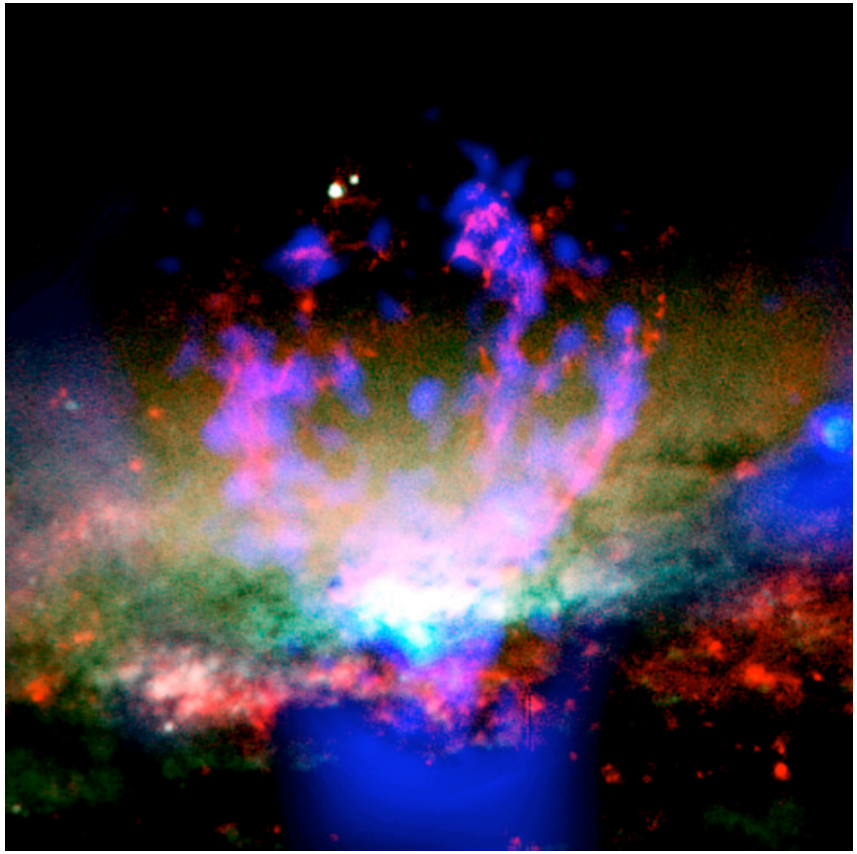
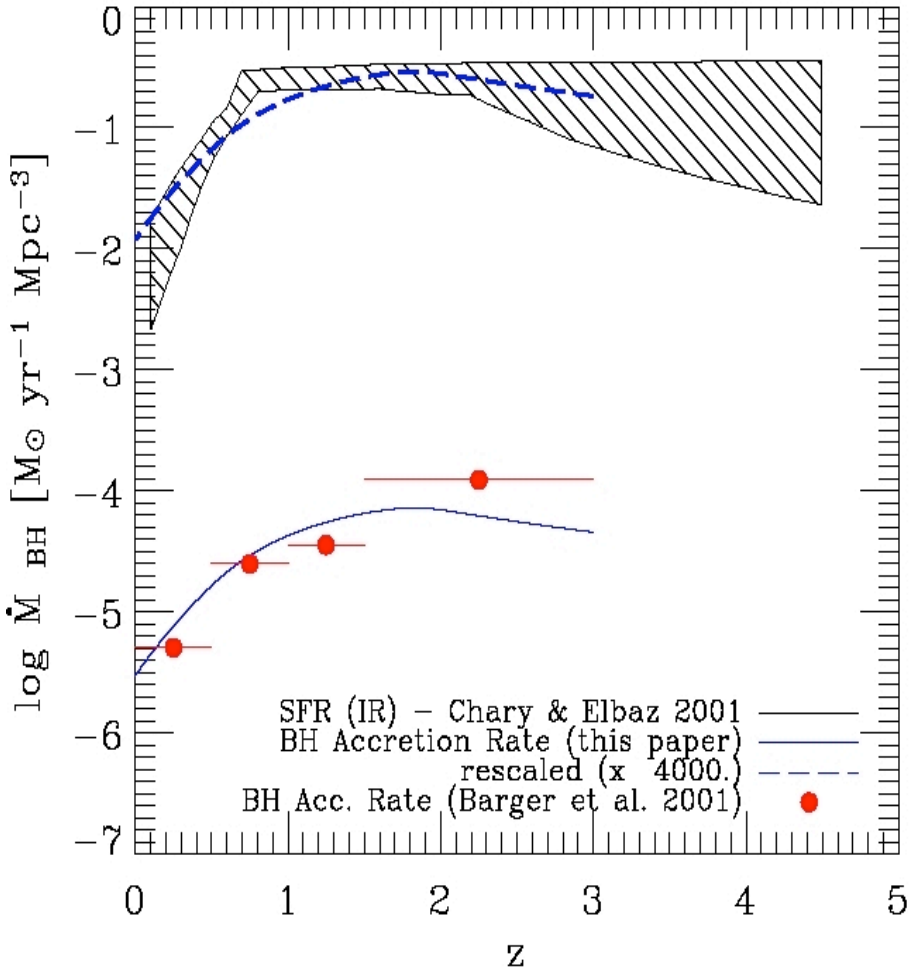
The Co-Evolution of Black Holes &





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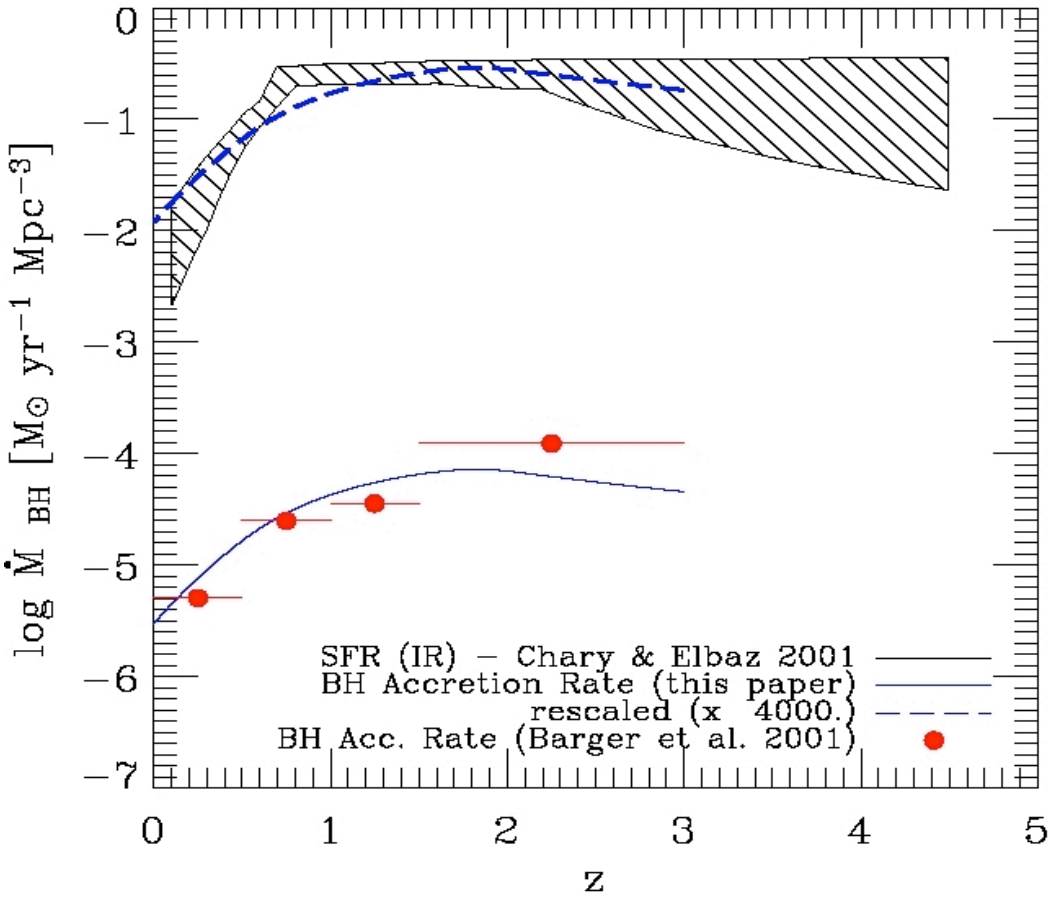
- A. von der Linden – MPA
- S. White – MPA

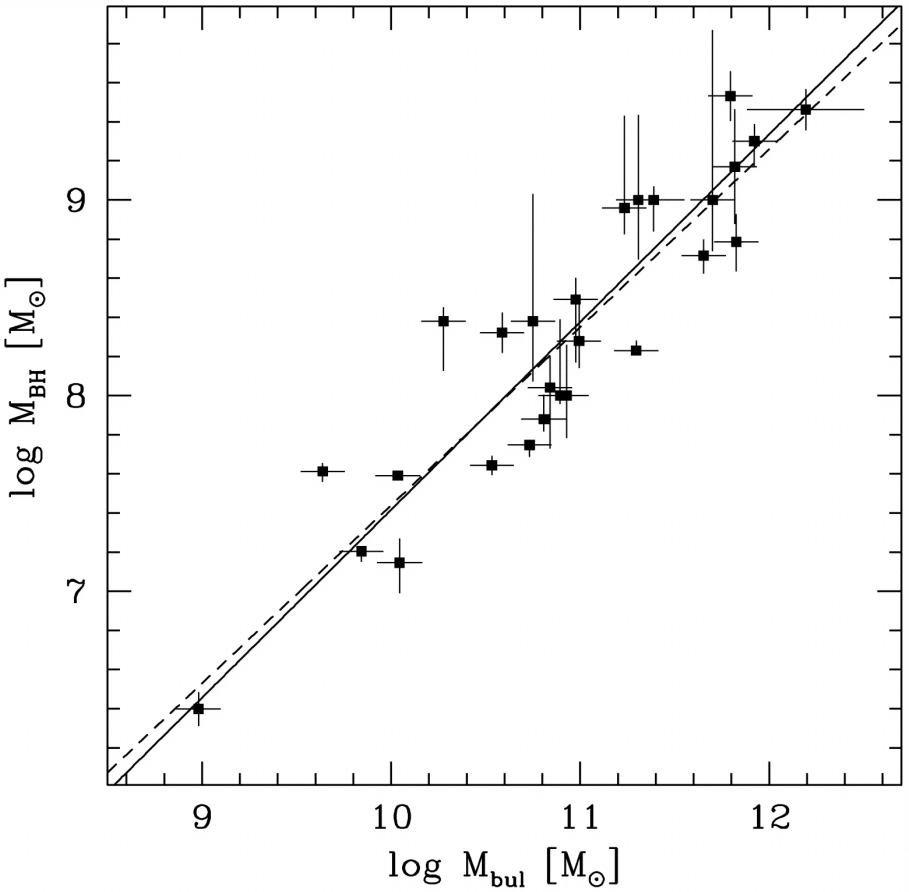
The SDSS & GALEX Teams

THE CO-EVOLUTION OF GALAXIES & BLACK HOLES

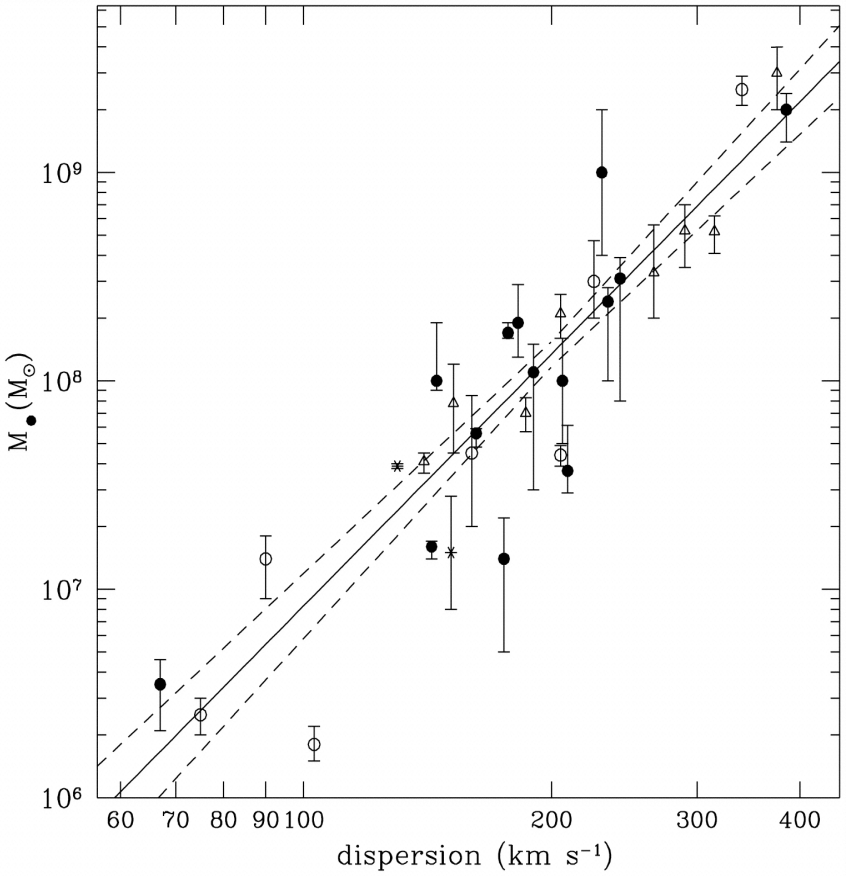


Marconi et al.

BLACK HOLE MASS STRONGLY LINKED TO BULGE PROPERTIES

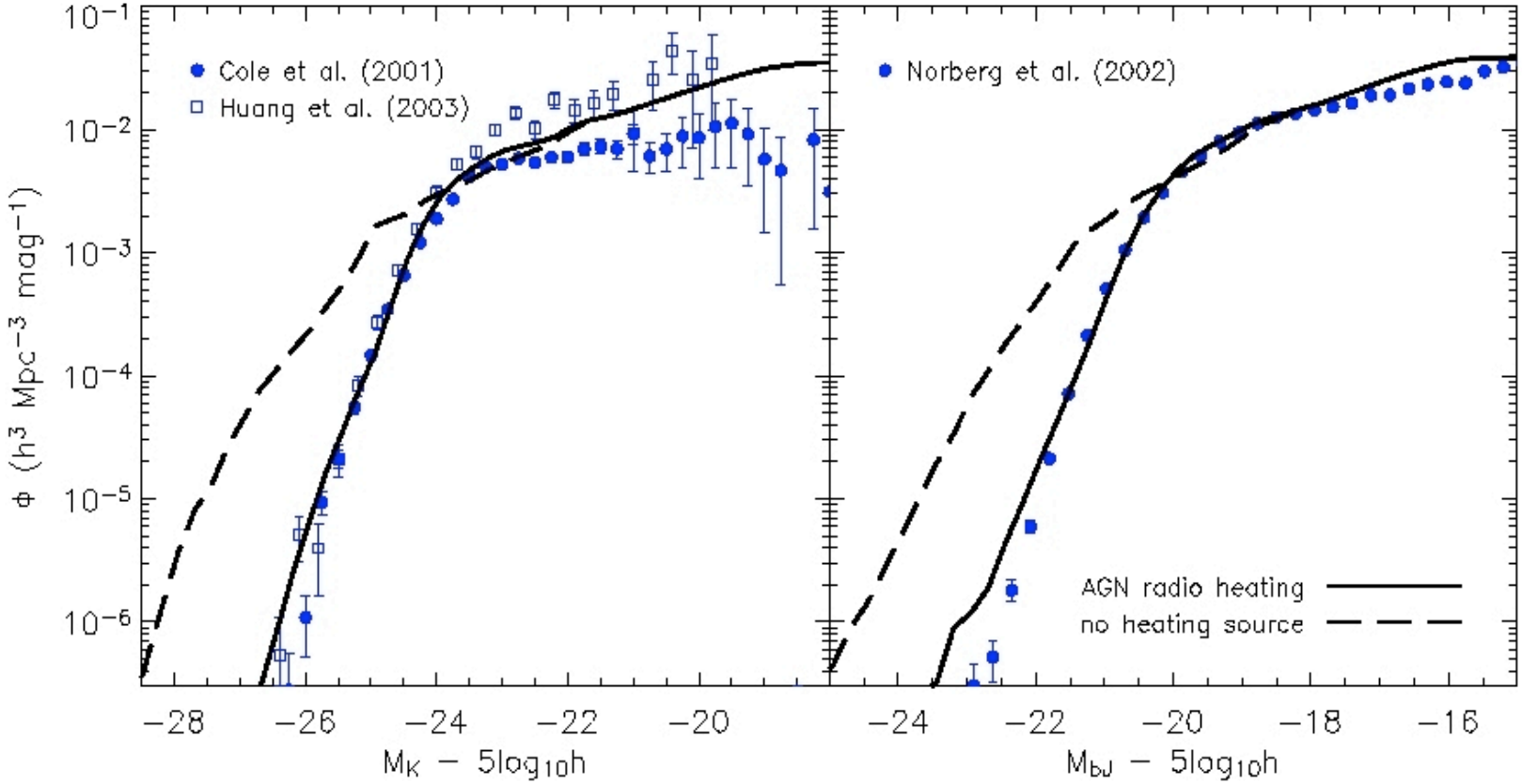


Marconi & Hunt



Tremaine et al.

AGN FEEDBACK CRUCIAL IN GALAXY EVOLUTION?

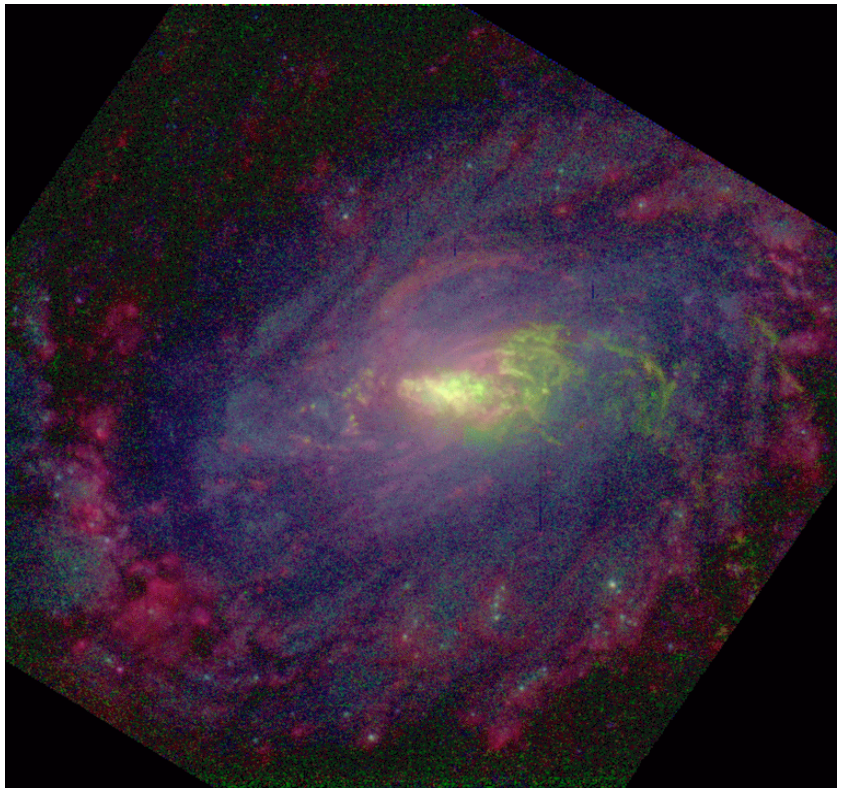


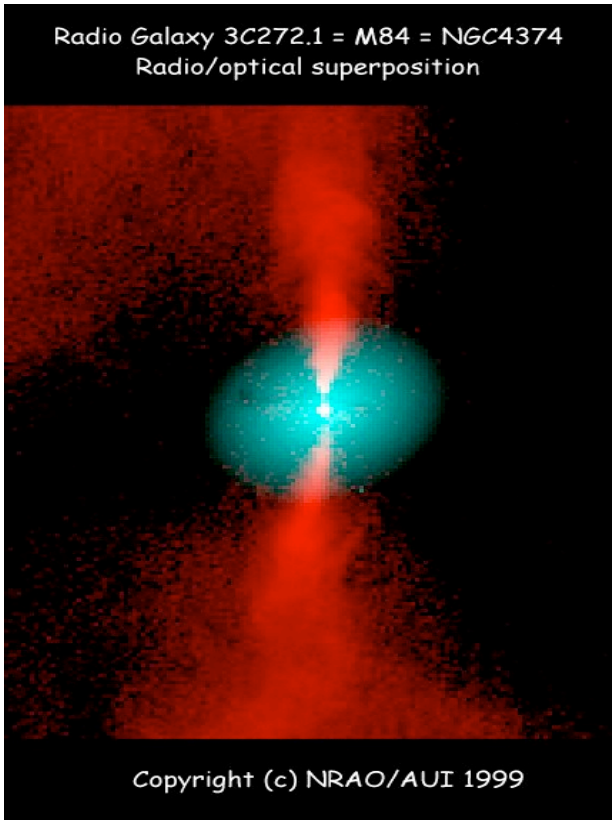
- Cures “over-cooling” problem at high masses? (e.g. Croton et al.)

Motivating Questions

- By what processes are the formation of stars and the growth of black holes linked in galactic bulges?
- What form does feedback from AGN take, and what is its effect on galaxy formation?
- Can we see these processes operating in the local universe (where they can be studied in detail)?

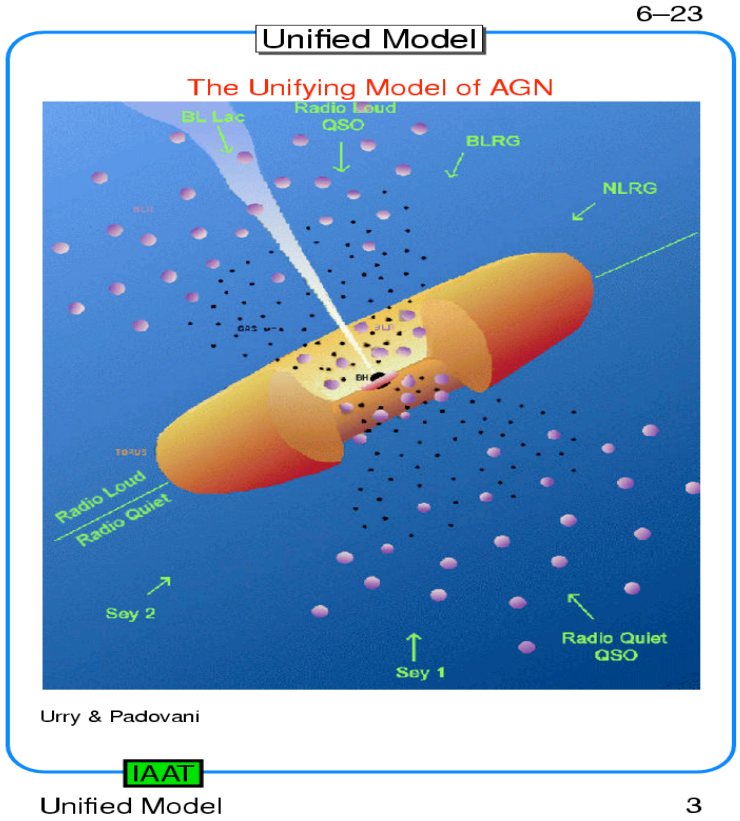
Preview

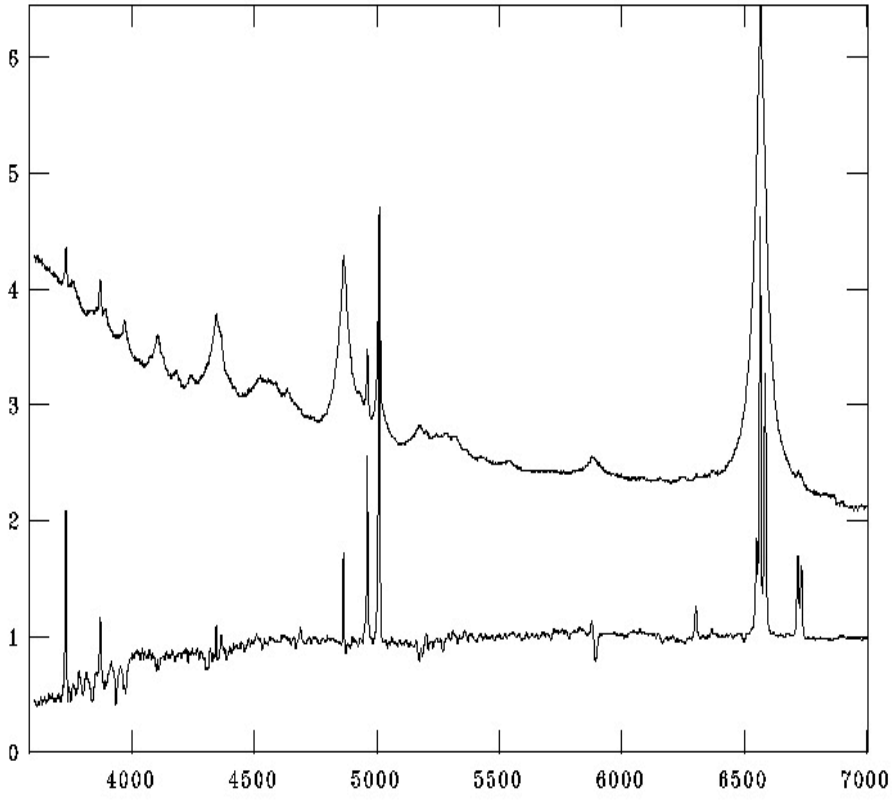




- Two primary independent modes in the local universe
- Seyfert galaxies (high accretion rates/efficiency)
- Radio galaxies (low accretion rates/low efficiency)

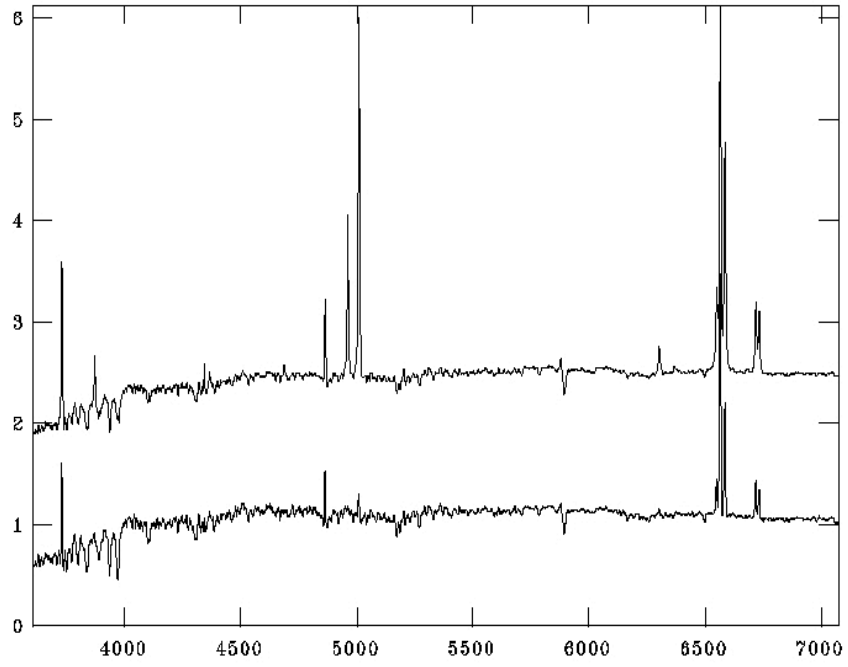
The Standard “Unified” Model

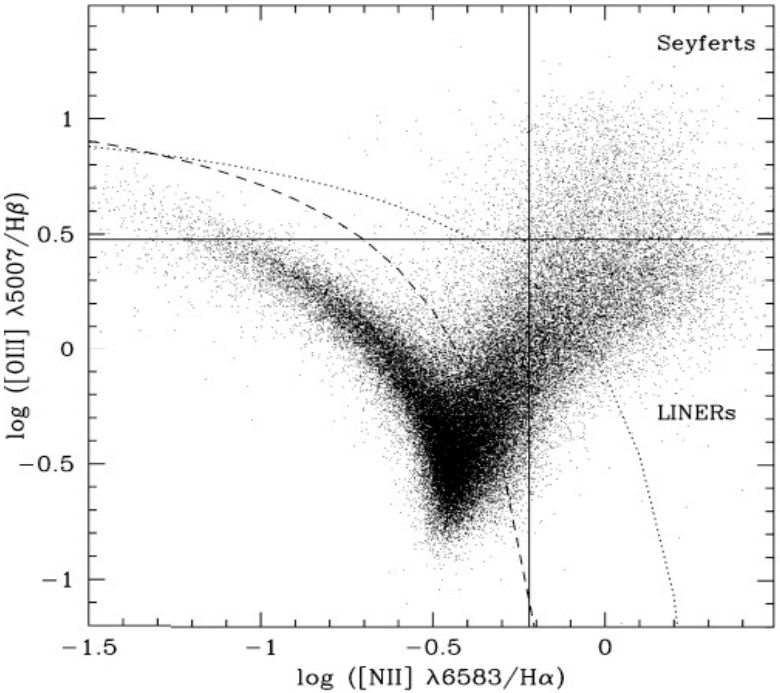




- View “central engine” directly in Type 1 AGN
- Central engine occulted in Type 2 AGN
- Powerful jets in Radio Galaxies

Emission-Line AGN



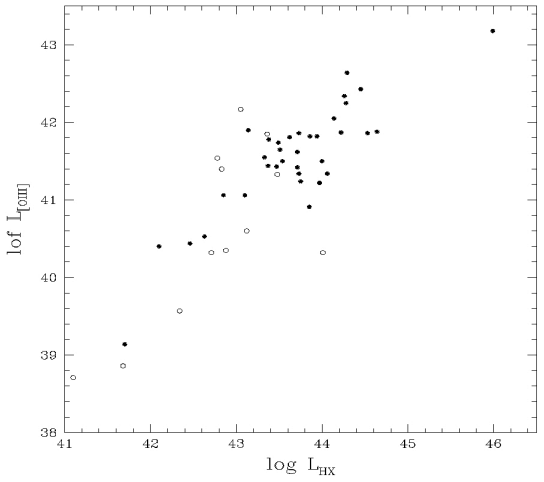


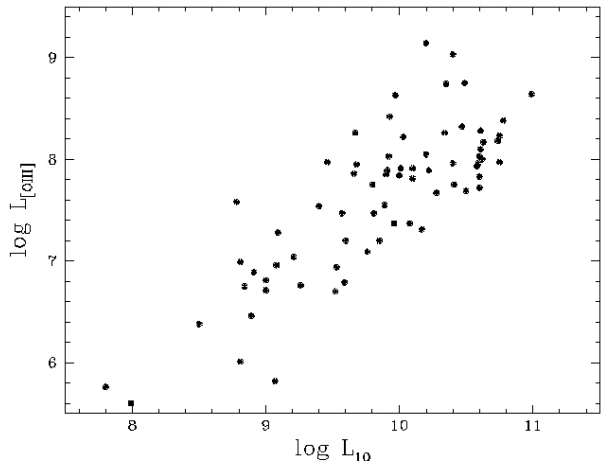
Classification AGN vs. SF: emission-line ratios

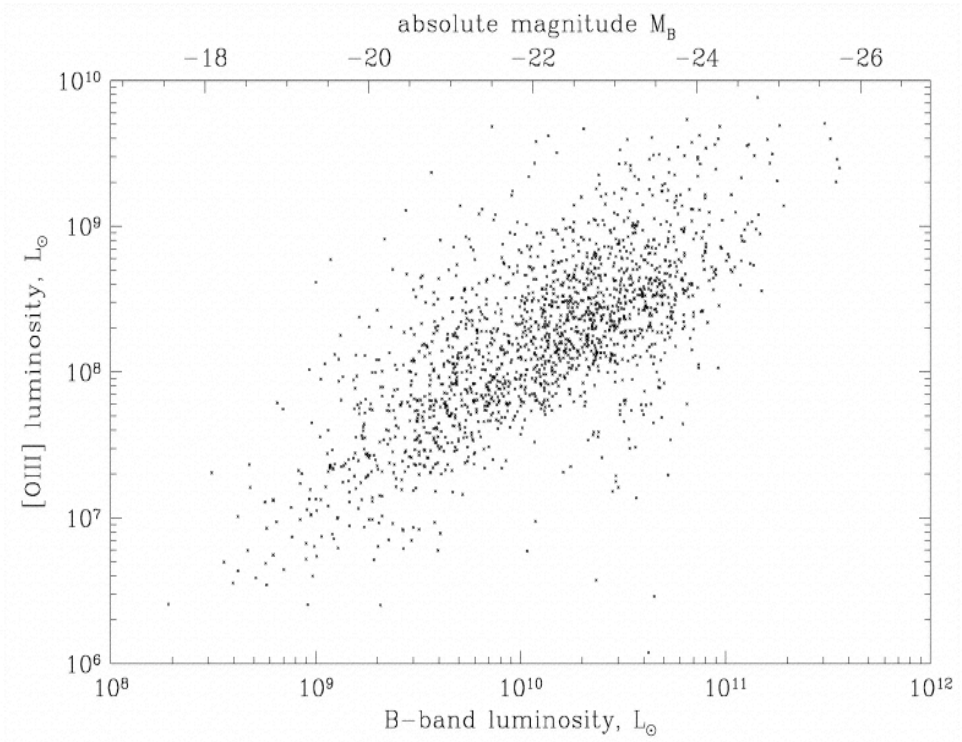
[OIII]5007 as AGN tracer

Strongest AGN line and minimal contribution from SF

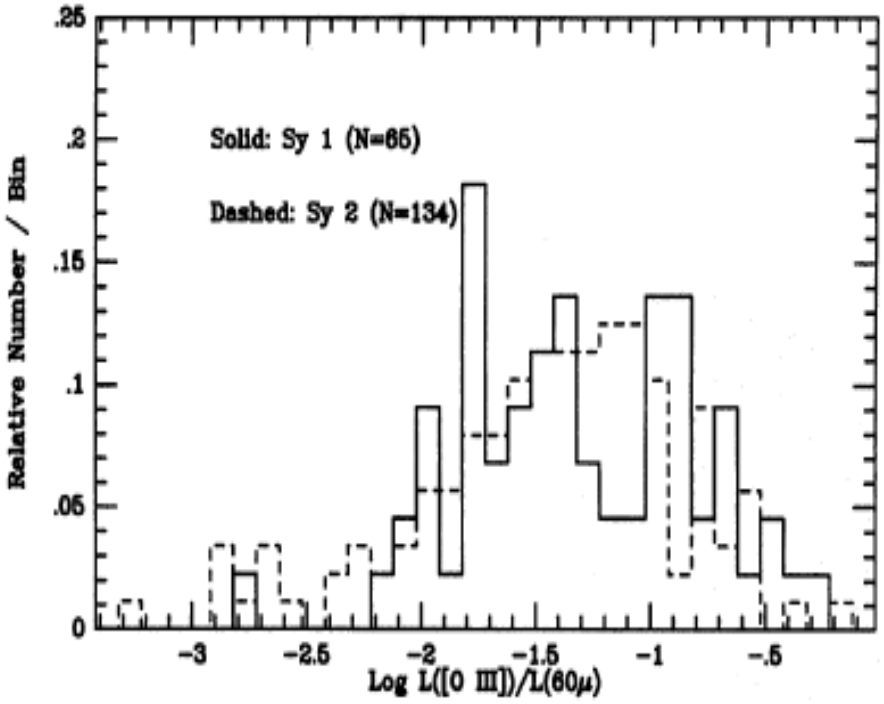
The [OIII] Lines as a proxy for the bolometric luminosity

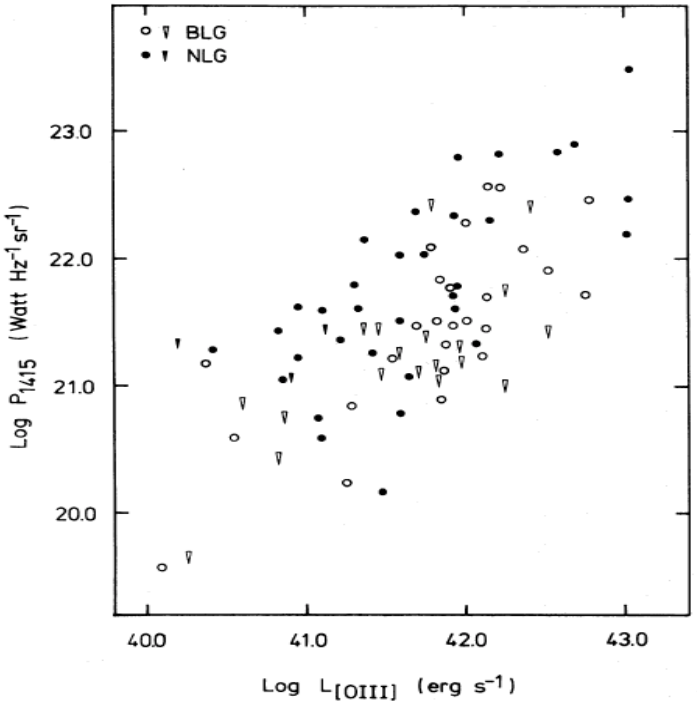






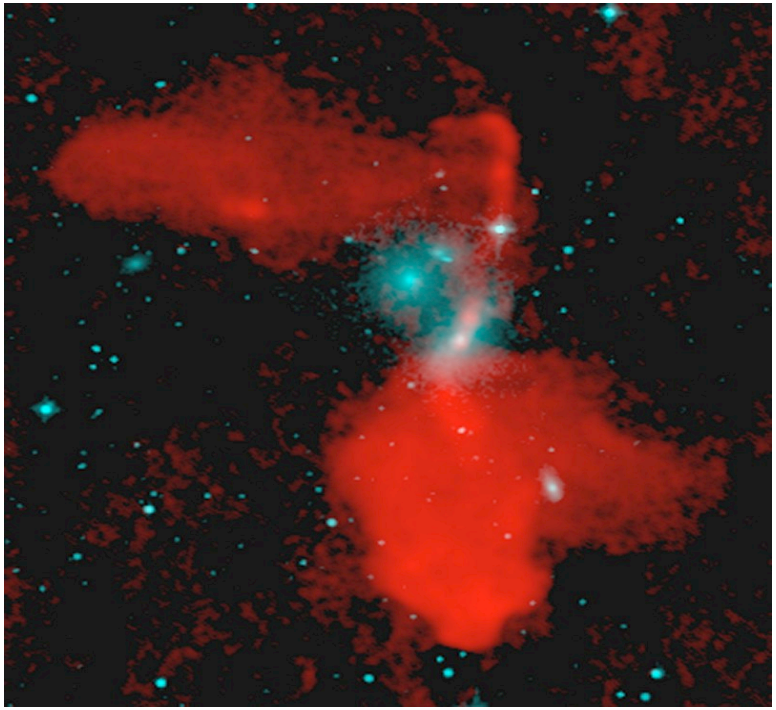
More [OIII] Propaganda…





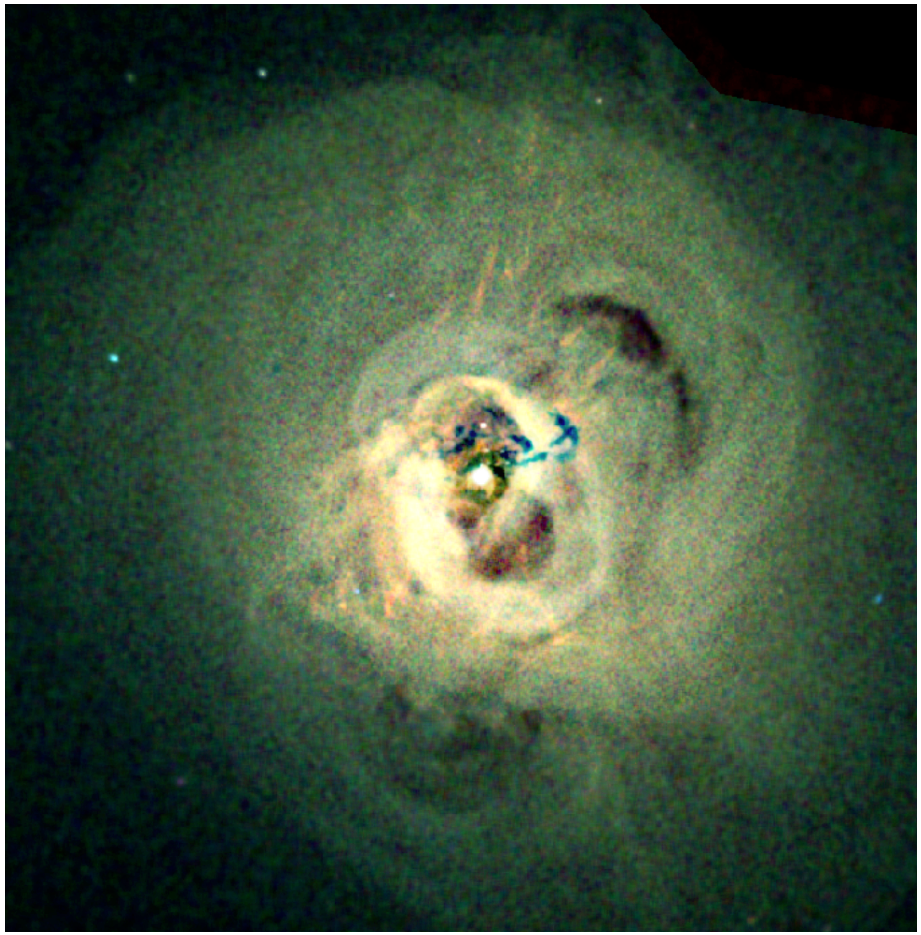
- "Raw" [OIII] luminosity provides estimate of bolometric luminosity to within factor ~3 for typical low-z AGN
- We correct for extinction using Balmer decrement (so, we should do better than the above)

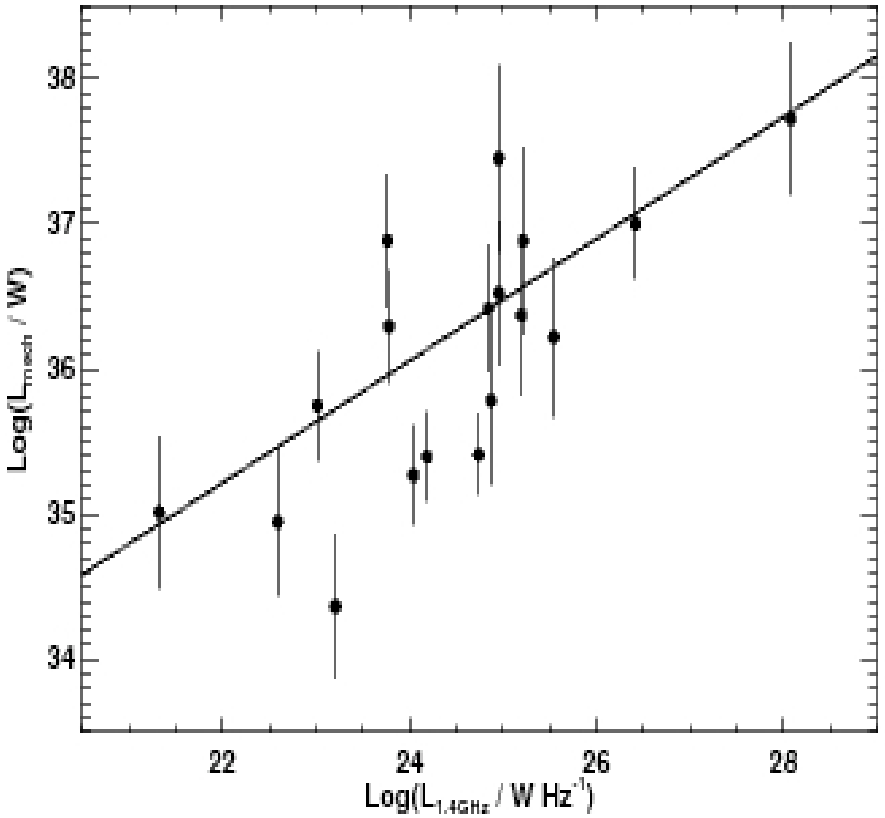
Radio Galaxies



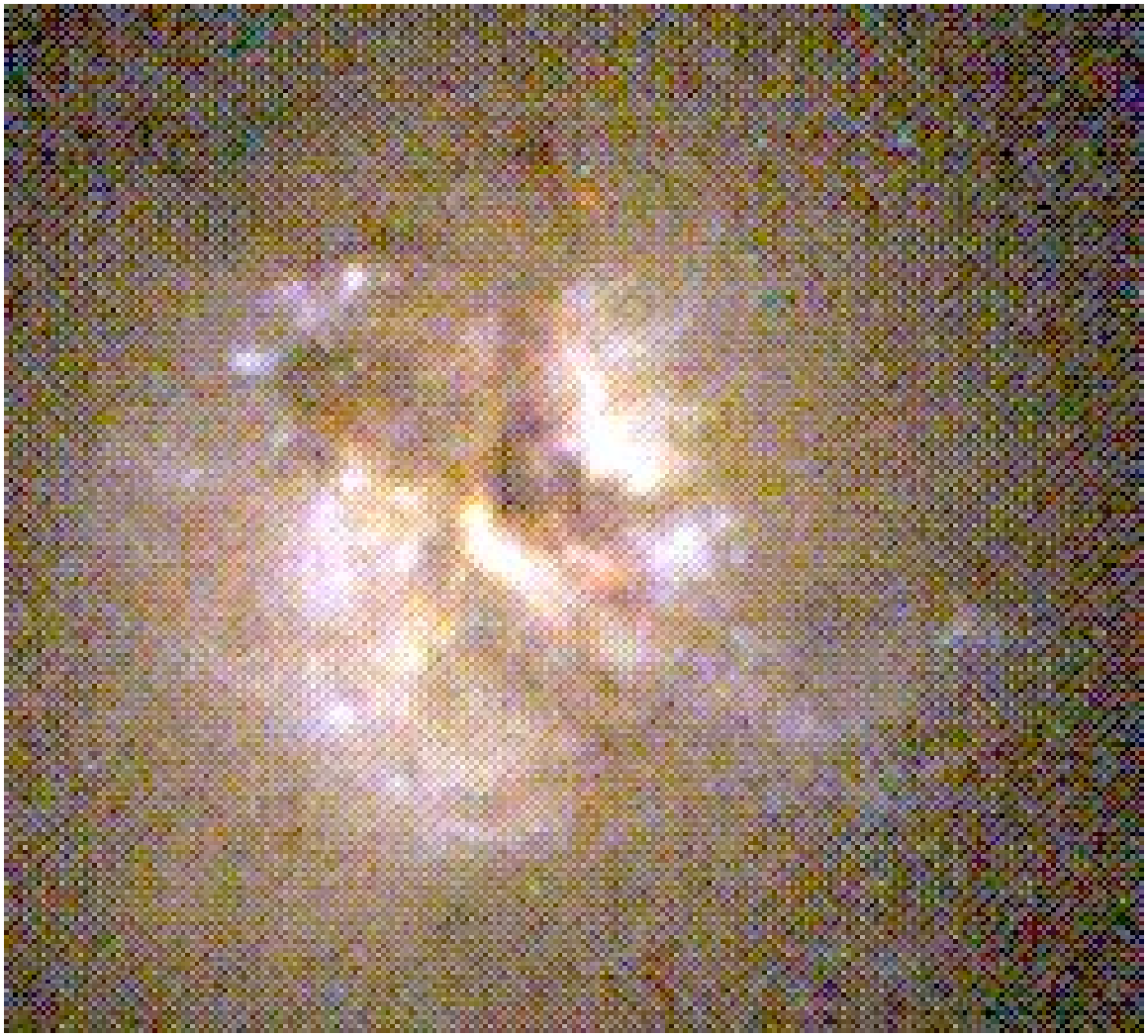
- Match SDSS galaxies with FIRST+NVSS
- Separation into radio galaxies vs. SF based on SDSS spectroscopy
- These are low-power radio galaxies (~FR I)

Radio Jets: Energetics based on cavities inflated in the hot ICM

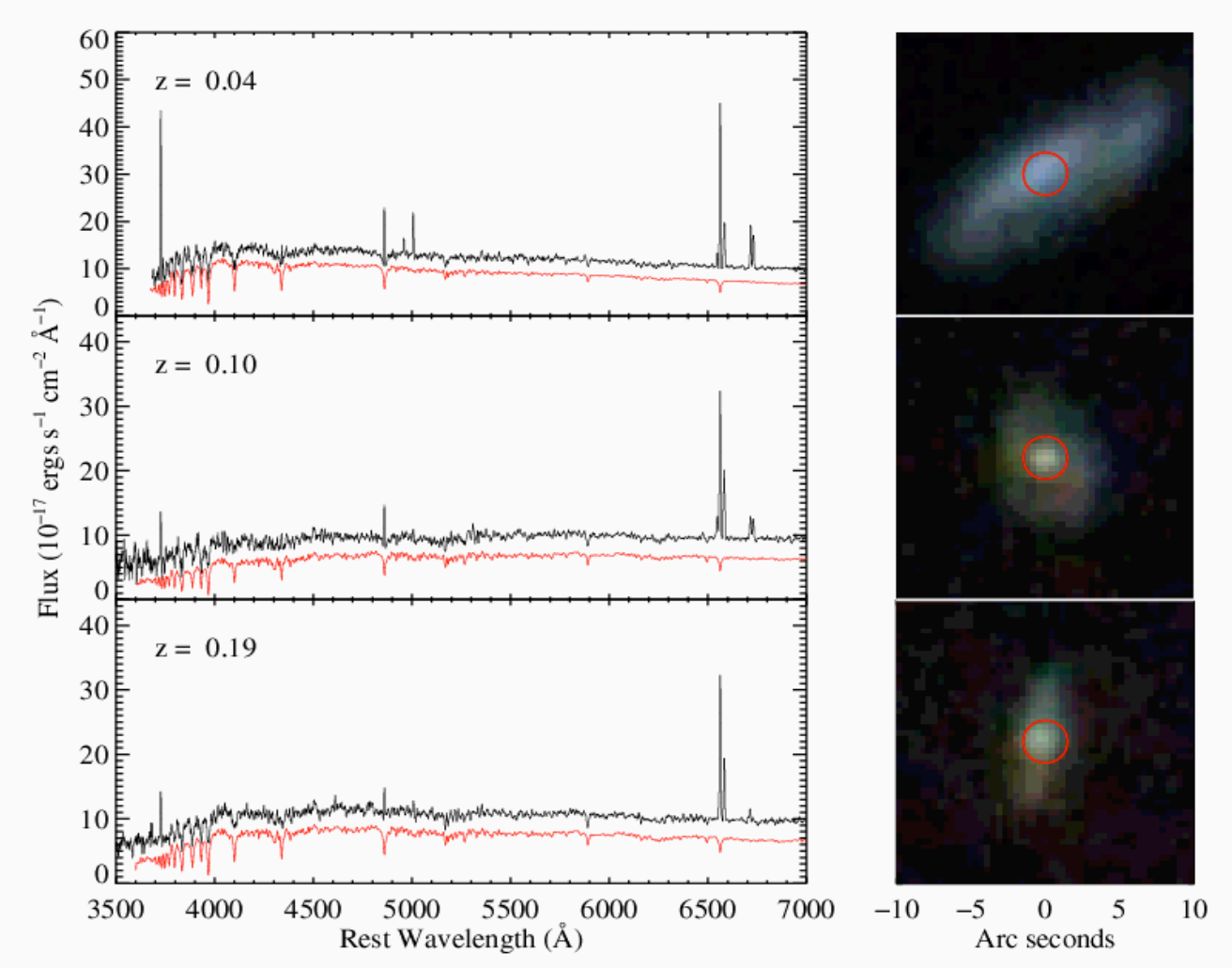




Part I: The Link Between Star



SDSS SPECTRA: The Bulge

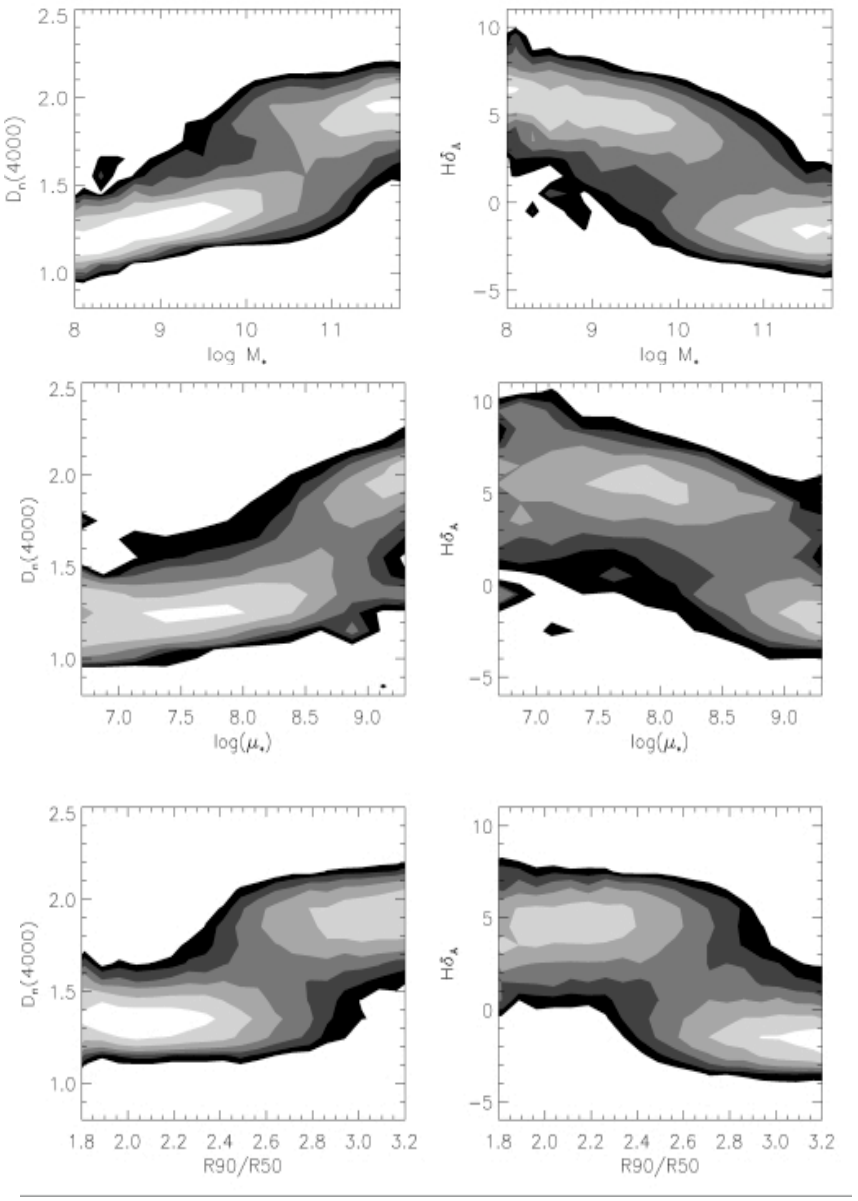


THE BIMODAL SDSS GALAXY POPULATION

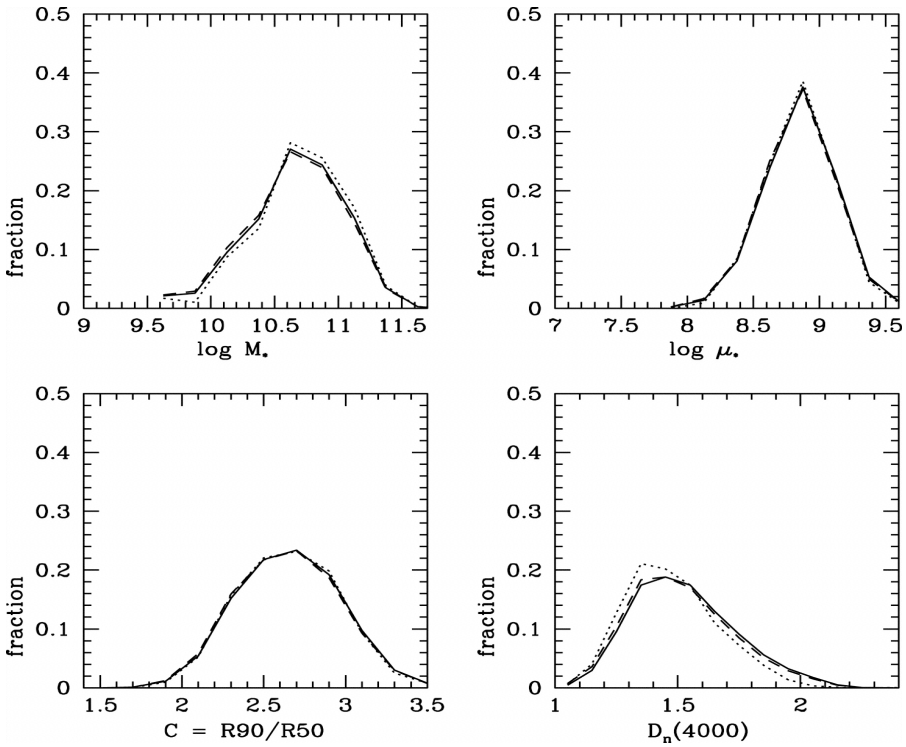
Characteristic scales for transition from old to young:

- $M_* \sim 3 \times 10^{10}\ M_\odot$
- Low mass galaxies are young, high mass galaxies are old
- $\mu_* \sim 3 \times 10^{8}\ M_\odot/kpc^2$
- Low density galaxies are young, high density galaxies are old
- $C \sim 2.6$
- Low-concentration (late-type) galaxies are young

  High-concentration (early-type) galaxies are old
- Black Holes: the domain of massive, dense, high-concentration galaxies (big bulges)

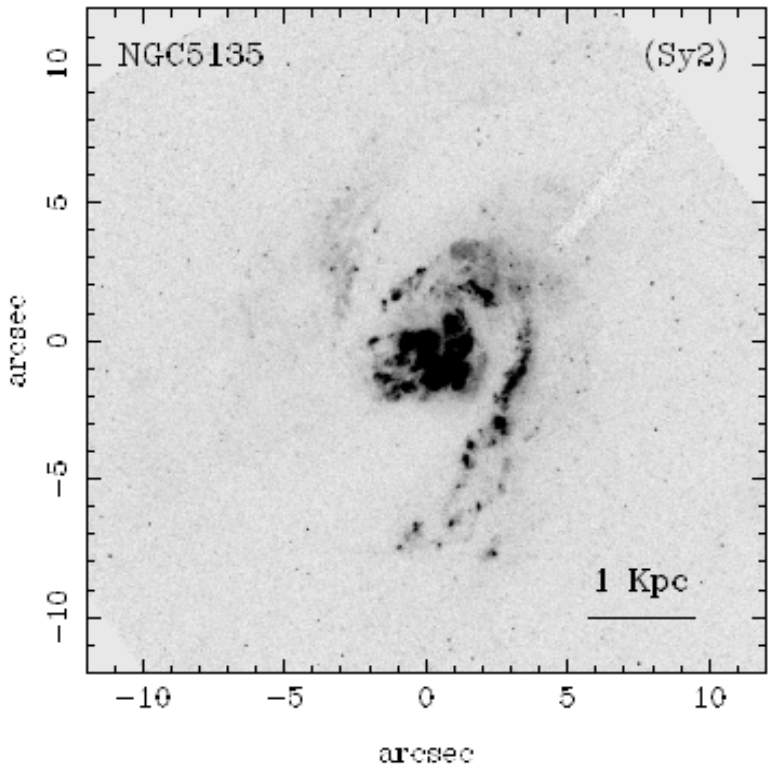


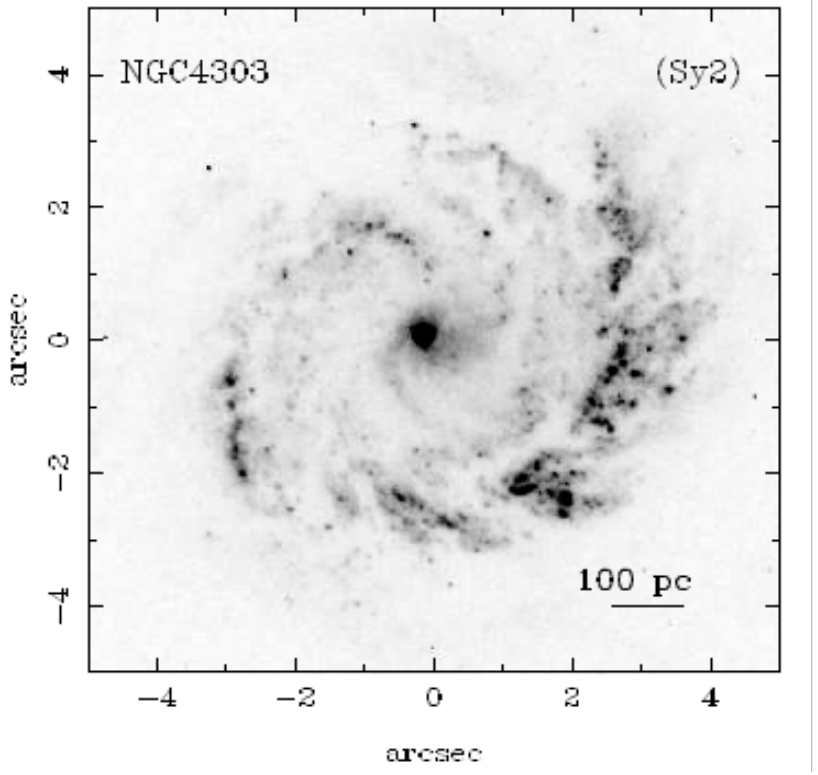
Where do emission-line AGN live?



- The production of [OIII] emission by AGN is dominated by “hybrid” galaxies
- Near the boundaries between the bimodal population
- Structures/masses more like early-type galaxies
- Bulges: unusually young stellar population

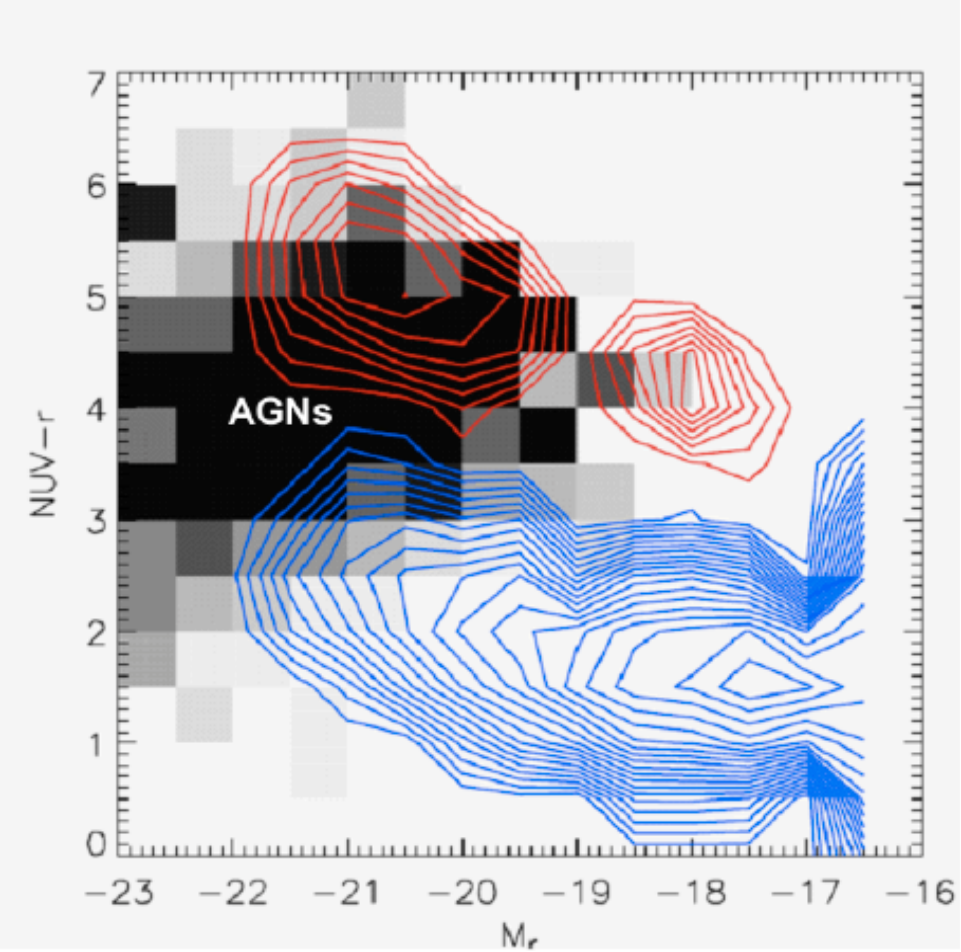
Star-formation in AGN Bulges





- Probe with HST UV images of nearby AGN (Munoz Marin et al. 2007)

The GALEX Perspective

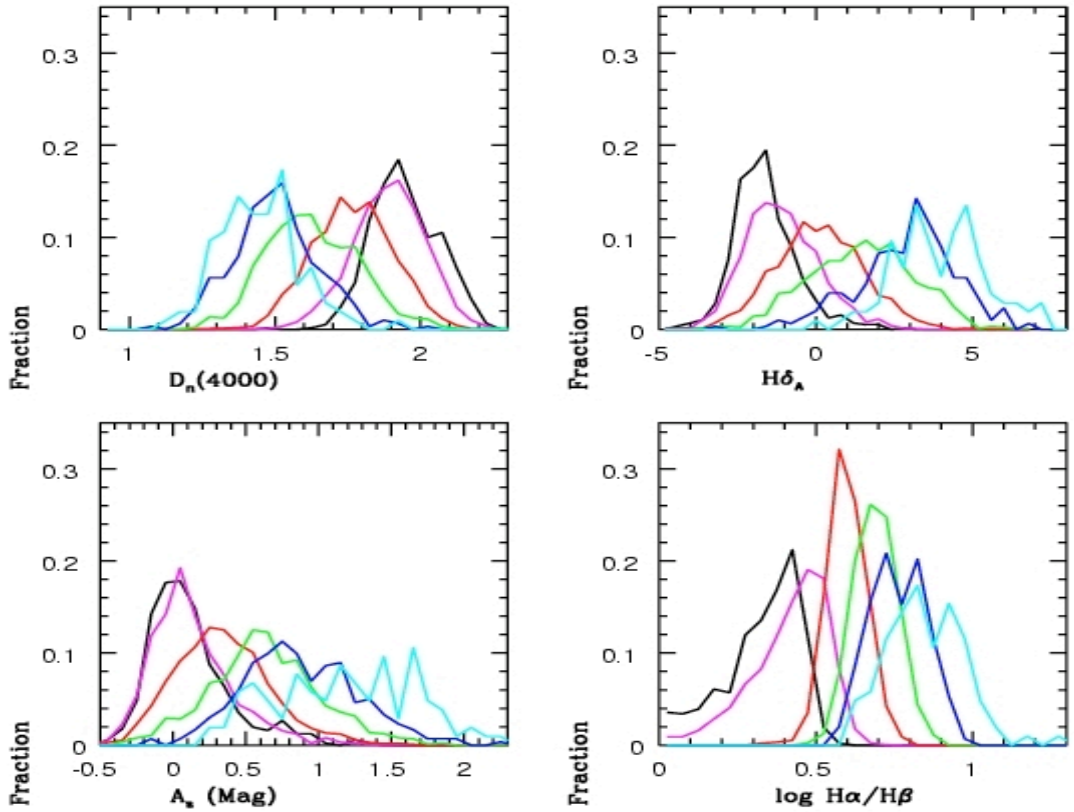


The bimodality in the galaxy population is even clearer

"No Mans Land" (AKA the "Green Valley") is dominated by emission-line AGN

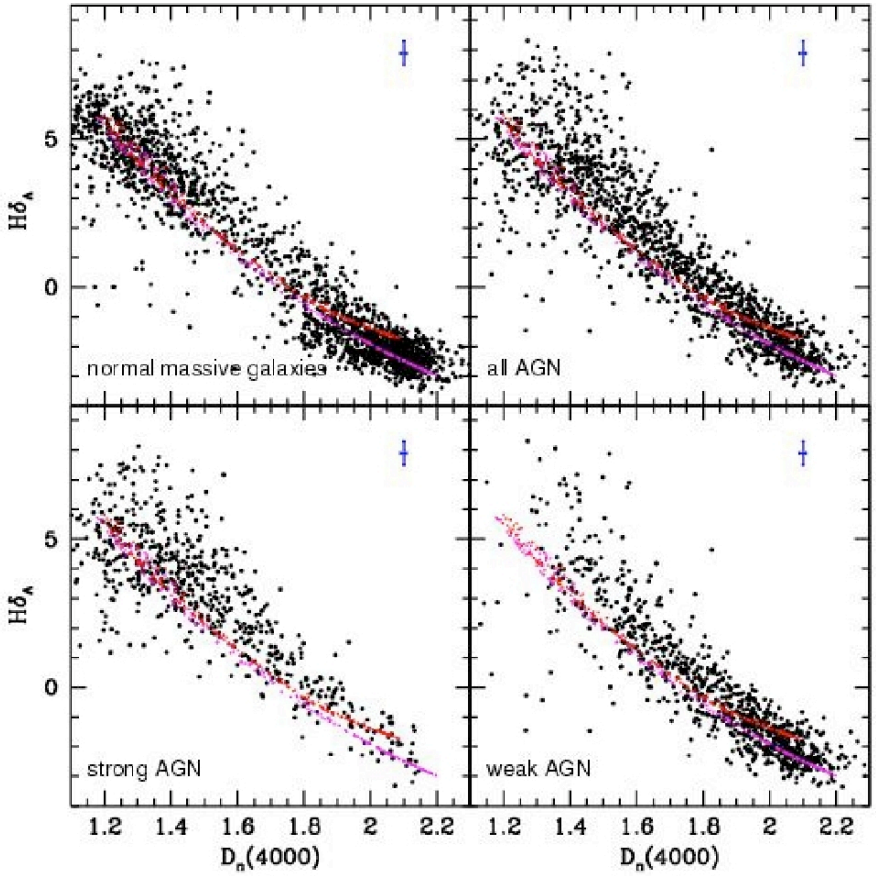
Hybrid/Transition galaxies

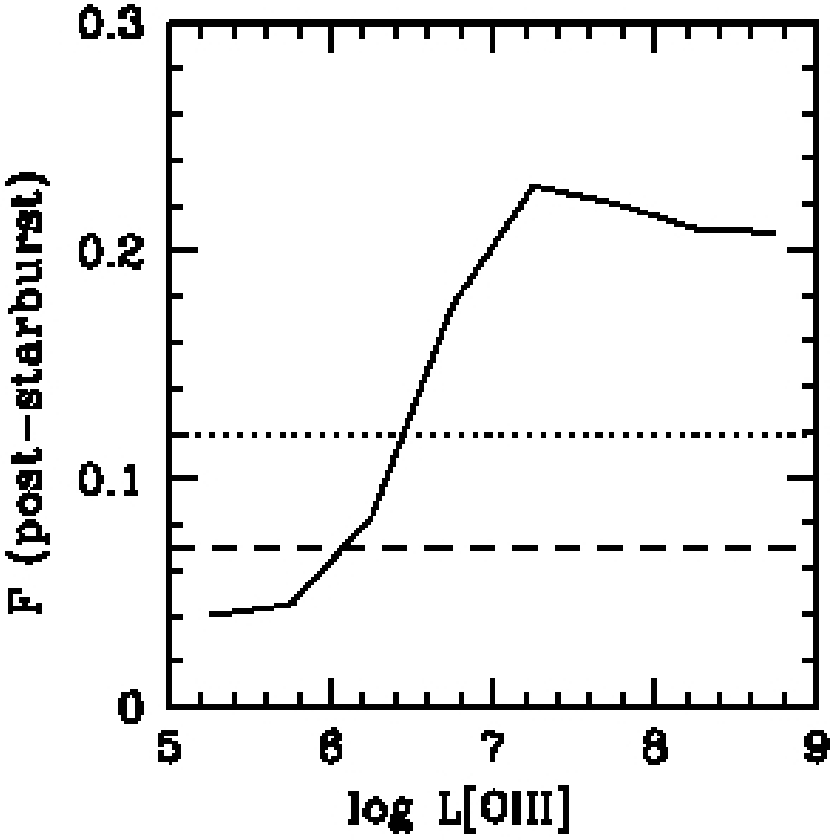
Luminosity Dependence: Bulge



- As the AGN luminosity increases the stellar population in the bulge becomes younger
- And the amount of dust/cold-gas increases

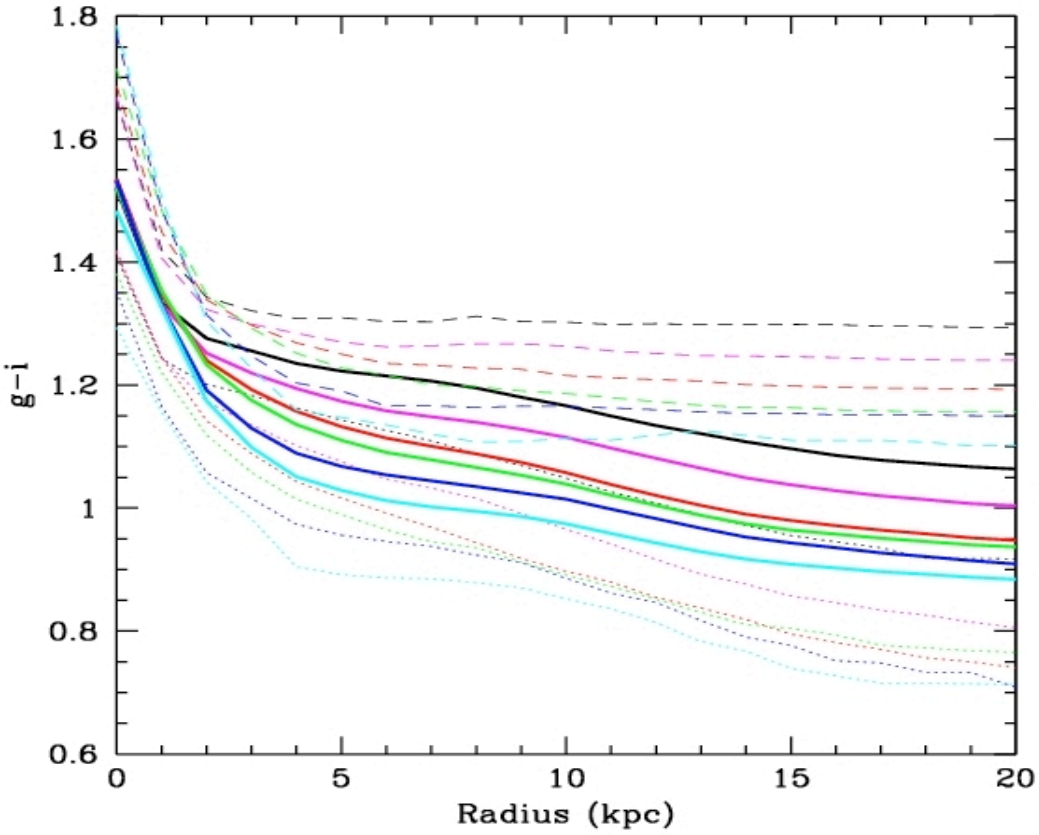
Luminosity Dependence





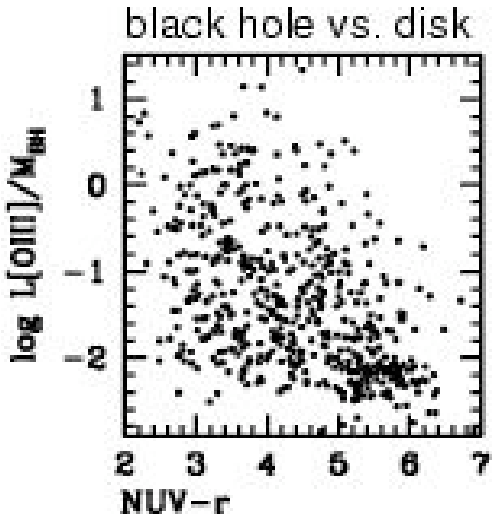
- At higher AGN luminosities, the fraction that are post-starbursts is higher

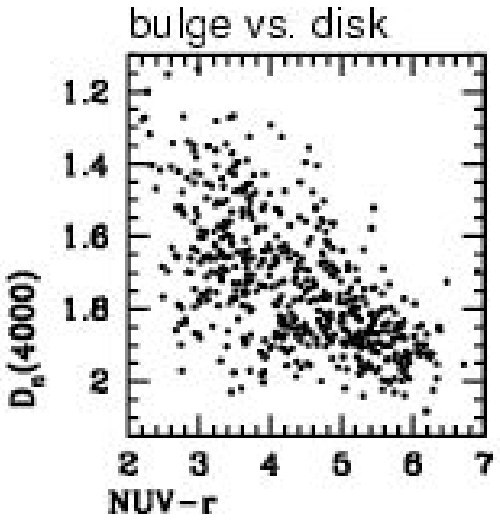
Luminosity Dependence: Disk

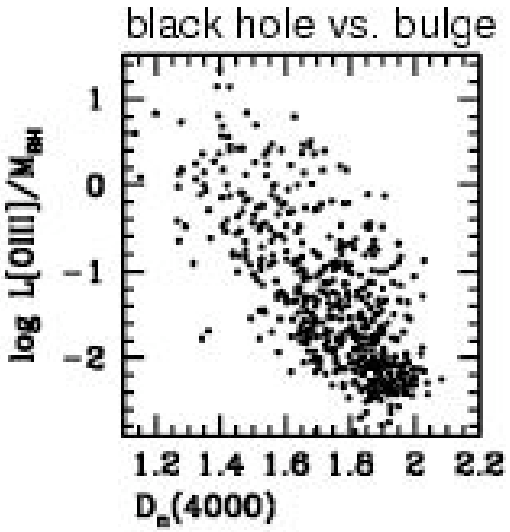


- More luminous AGN occur in galaxies with younger disks

Disk vs. Bulge vs. Black Hole

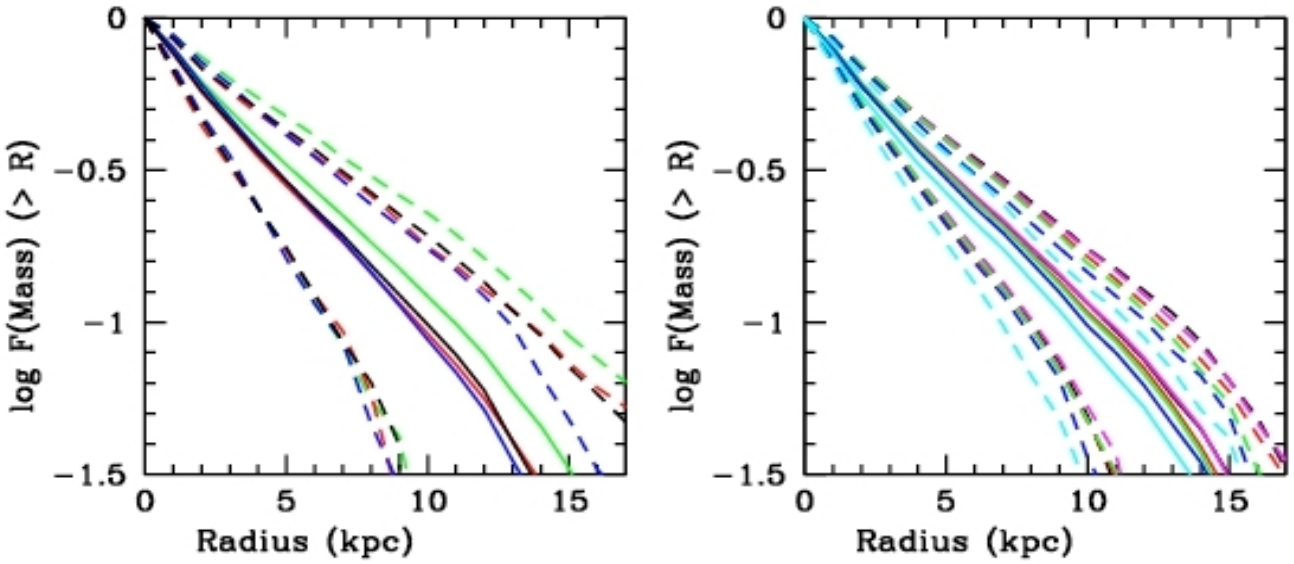






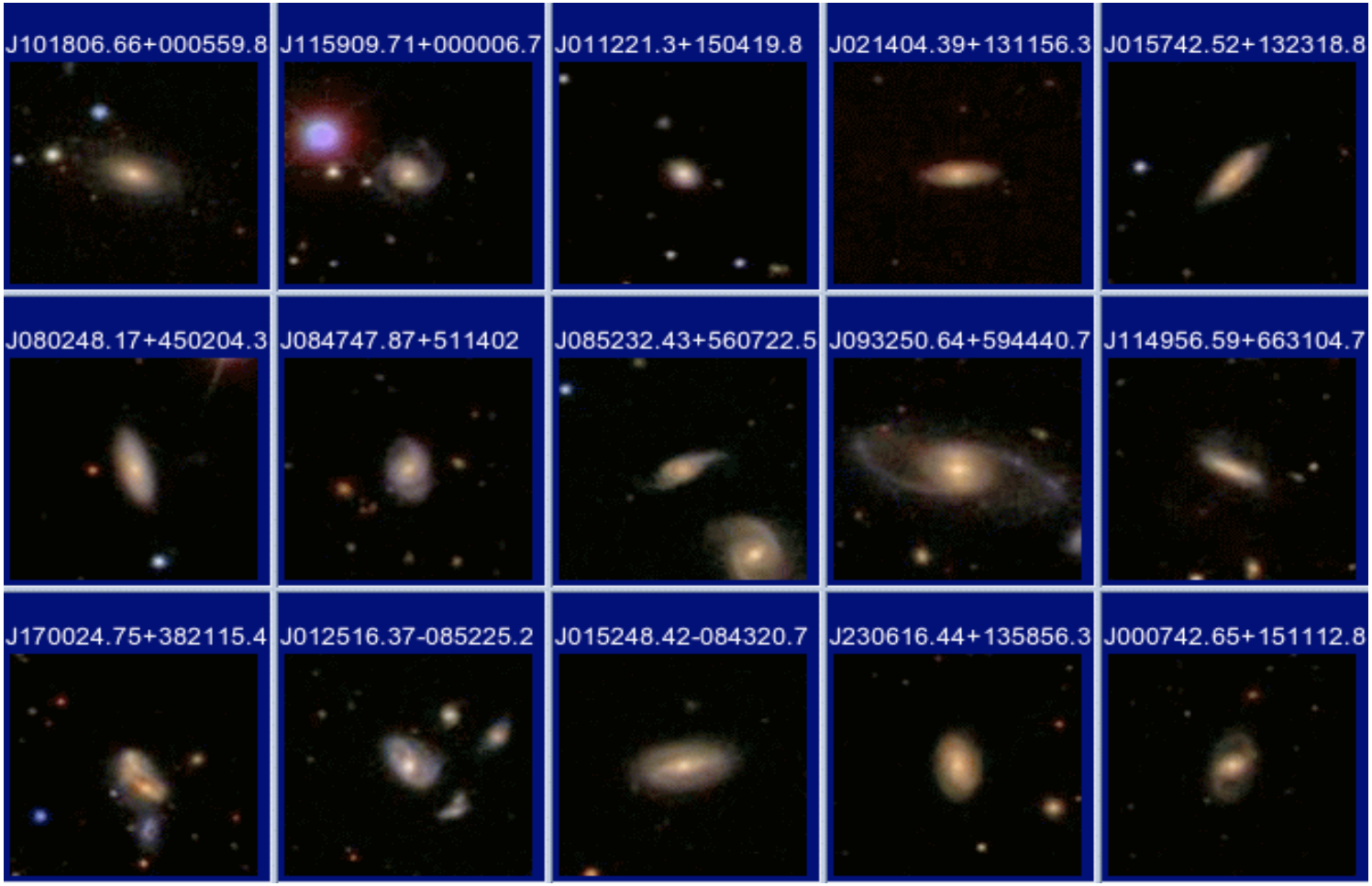
- A young disk is necessary…but not sufficient for the growth of the bulge and black hole
- A young bulge is necessary and sufficient for black hole growth
- Disk gas as the long-term reservoir
- What's the transport mechanism/trigger?

Stellar Mass Profiles



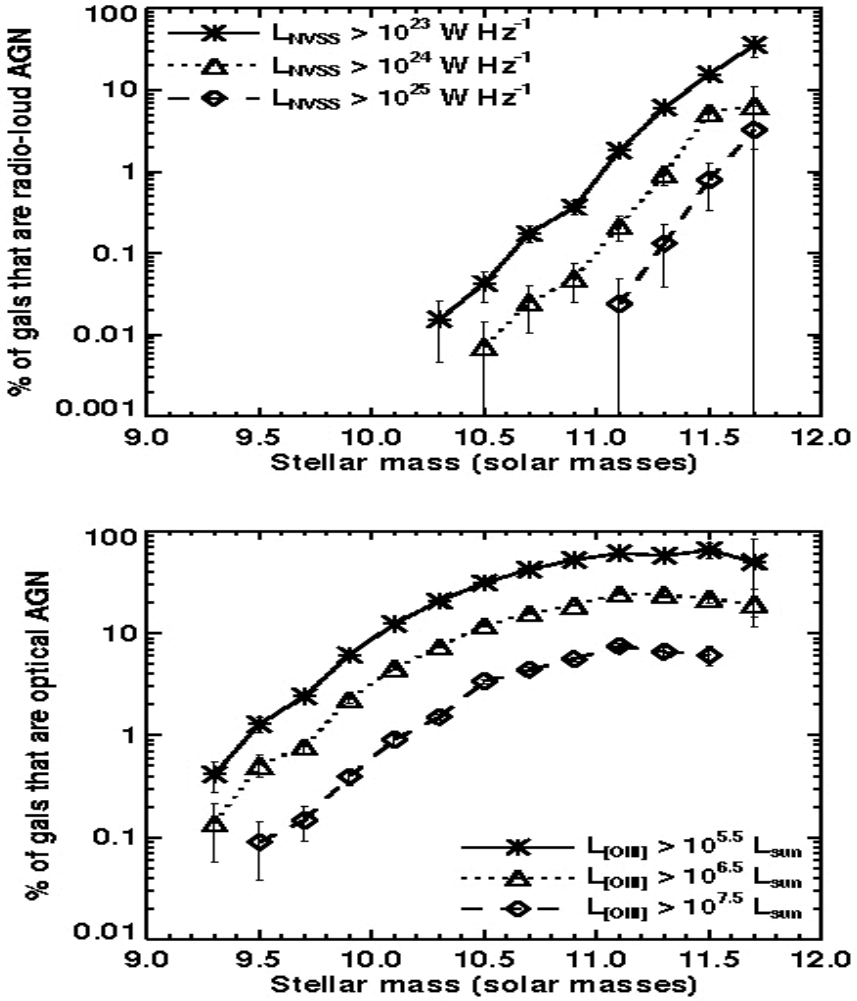
- Galaxies with rapidly growing black holes and bulges have very similar stellar mass profiles to red/dead galaxies with same velocity dispersion
- The trigger does not involve a major “event”

Morphology

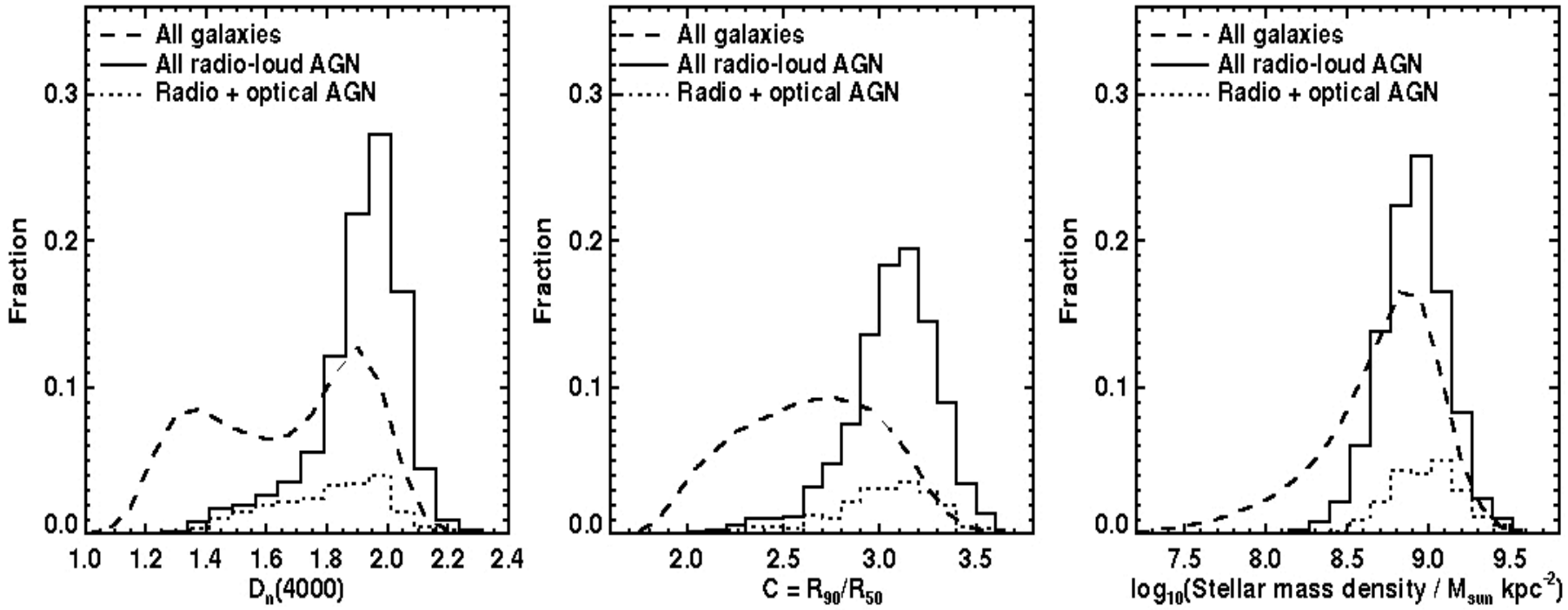


- Usually ~normal early-type disk galaxies

How about radio galaxies?

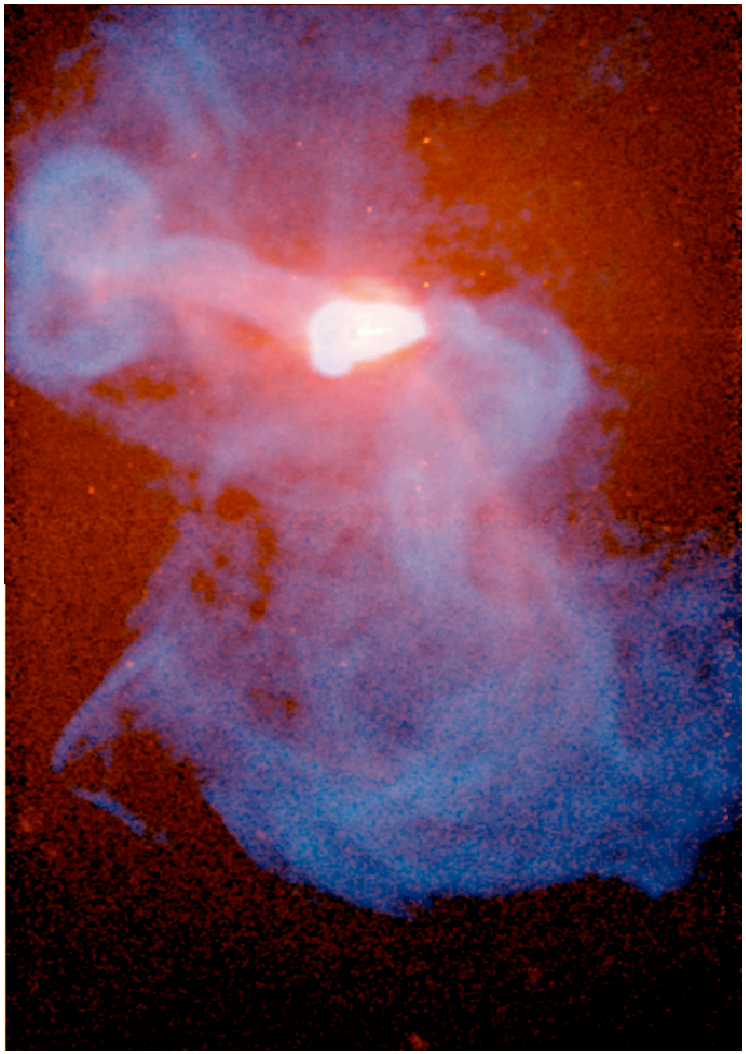


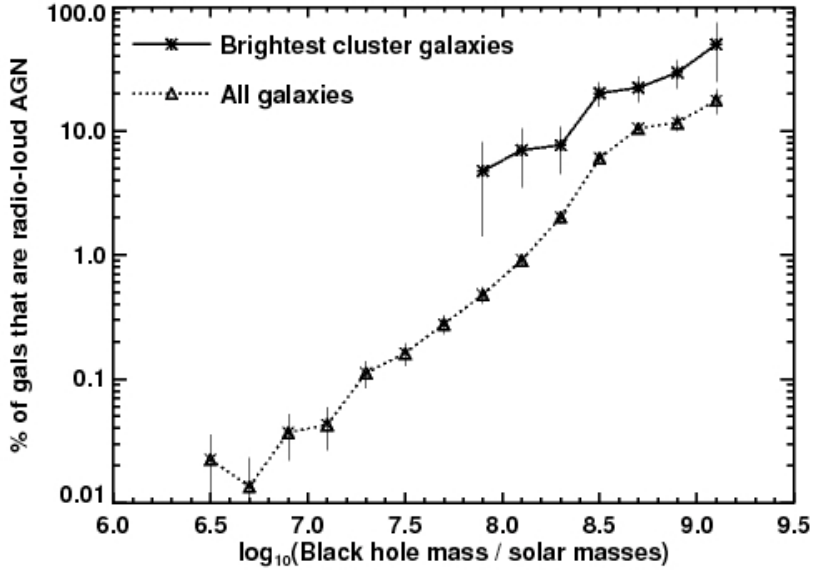
- They are the most massive galaxies

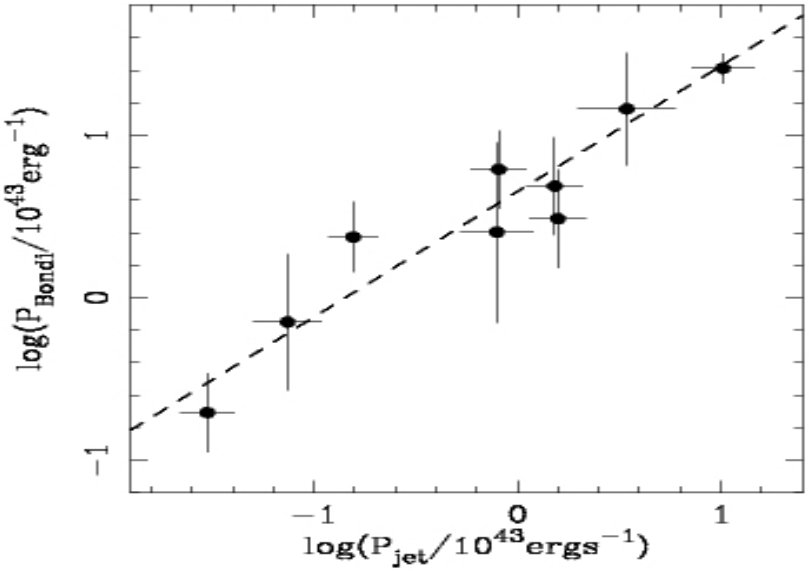


- Structural properties: giant elliptical galaxies
- Old stellar populations (normal)
- Very different from emission-line AGN

Fueling by Cooling of Hot Gas



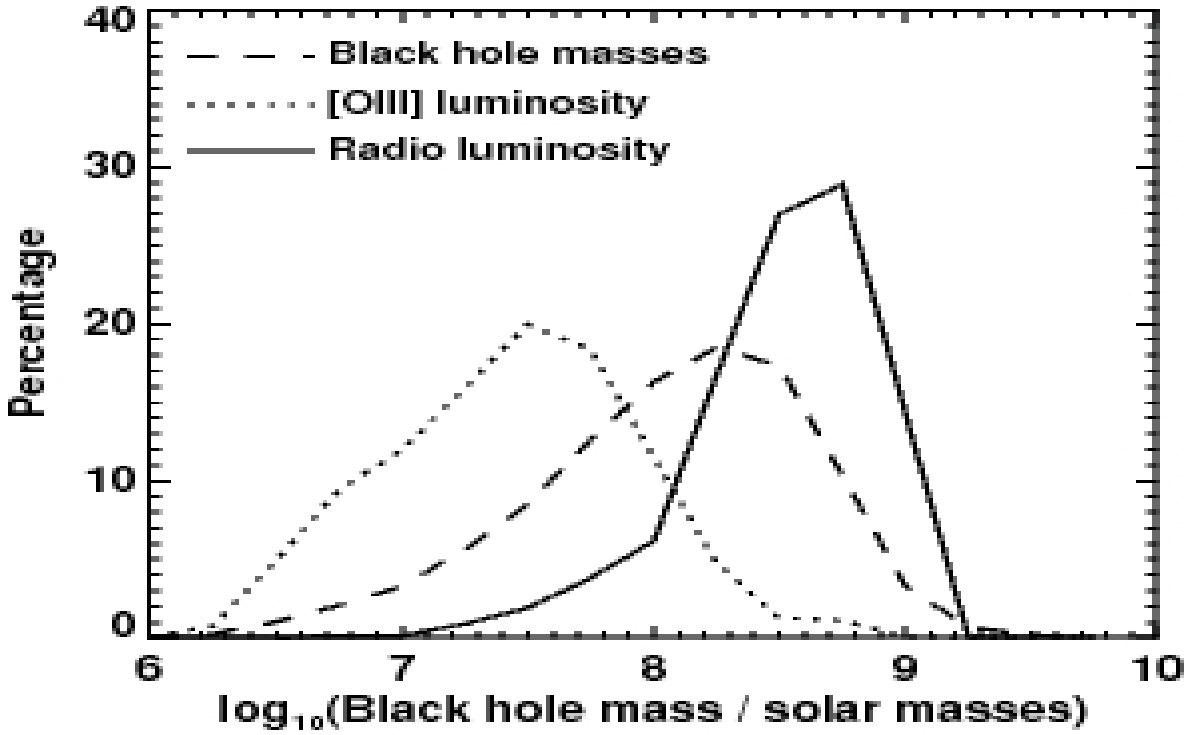




BLACK HOLE DEMOGRAPHY

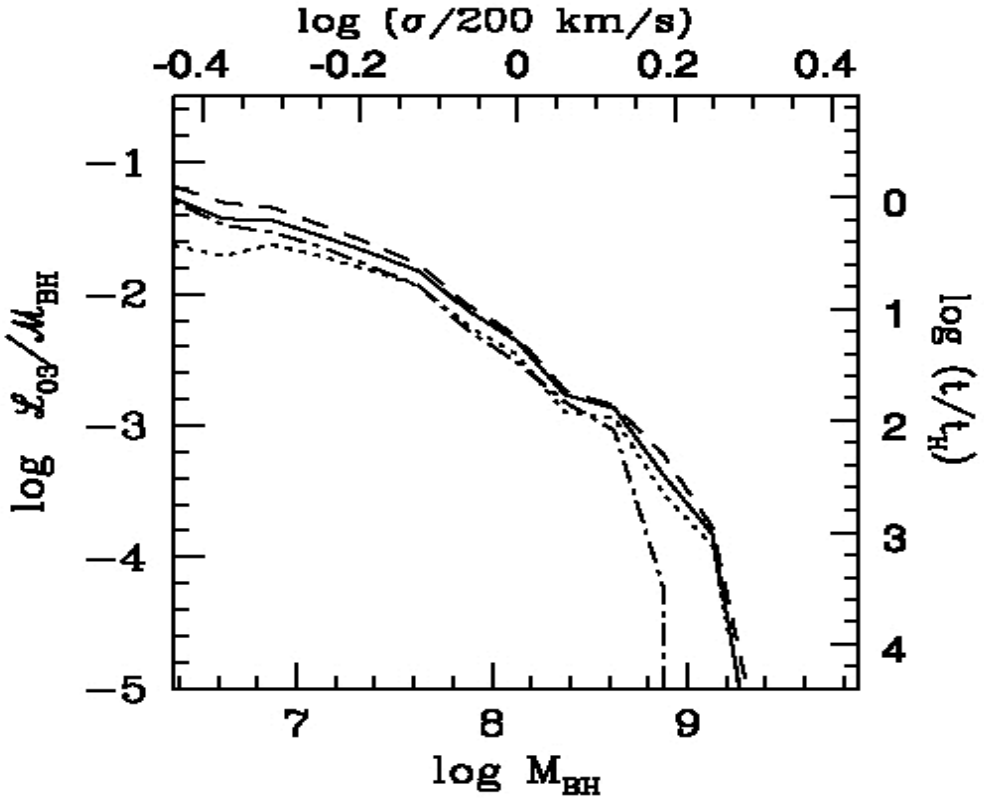
- Estimate black hole masses using the stellar velocity dispersion (AGN hosts are bulge-dominated)
- Estimate the accretion rate using the bolometric luminosity derived from [OIII]
- Accretion rate associated with radio galaxies can be neglected to first order
- Perform volume averages over SDSS

WHICH BLACK HOLES ARE GROWING?



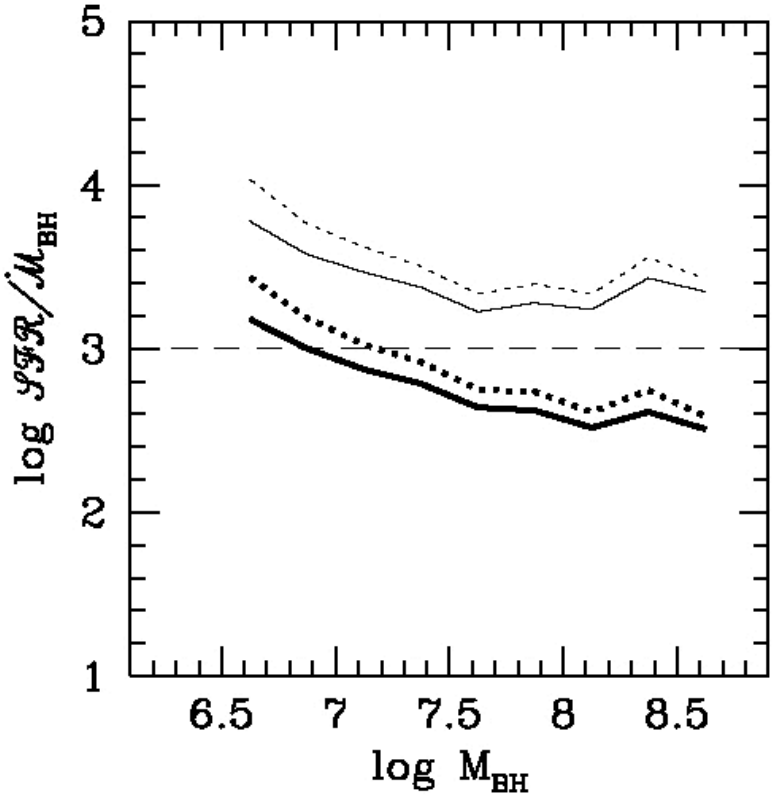
- Mass resides in the more massive black holes
- Growth dominated by less massive ones
- Radio sources are the most massive ones

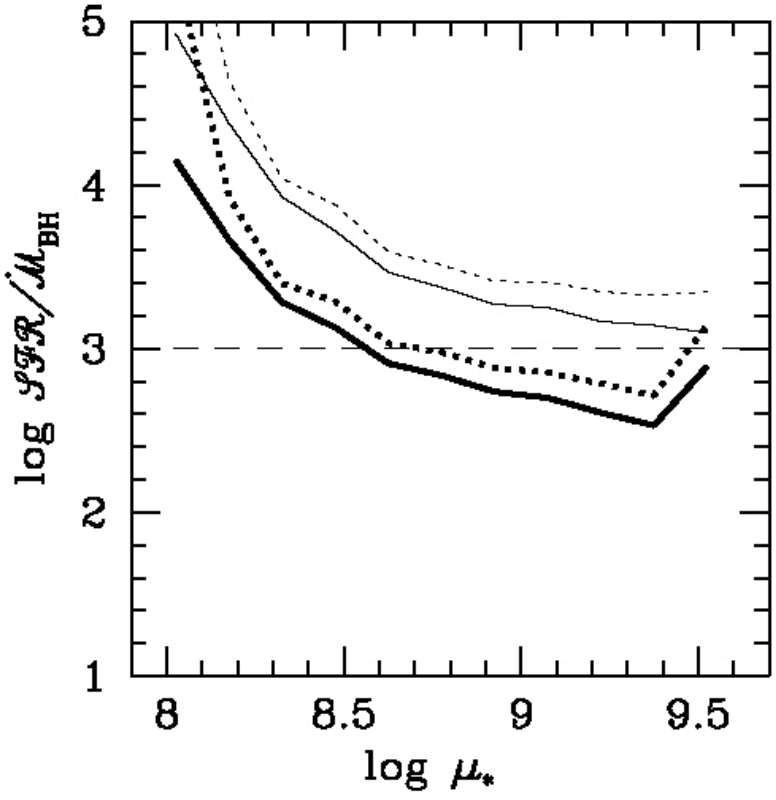
MASS-DOUBLING TIMES



- Only ~ Hubble Time for lower mass black holes
- Orders-of-magnitude longer for the most massive black holes (“dead quasars”)

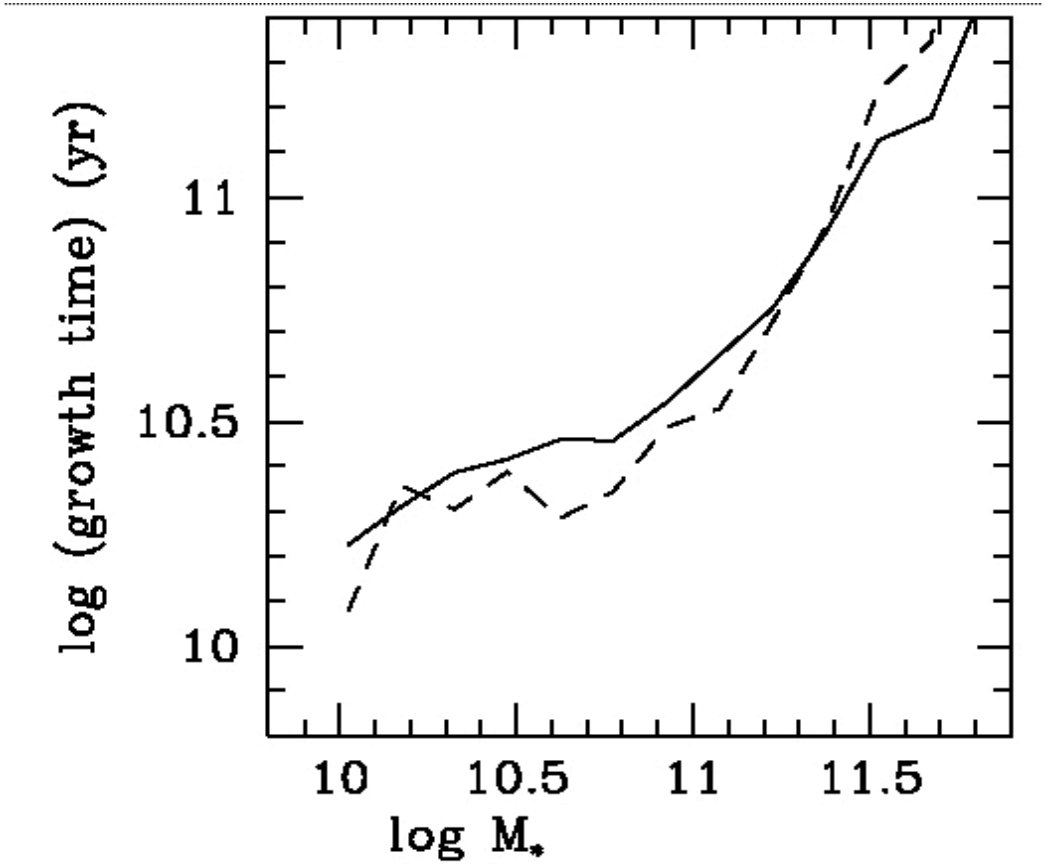
BLACK HOLES & BULGES





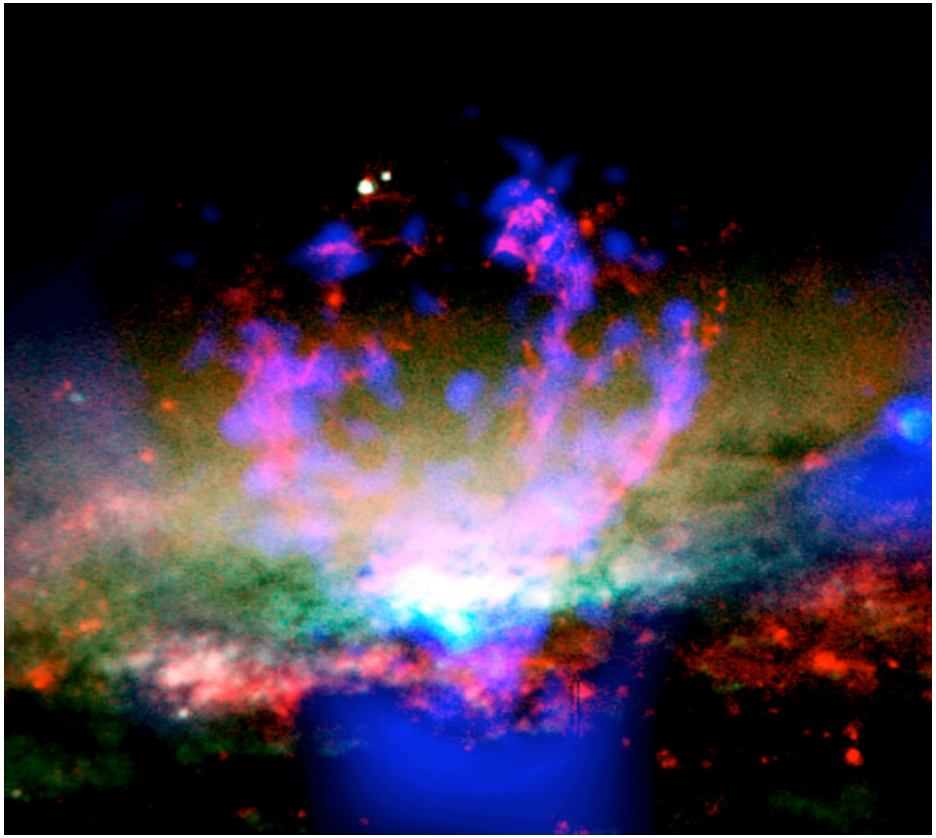
Ratio of SF/black-hole-growth: volume average over early-type galaxy population is ~1000

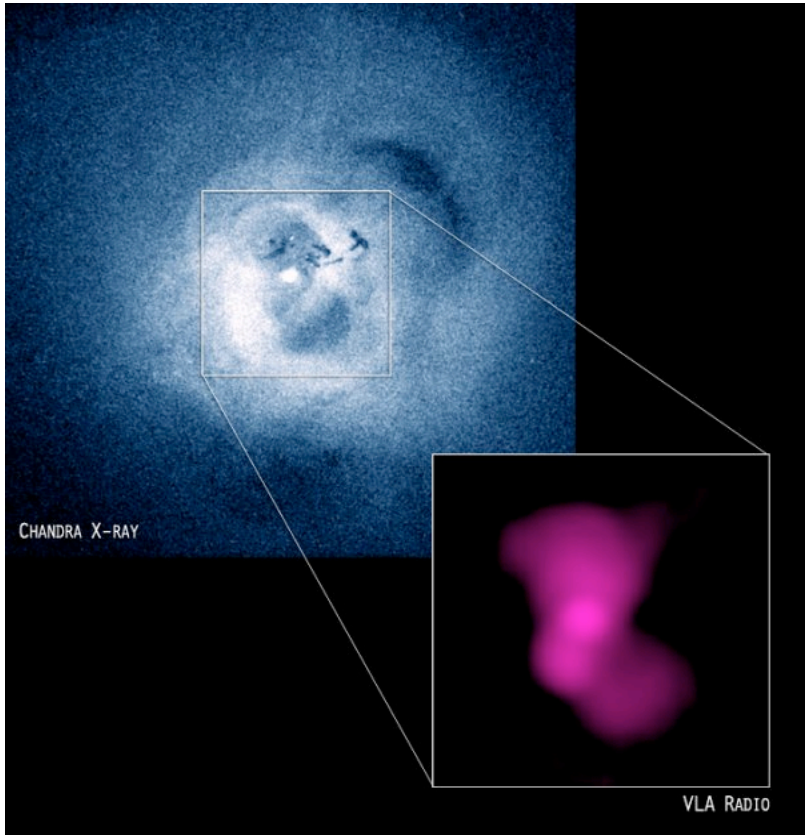
DOWNSIZING



- The mass-doubling timescales of the populations of black holes and bulges both increase in parallel with increasing mass

Part II: AGN Feedback

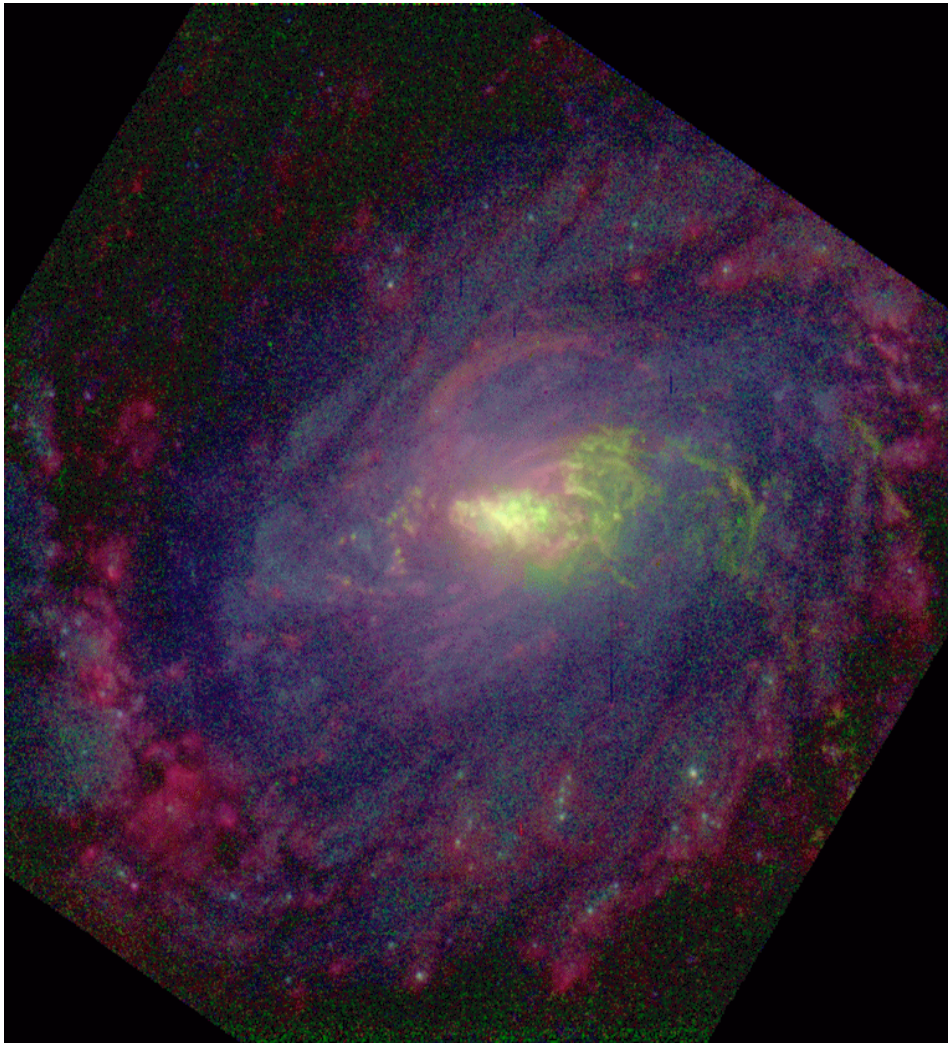




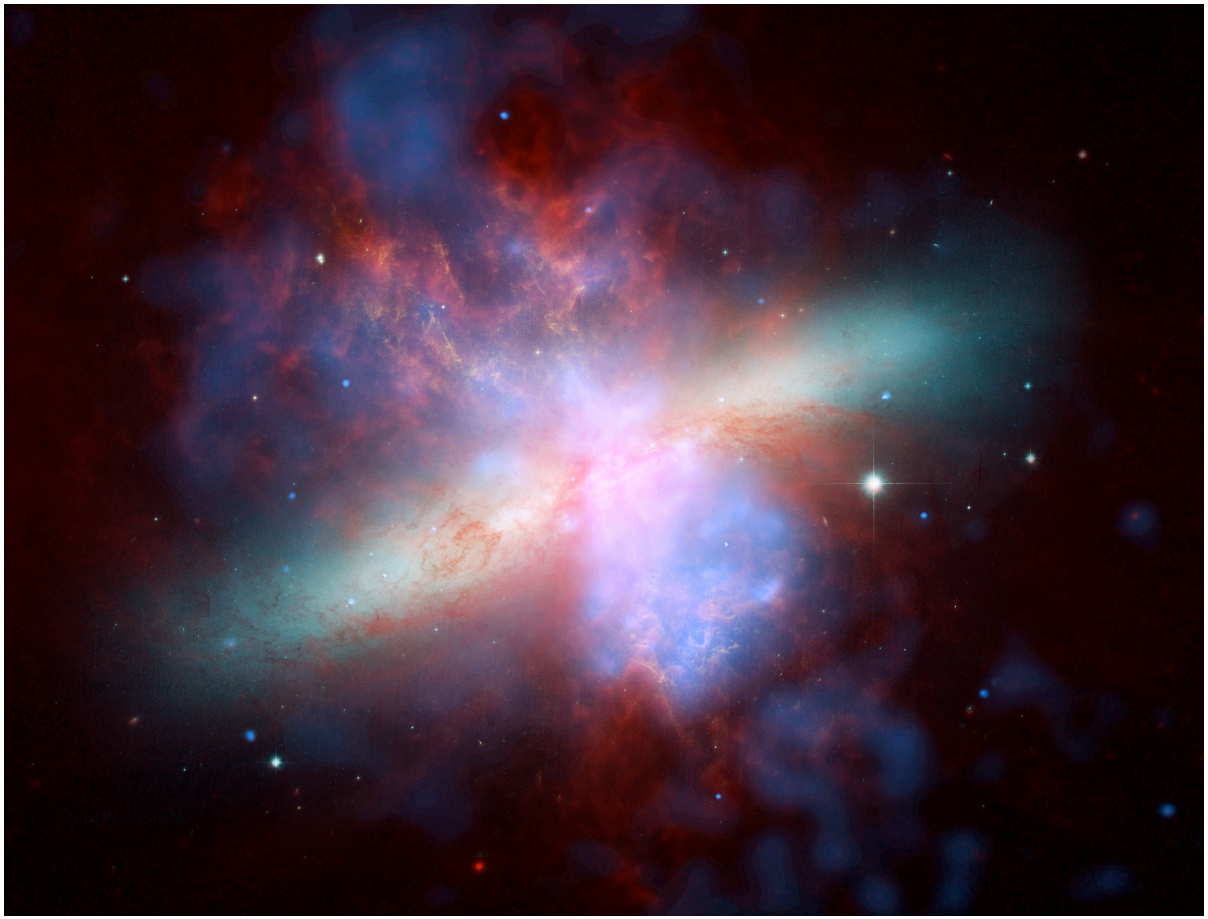
- This comes in three flavors:
- Radio sources, supernovae, and “quasar winds”

Supernovae vs. Quasar Winds

- Strong link between black hole growth (strong AGN) and star formation in the bulge
- How do we sort out the contributions of supernovae vs. the AGN in driving a wind?

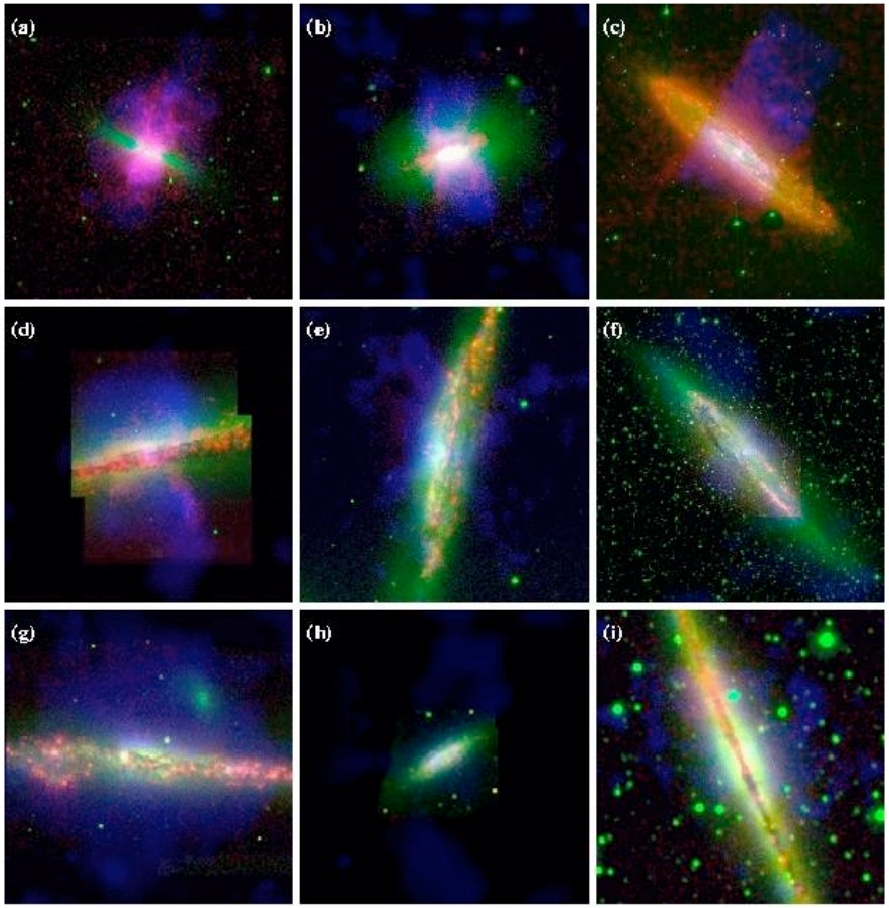


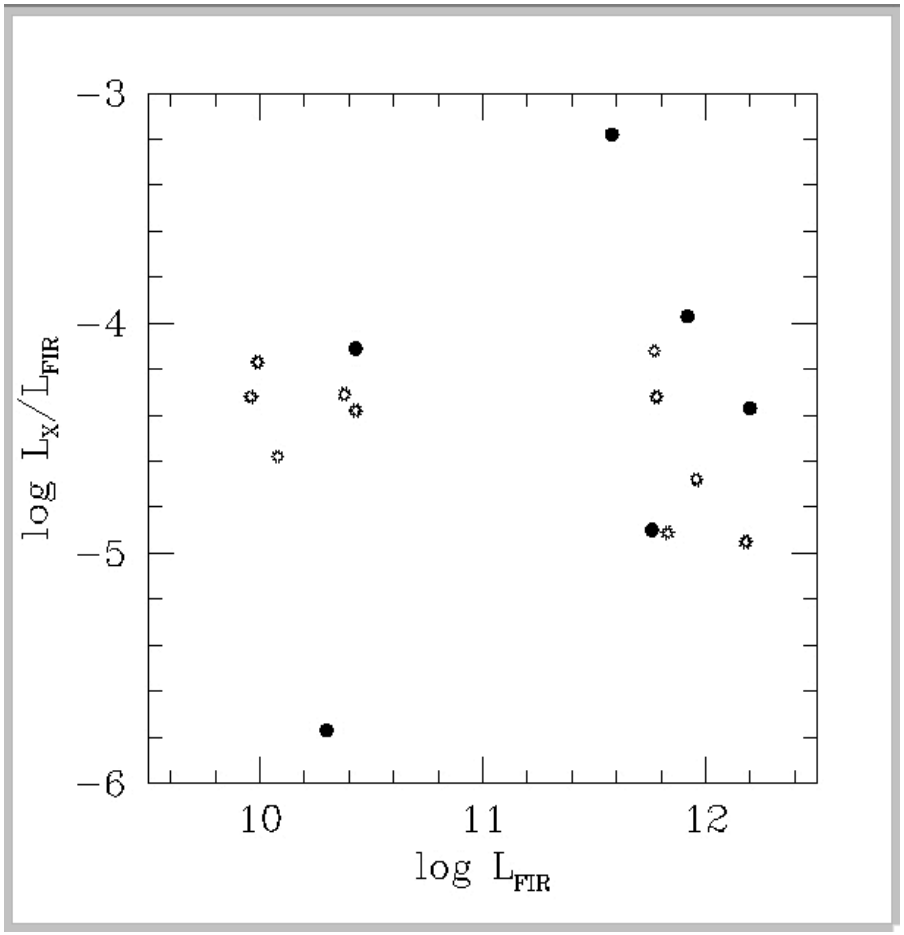
Supernova-Driven Winds



- Star formation accompanies black hole growth
- Star formation drives winds (with or without an AGN)
- KE ~10^60 ergs for 10^8 solar mass BH (~0.6% Mc^2)

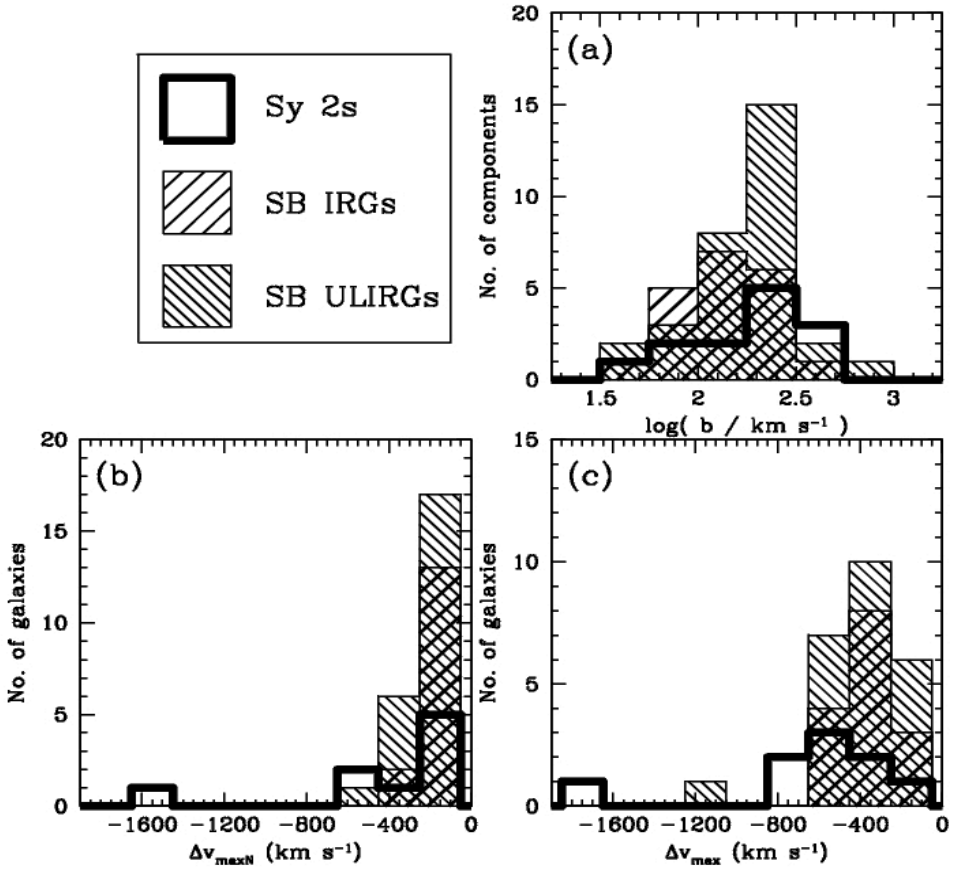
Does the AGN Matter?

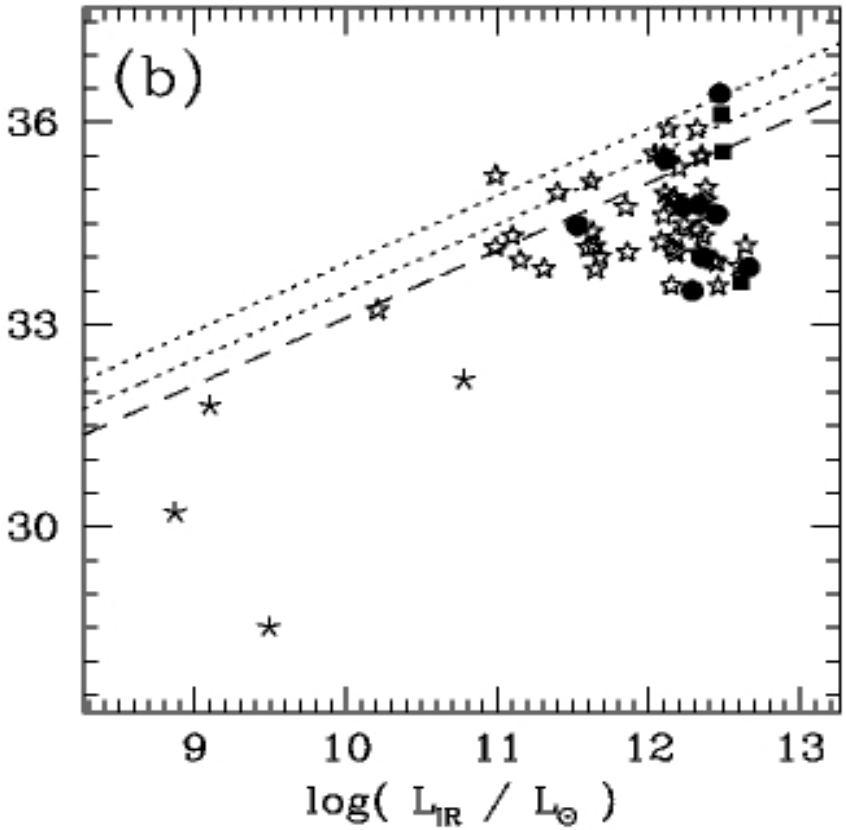




- No excess soft X-ray emission from the wind in AGN+starburst vs. pure starburst

Does the AGN Matter?



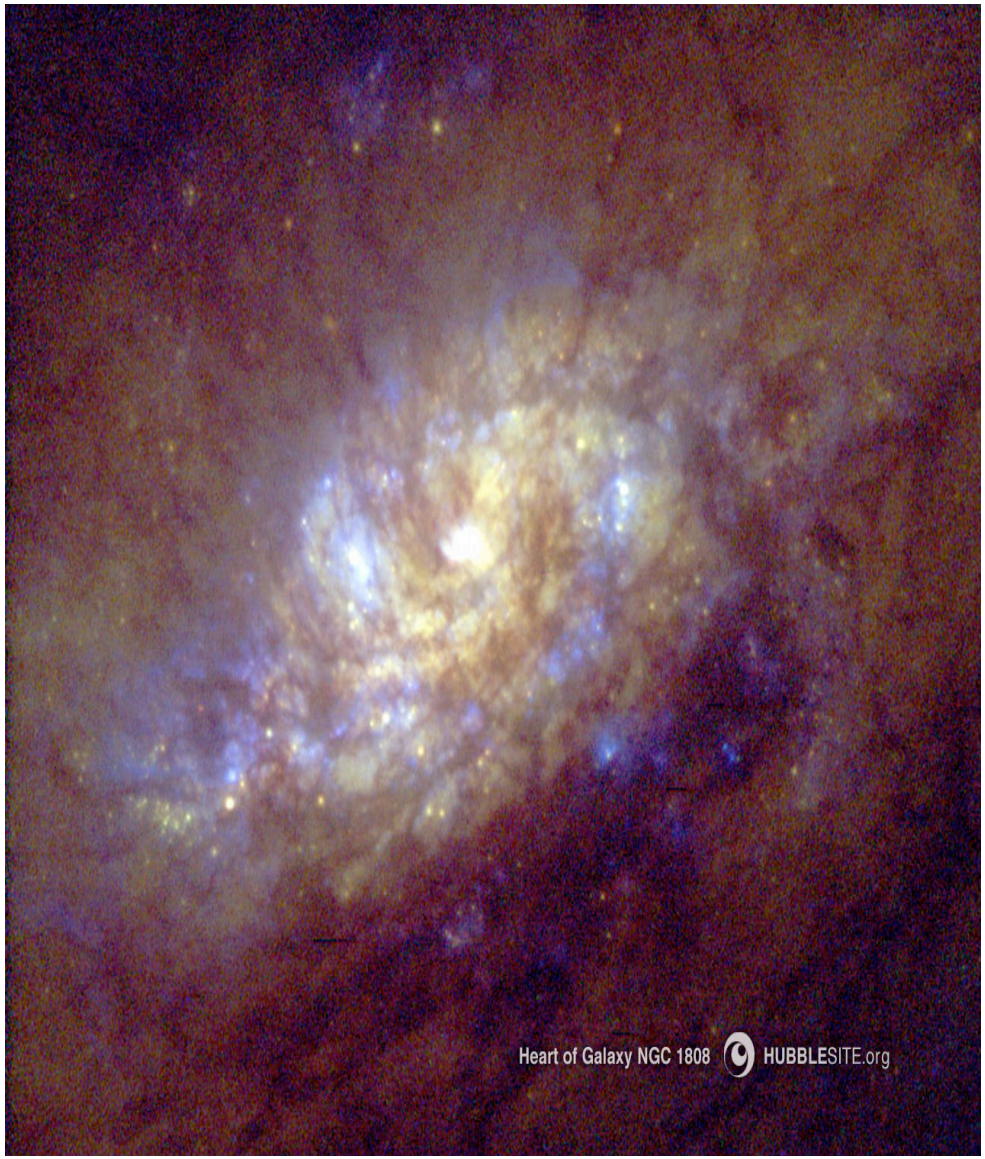


- No evidence for higher outflow rates or velocities in Na D absorption-lines in AGN vs. starbursts

Rupke et al.

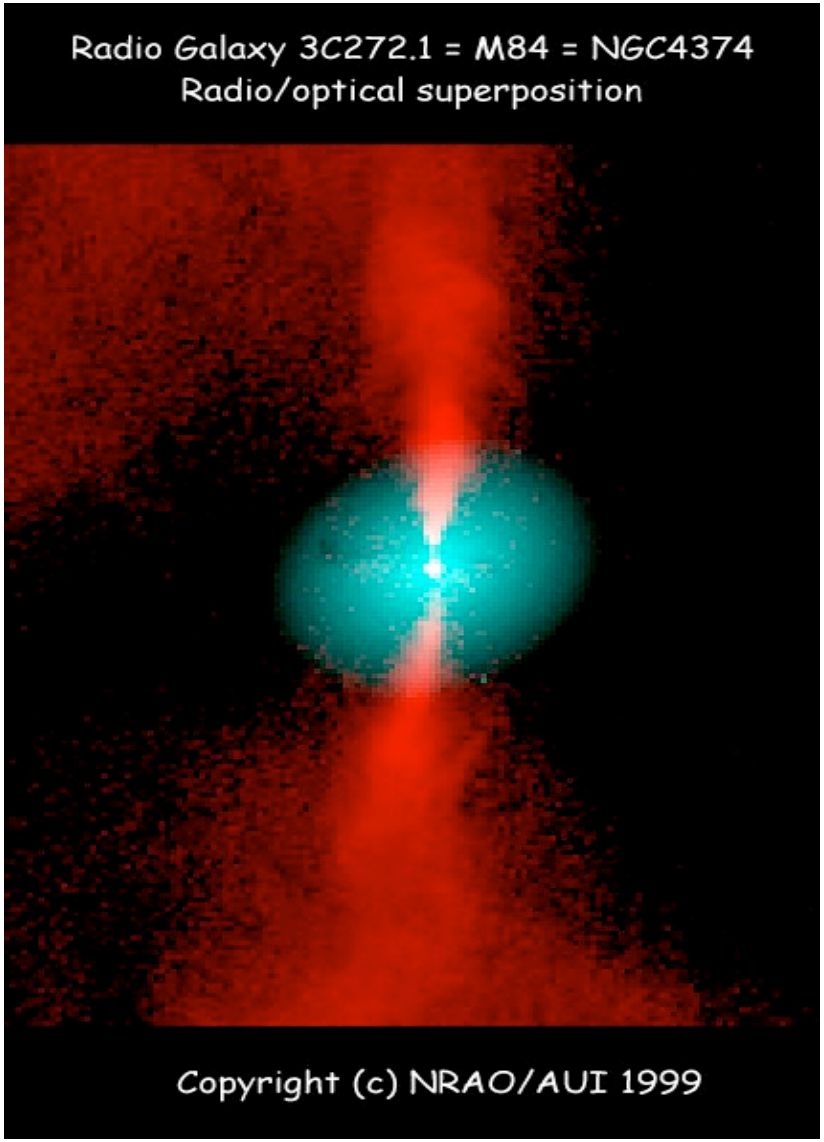
THE LIVING…

- Powerful AGN need a black hole & cold fuel
- Also fuels star formation
- This combination now exists only in less massive bulges (“downsizing”)
- Just above transition in galaxy population
- Fueling: Not major mergers
- Feedback: supernova-driven winds dominate
- Not clear that this drives an abrupt “transformation”

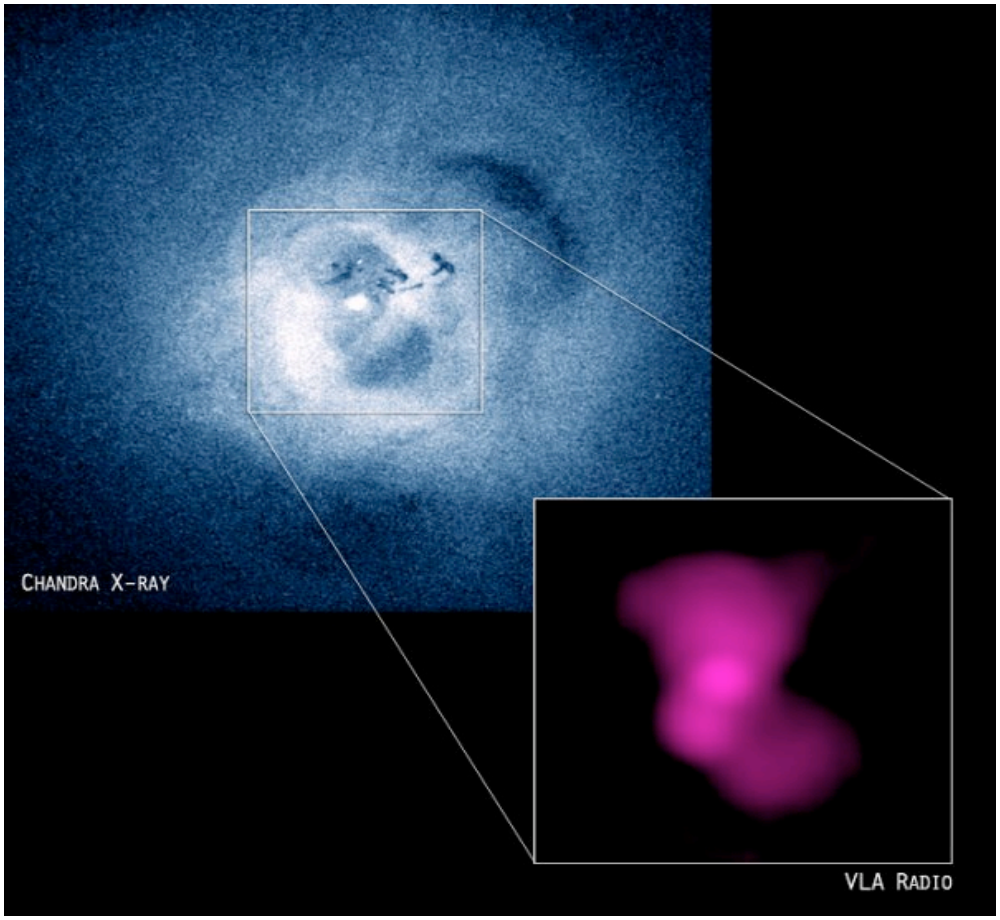


...AND THE DEAD

- The most massive black holes (and their host galaxies) formed at redshifts ~ 2 to 3
- “Dead quasars” simmer as radio galaxies



FUELING & QUENCHING



- Fuel source: the cooling of hot gas?
- Star formation suppressed by radio source heating?
- Maintains the red sequence