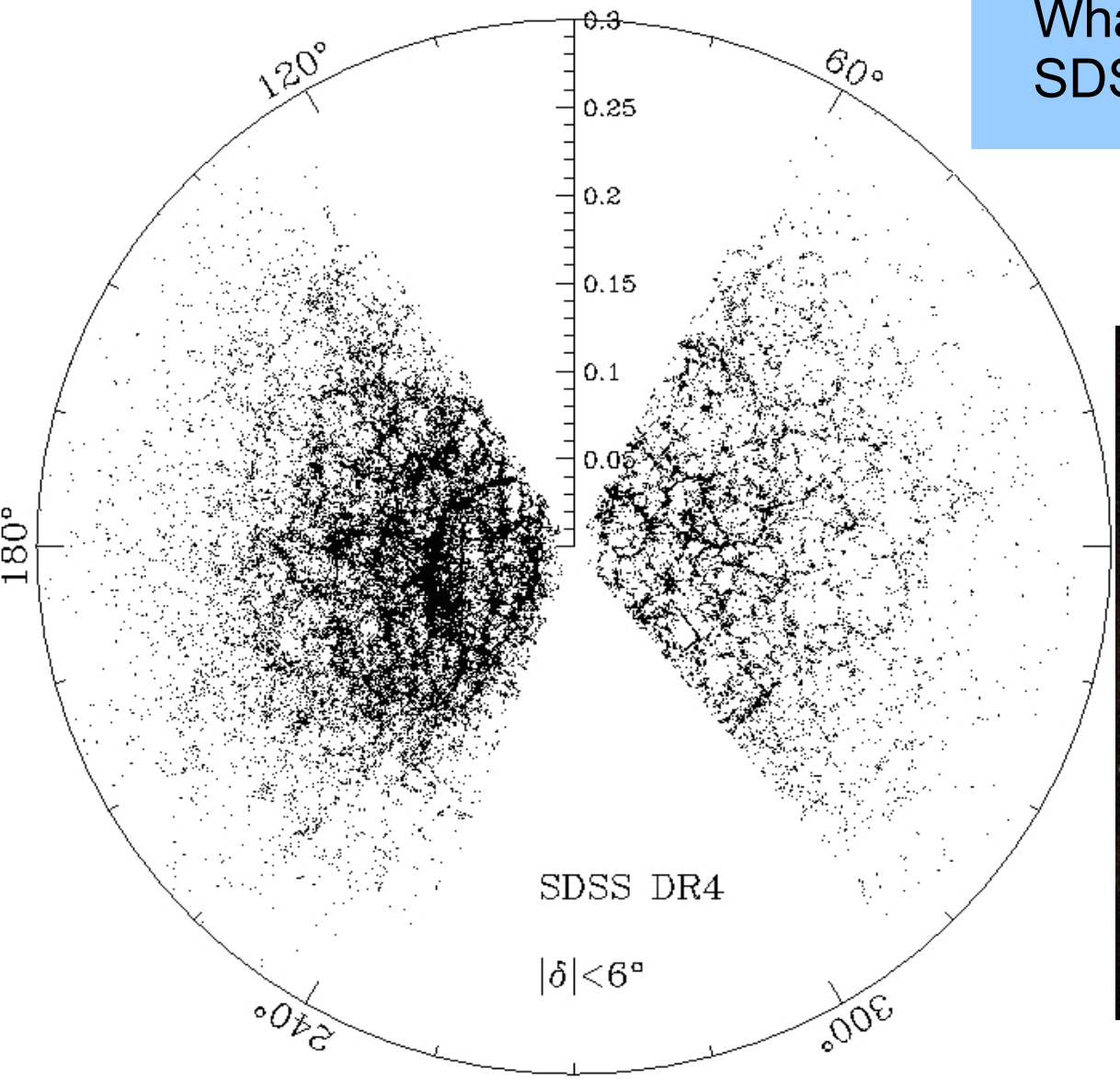
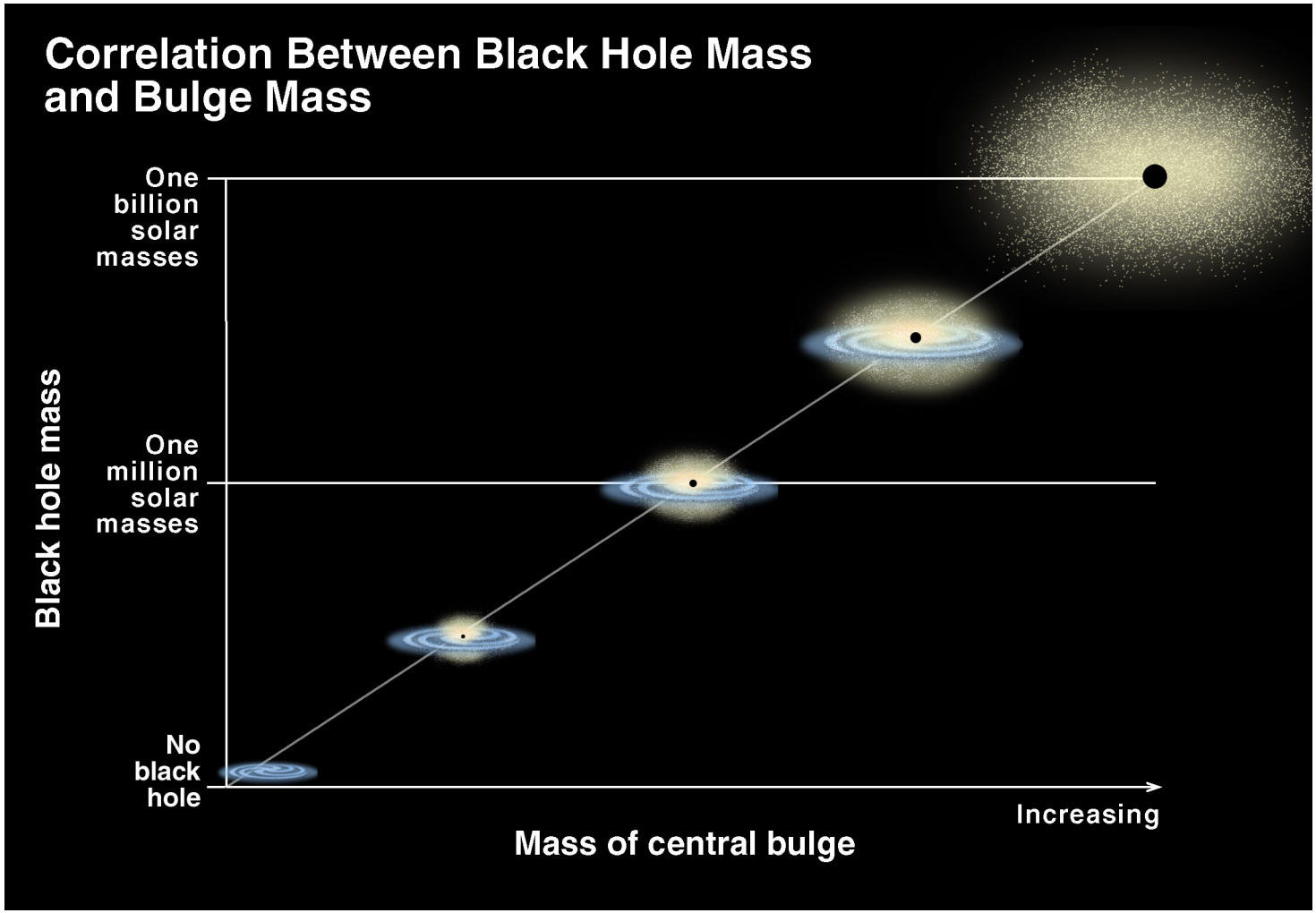
# The Co-evolution of Galaxies and their Supermassive Black Holes

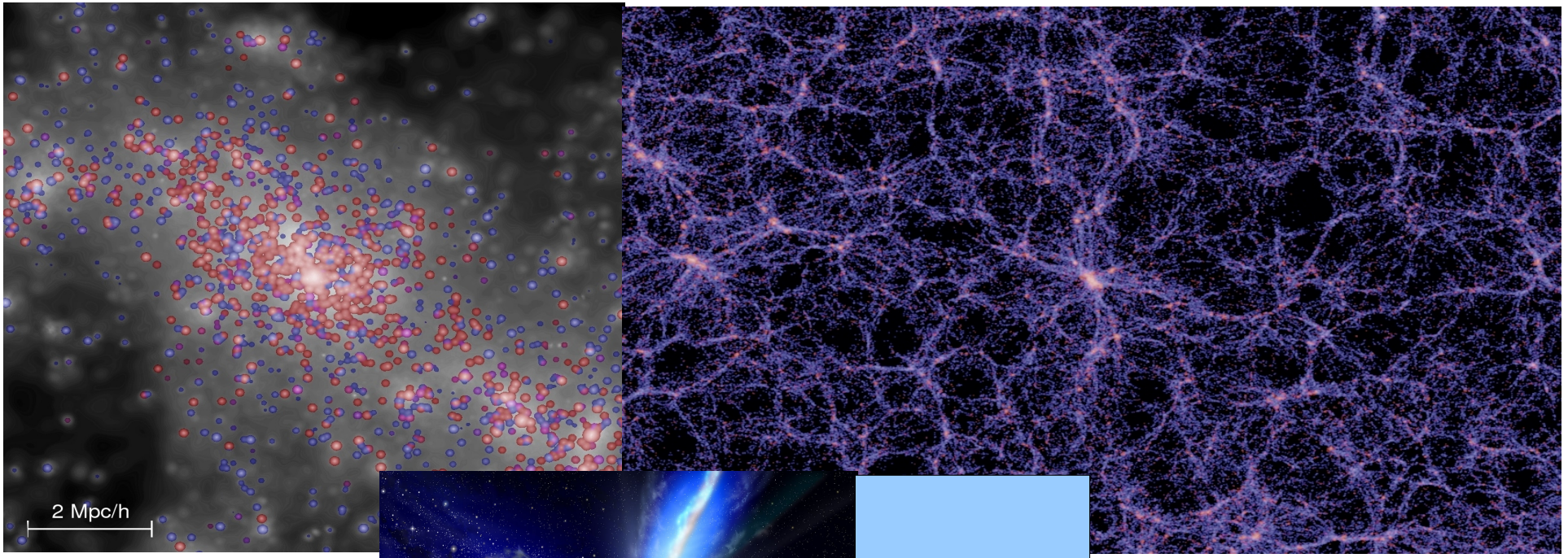
What have we learned from the SDSS?




**Revolution** in in our understanding of galaxy formation:

1) All galaxy bulges contain supermassive black holes
2) The mass of the black hole is tightly correlated with the mass of the bulge.



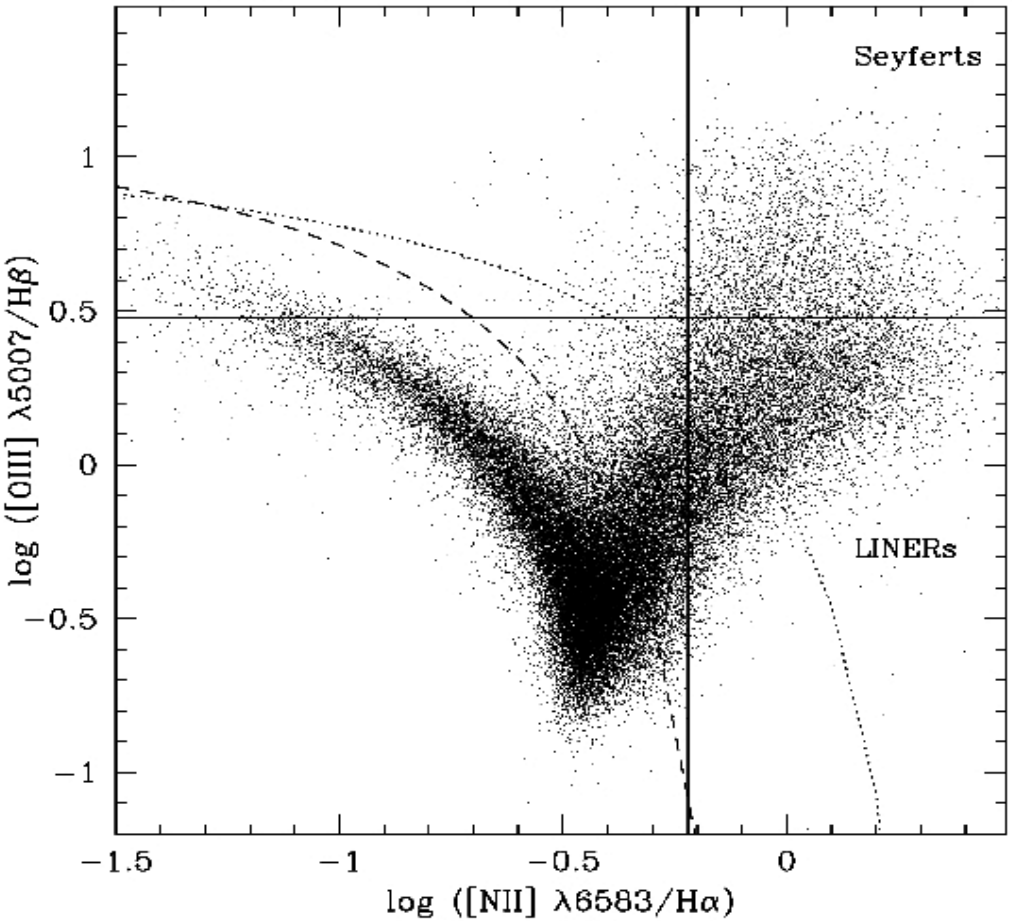

2 Mpc/h

?


2 Mpc/h
125 Mpc/h

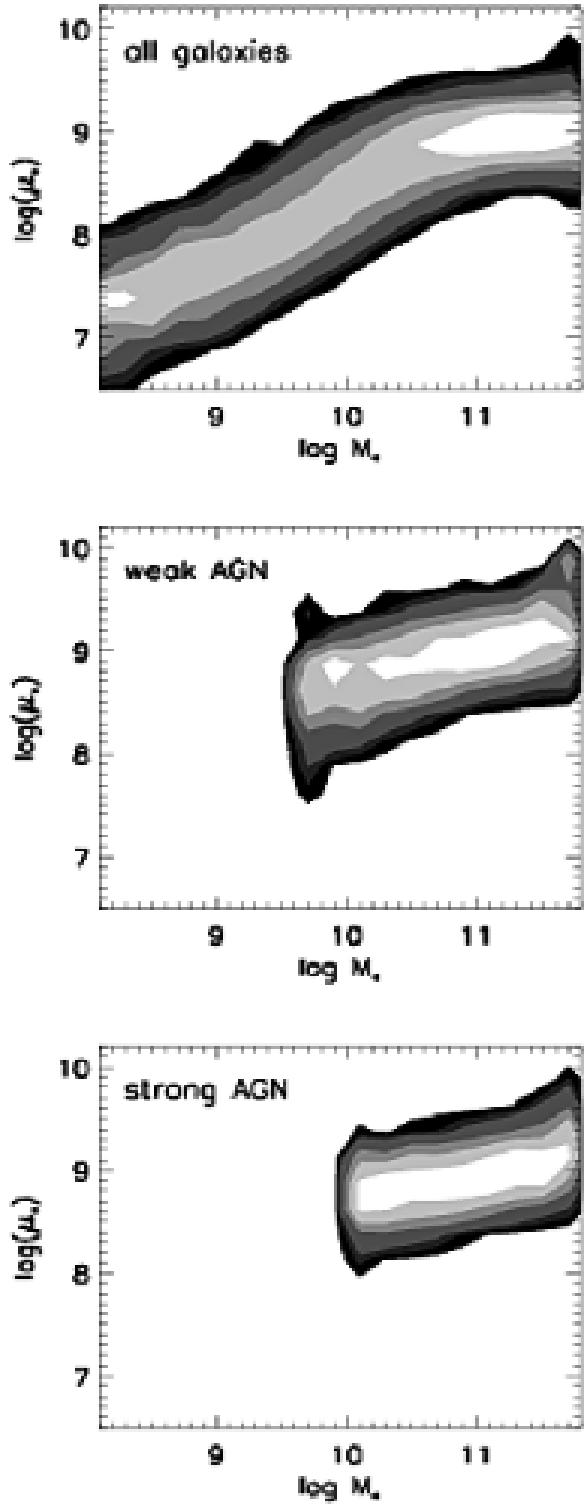
# Surveys of Type II AGN at Low Redshifts from SDSS

(for detailed analysis of host galaxy properties)




Kauffmann et al 2003

80,000 out of 400,000 galaxies are classified as AGN

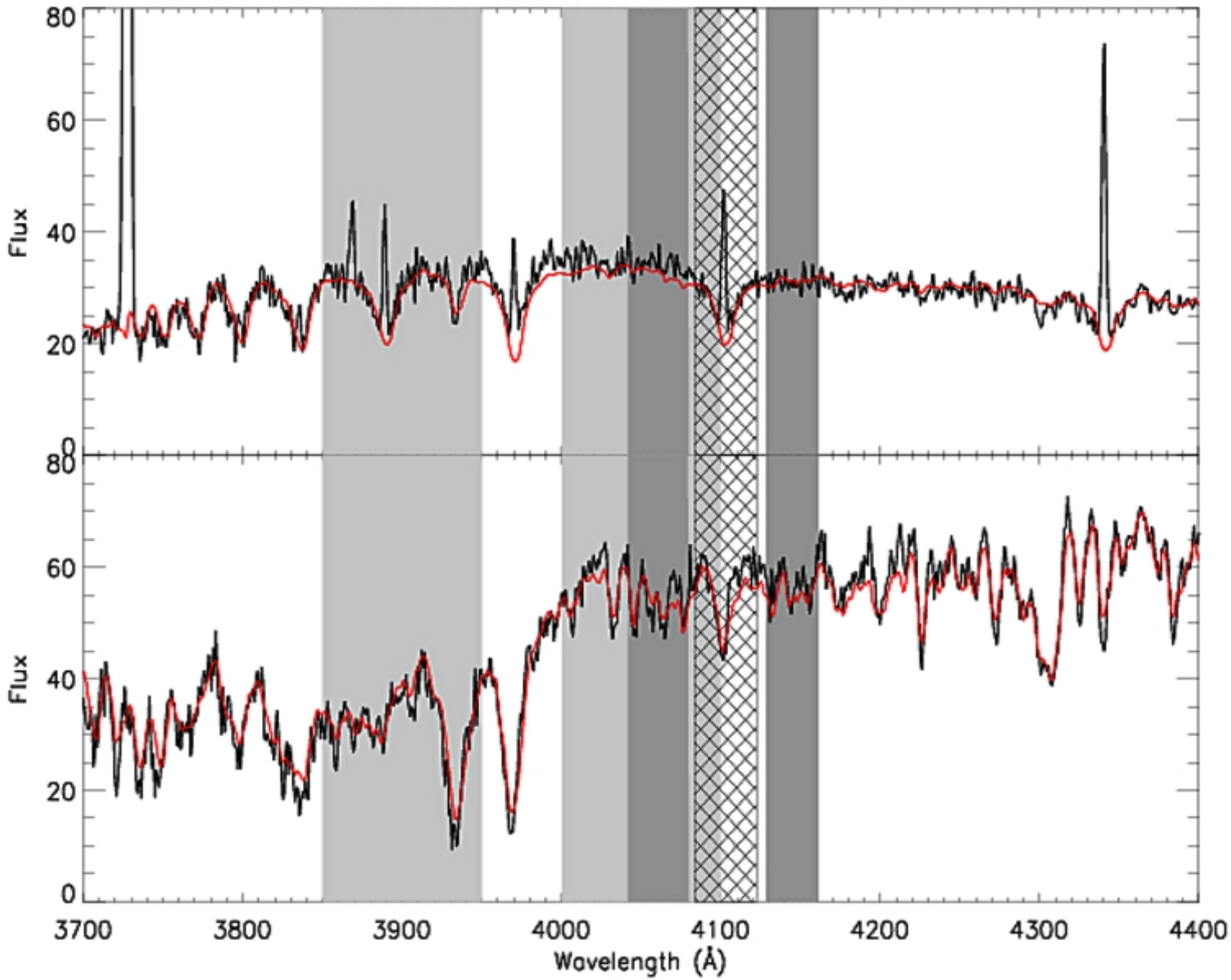



# The Stellar Masses and Structural Properties of AGN Hosts

**Main Conclusion:**
all AGN live in the same region of parameter space as massive, early-type galaxies

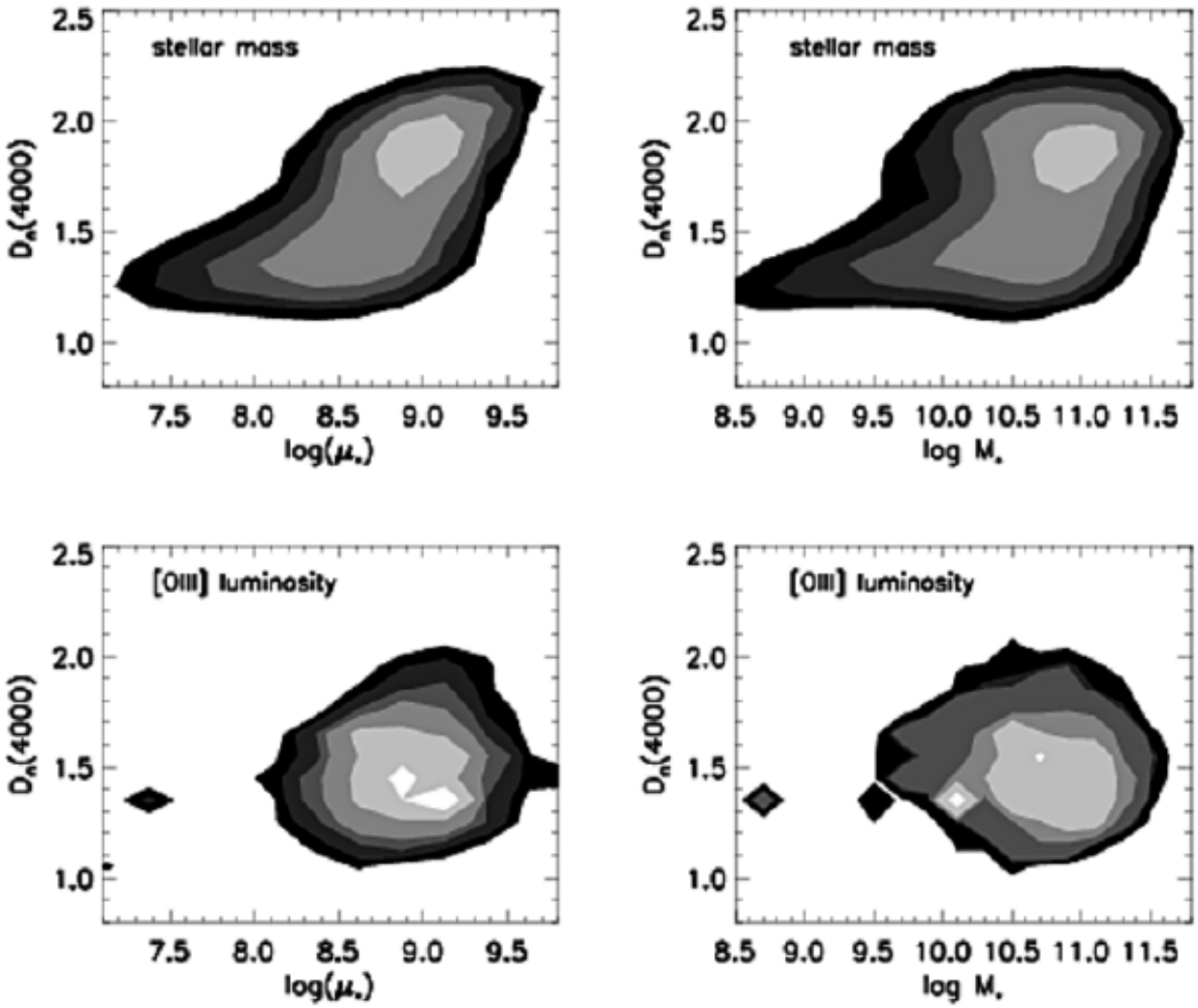
# How to measure stellar age and recent SFH

Kauffmann et al (2003)



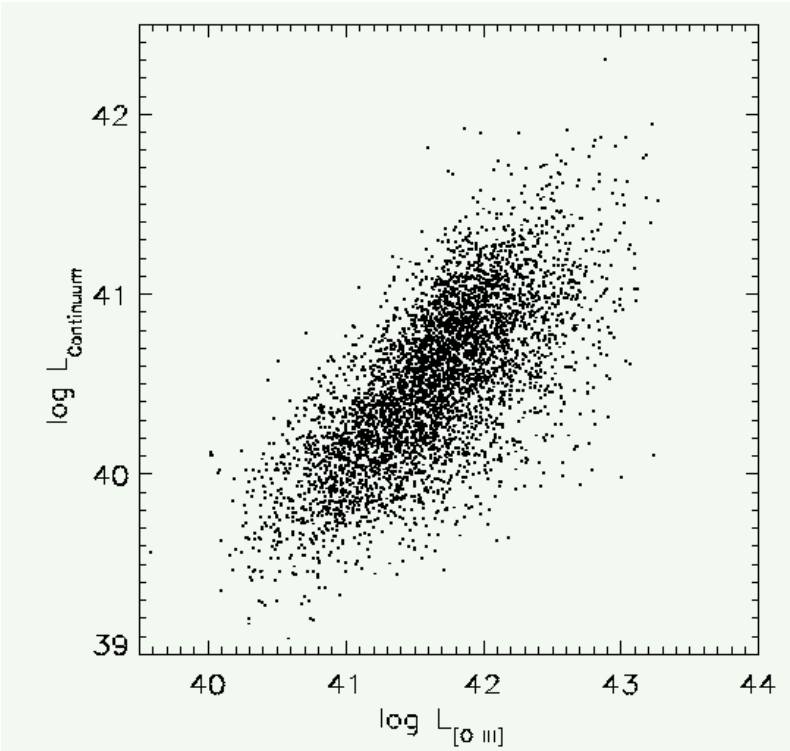
# The Stellar Ages of AGN Hosts

**Main Conclusion:** Most of the OIII luminosity is coming from massive, early-type galaxies with YOUNG stellar populations.

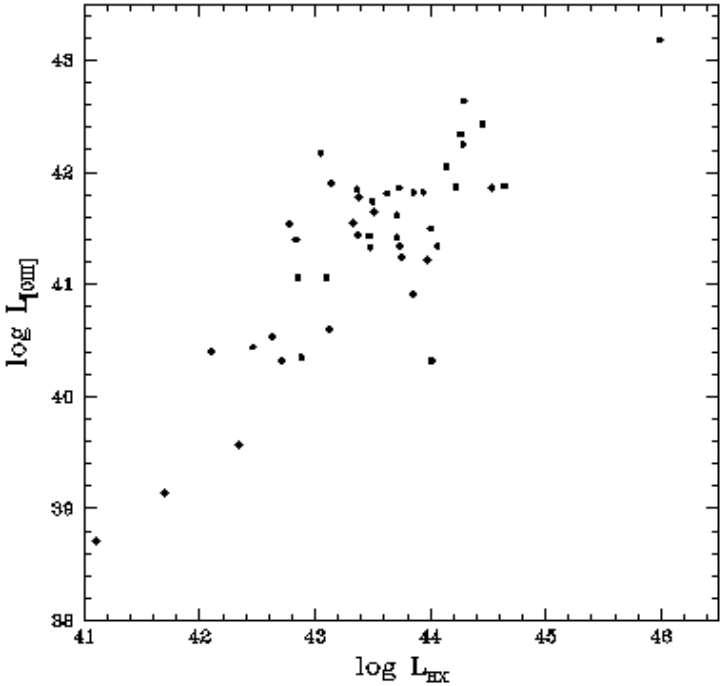


# Accretion

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

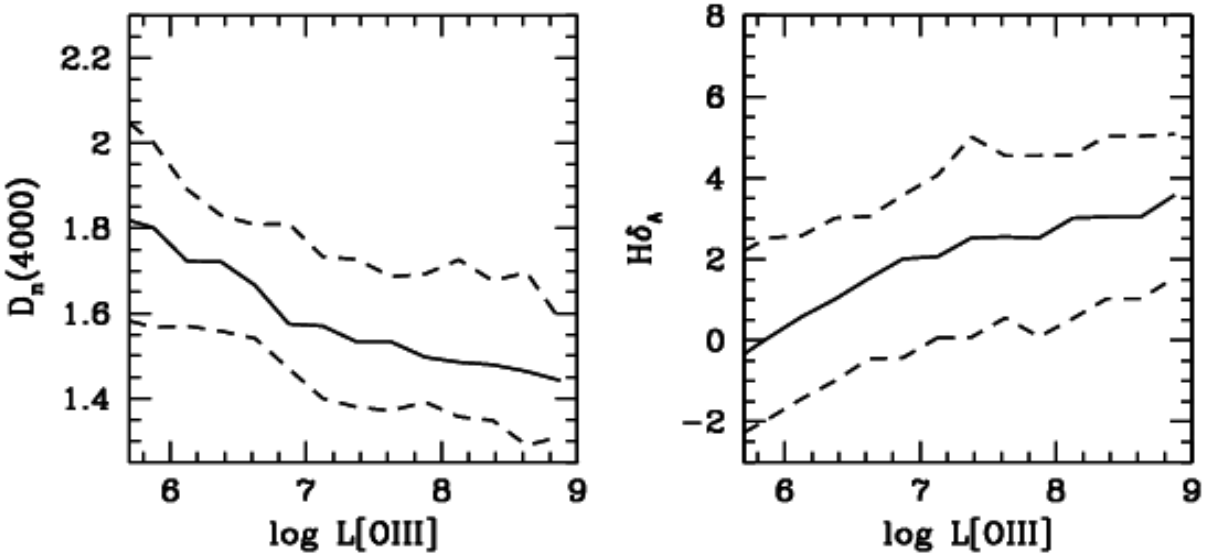



Correlation of [OIII] luminosity with continuum luminosity for Type 1 AGN (Zakamska et al 2003)

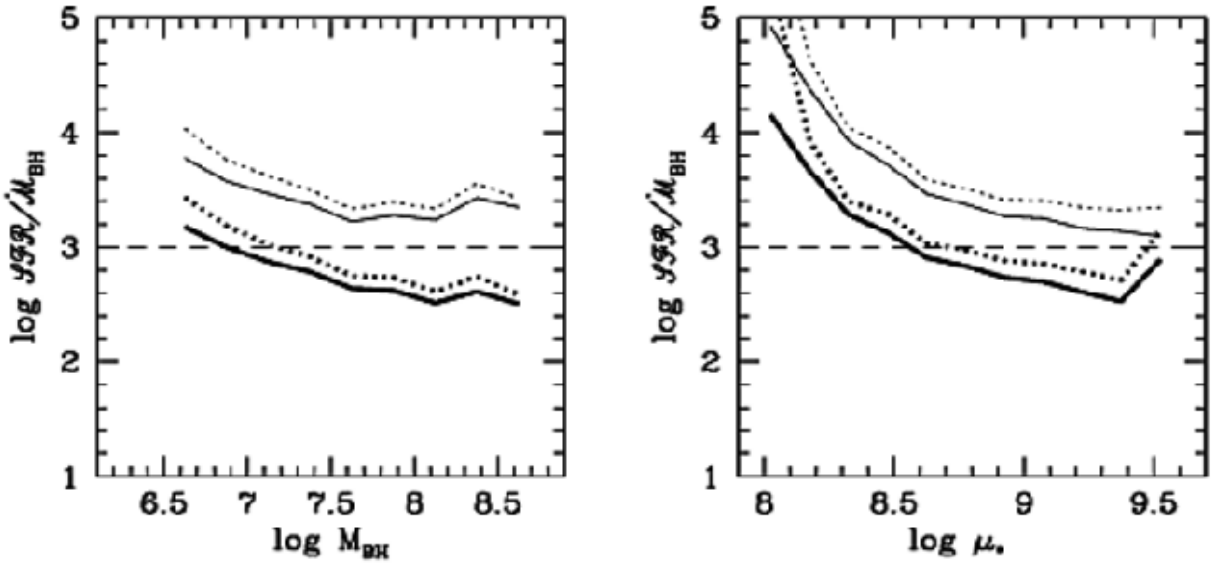



Correlation of [OIII] luminosity with hard x-ray luminosity (Heckman et al 2005)

# The Starburst-AGN Connection ( Heckman et al 2004)

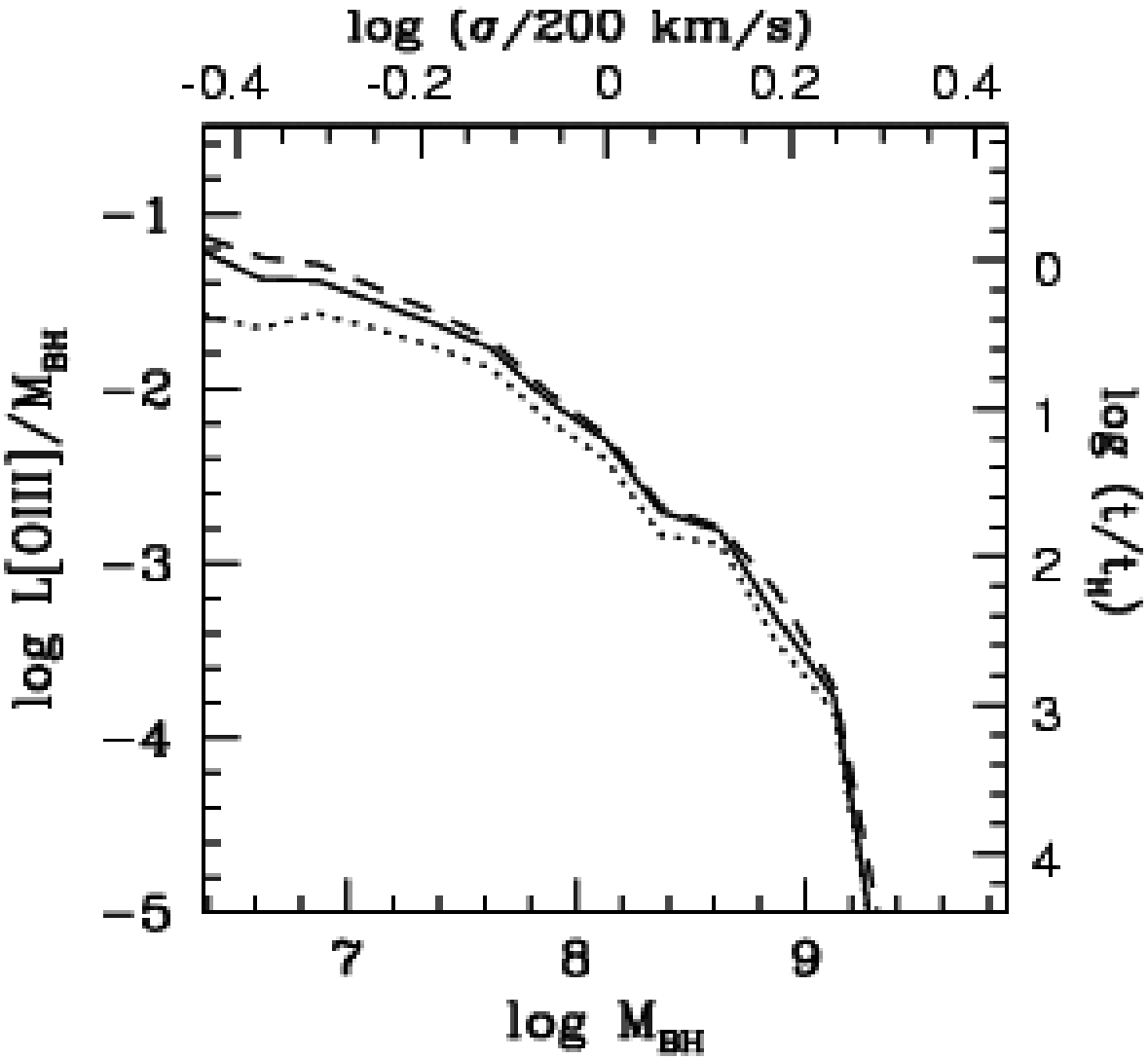



More strongly accreting AGN have younger stellar populations



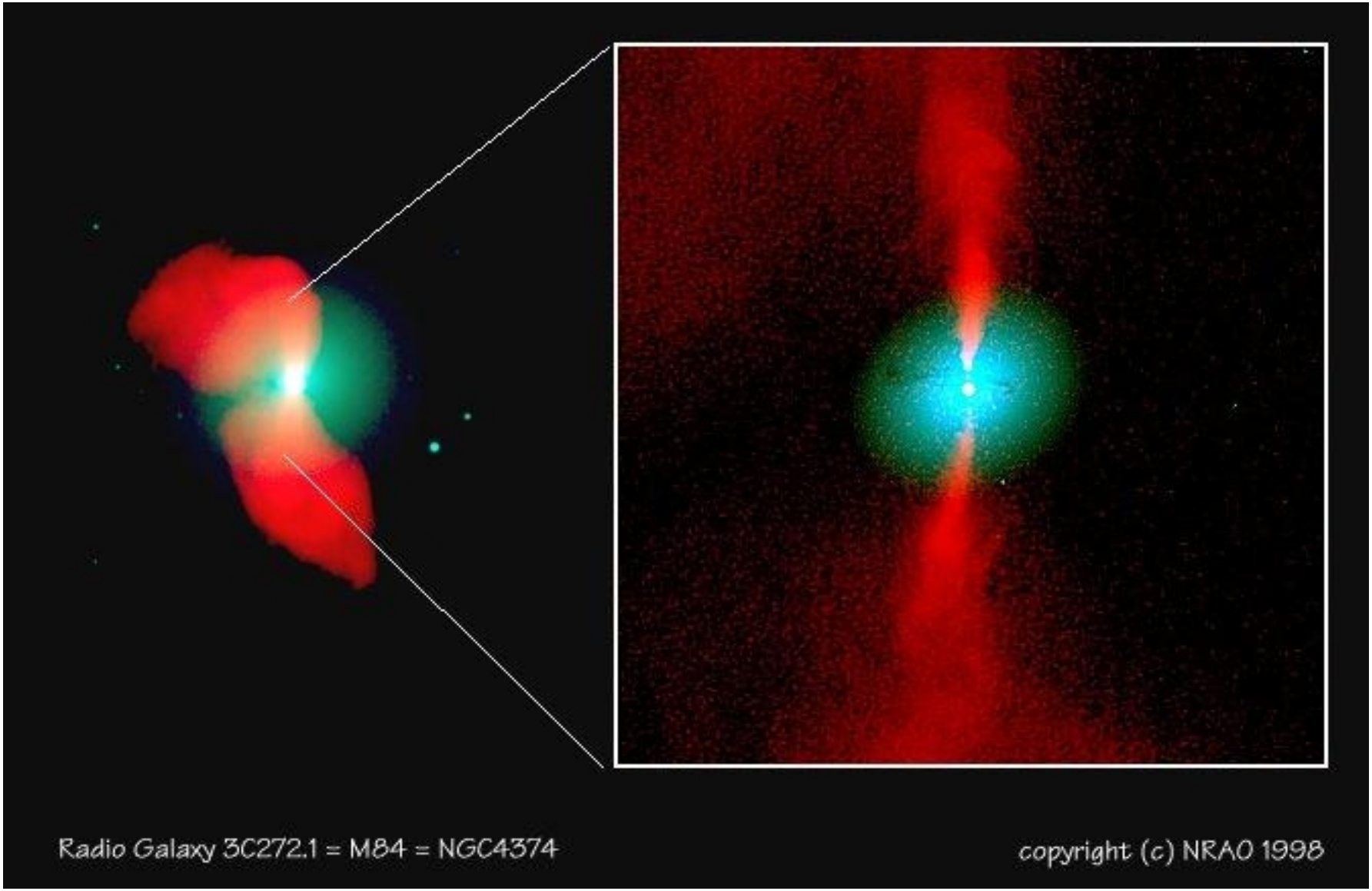

The average ratio between the star formation rate in the bulge and the accretion rate onto the black hole is 1000 – remarkably close to the ratio of bulge mass to black hole mass.

**Most of the accretion today is occurring onto low mass black holes** (consistent with down-sizing) **.**



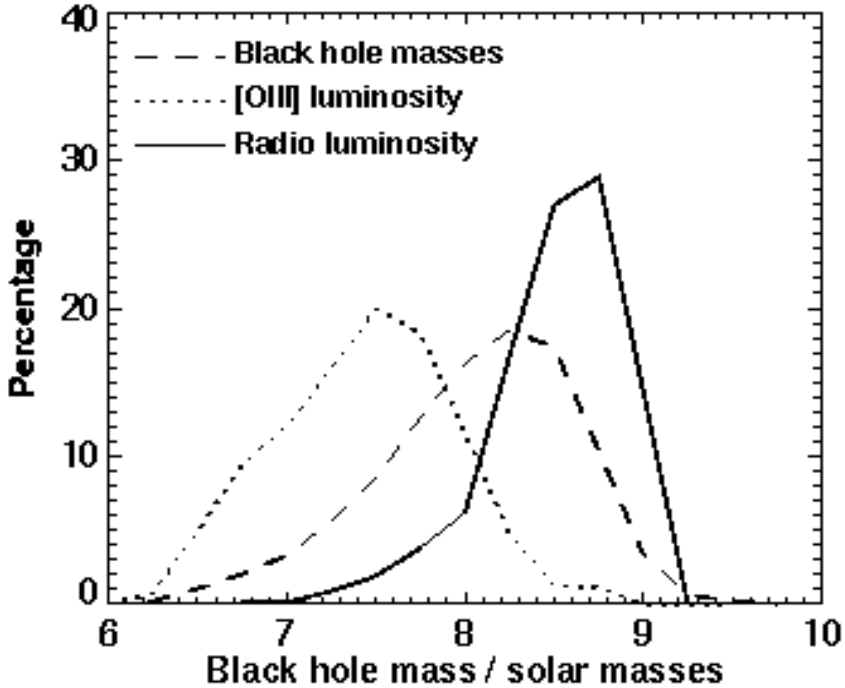

Heckman et al 2004

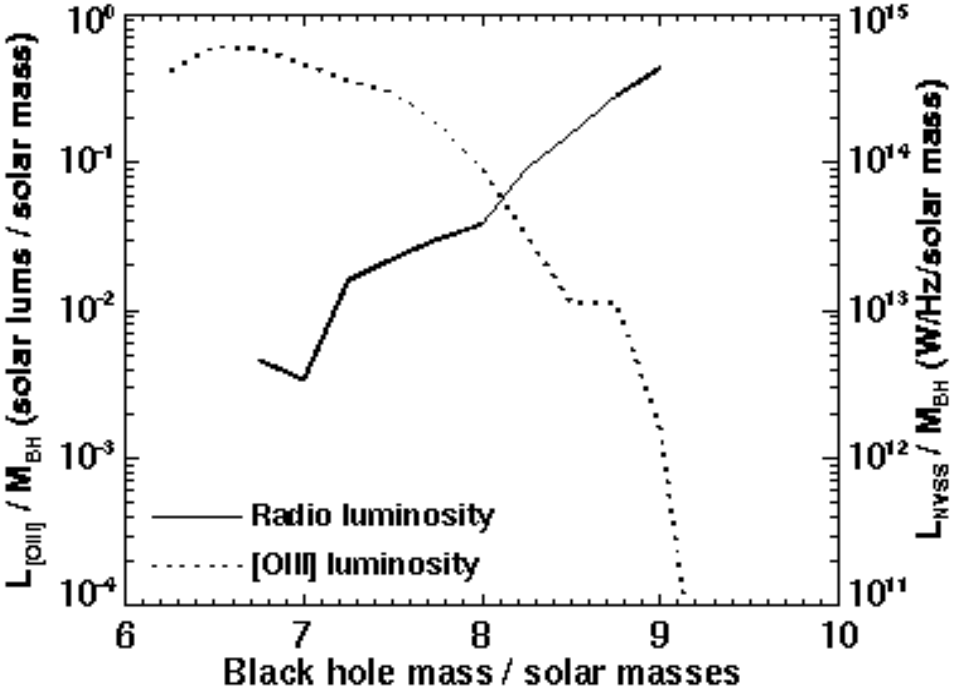
# What about radio-loud AGN?



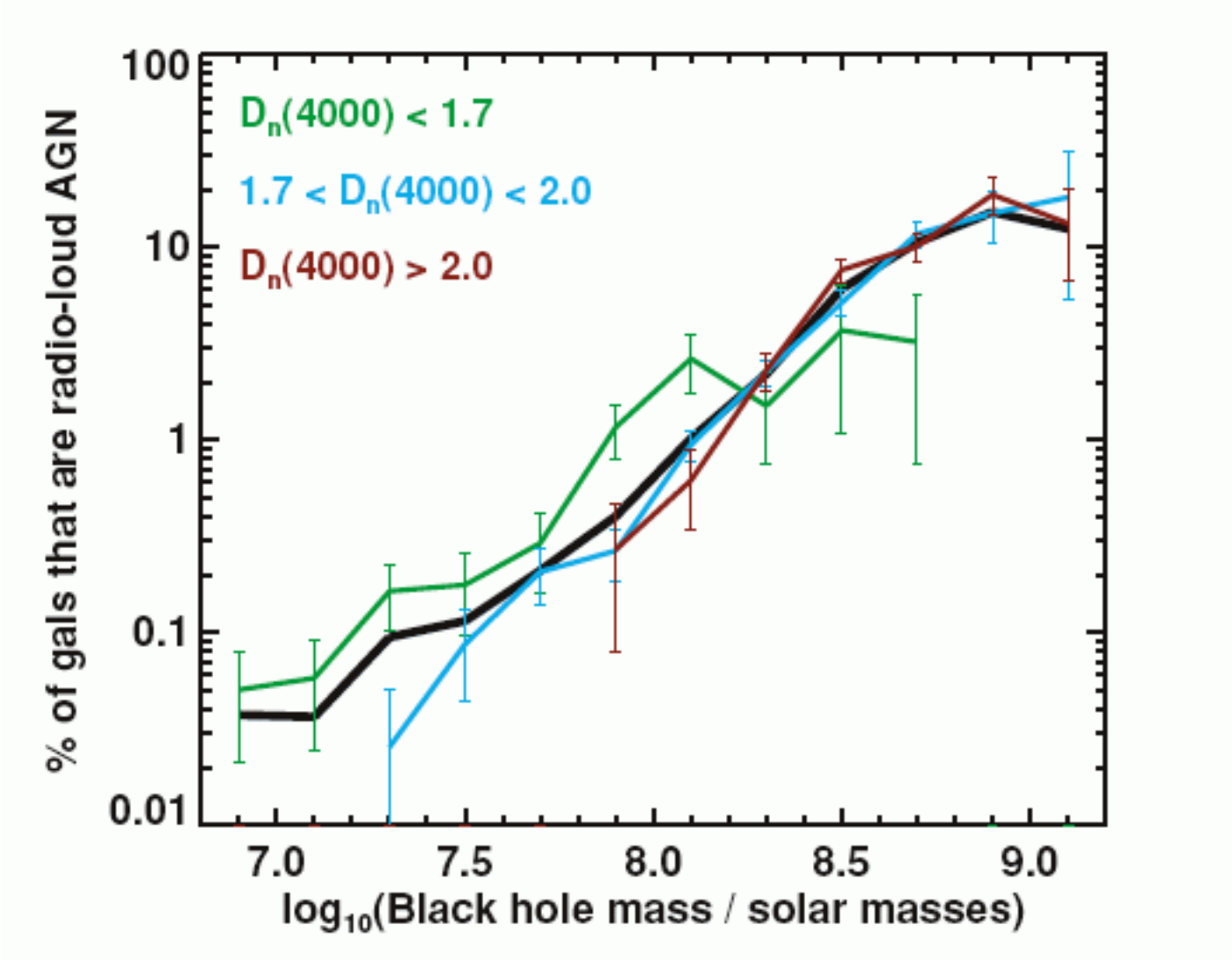
Radio galaxies are strongly biased towards high mass galaxies that contain massive black holes.

Best et al 2005



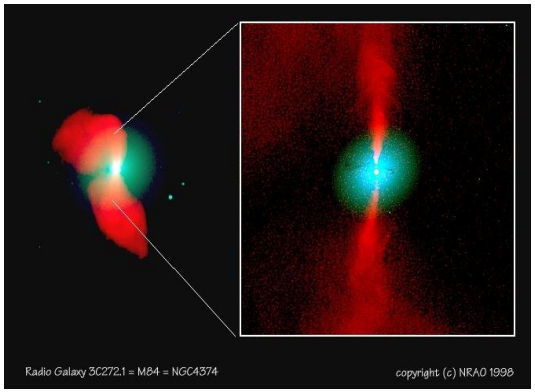
# Probability of Radio-loud AGN Activity is independent of Stellar Age



# CONCLUSIONS FROM STUDYING HOST GALAXIES

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

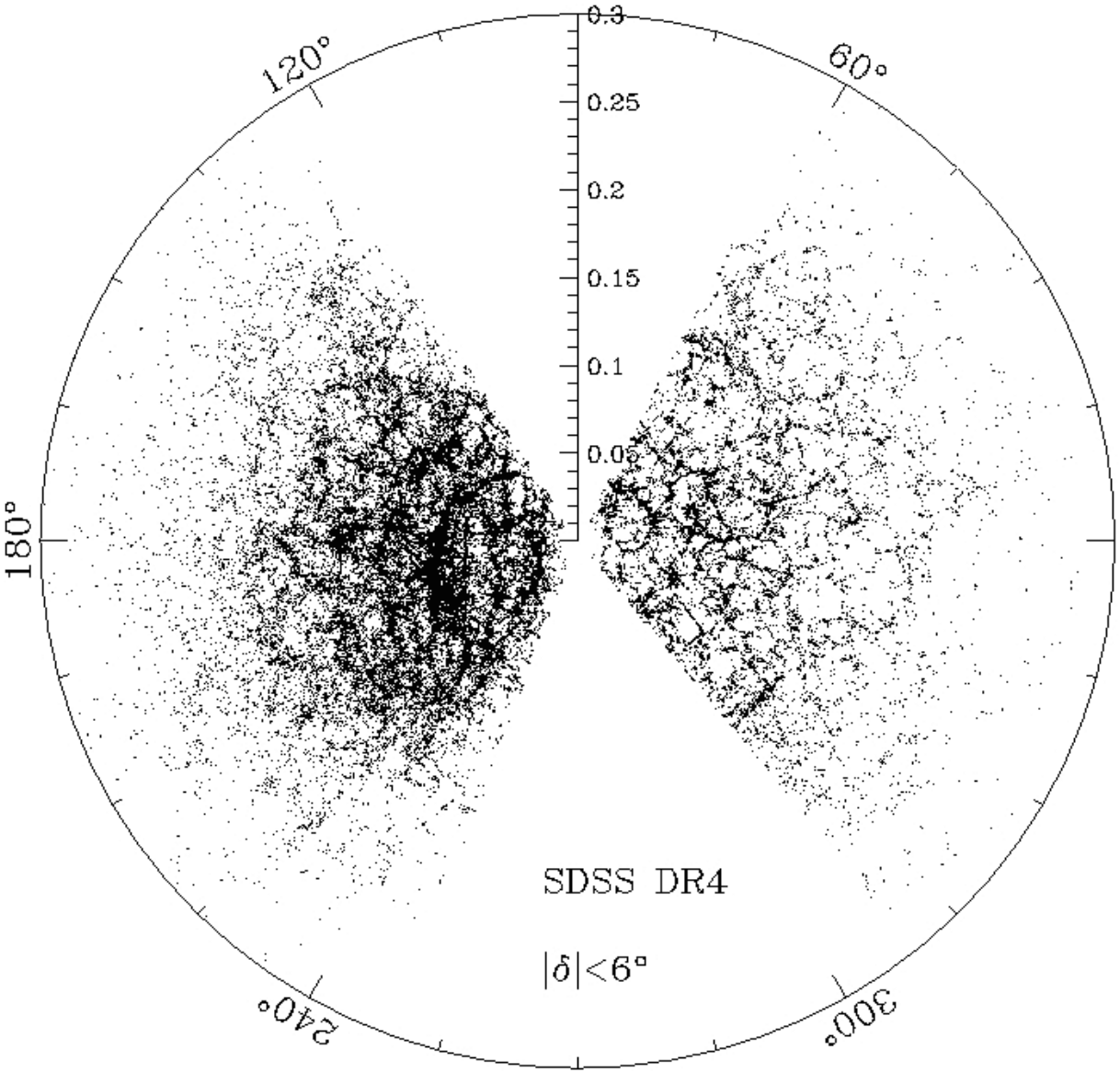
1) lower mass black holes
2) structurally early-type galaxies
3) more powerful AGN found in galaxies with younger stellar populations

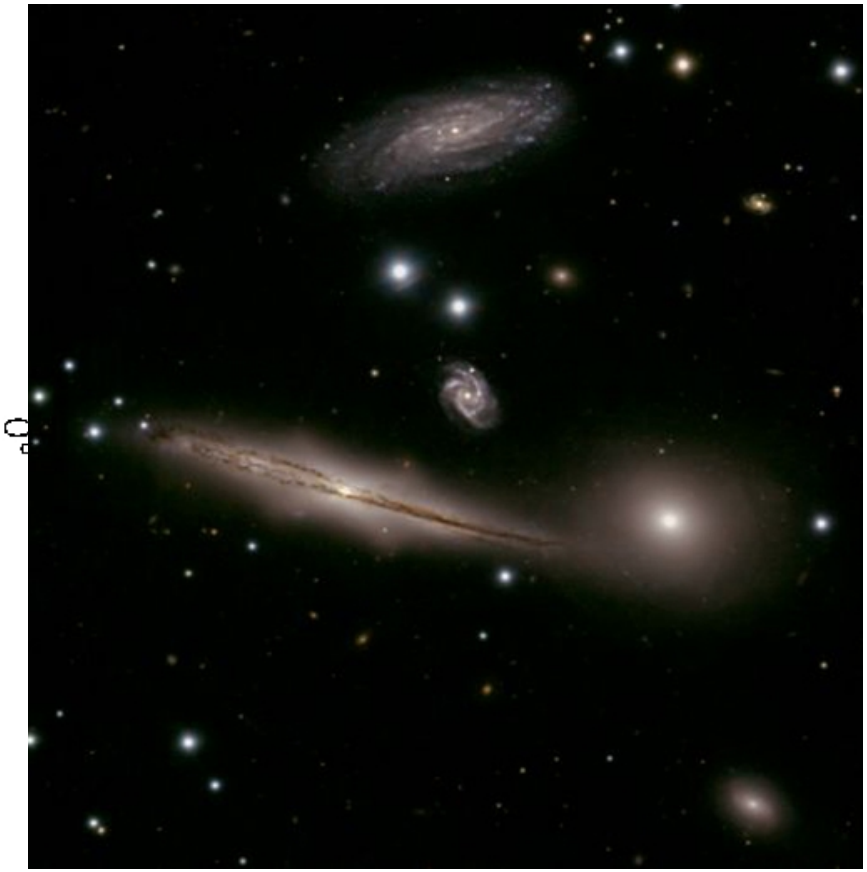



Present-day Optical Radio-AGN activity is linked to:

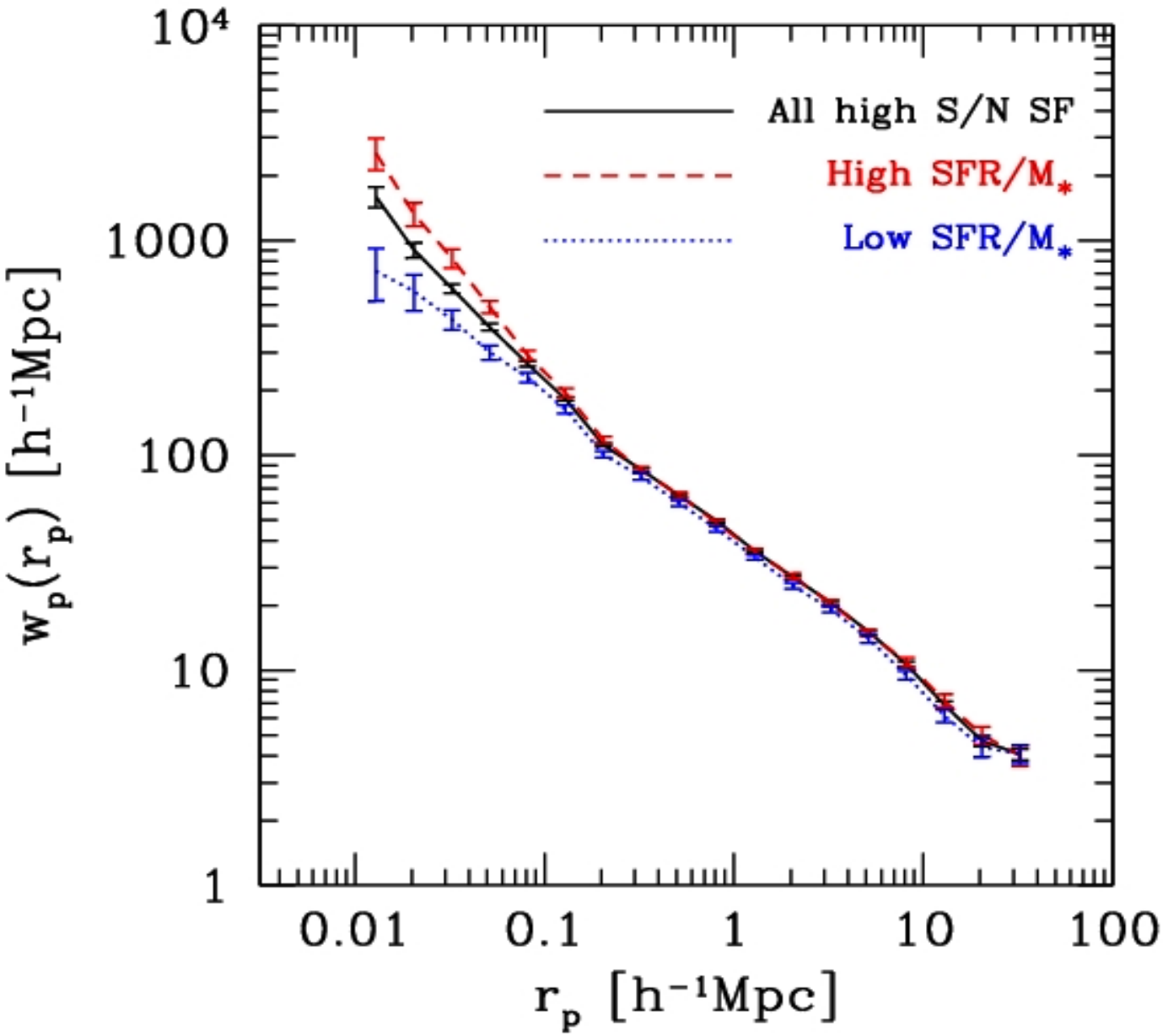
1) high mass black holes
2) structurally early-type galaxies with
3) no apparent dependence on mean stellar age

# STUDYING THE ENVIRONMENTS OF AGN IN SDSS



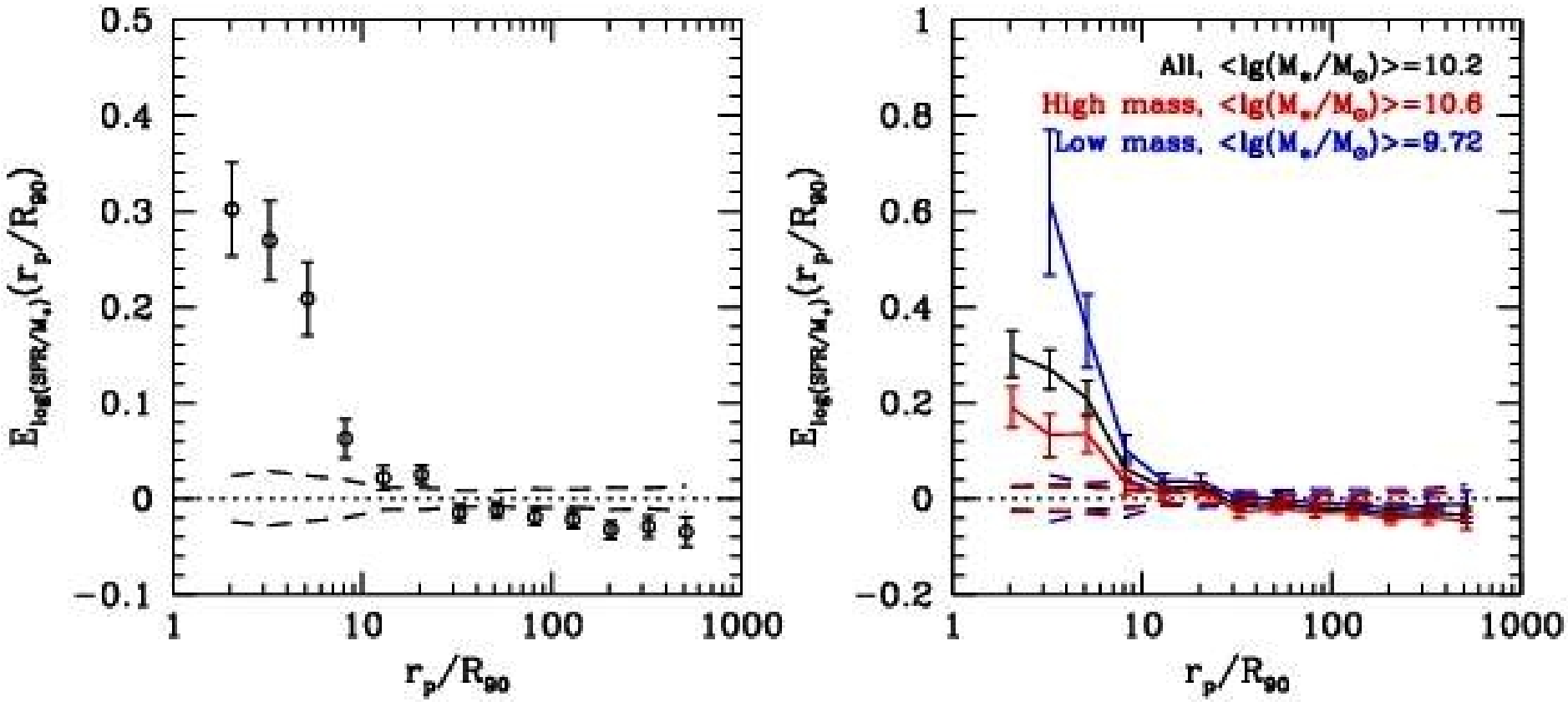
# Galaxy environment on Small Scales: a probe of mergers/interactions




**Below 100 kpc**, the cross-correlation amplitude between emission line galaxies and the "background" population exhibits a strong dependence on SFR/M*

**Cheng Li et al 2007**

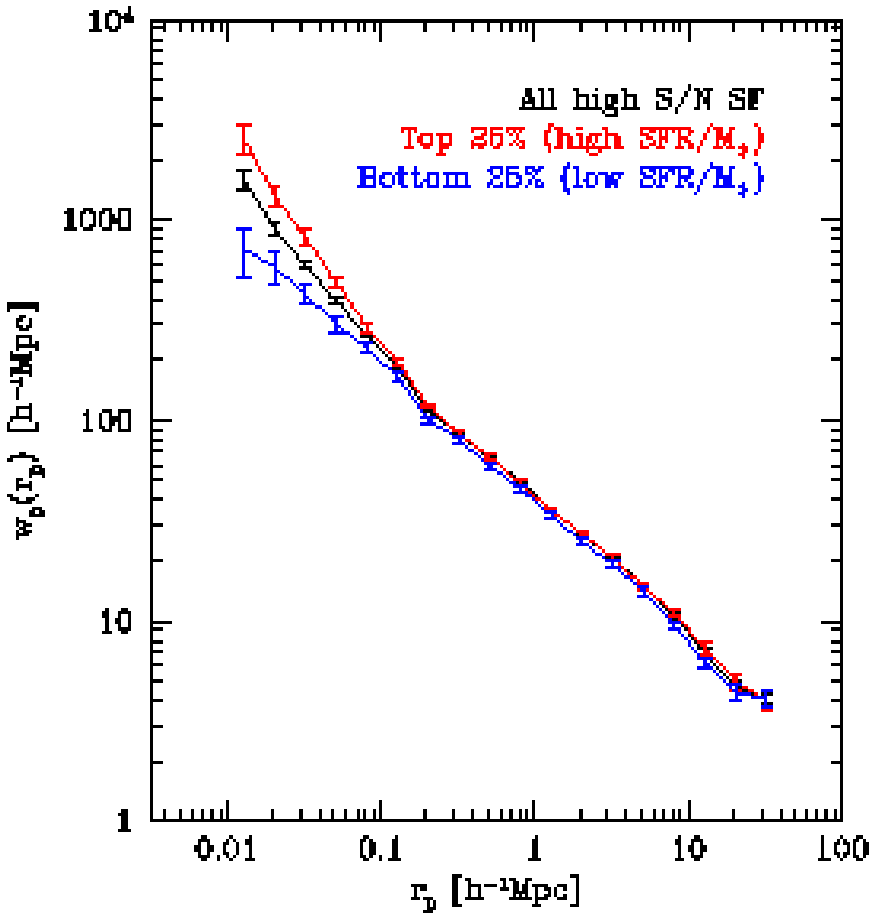
# How MUCH is star formation enhanced by the presence of a close companion?

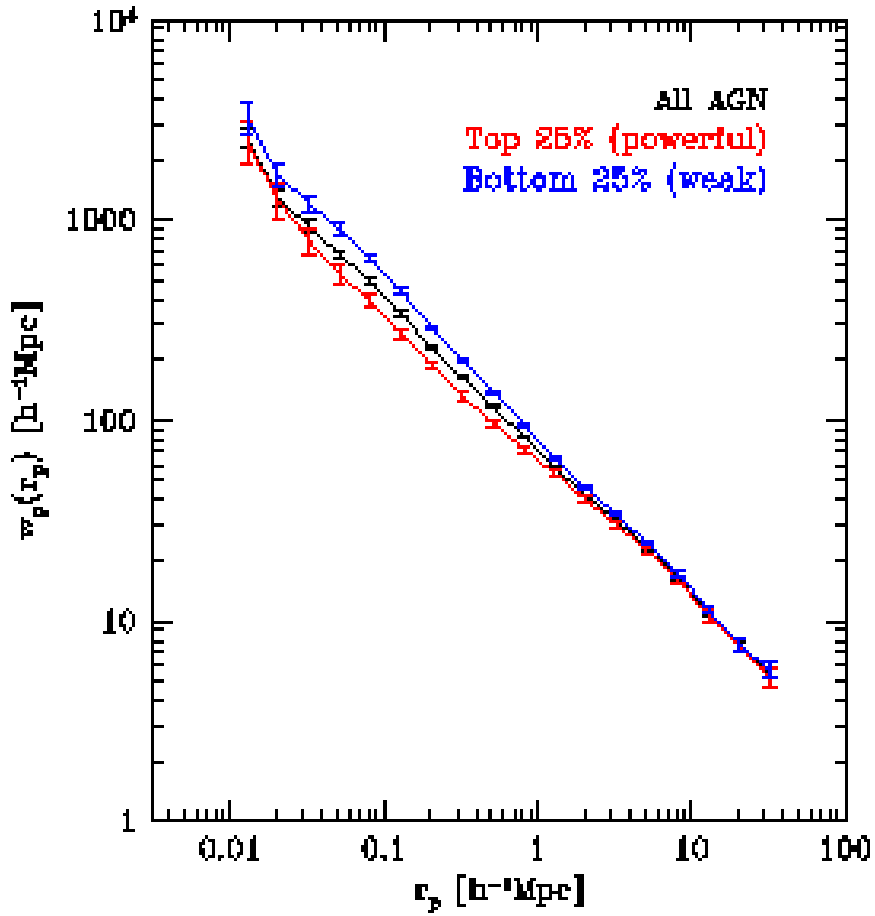



**The enhancement depends on stellar mass.**

# BUT ARE MERGERS THE DRIVER OF OPTICAL AGN ACTIVITY?

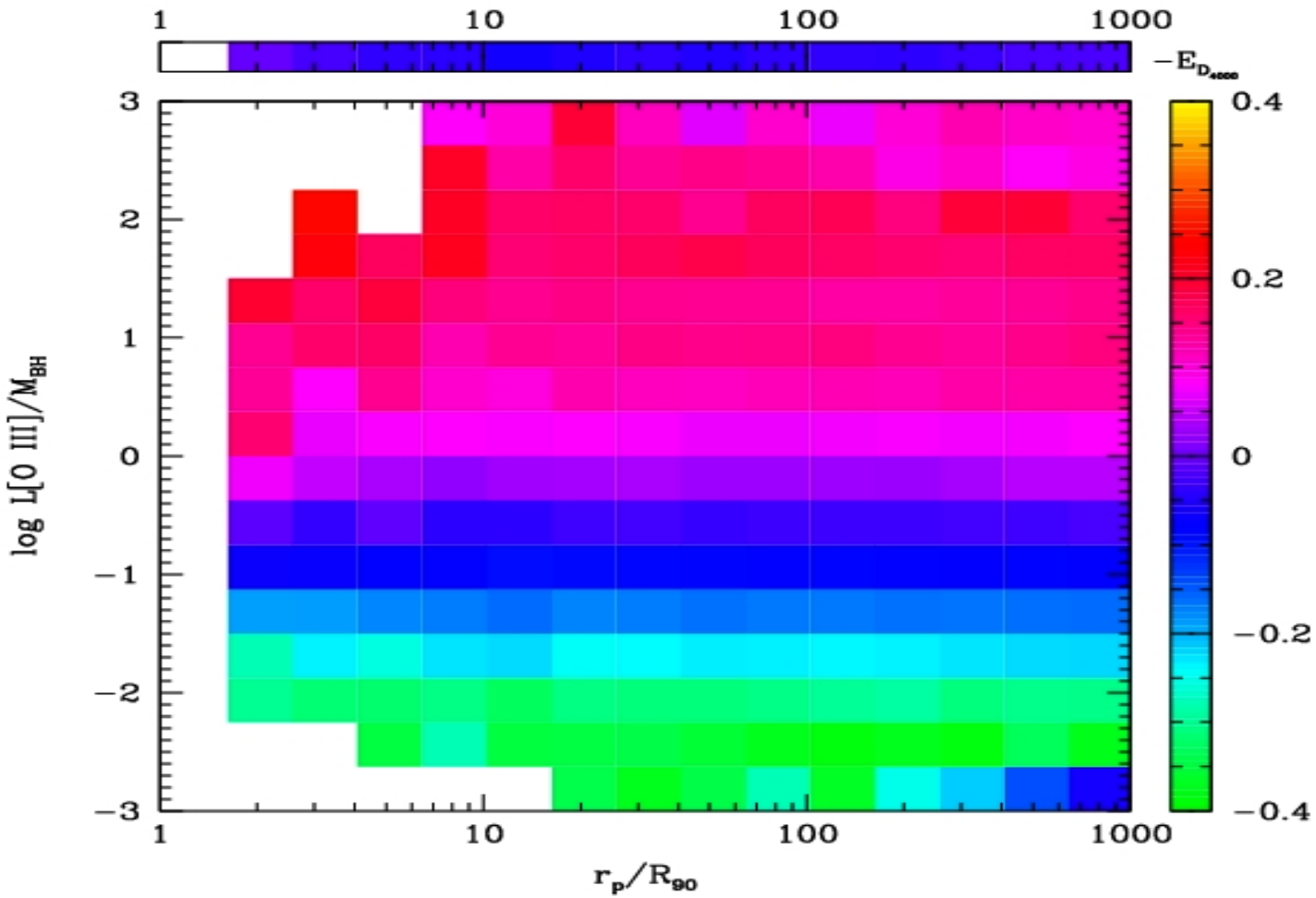
The cross-correlation function  star-forming galaxies compared to AGN.



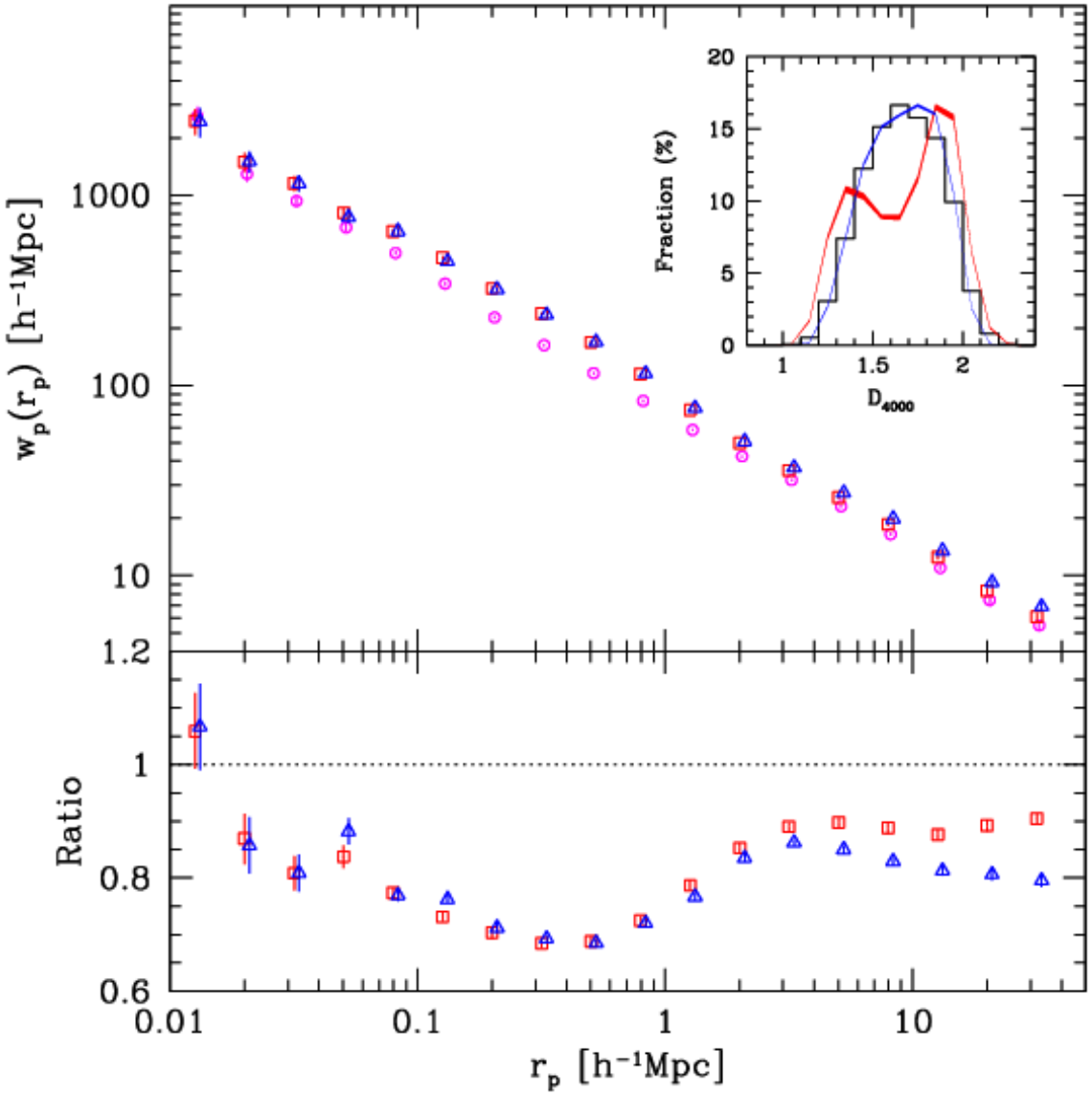

Li et al 2007

Conclusion: The enhanced star formation due to a close neighbour and the enhanced star formation associated with strong AGN activity are NOT connected with each other.

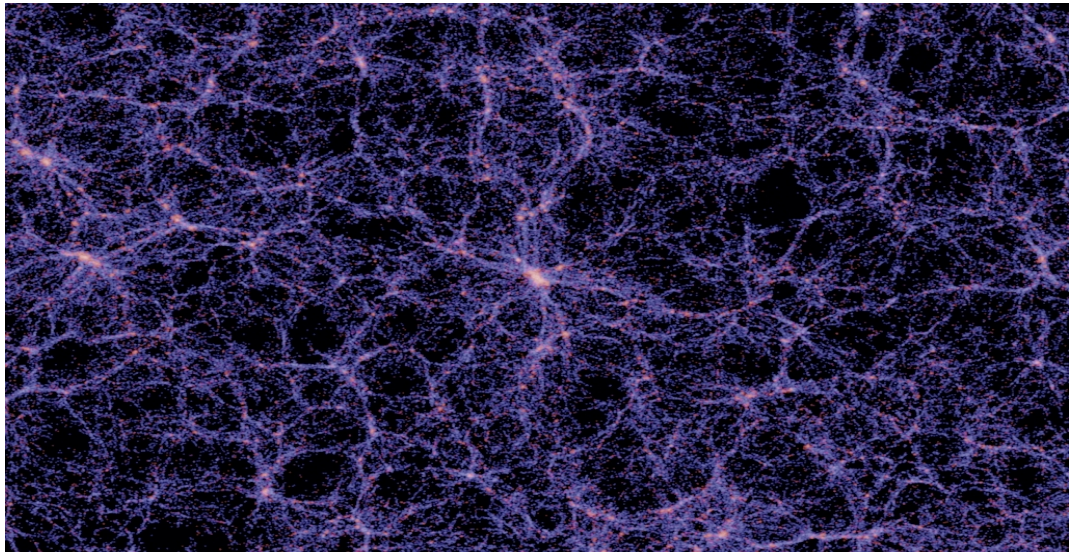


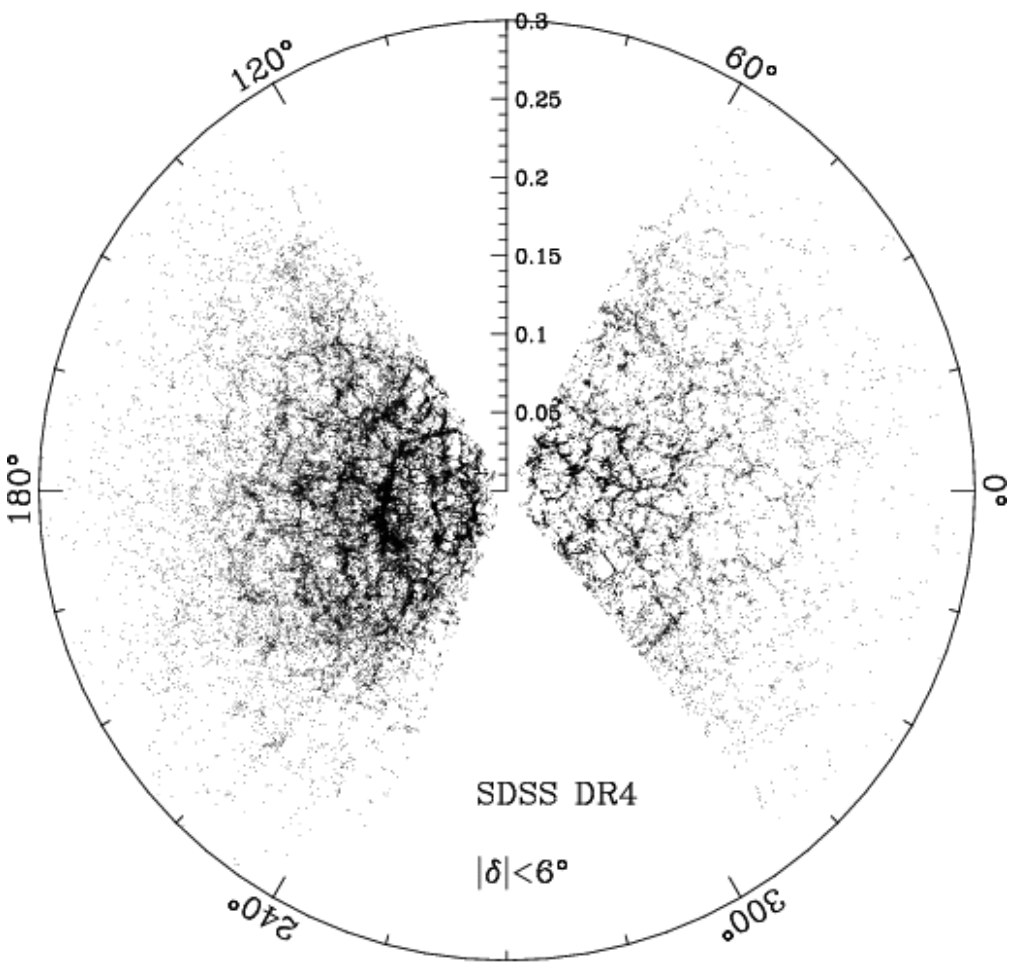

**If galaxy interactions trigger optical AGN activity, there must be a significant DELAY...**

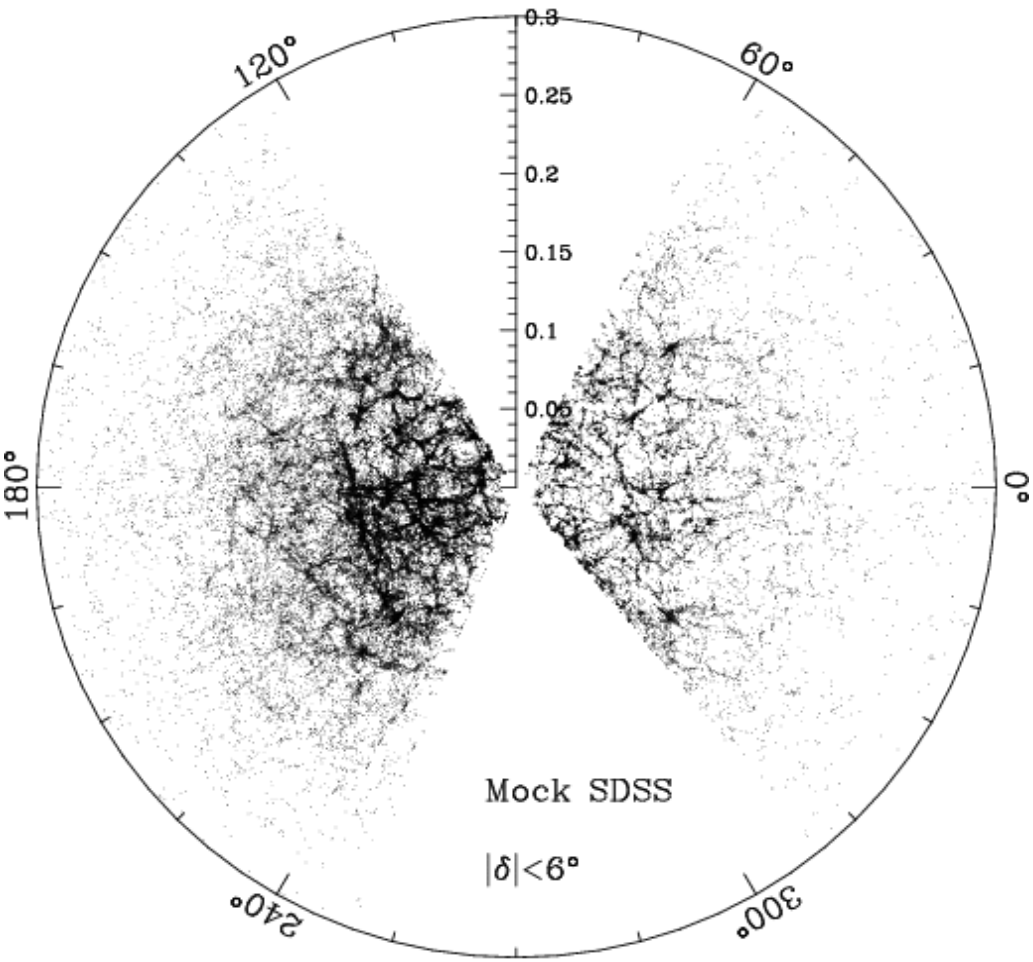
# HOW CAN WE INTERPRET THE "SUPPRESSION" OF OPTICAL AGN ACTIVITY ON INTERMEDIATE SCALES?



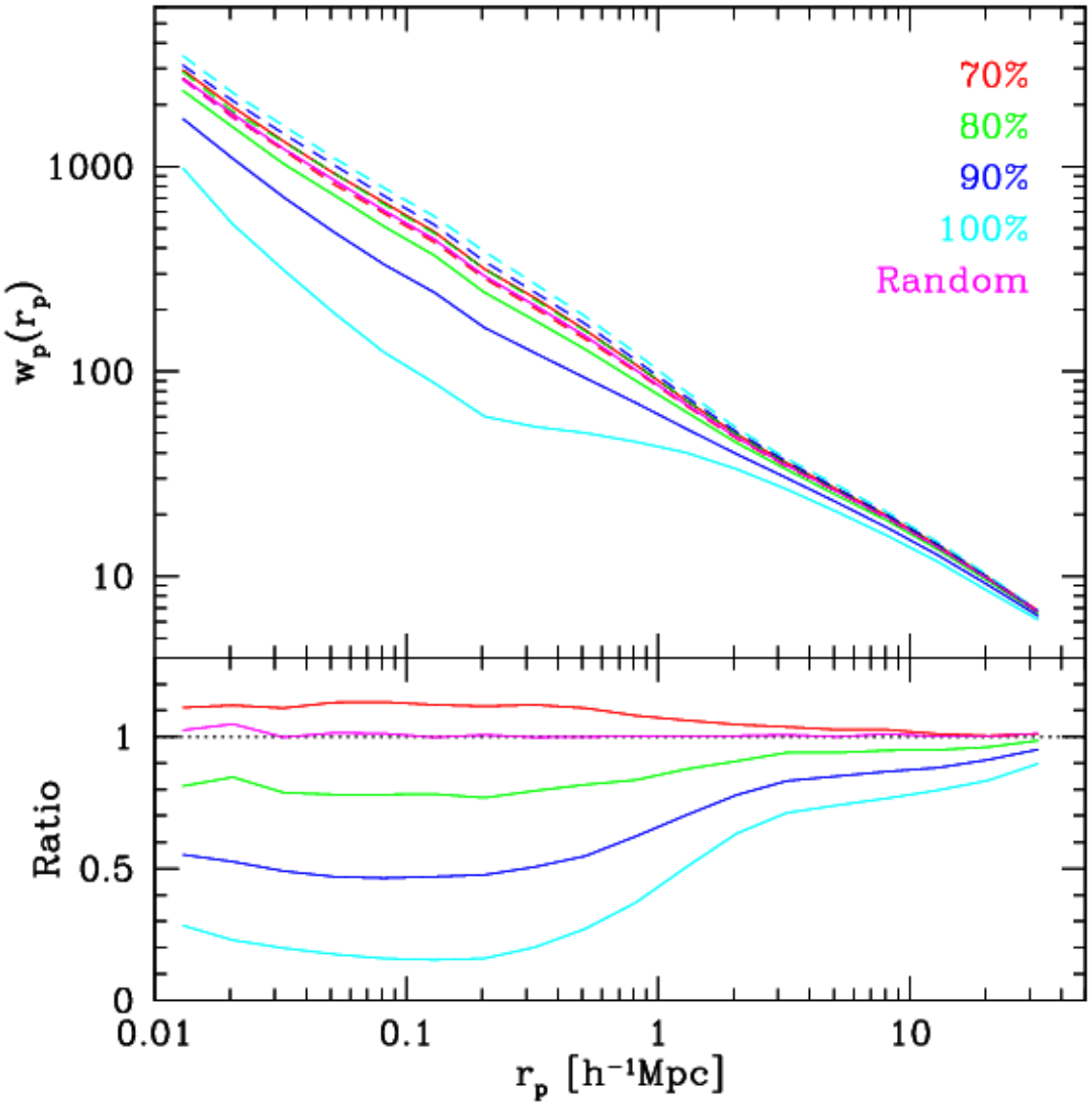

**What we are trying to model** : the cross-correlation function of AGN compared to a control sample of non-AGN matched in redshift, stellar mass and concentration index.

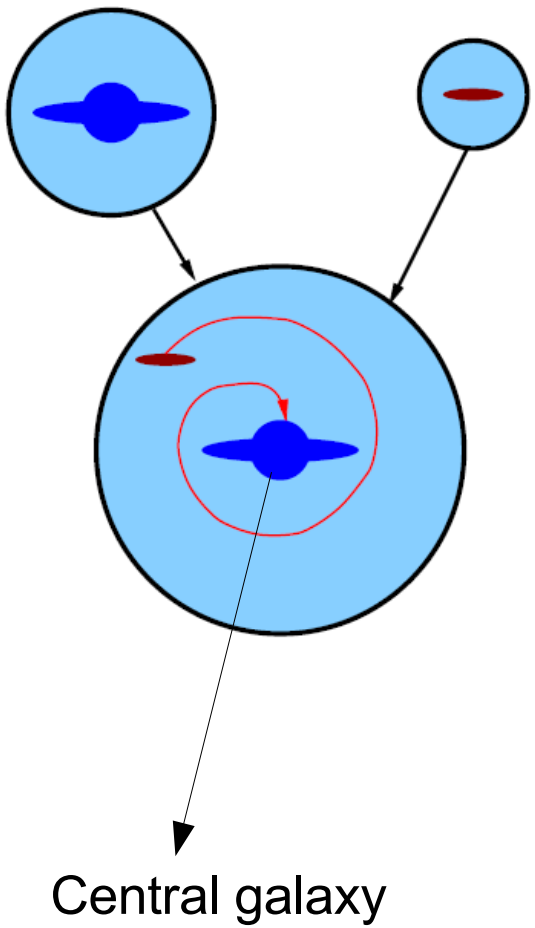


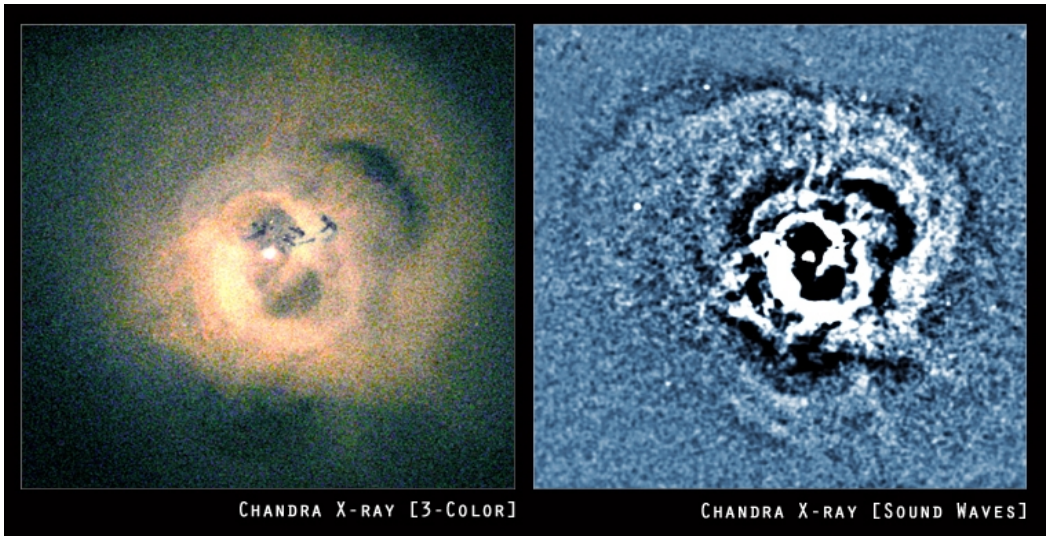

120°
60°
180°
0°
240°
300°
0.3
0.25
0.2
0.15
0.1
0.05
SDSS DR4
|δ|<6°


120°
60°
180°
0°
240°
300°
0.3
0.25
0.2
0.15
0.1
0.05
Mock SDSS
|δ|<6°

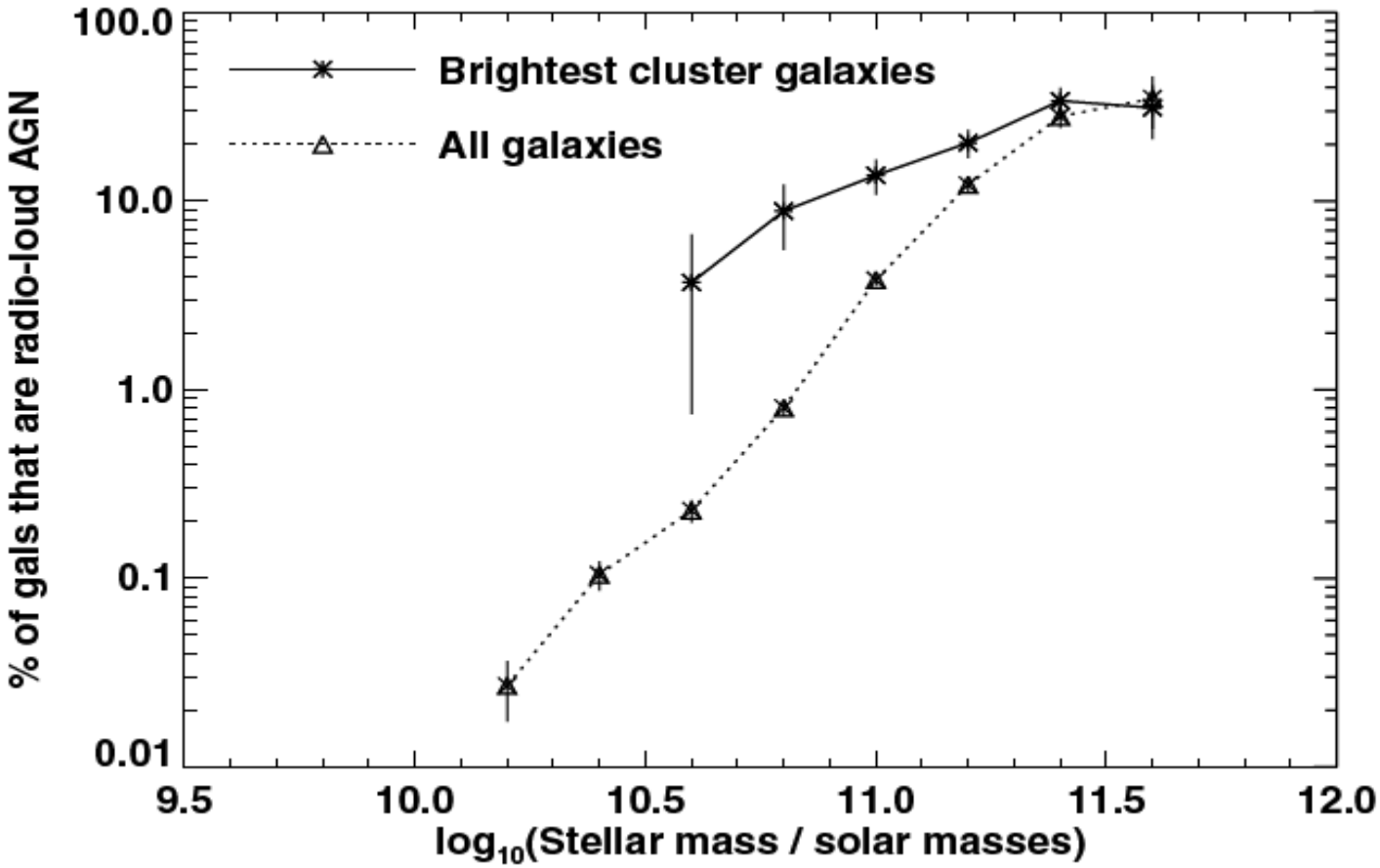
**A MODEL THAT FITS:** AGN ARE PREFERETIALLY LOCATED AT THE CENTERS OF THEIR DARK MATTER HALOS





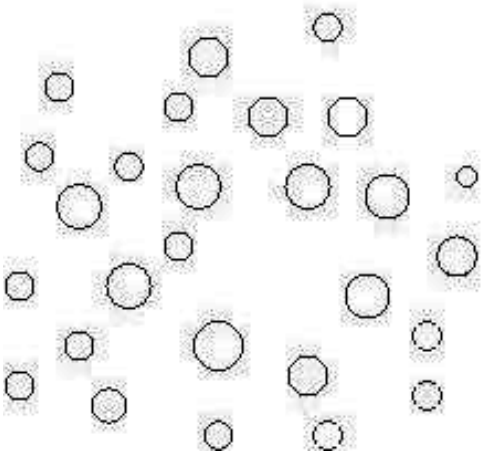

**At fixed stellar mass,** radio AGN activity is enhanced in galaxies that sit at the **centers** of groups and clusters.

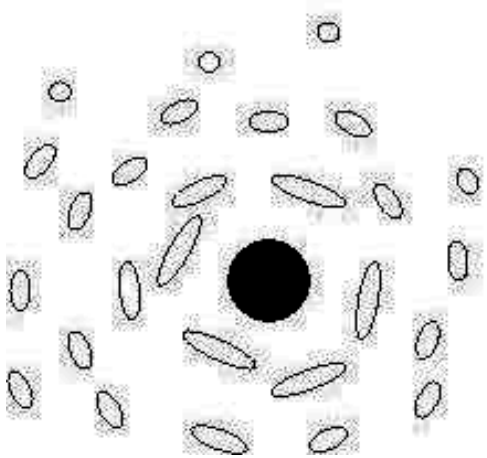



Best et al 2007

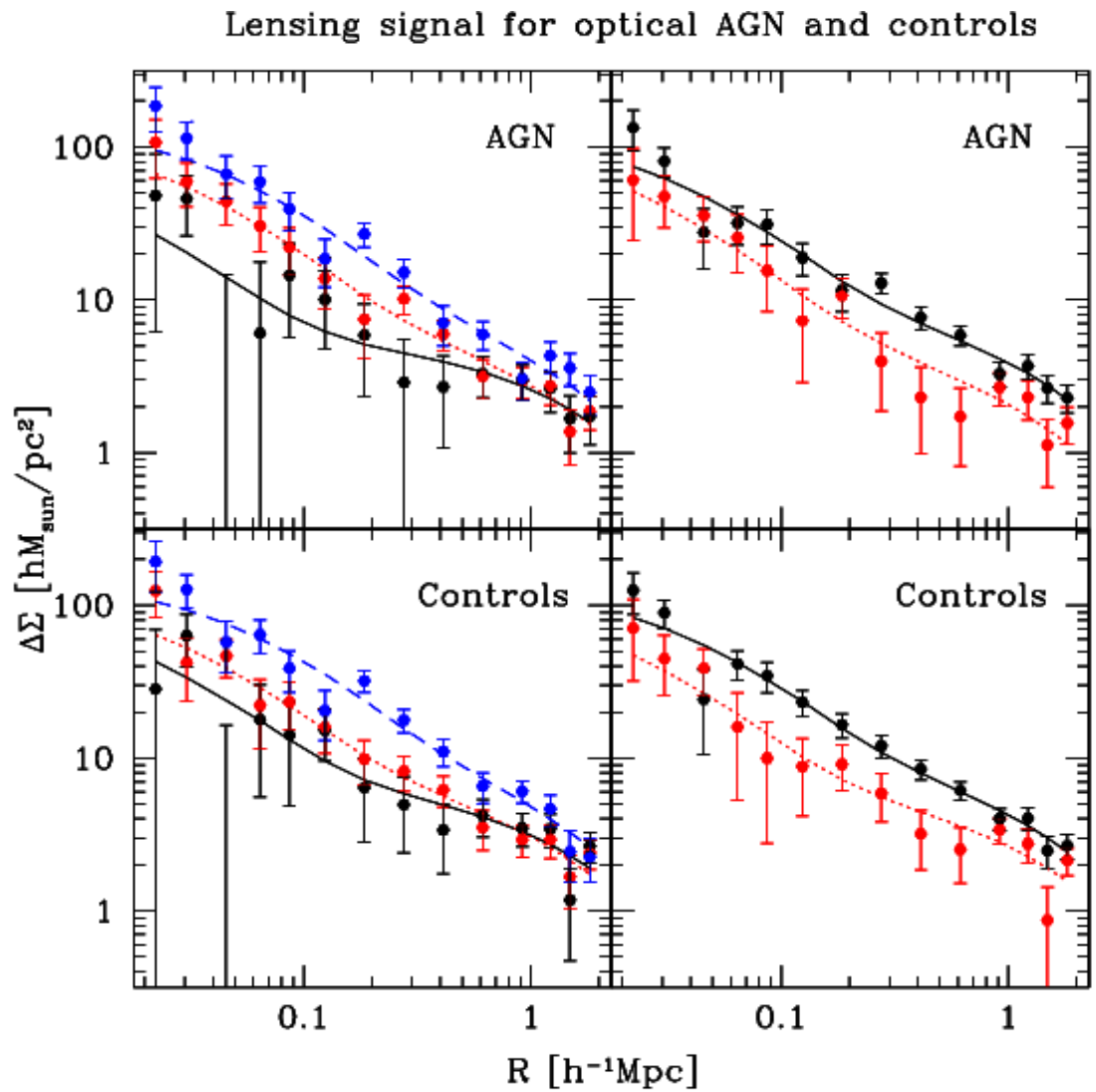
# Direct Measurements of the Halo Masses of AGN through Galaxy-Galaxy Lensing

Rachel Mandelbaum et al (2008)

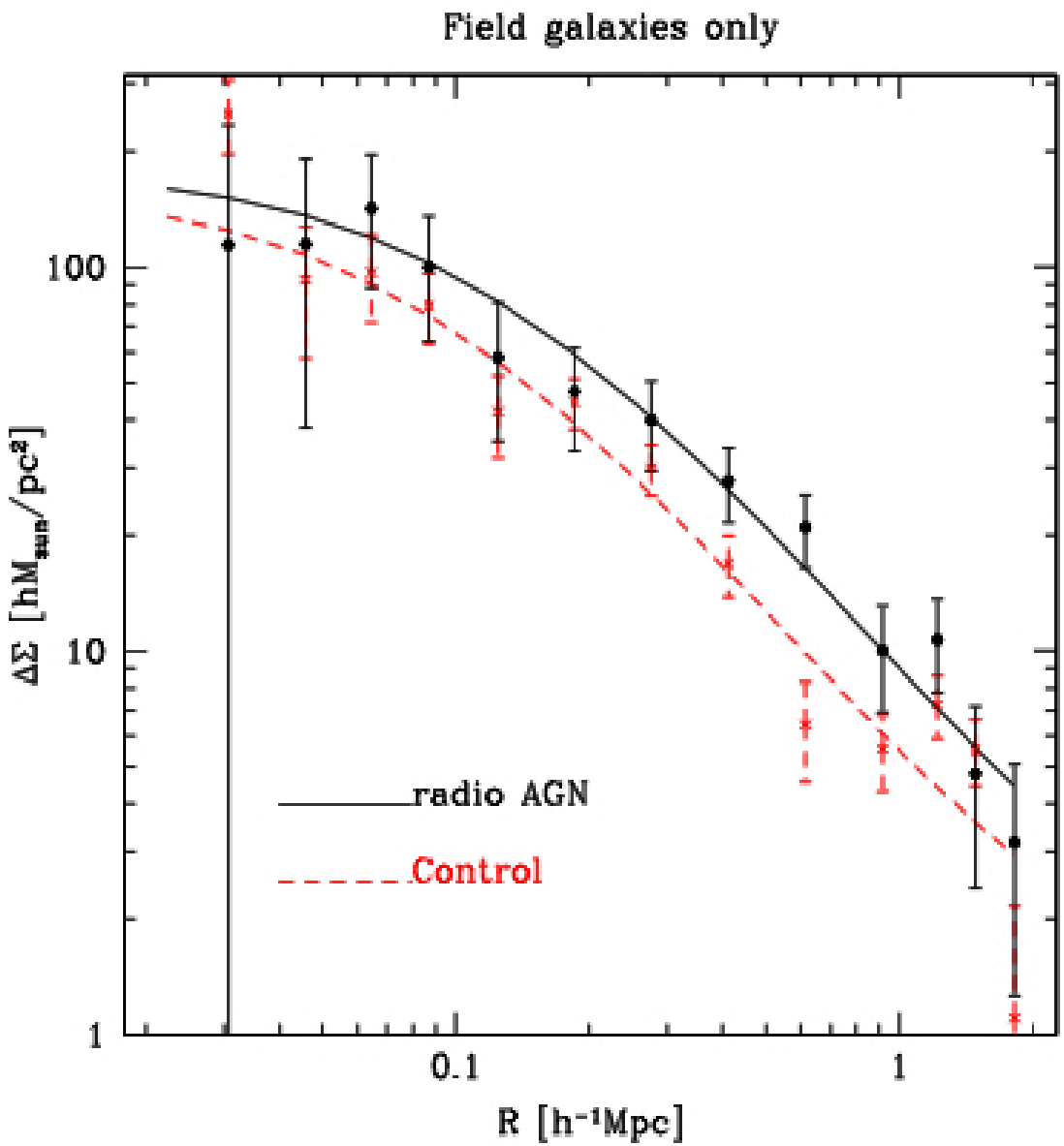




200 kpc

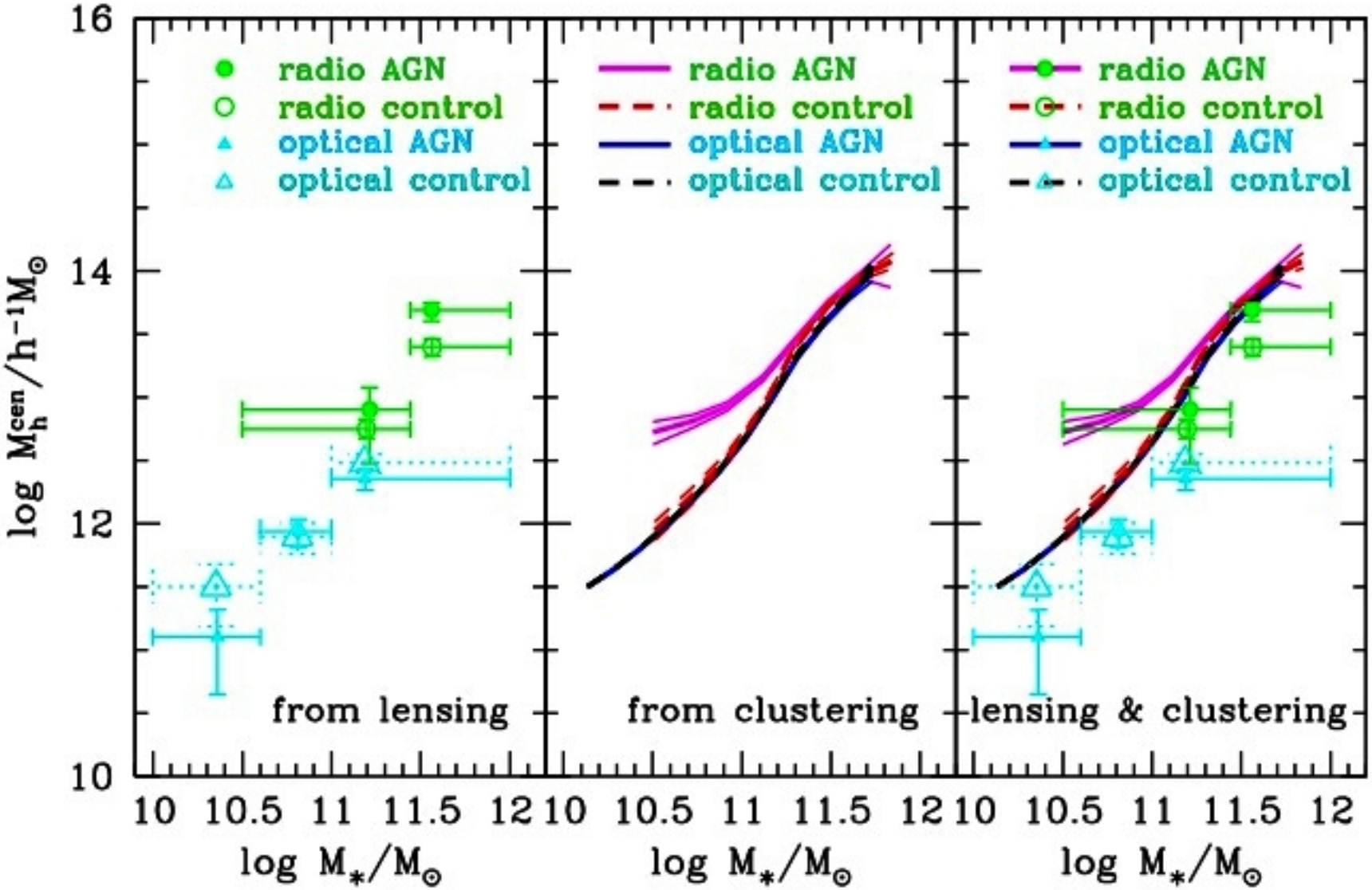


# Proof that the dark matter halo plays an important role in understanding radio AGN

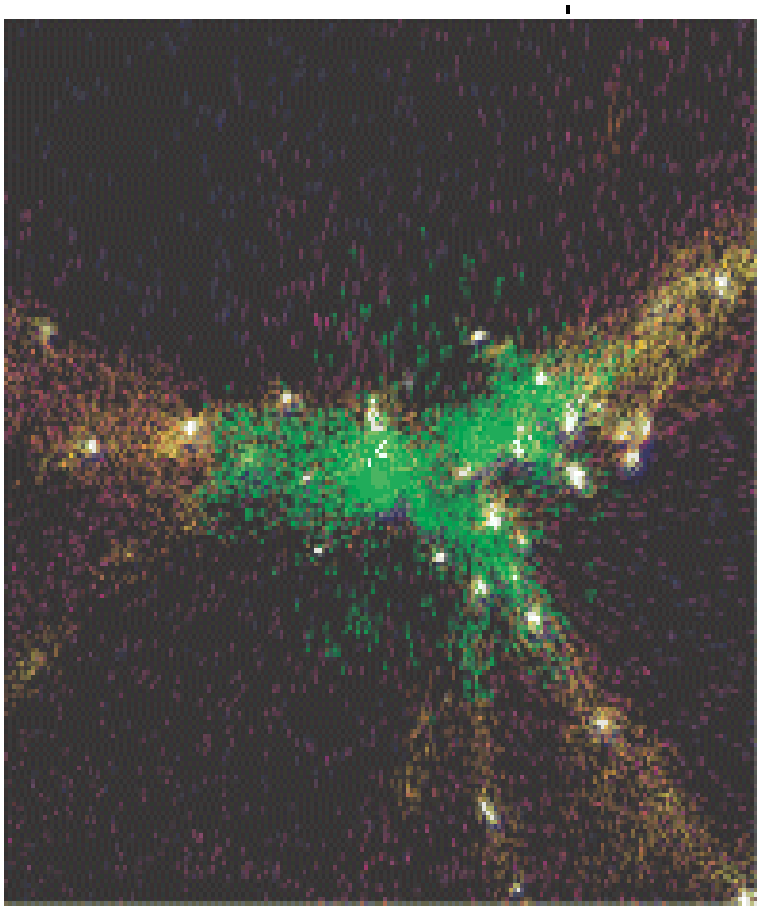



Cluster galaxies have been excluded

# Halo masses of optical and radio-loud AGN derived from weak lensing and clustering



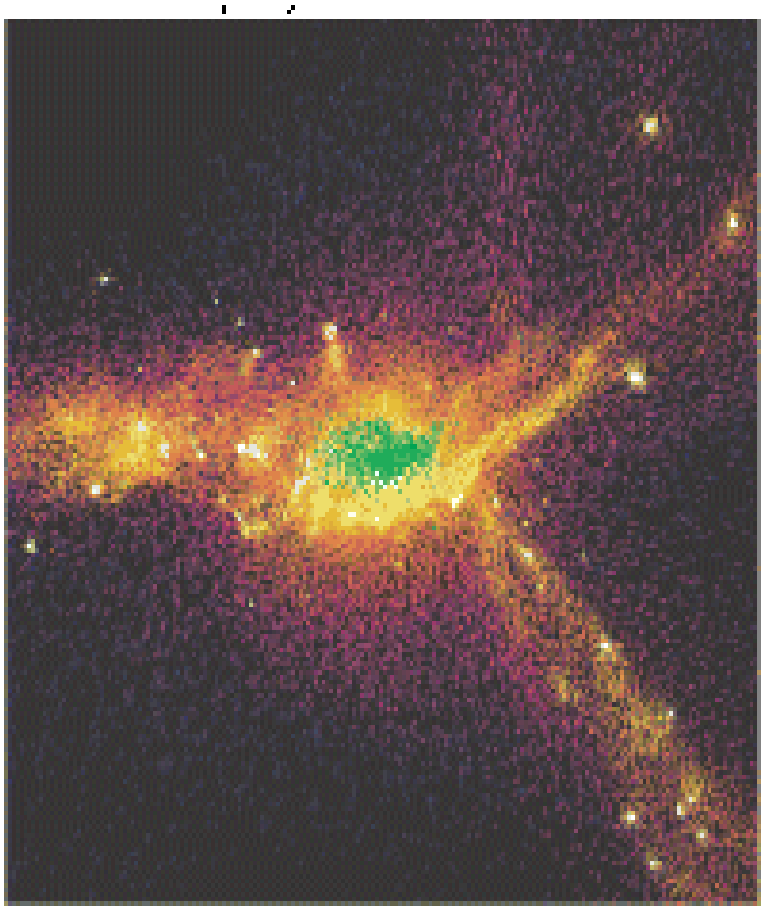
**COLD ACCRETION ALONG FILAMENTS**



Halos less than 10^12 M_solar

**OPTICAL AGN**

**GAS COOLS QUASI-STATICALLY**



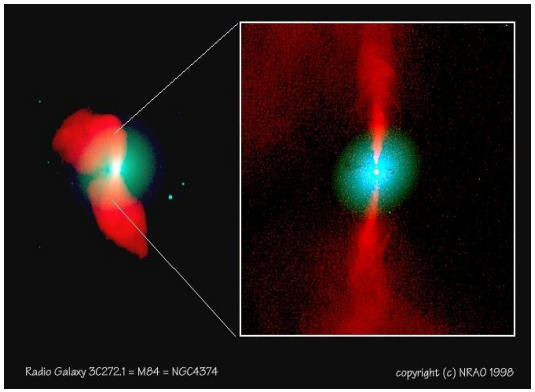
Halos greater than 10^12 M_solar

**RADIO AGN**

# CONCLUSIONS FROM STUDYING ENVIRONMENTS

Present-day Optical (emission-line) AGN activity:

1) No evidence of any enhancement due to the presence of a close companion.
2) More weakly clustered than control galaxies on “intermediate” scales (100 kpc-1 Mpc)
3) In dark matter halos with masses ~10^12 M_solar




Present-day Optical Radio-AGN activity:

1) strongly enhanced in galaxies that are at the centres of their own dark matter halos.
2) In dark matter halos with masses ~few x 10^13 M_solar

# CHALLENGE FOR THE FUTURE:

**TO CLOSE THE LOOP, IT IS NECESSARY TO UNDERSTAND THE IMPACT OF AGN ON THE SURROUNDING GAS :** Feedback