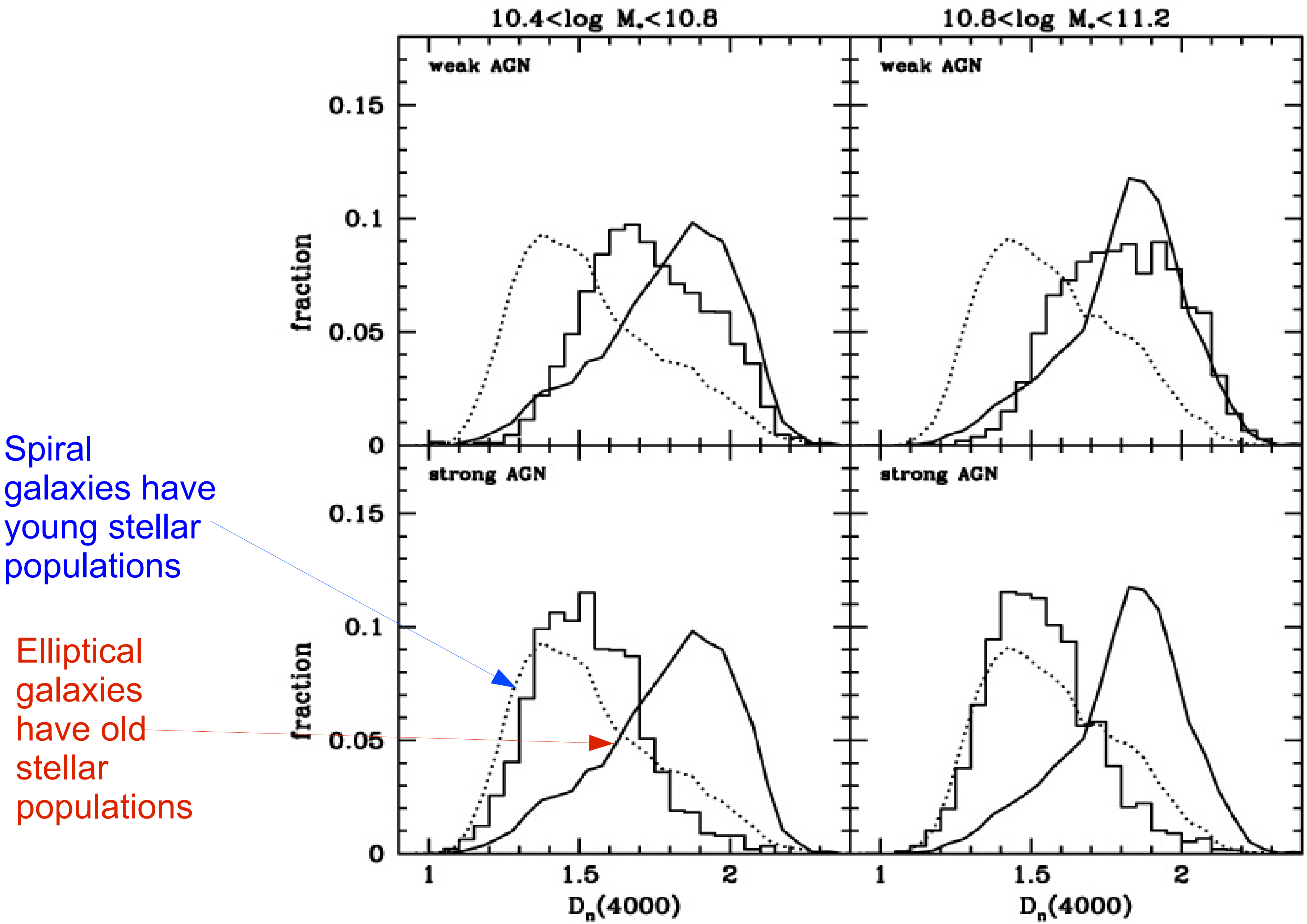


No AGN and no evidence for black holes in galaxies like these.

The stellar structure of the host galaxies of AGN is closest to early-type (elliptical)

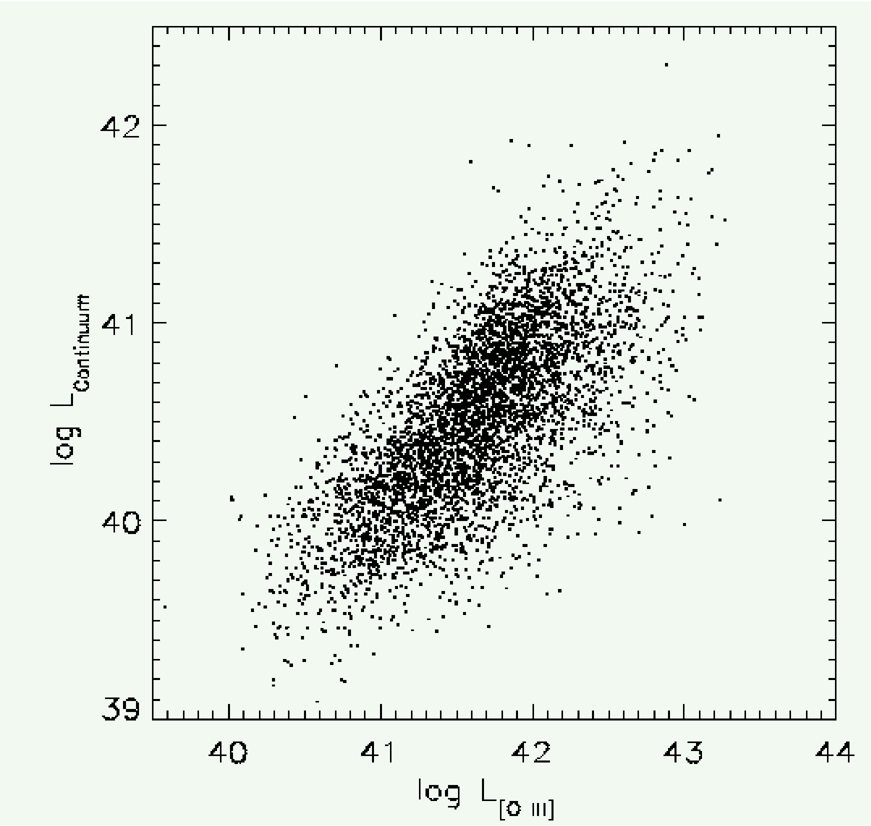


The stellar populations of the host galaxies of strong AGN are closest to late-type (spiral)

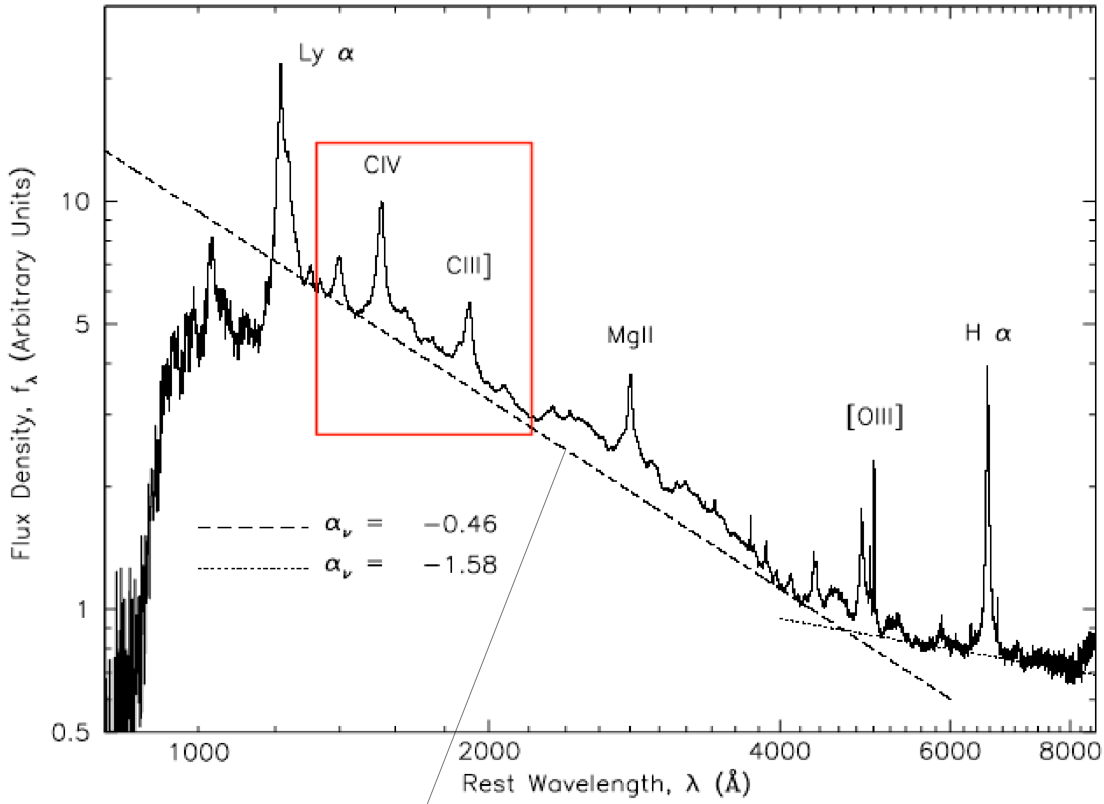


Accretion

The [OIII] Line Luminosity as a Black Hole Accretion rate indicator



Correlation of [OIII] luminosity with bolomertic continuum luminosity for Type 1 AGN

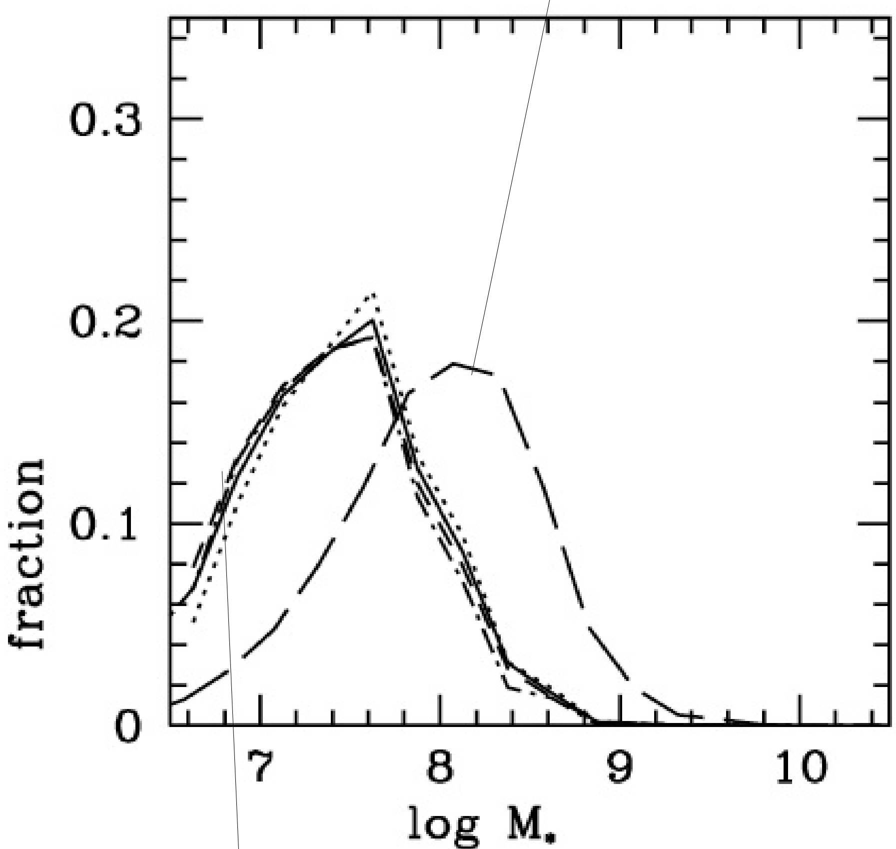


Continuum is from accretion disk

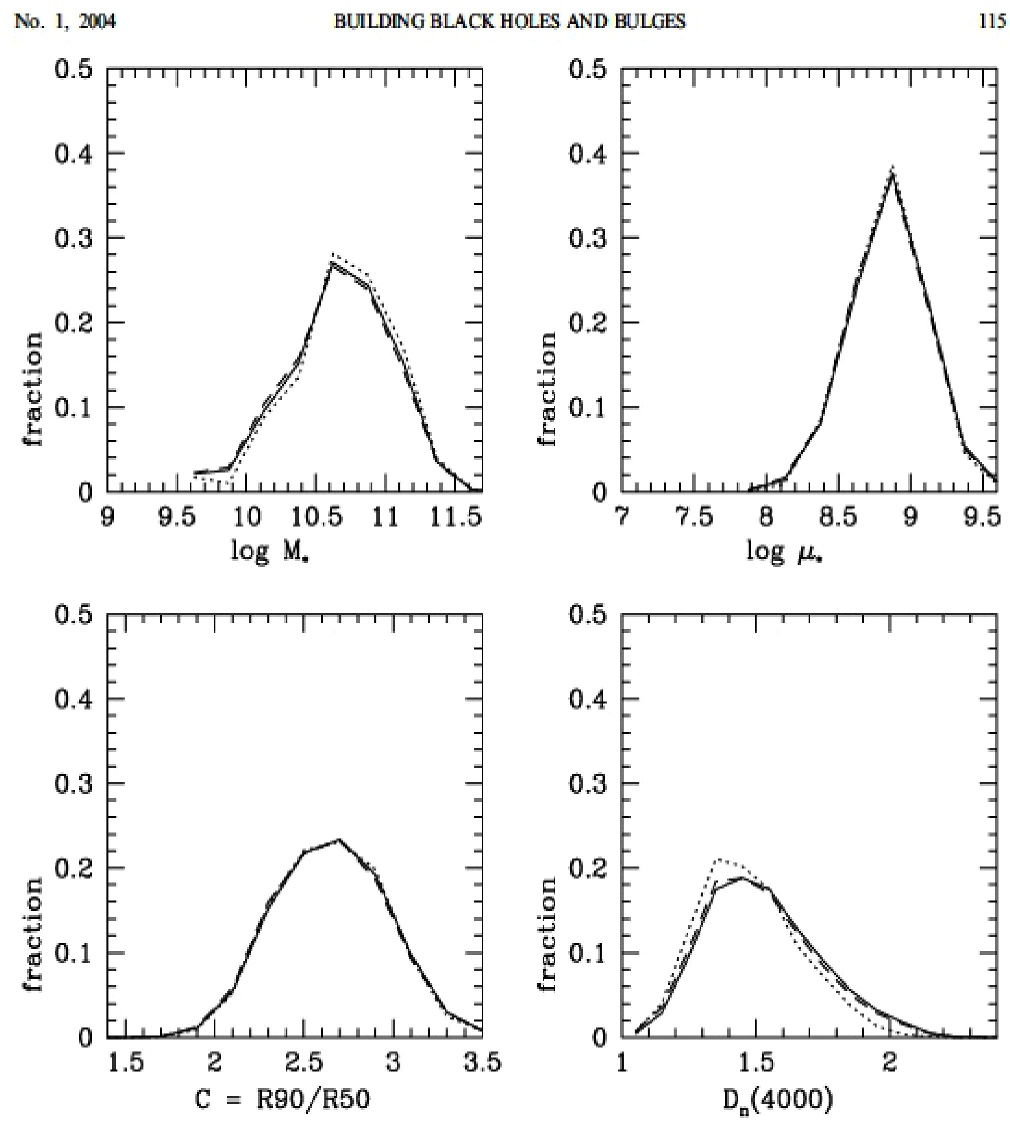
Which black holes and galaxies are currently accreting?

Distribution of Σ L[OIII] as a function of galaxy properties

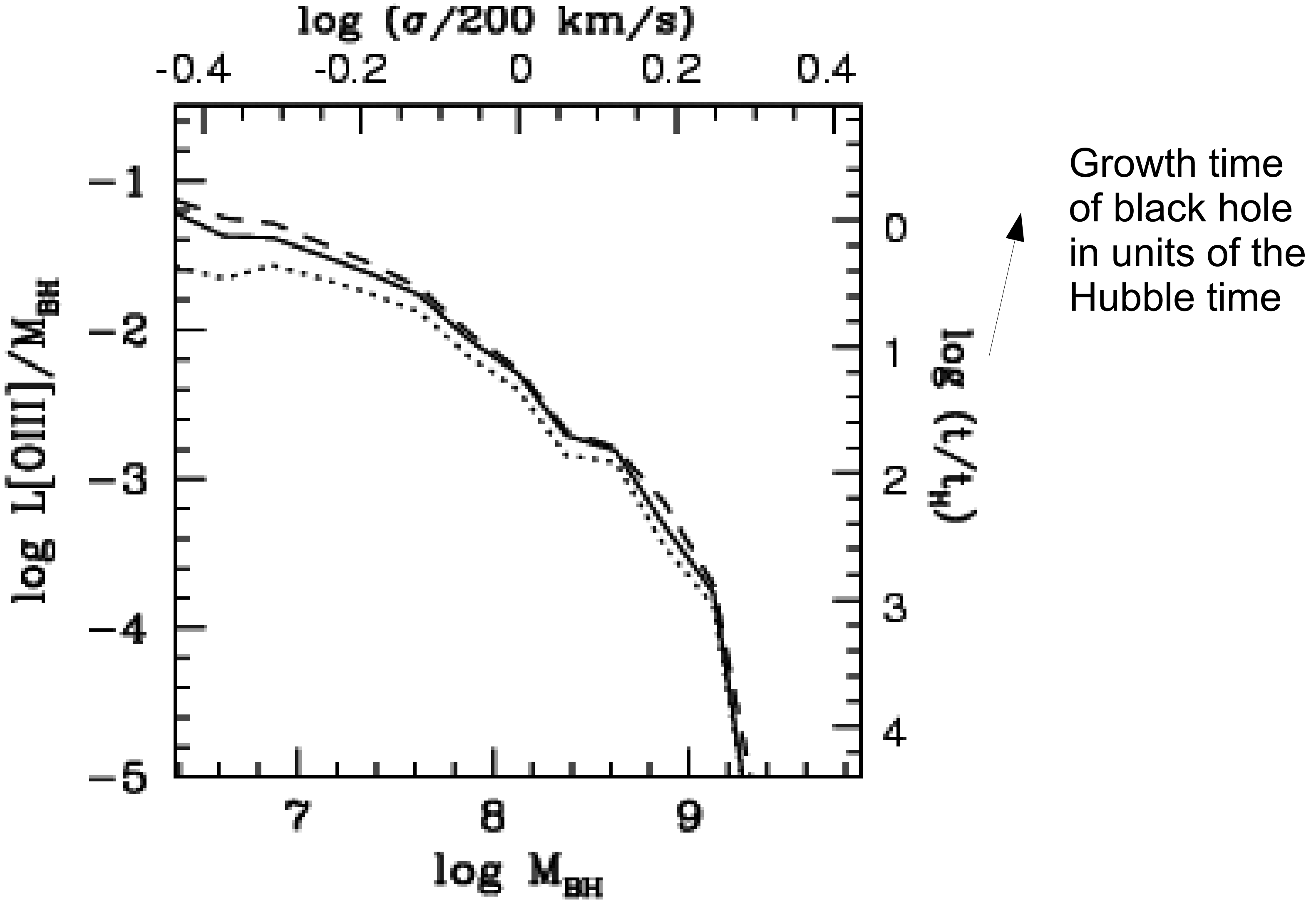
Distribution of Σ M $_{\text{black hole}}$



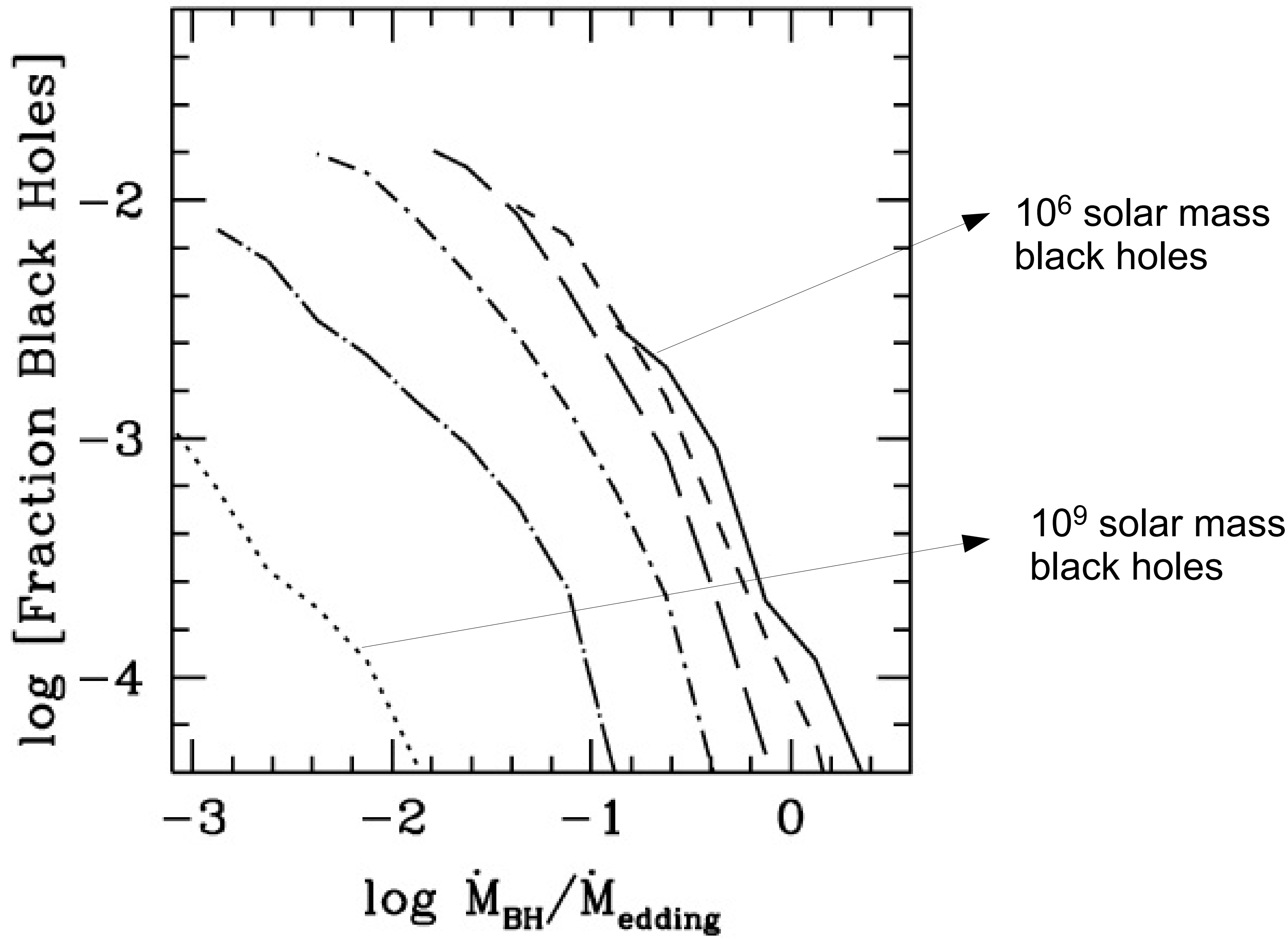
Distribution of Σ L[OIII] as a function of M $_{\text{black hole}}$



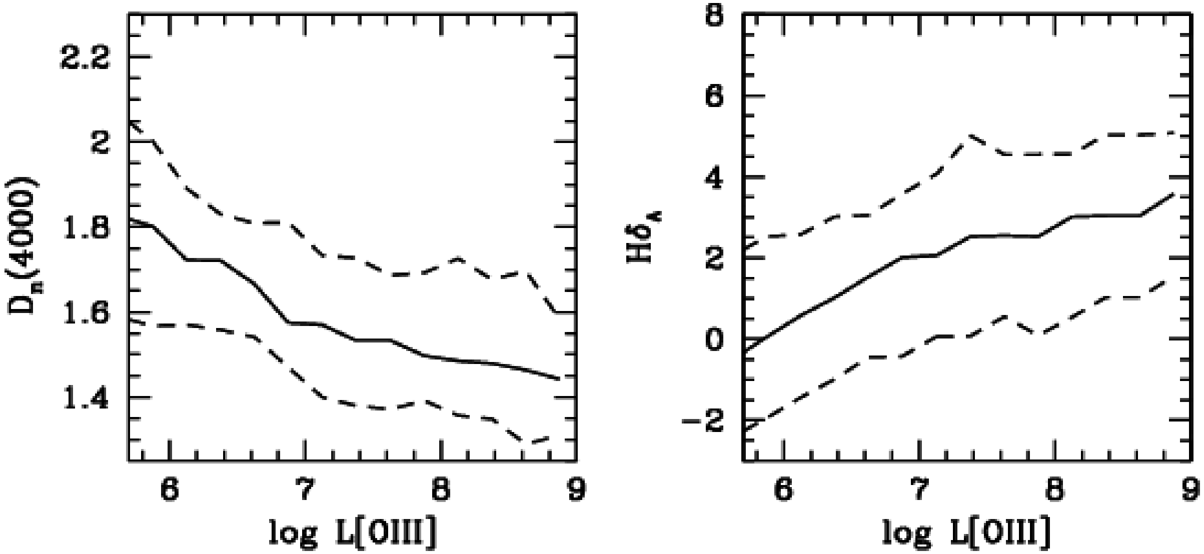
Most of the accretion today is occurring onto low mass black holes in galaxies like our own Milky Way ==> Massive black holes formed early on in the Universe and then stopped growing



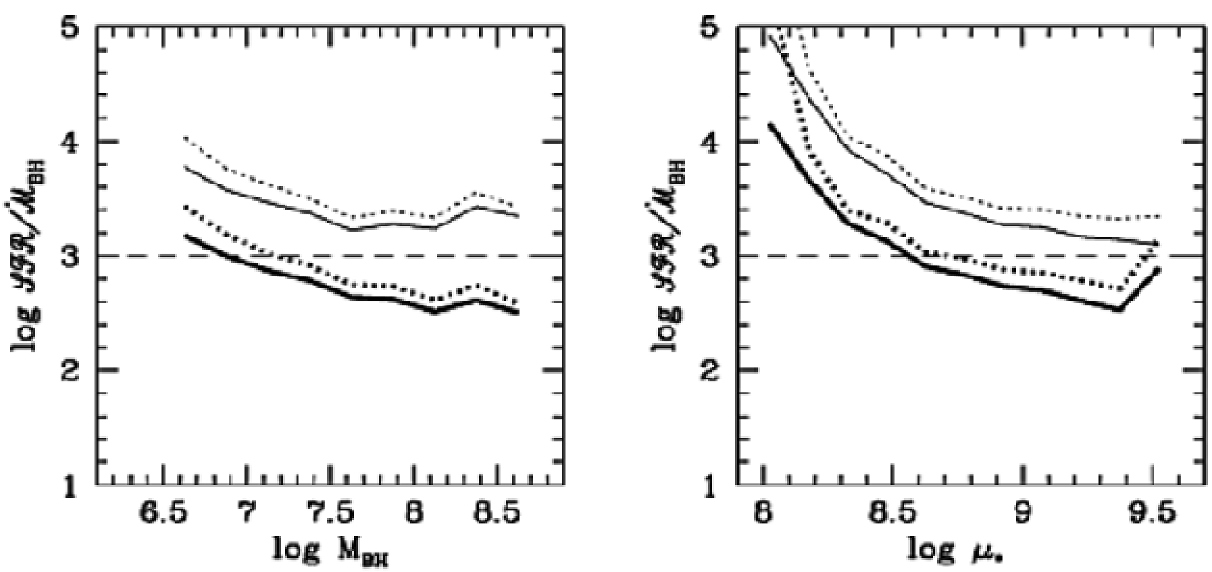
Distribution of accretion rates (in units of the Eddington accretion rate) for black holes of different mass



The Starburst-AGN Connection

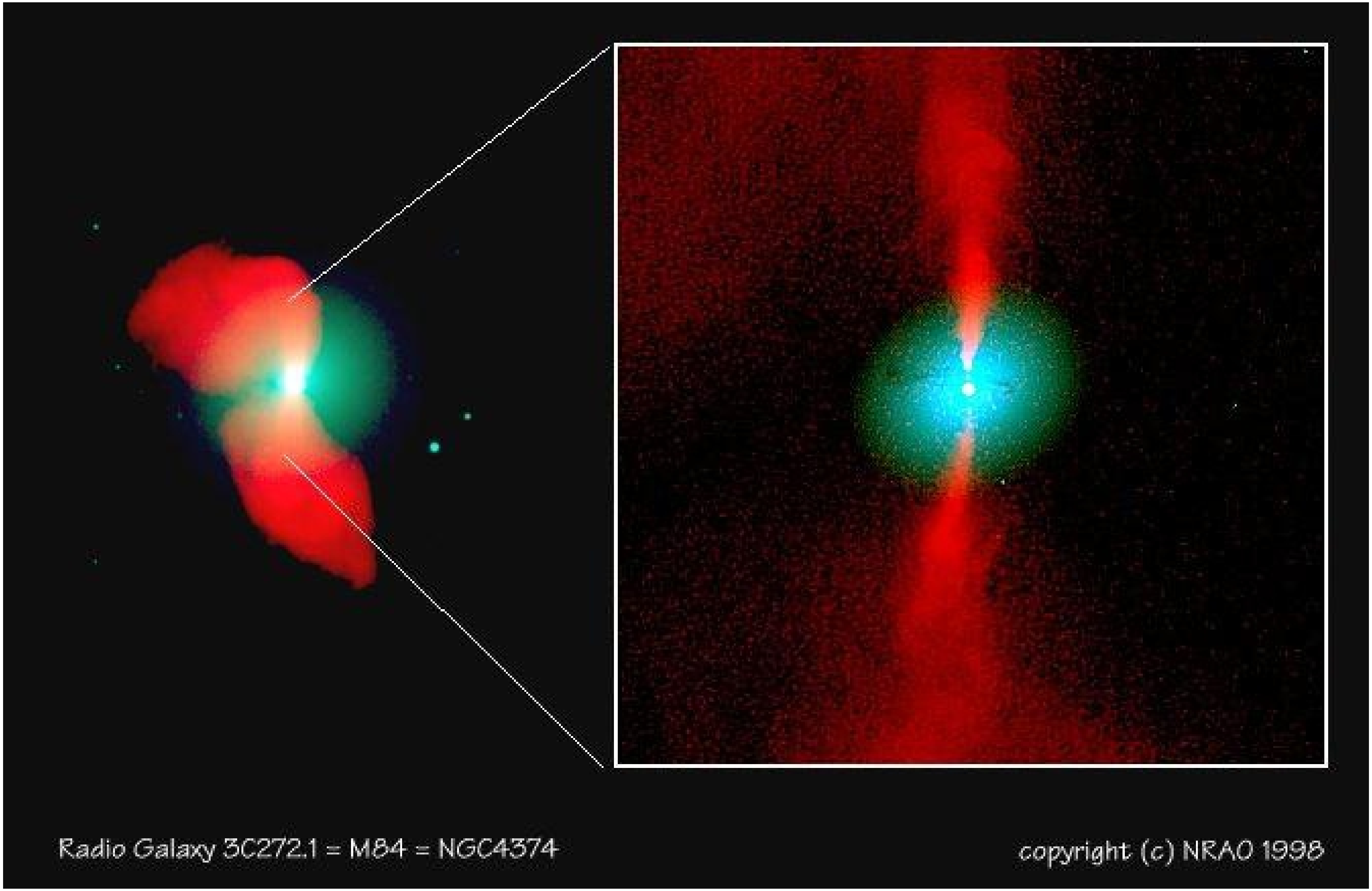


More strongly accreting AGN have younger stellar populations

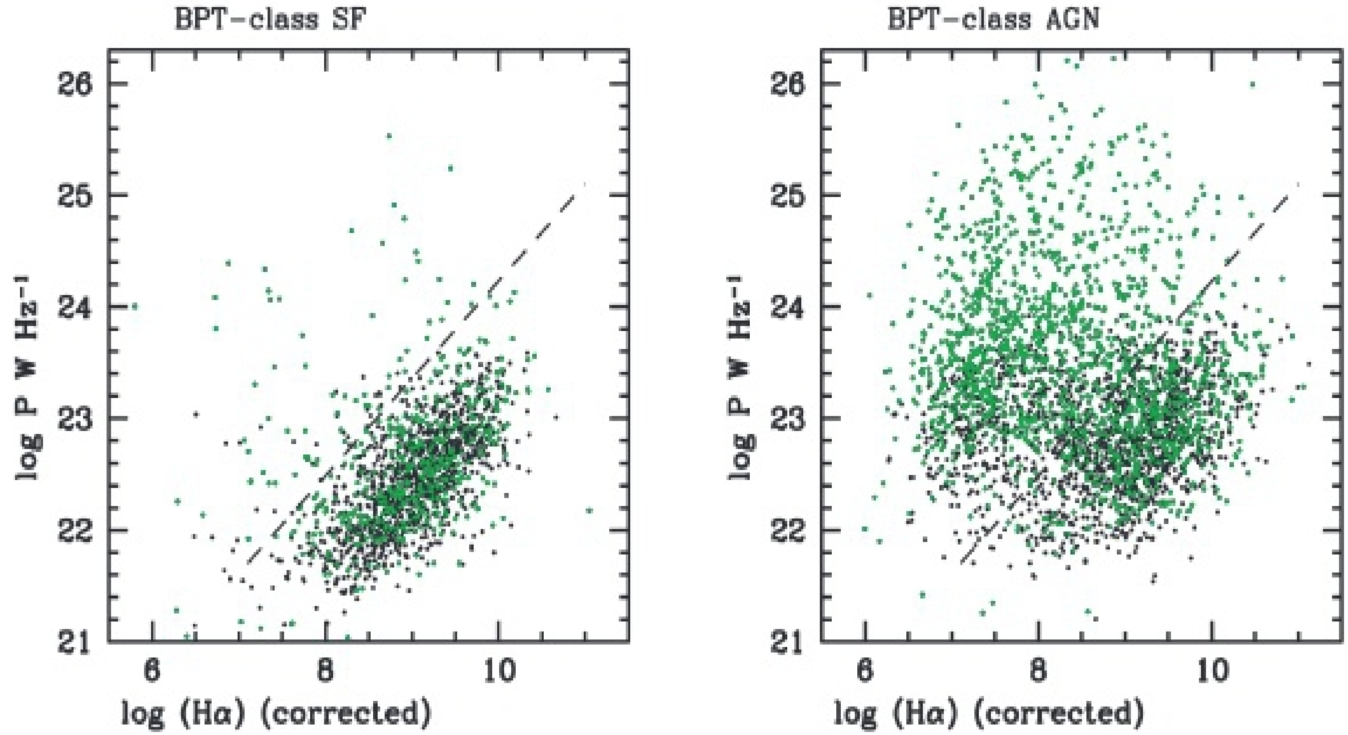


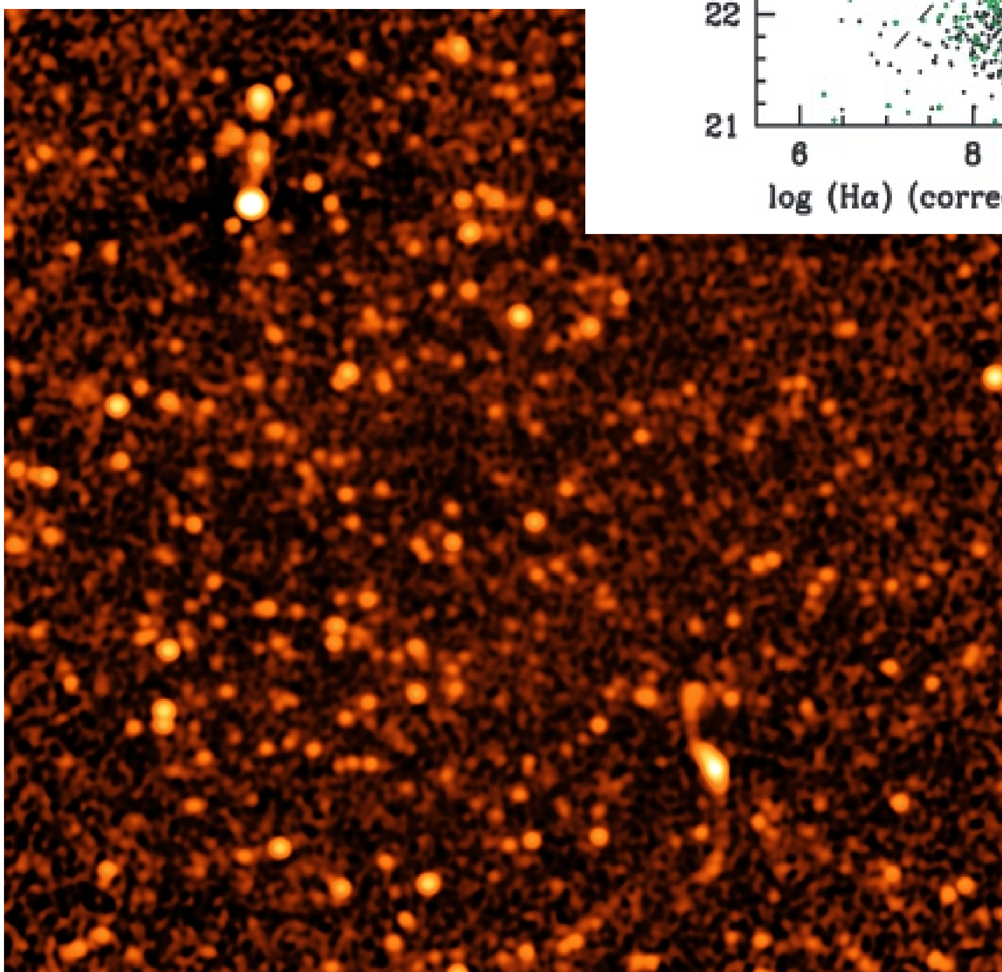
The average ratio between the star formation rate in the bulge and the accretion rate onto the black hole is 1000 – remarkably close to the ratio of bulge mass to black hole mass.

What about radio-loud AGN?



Deep wide-field radio surveys can be cross-correlated with SDSS optical surveys

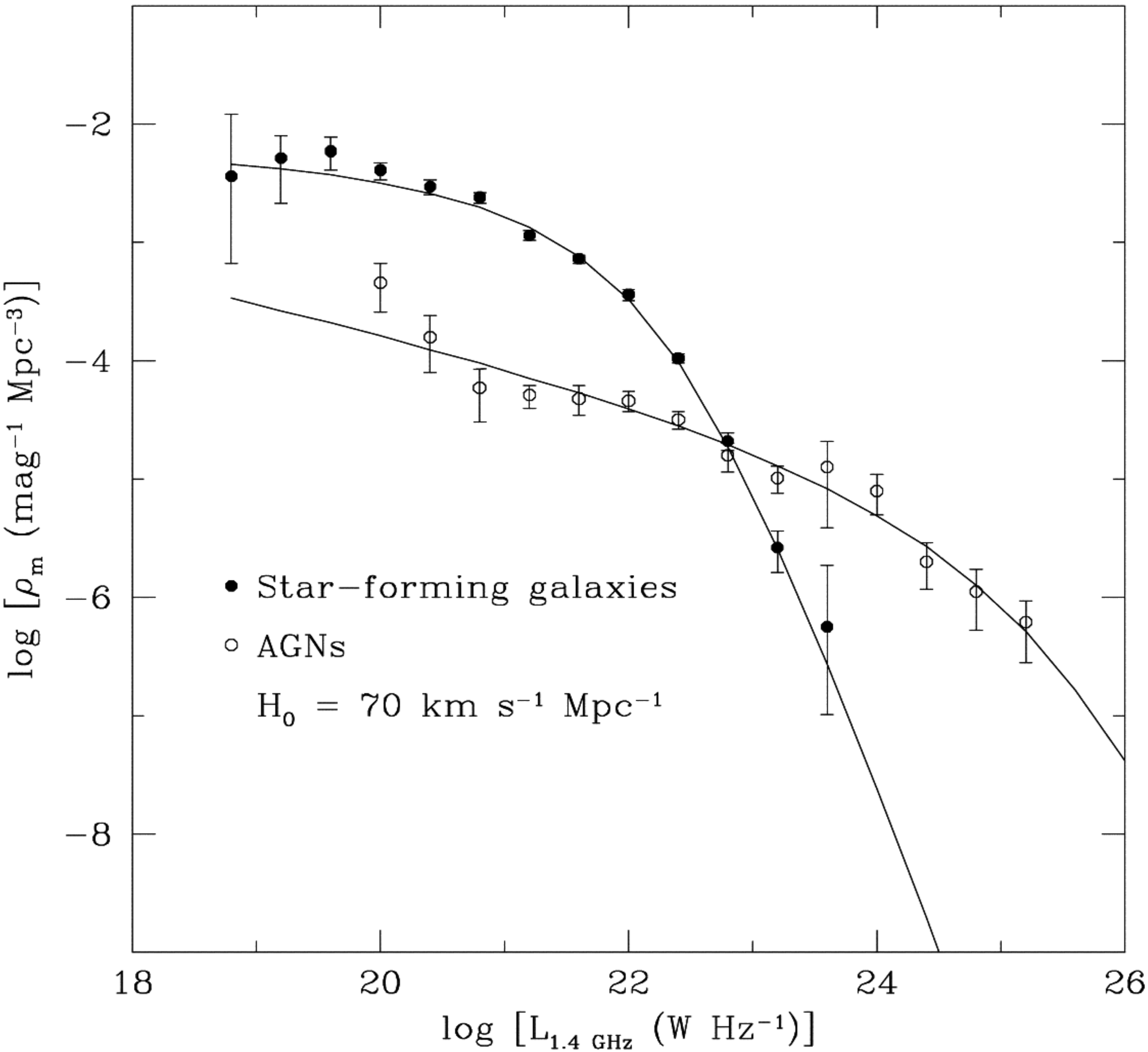


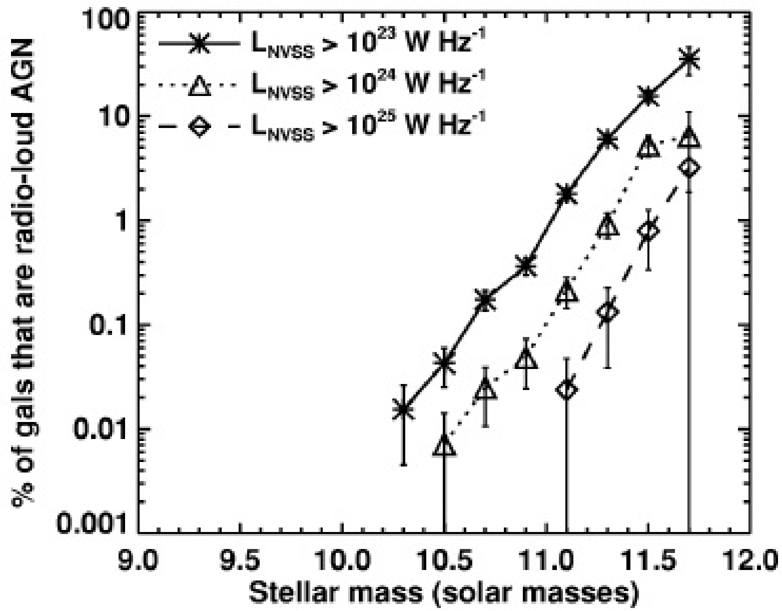


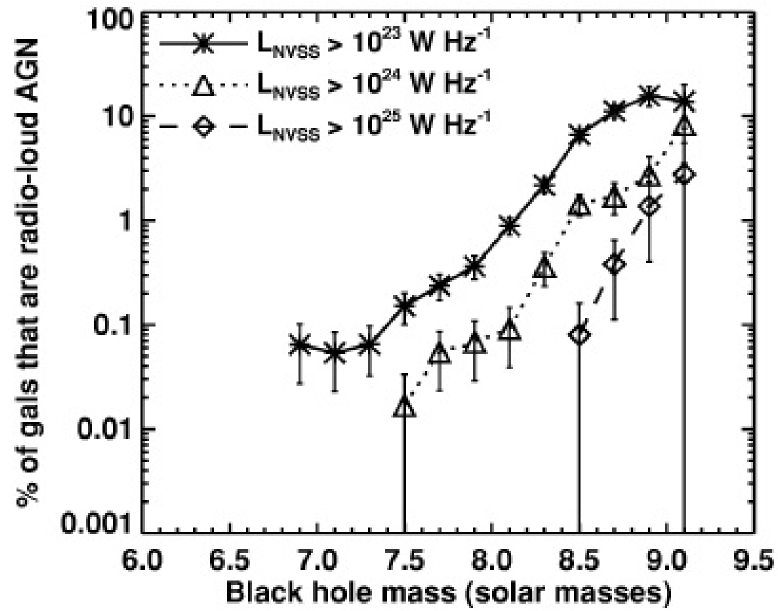
Radio synchrotron emission arises from electrons accelerated in supernovae shocks: correlation between radio emission and star formation rate as measured by Halpha emission

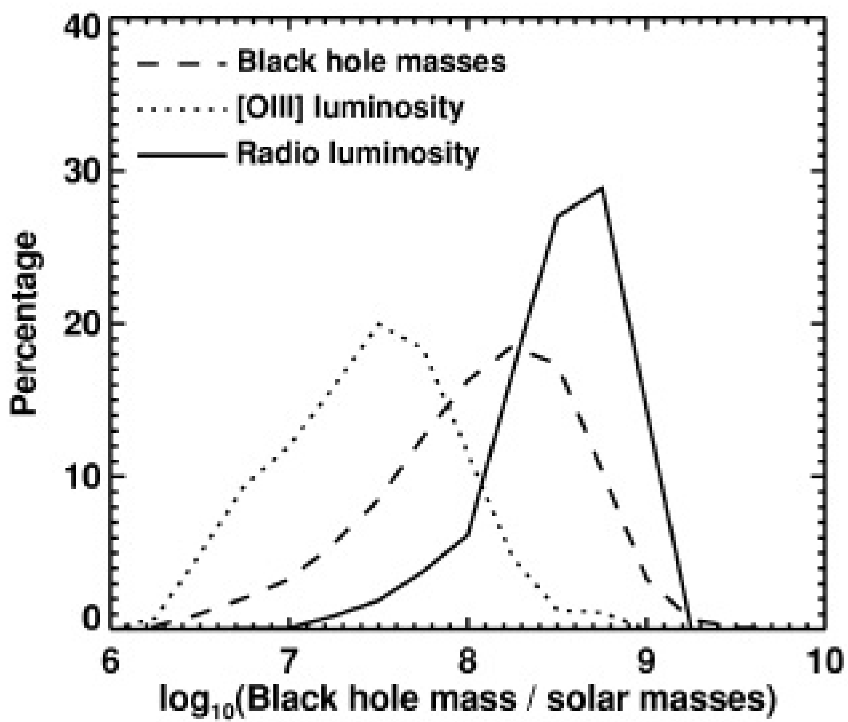
Radio AGN can be identified by their excess radio luminosity with respect to this correlation

Radio luminosity function for star-forming galaxies and radio AGN







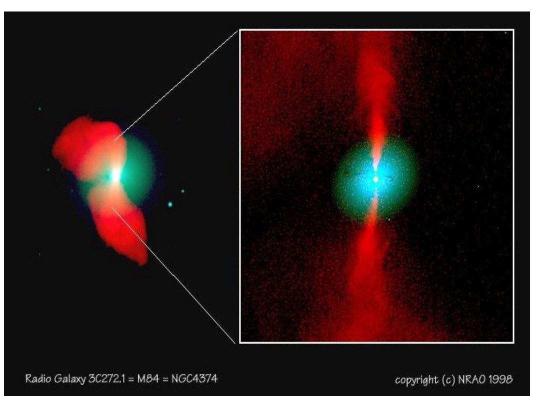


Radio AGN are found most frequently in the very most massive galaxies: **more massive than the hosts of optical AGN**

CONCLUSIONS FROM STUDYING HOST GALAXIES

Present-day Optical (emission-line) AGN activity is linked to:

1) lower mass black holes
2) galaxies with low mass bulges
3) more powerful AGN found in galaxies with younger stellar populations

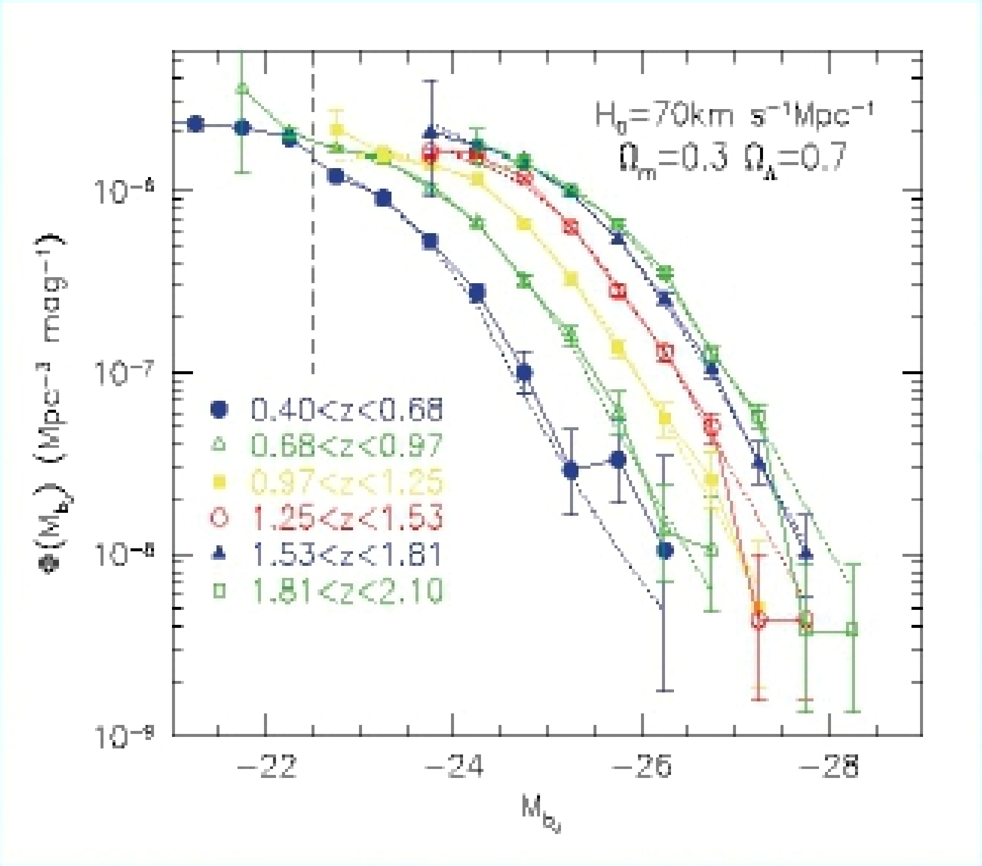


Present-day Optical Radio-AGN activity is linked to:

1) high mass black holes
2) galaxies with higher mass bulges
3) no apparent dependence on mean stellar age

Cosmic Evolution of the AGN Activity

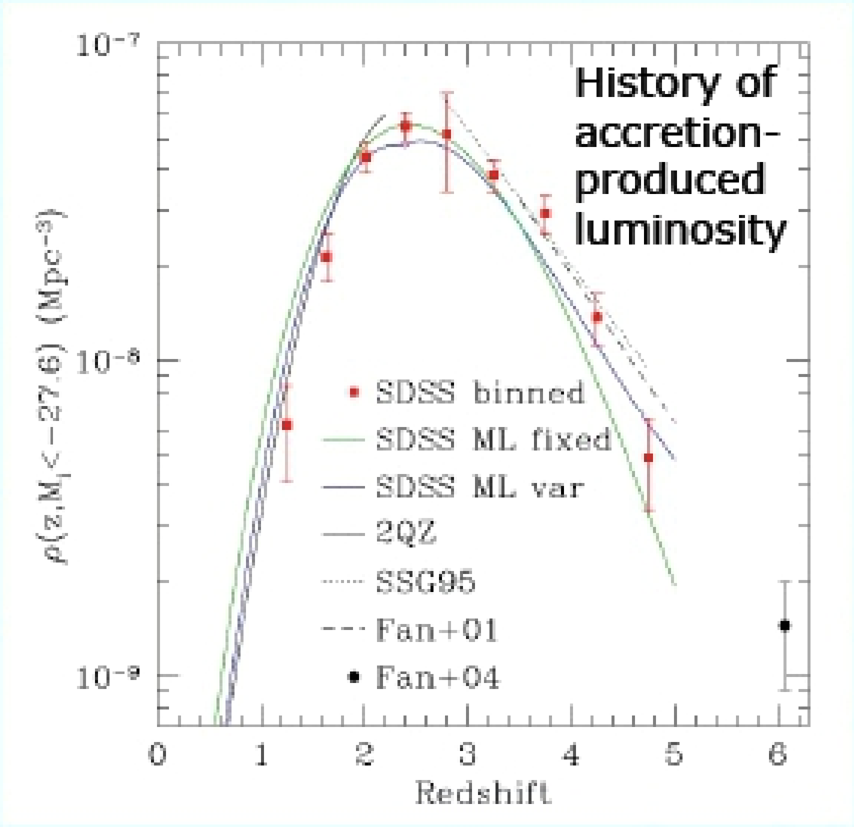
- Describe the distribution of accretion luminosities at different cosmic epochs by the "quasar-luminosity-function" at different redshifts



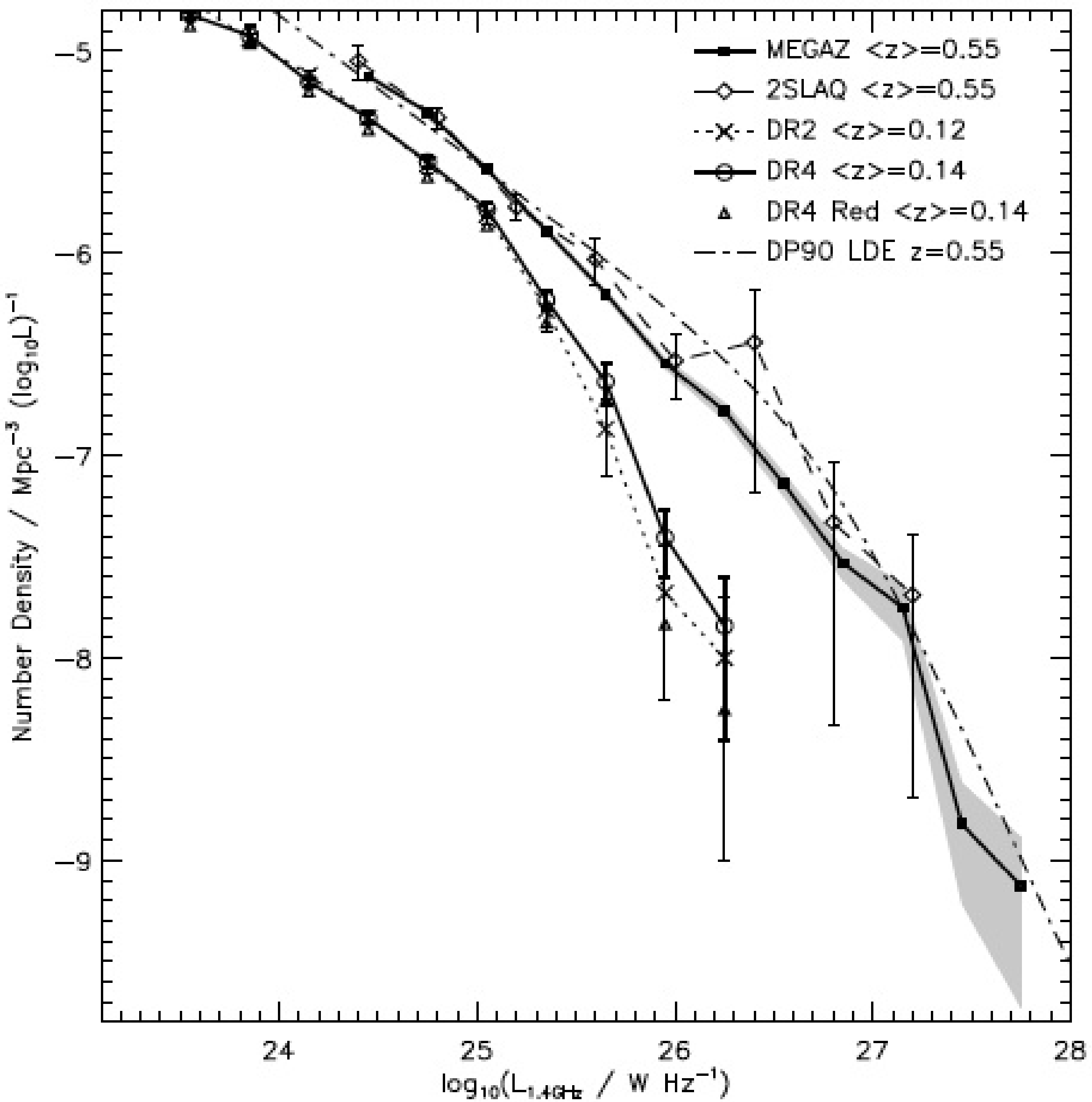
2DF Survey: Croom et al 2004

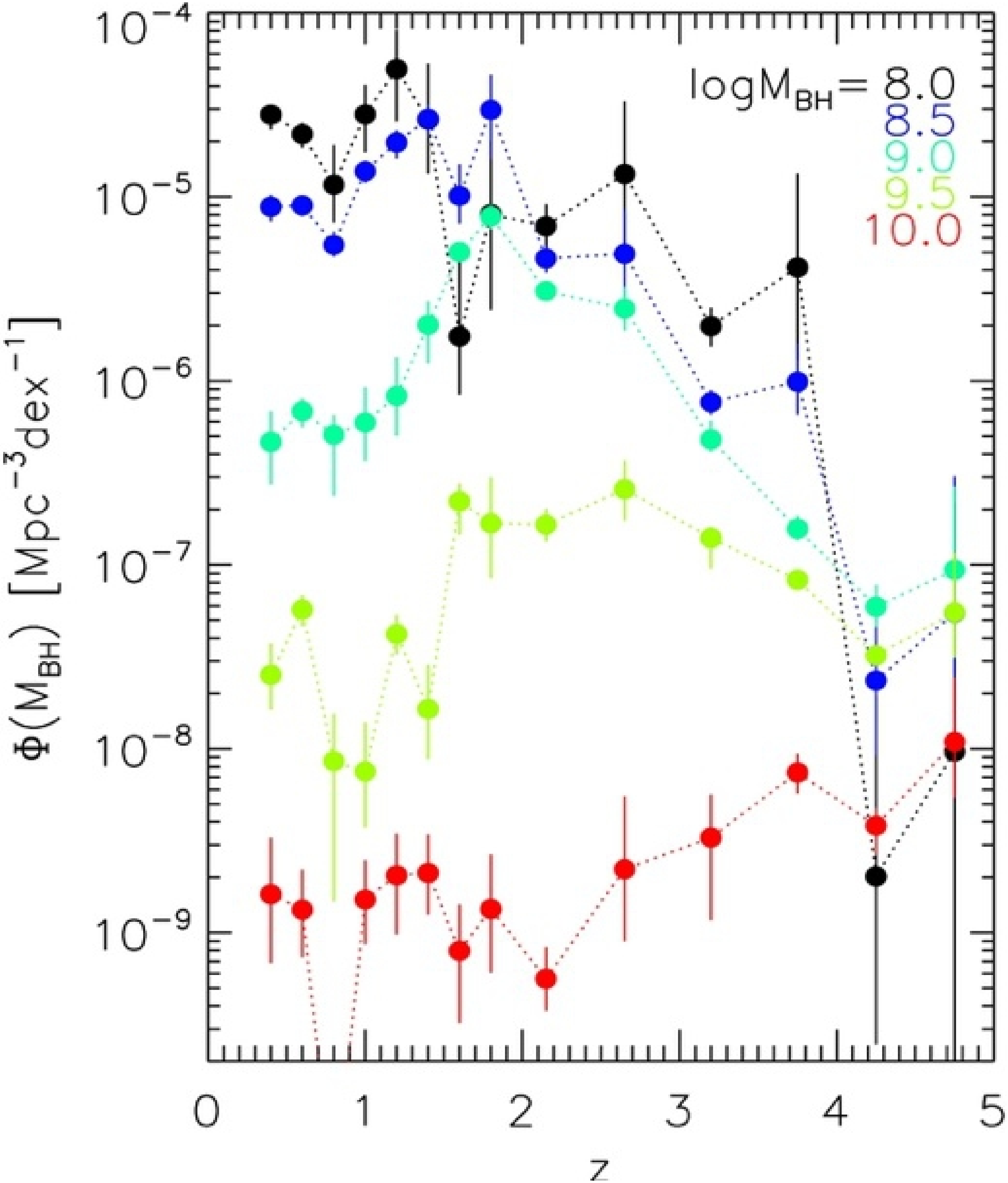
Abundance of luminous QSOs has decreased by 2 orders of magnitude since early epochs!

(e.g. SDSS Richards et al 2006)

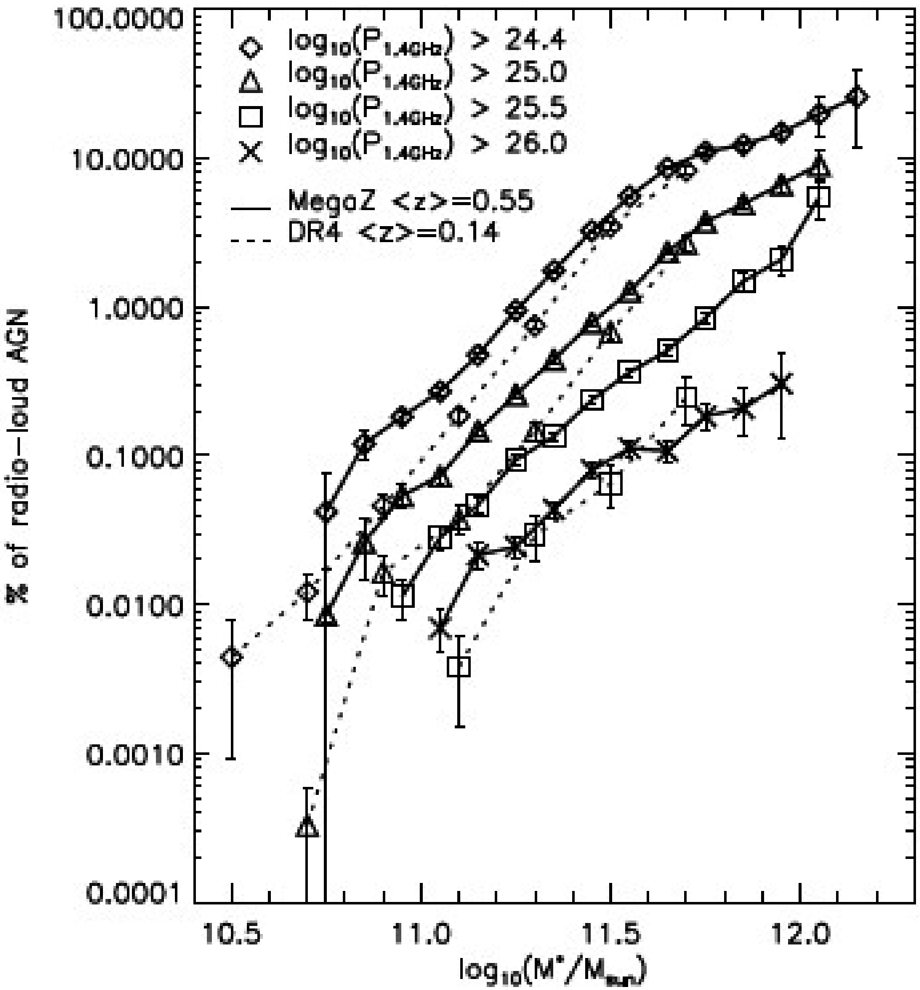


Likewise radio AGN are more luminous at higher redshifts ==> Higher accretion rates onto the black holes

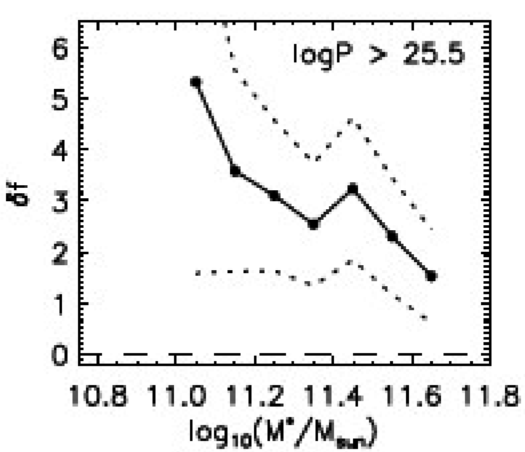


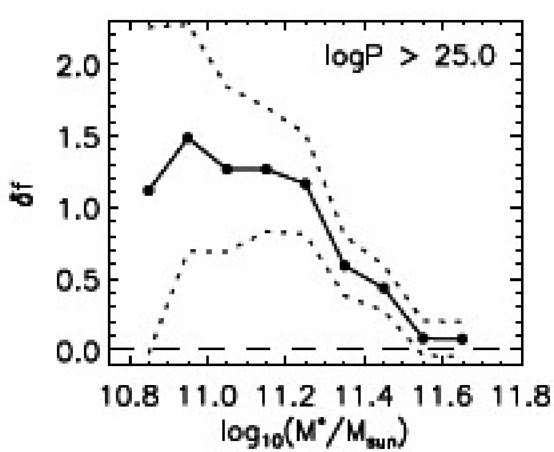


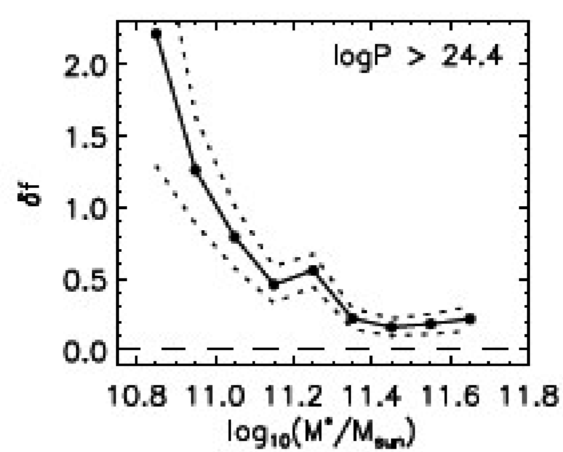
In the optical, it is the high mass black holes that exhibit greater nuclear activity in the past.



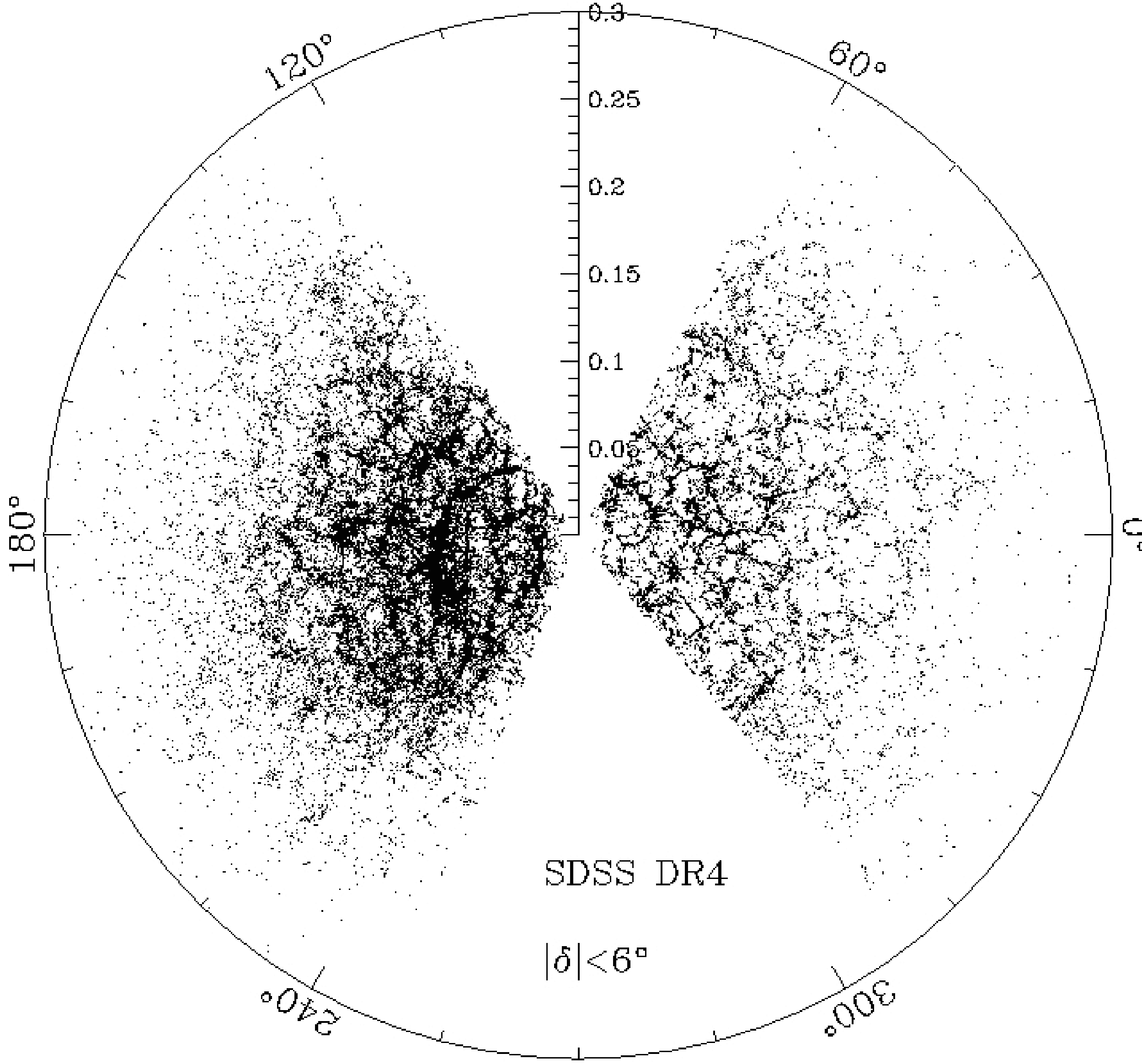
It is the lower mass galaxies that exhibit more nuclear activity in the radio in the past.

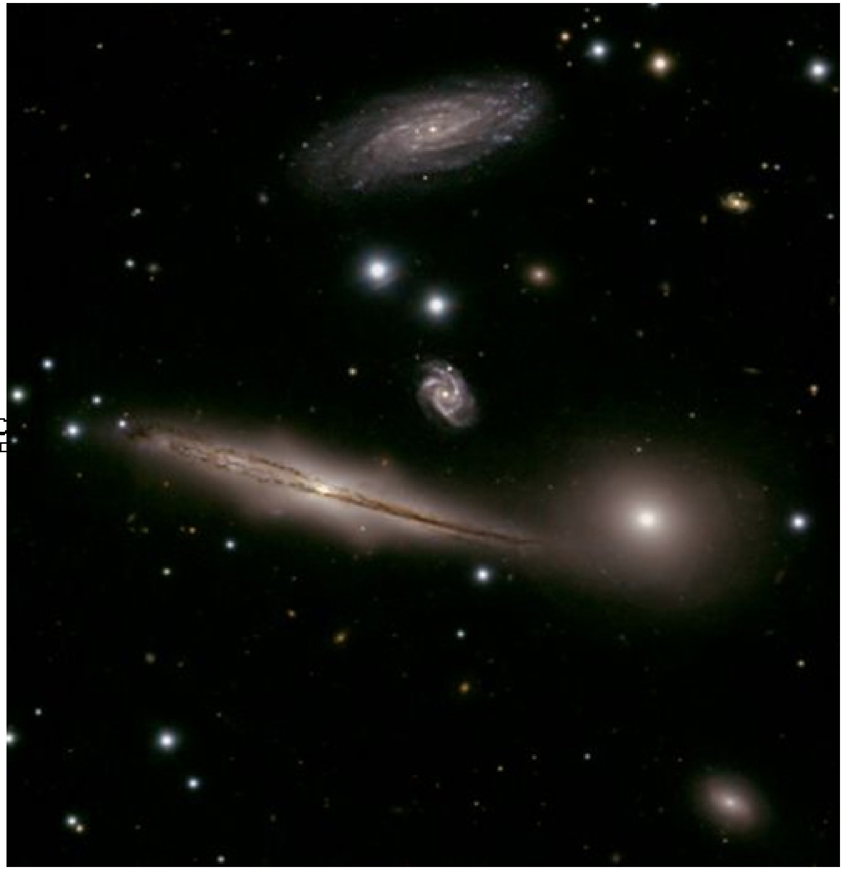


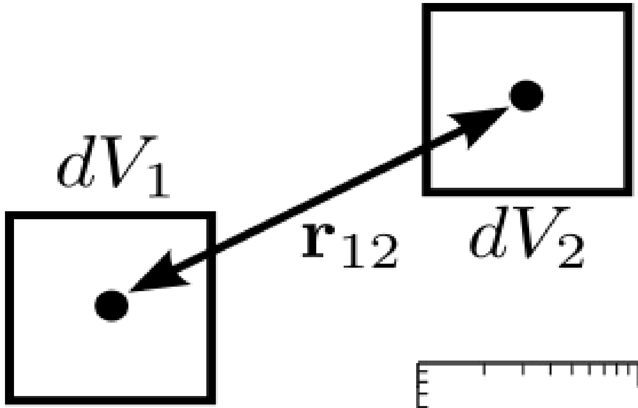




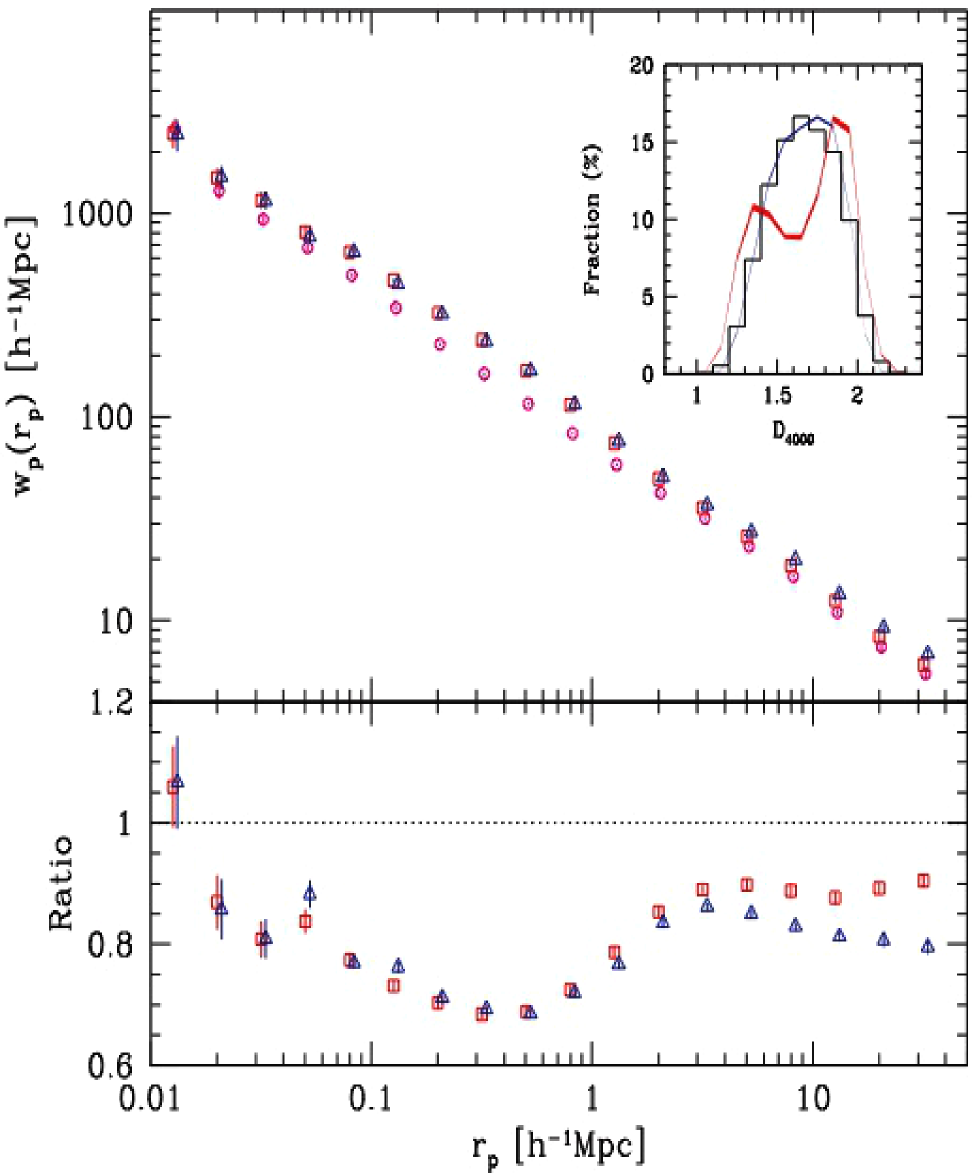
STUDYING THE ENVIRONMENTS OF AGN IN SDSS







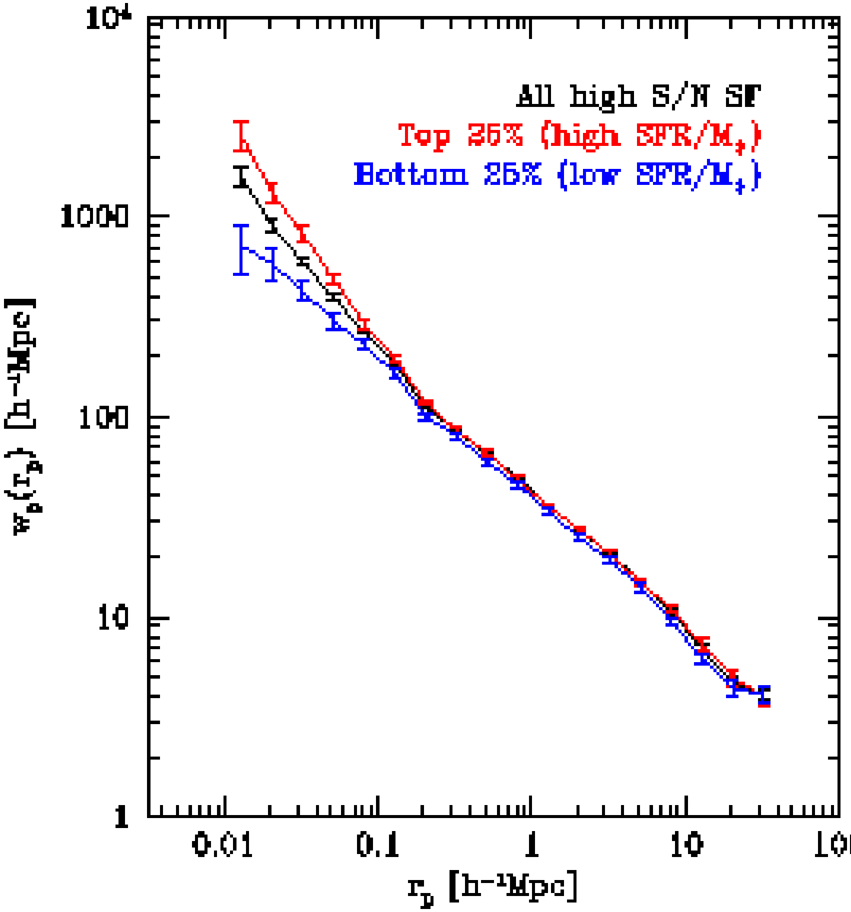
Two-point correlation function defined as the excess probability to find two galaxies separated by distance r, compared to a randomly-distributed sample.

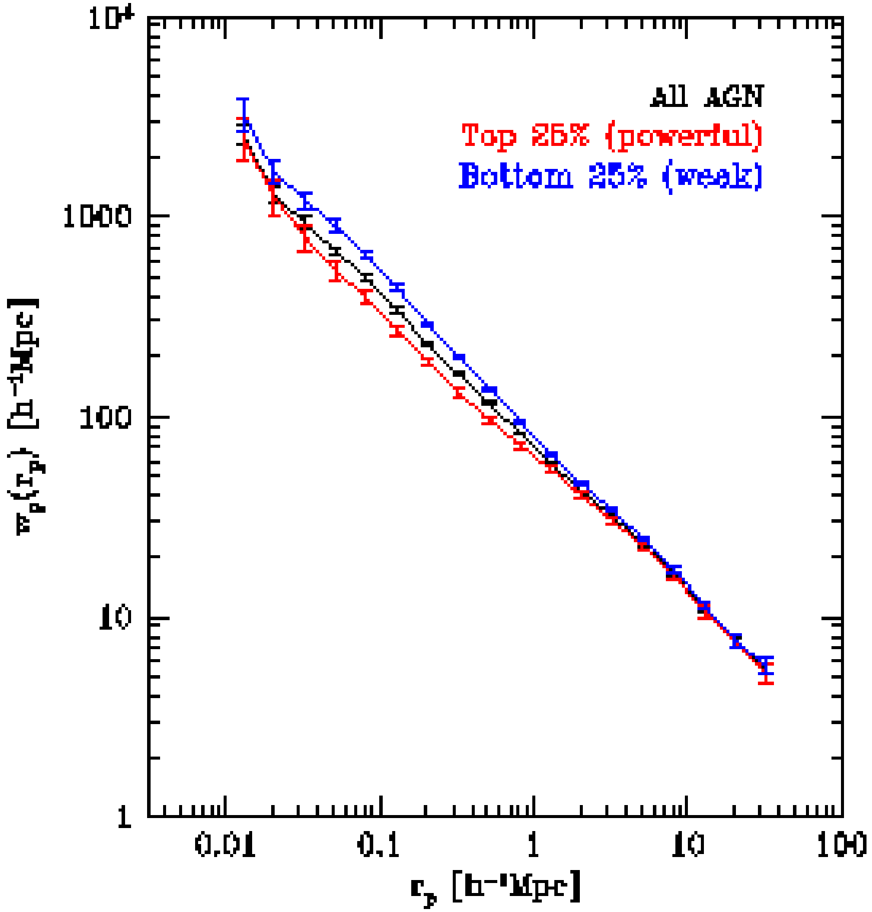


Optical AGN are more weakly clustered than control samples of non-AGN matched in stellar mass, redshift, concentration index, stellar surface density, and stellar age.

Galaxy interactions/mergers trigger more star formation, but apparently NOT more AGN activity

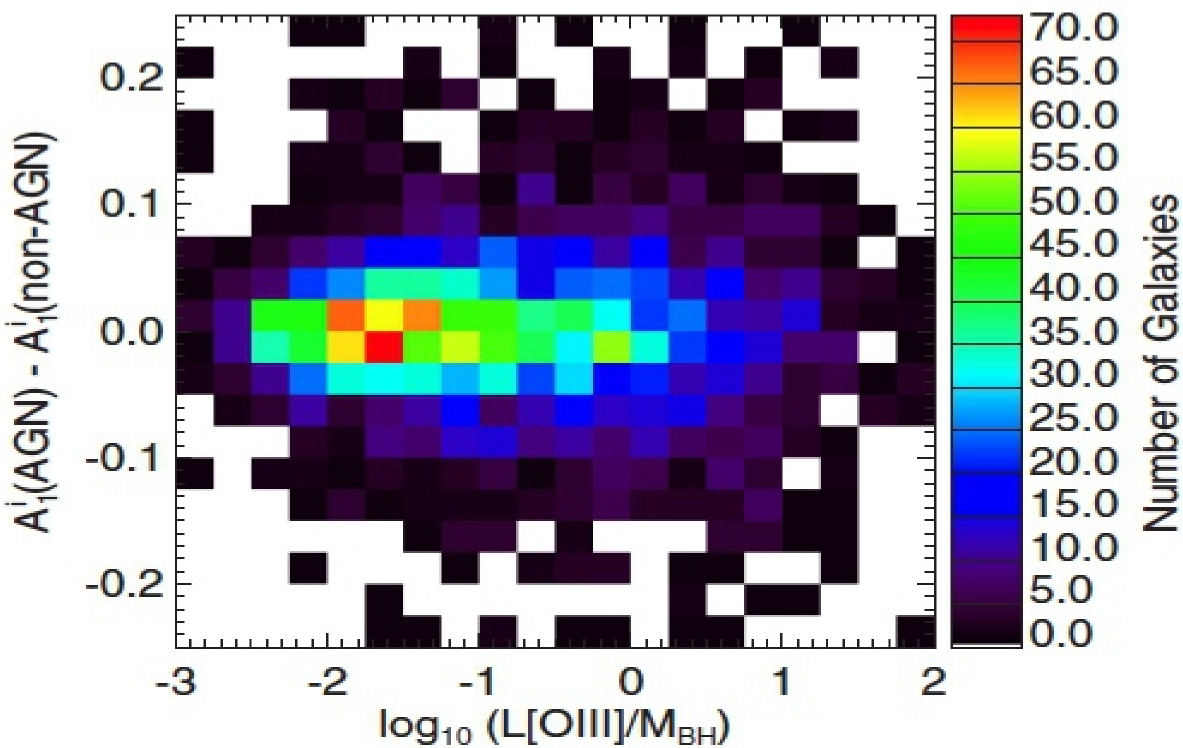
The cross-correlation function star-forming galaxies compared to AGN.





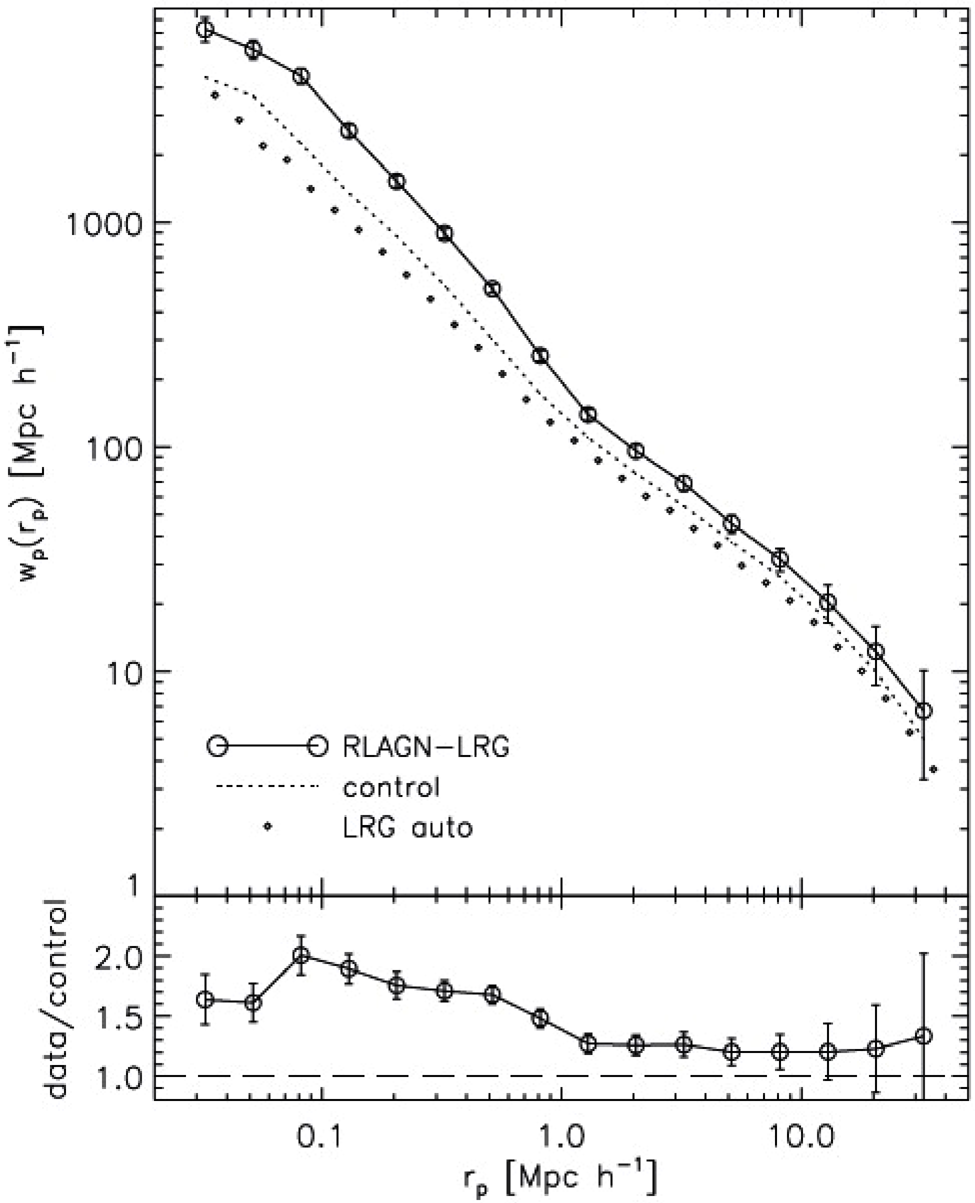
Lopsided galaxy

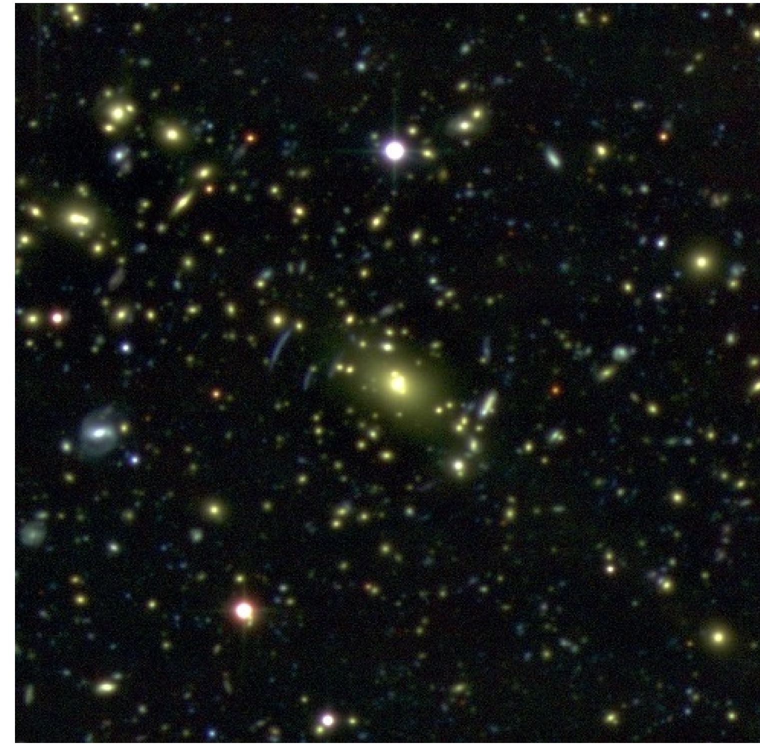
Symmetric galaxy

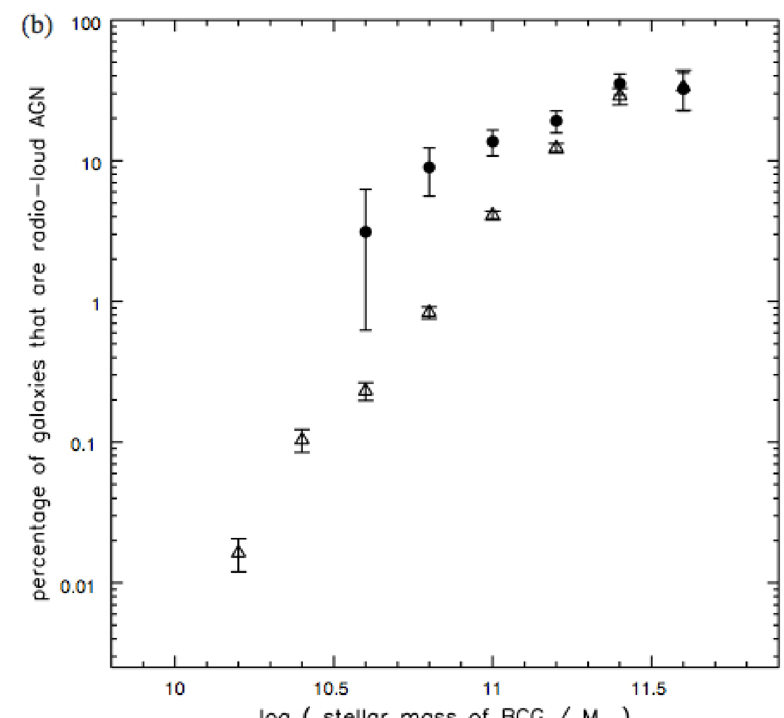


No evidence for excess of lopsided AGN hosts compared to matched control samples of non-AGN

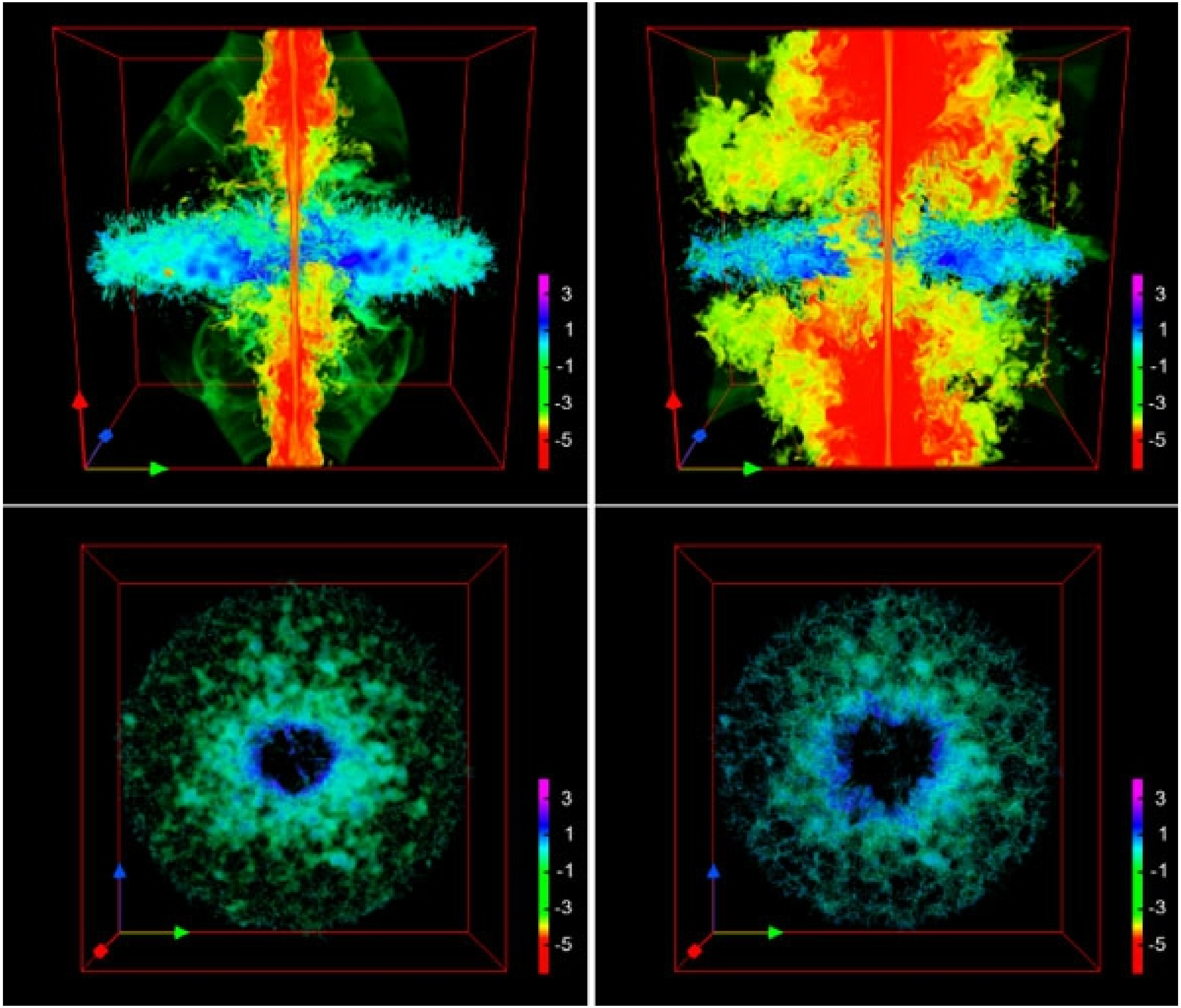
Radio-loud AGN are more strongly clustered than control samples – frequently found in the BCG (brightest cluster galaxy)

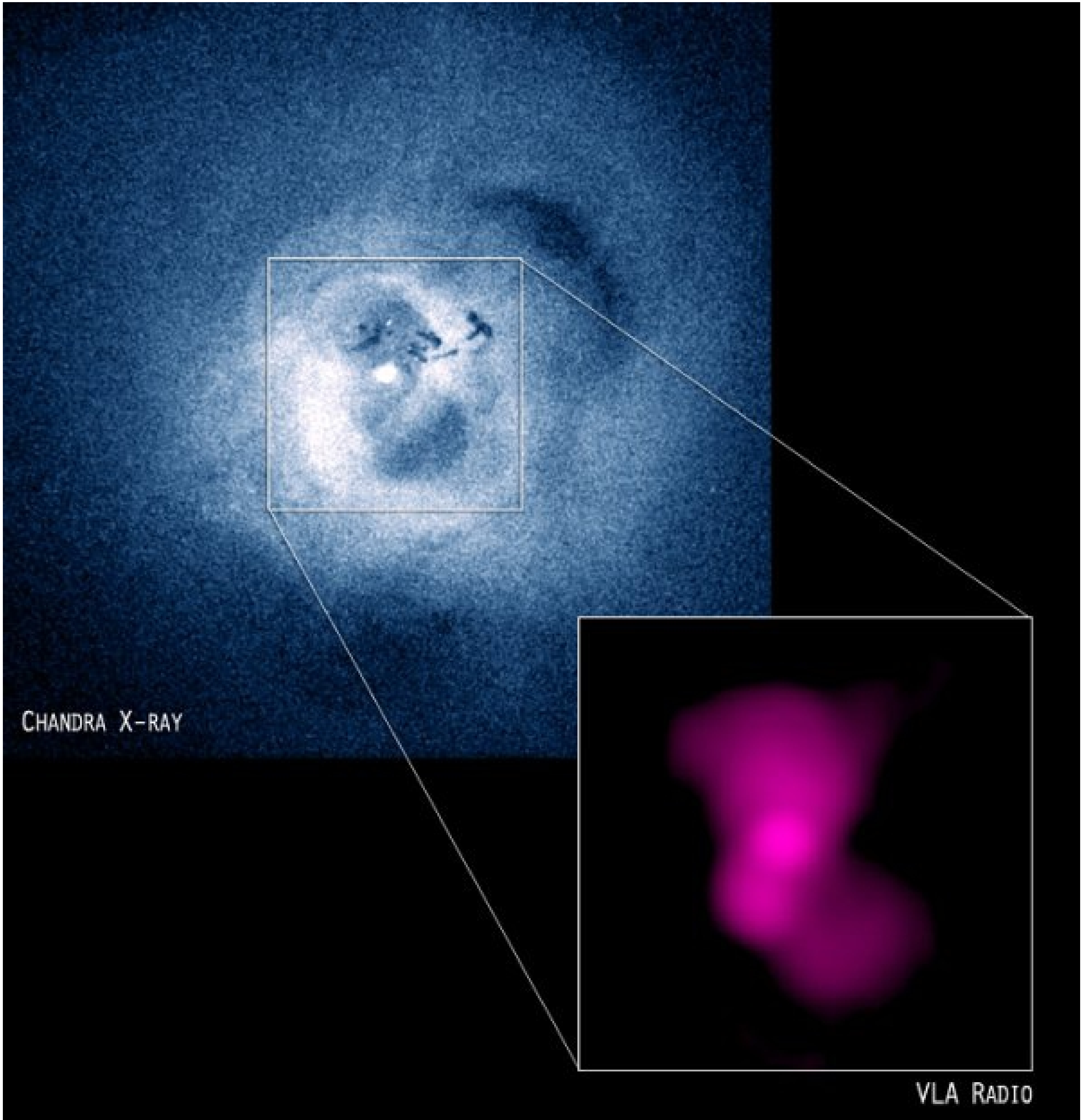




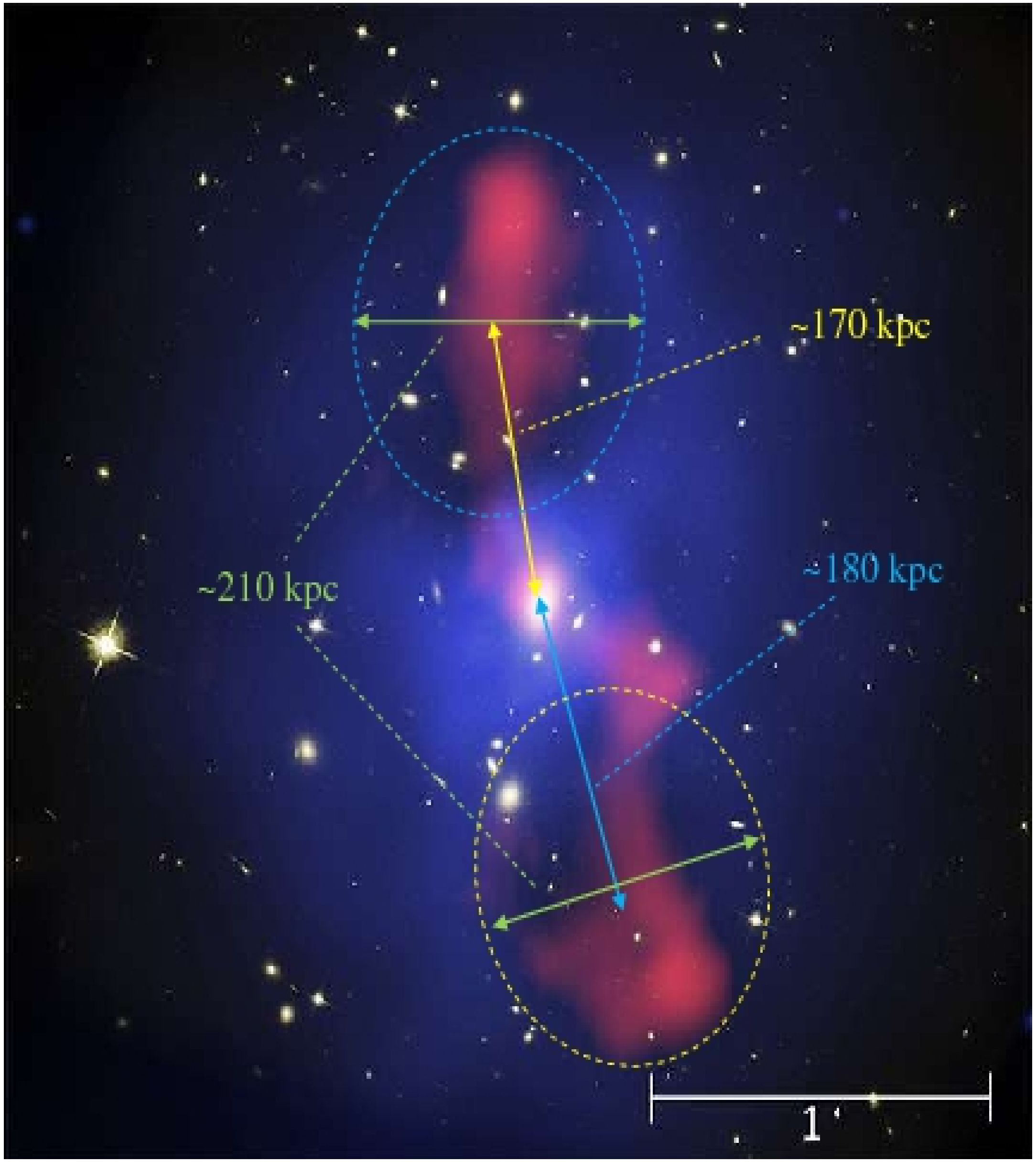


AGN "Feedback" : Impact on Galaxy Formation

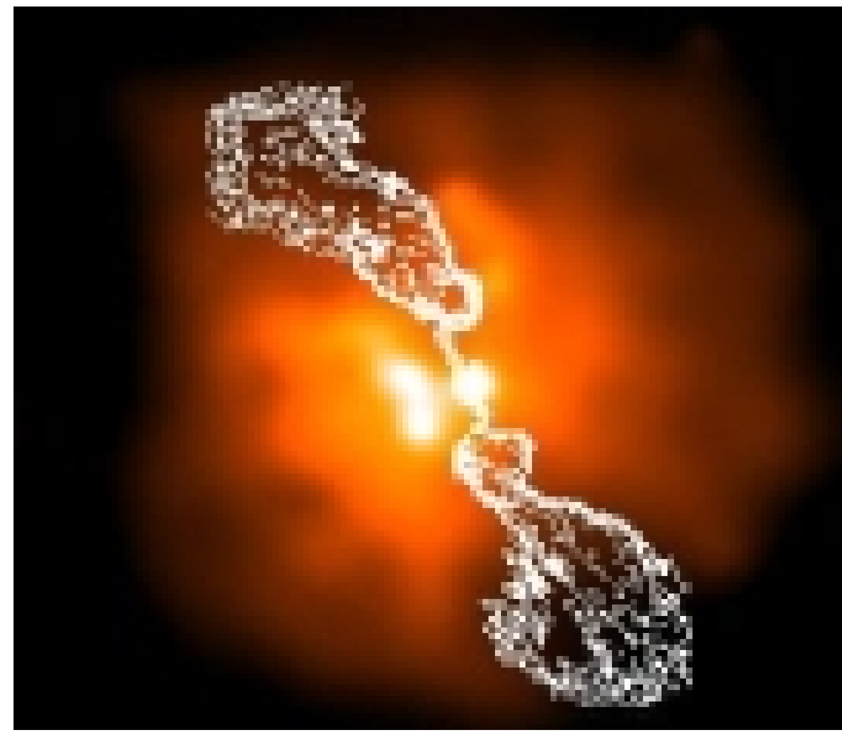




RADIO-AGN ACTIVITY INFLUENCING THE GAS IN THE PERSEUS CLUSTER



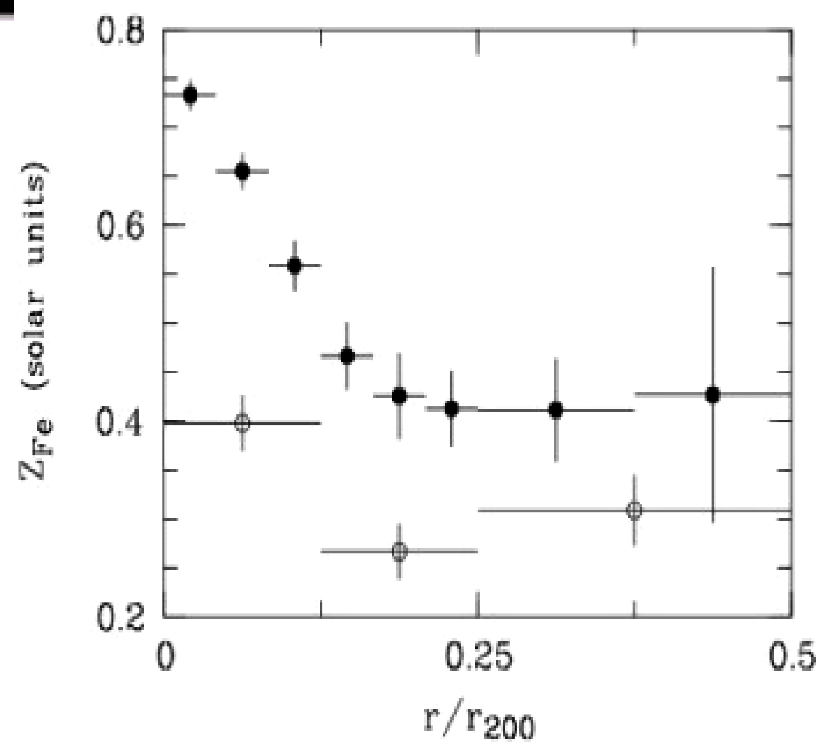
More examples of cavities in X-ray emission filled in with radio synchrotron emitting plasma



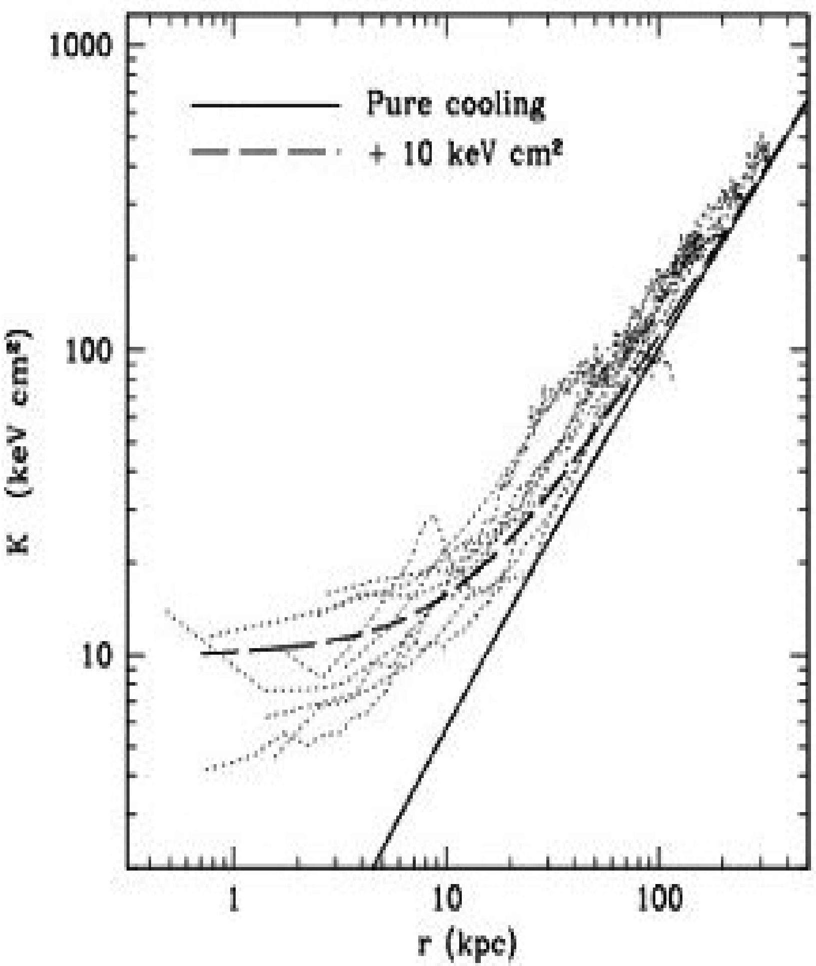
Hα emission traces filamentary structure of gas that have been "uplifted" from the central galaxy

Figure 7 from B R McNamara and P E J Nulsen 2012 New J. Phys. 14 055023

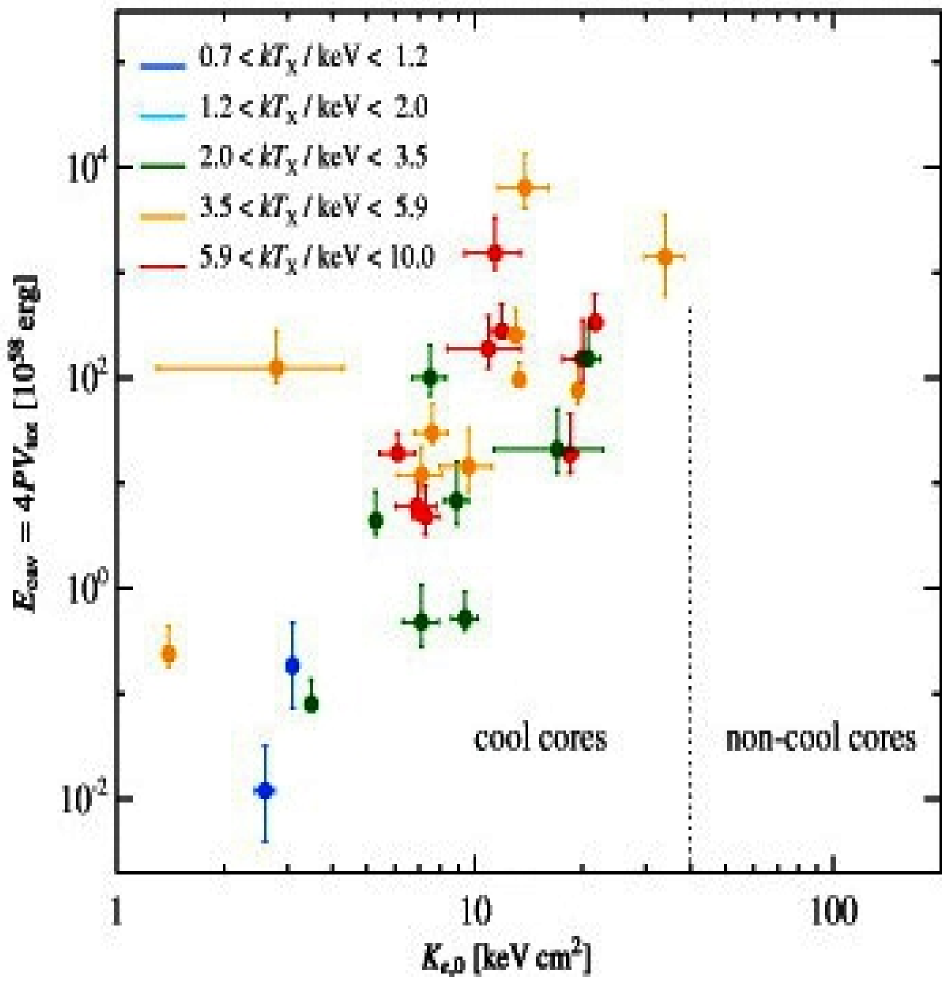
Figure 6 from B R McNamara and P E J Nulsen
2012 New J. Phys. 14 055023



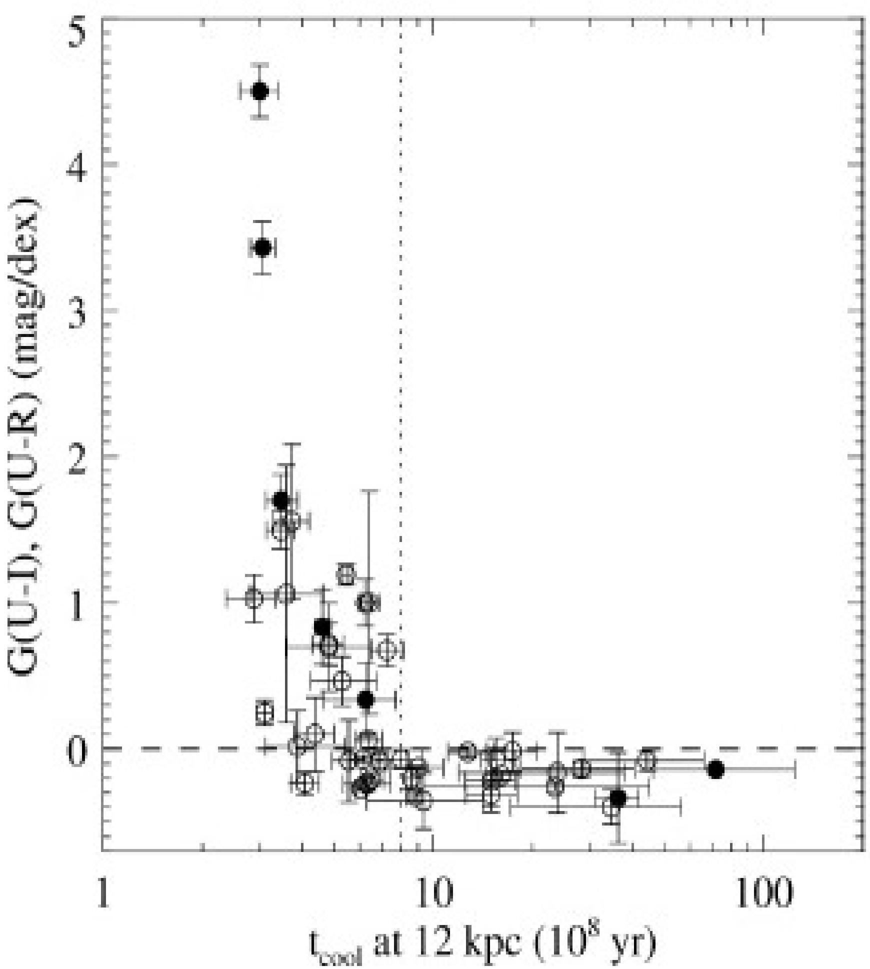
Entropy profiles of clusters

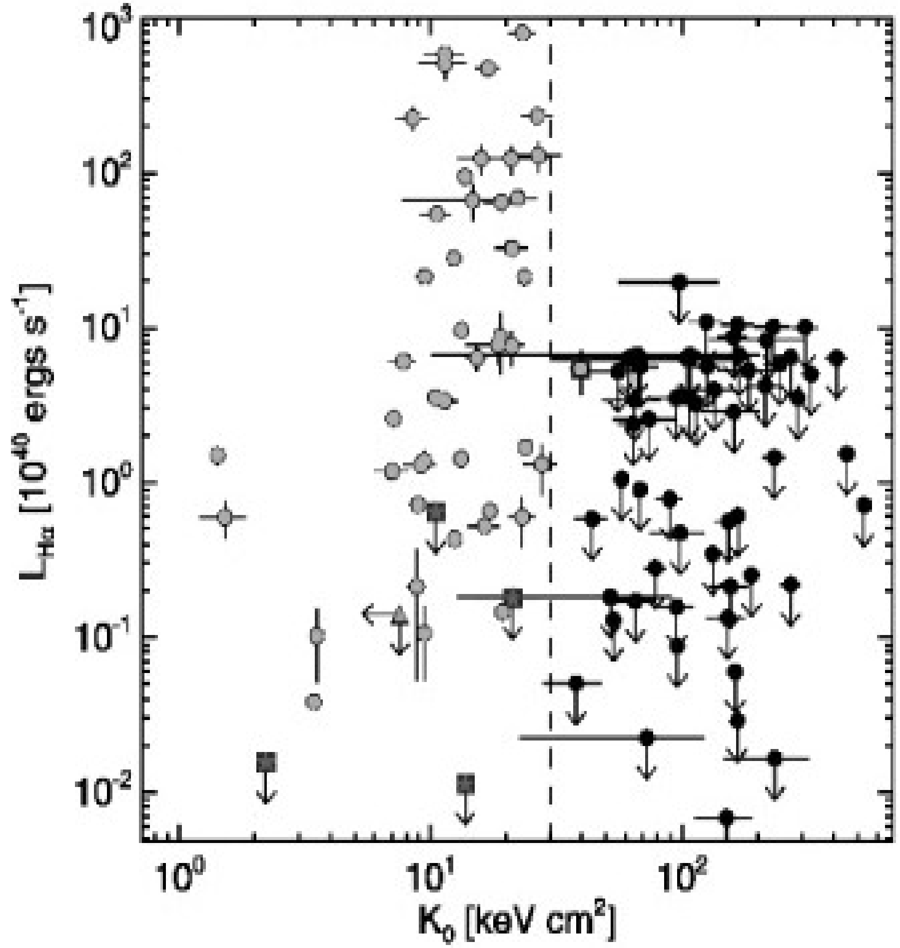


Central entropy versus radio power



Central entropy determines whether there is star formation in the central galaxy

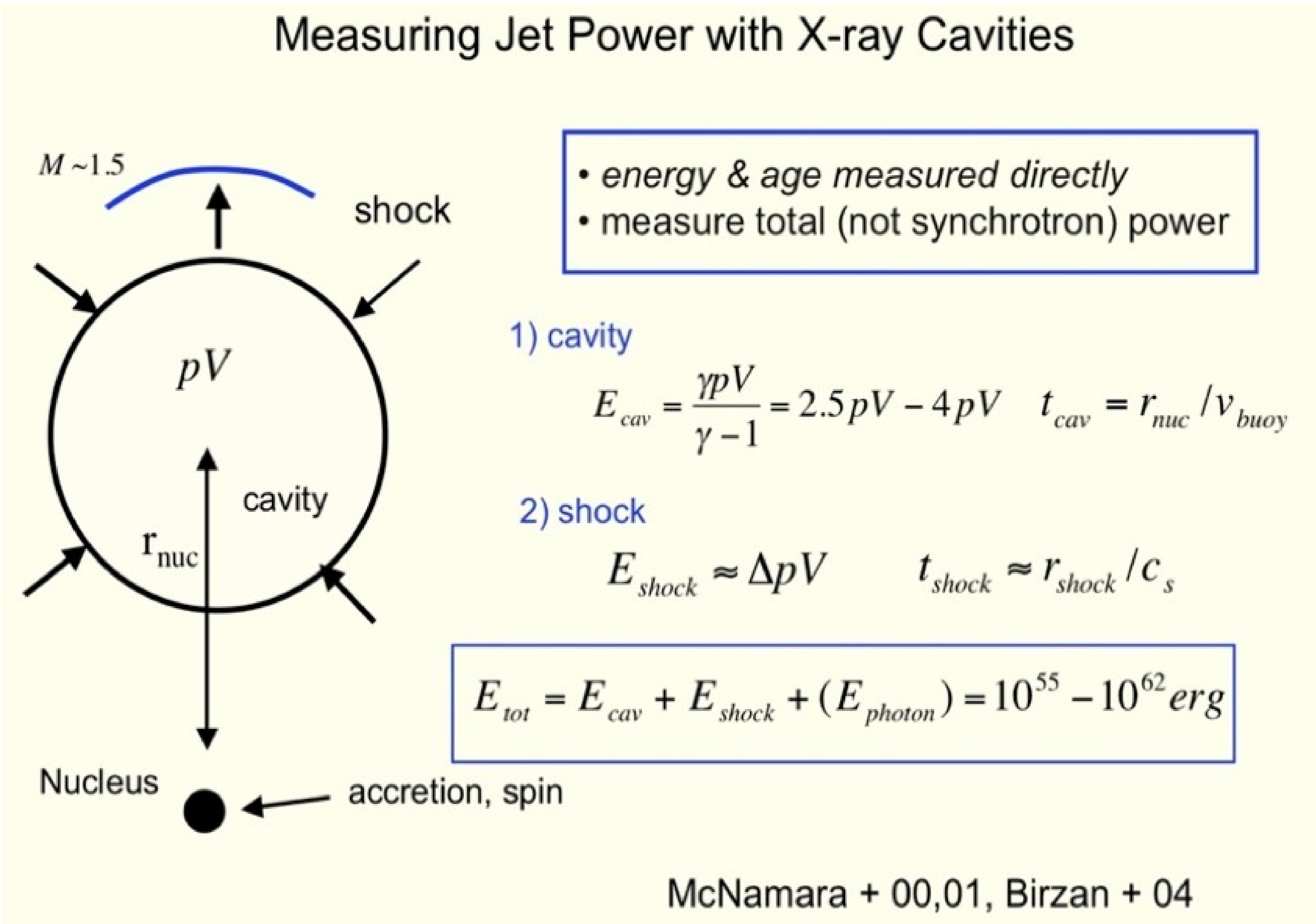




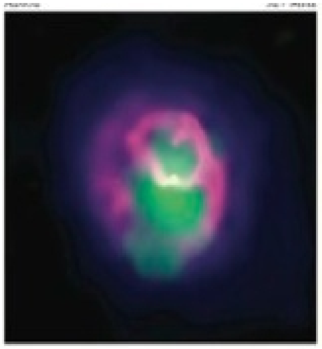
A possible picture is emerging from the data:

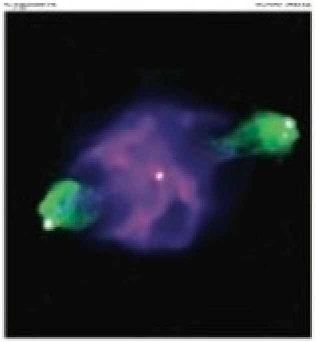
Jets from AGN (visible at radio wavelengths as a result of synchrotron emission) push gas and metals out of the central galaxy, and also heat the ambient gas, preventing from cooling and forming stars.

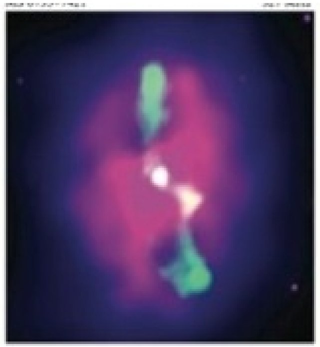
Density and temperature are derived from the X-ray spectra. Pressure $p = nkT$. Mechanical power of the jet can be approximated as the energy (~pV) of the detected cavities averaged over some timescale.

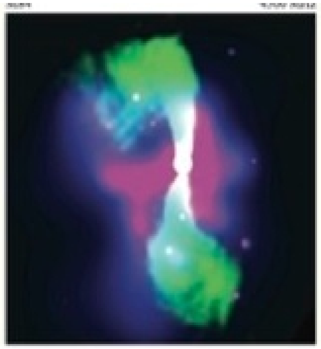


$$P_{cavity} \propto L_{radio}^{0.7}$$

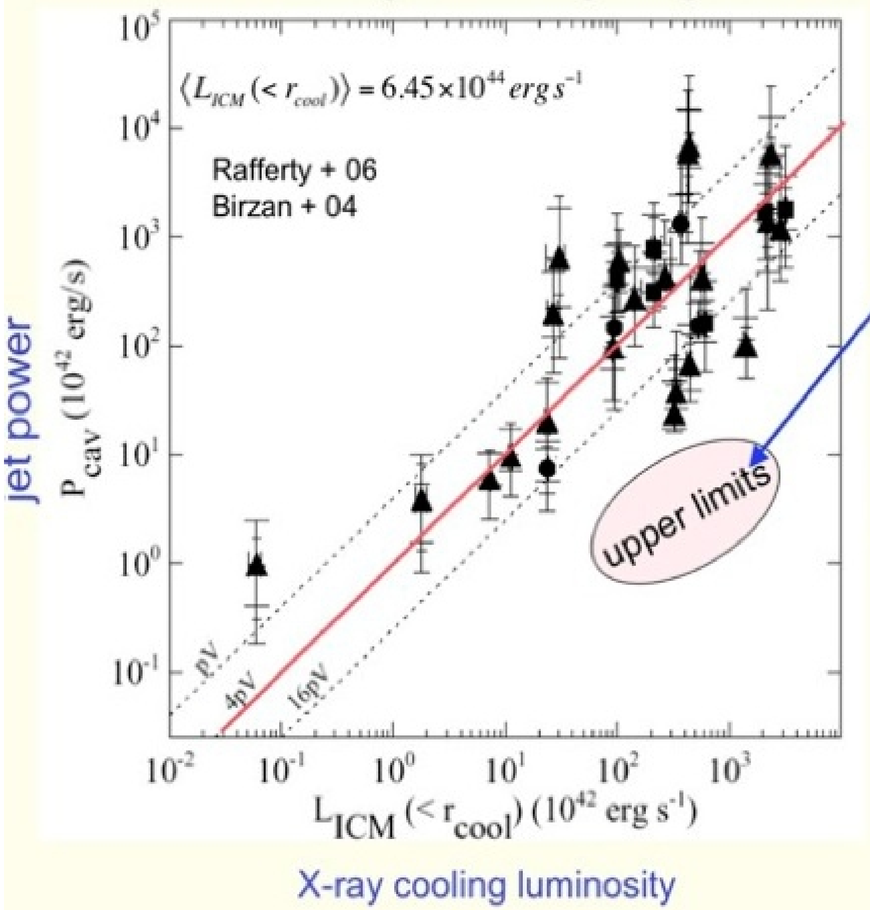








Heating & Cooling Diagram: CFs Quenched



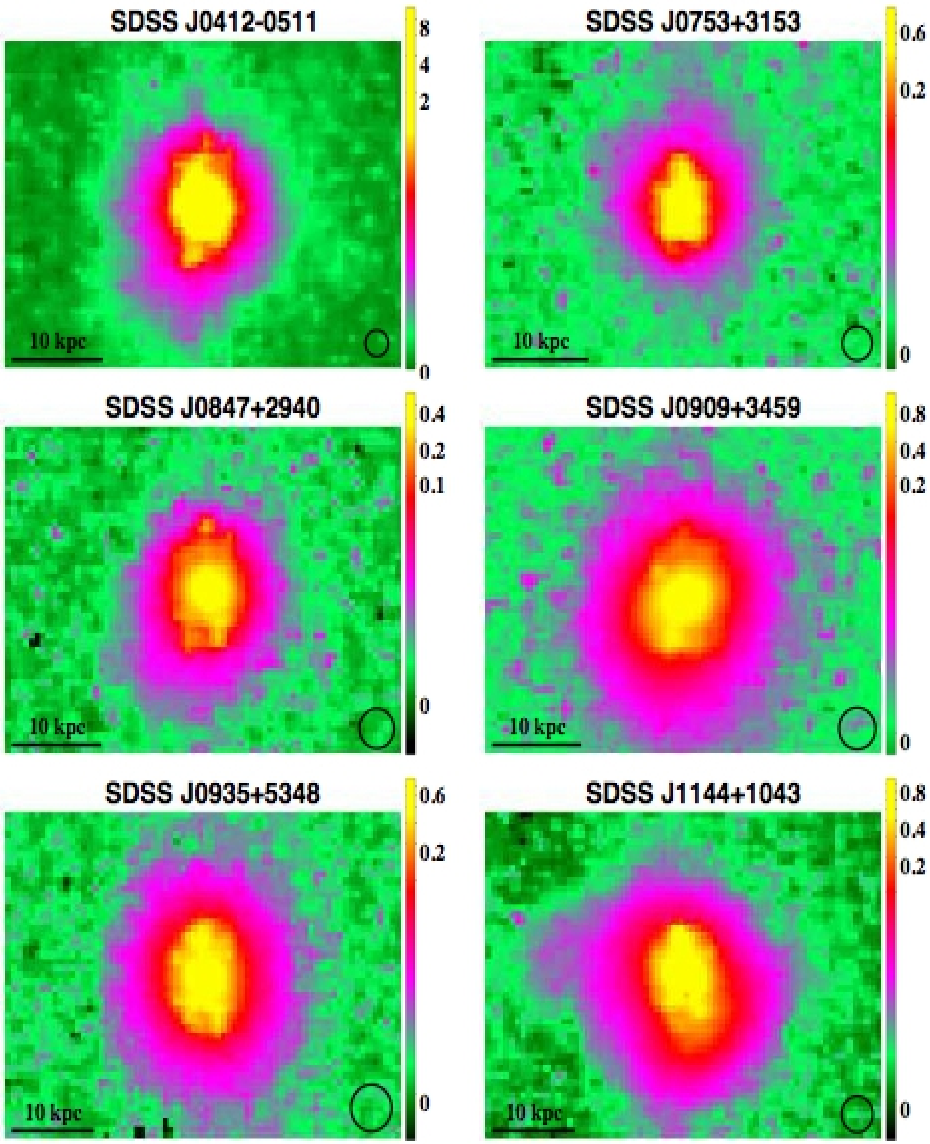
$$\Phi = \frac{P_{cav}\times f}{\langle L_{ICM}(< r_{cool})\rangle} = 1.1$$

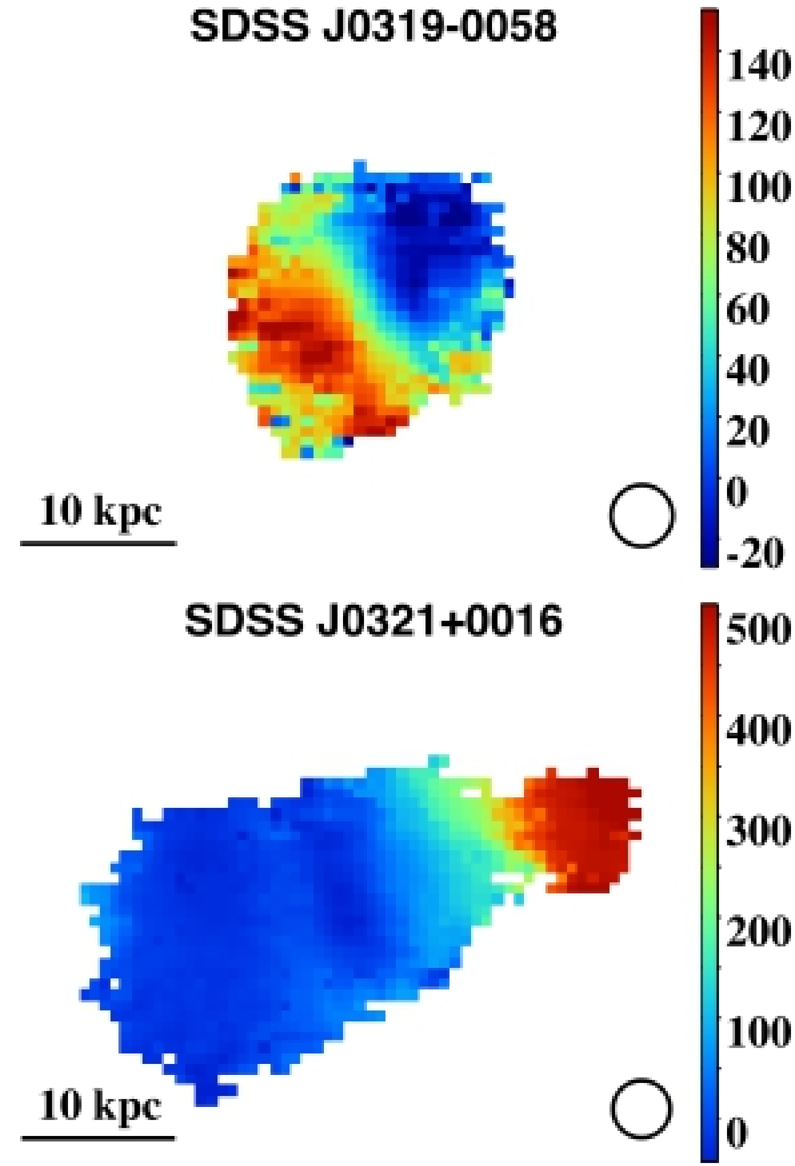
$f = 0.7$
(Dunn & Fabian 06)

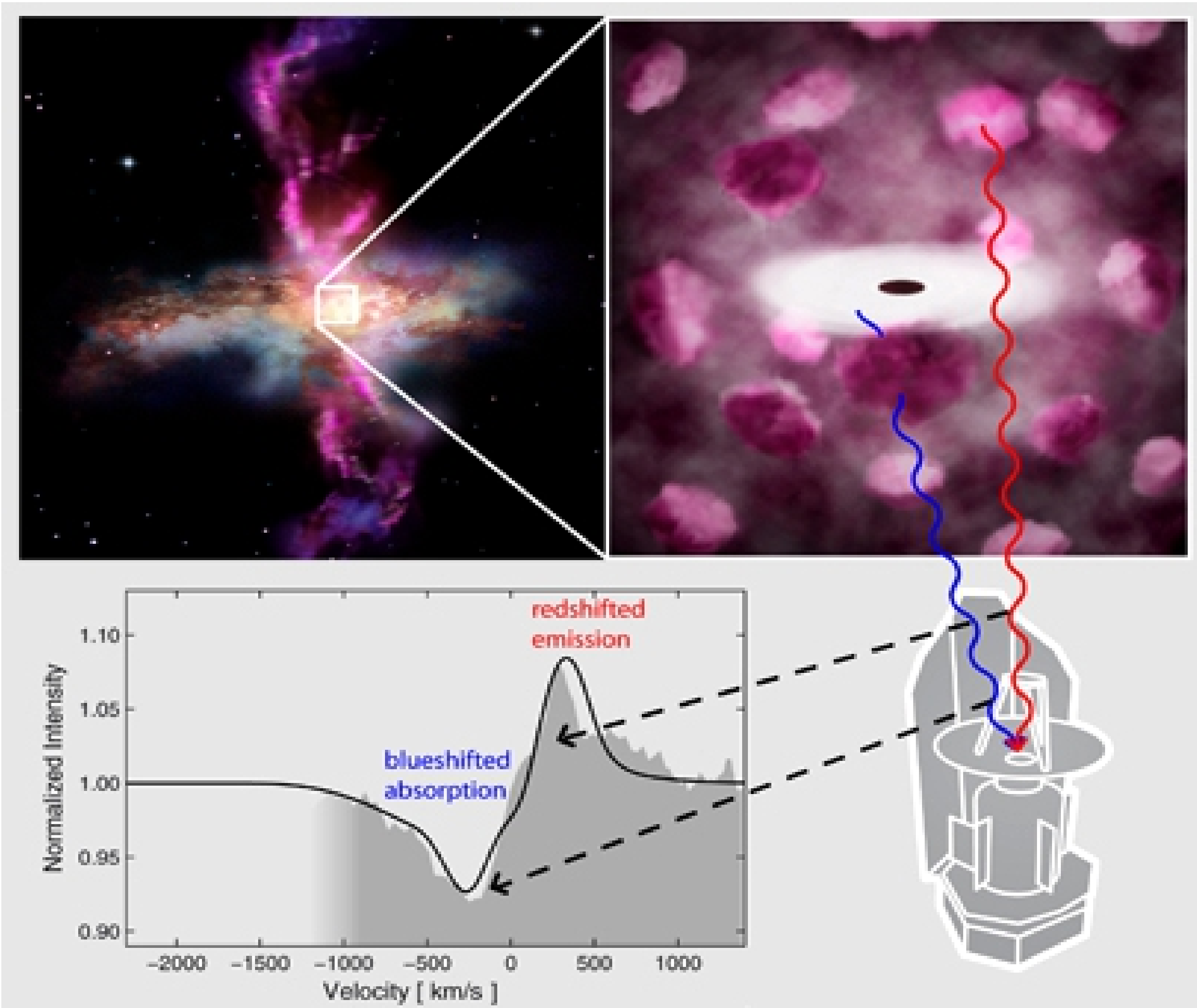
heating ~ cooling

Trend between heating and cooling!
Energy associated with cavities is sufficient to substantially reduce or quench cooling (in many cases)
Conclusion: radio feedback is likely to be important

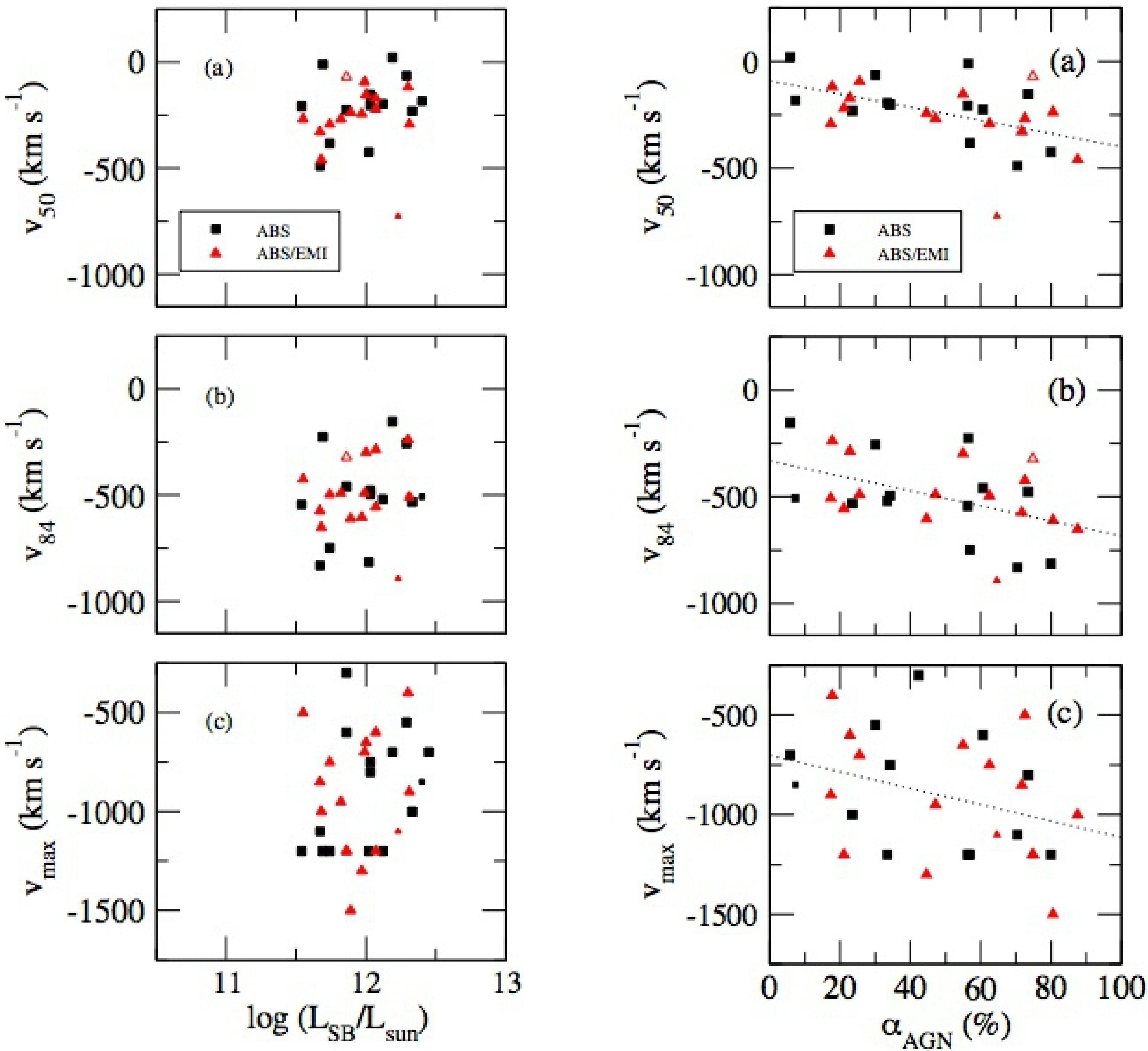
Outflows of ionized gas around Type II quasars also now seen. These ionized gas “halos” extend out to radii of 50 kpc and are very round in morphology. (Greene & Zakamska)







HERSCHEL observations of outflows of molecular gas in nearby quasars and AGN



(a)
(b)
(c)
ABS
ABS/EMI
v50 (km s-1)
v84 (km s-1)
vmax (km s-1)
log (LSB/Lsun)
αAGN (%)
0
-500
-1000
-1500
11
12
13
0
20
40
60
80
100

ACTUAL IMPACT OF OUTLOWS FROM QUASARS ON SUBSEQUENT EVOLUTION OF GALAXY NEEDS TO BE BETTER UNDERSTOOD