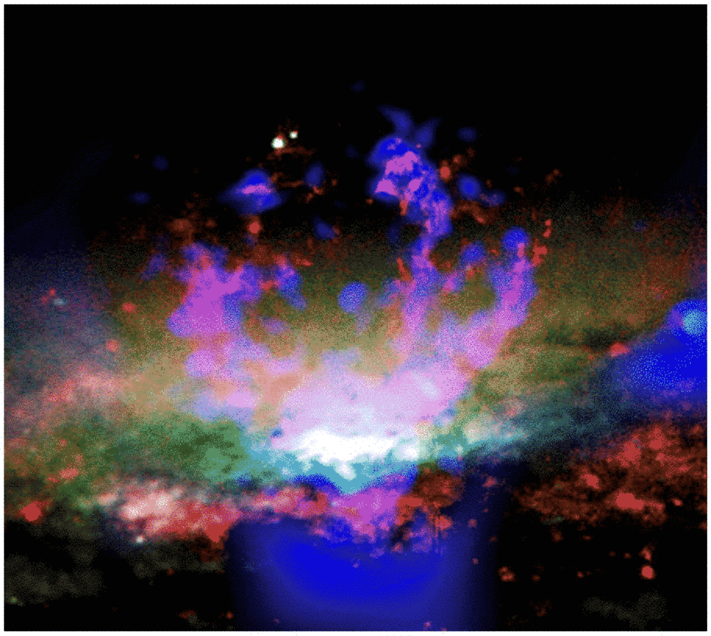
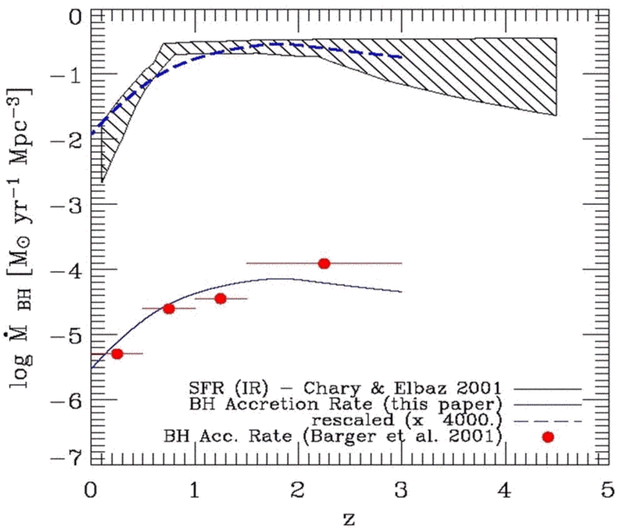
THE CO-EVOLUTION OF BULGES & BLACK HOLES



COLLABORATORS

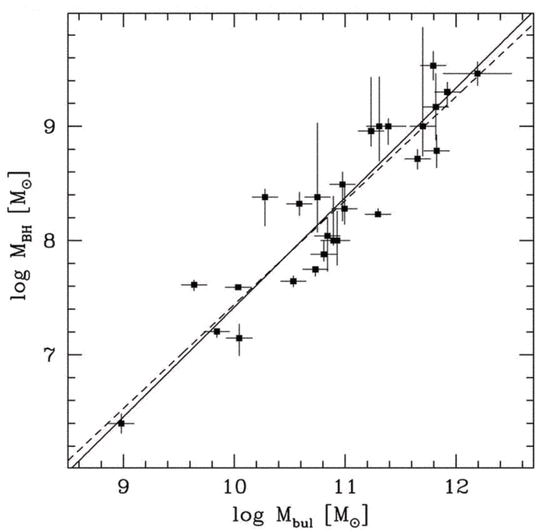
- G. Kauffmann – MPA (Garching)
- P. Best – ROE (Edinburgh)
- J. Brinchmann – CAUP (Portugal)
- S. Charlot – IAP (Paris)
- C. Tremonti – Steward Observatory
- S. White – MPIA (Garching)
- The SDSS Collaboration

THE CO-EVOLUTION OF GALAXIES & BLACK HOLES

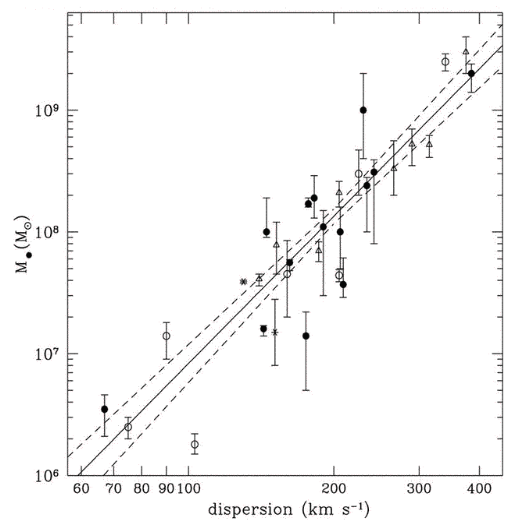


Marconi et al.

BLACK HOLE MASS STRONGLY LINKED TO BULGE PROPERTIES

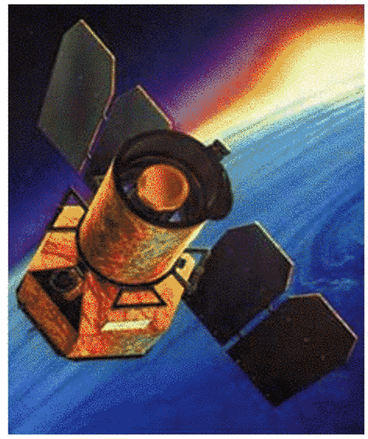


Marconi & Hunt



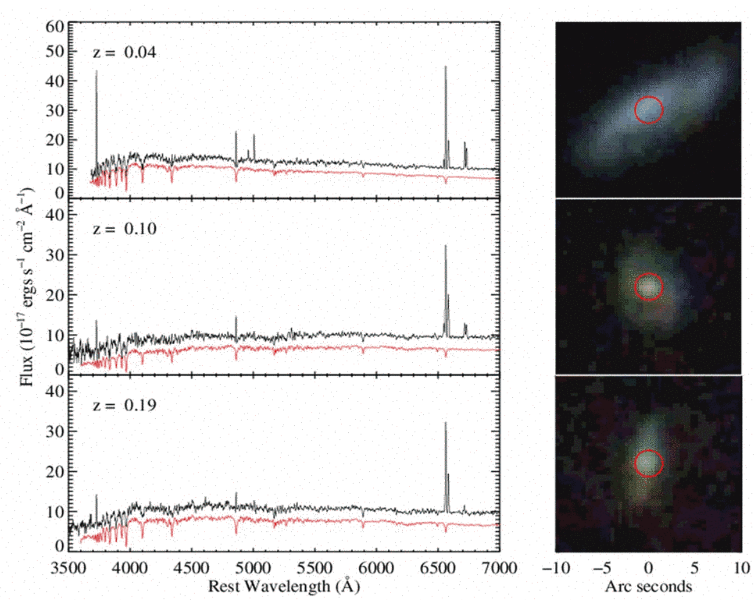
Tremaine et al.

WHAT'S THE RELEVANT ASTROPHYSICS?

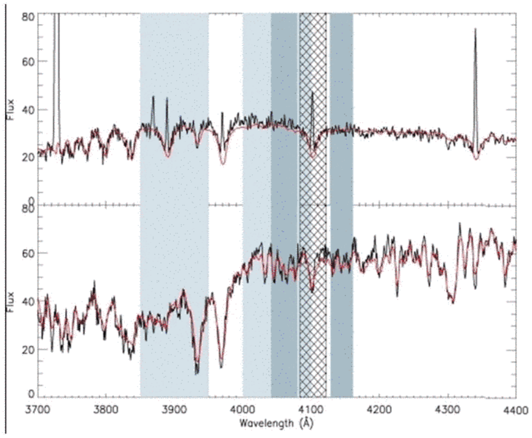


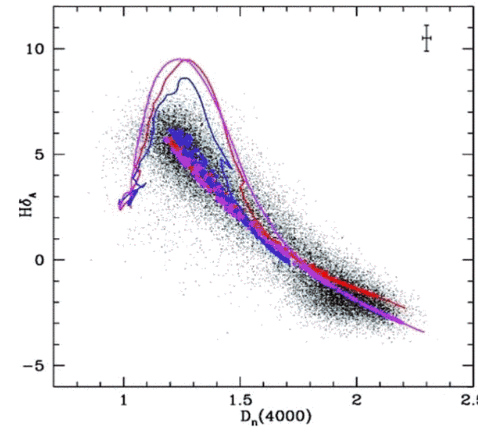
- THE SDSS + GALEX CAN ADDRESS THIS ROBUSTLY IN THE LOW-Z UNIVERSE

SDSS SPECTRA: The Bulge



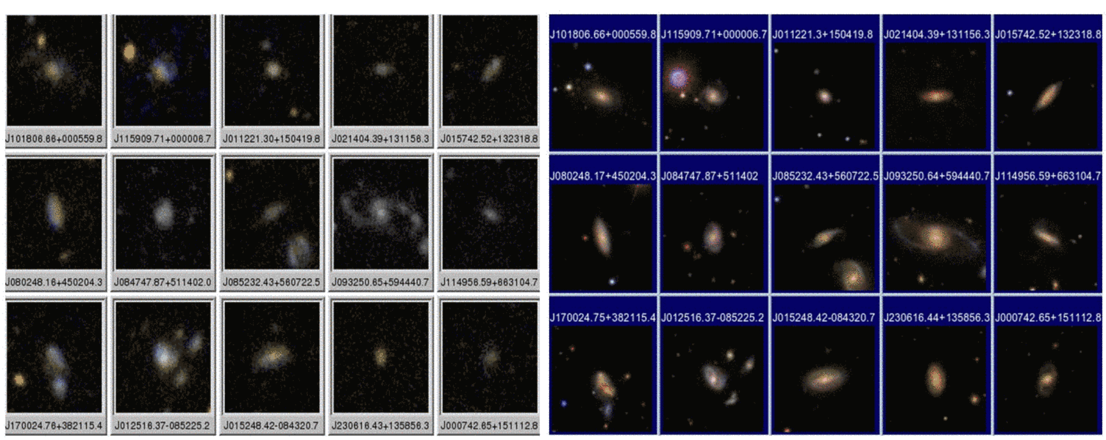
THE STELLAR POPULATION





- 4000 Å break strength "D4000": age
- Balmer absorption-line strength "Hδ-A": age + burstiness
- Extinction-corrected Hα luminosity: star formation rate

GALEX/SDSS Images: The Disk

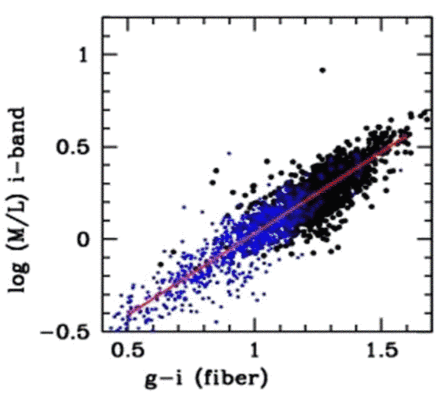


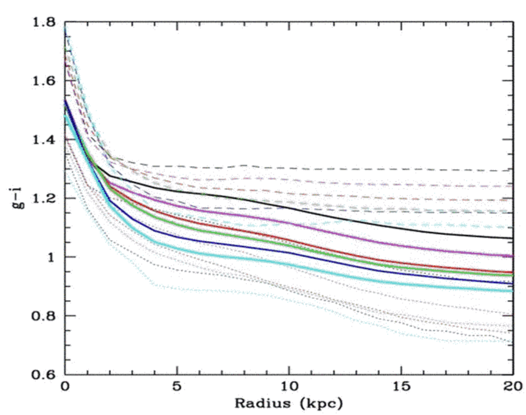
- Use the NUV-r and g-i colors to characterize the stellar population in the disk

Galaxy Structure

- Modeling D4000 and Hδ-A yields NIR stellar mass/light
- NIR luminosity yields stellar mass M_*
- Half-light radius R_{50} and hence effective surface-mass density $\mu_* = M_*/2\pi R_{50}^2$
- Concentration Index $C = R_{90}/R_{50}$:
  "Early Type" have $C \geq 2.6$
  "Late Type" have $C \leq 2.6$
- Stellar velocity dispersion σ_*

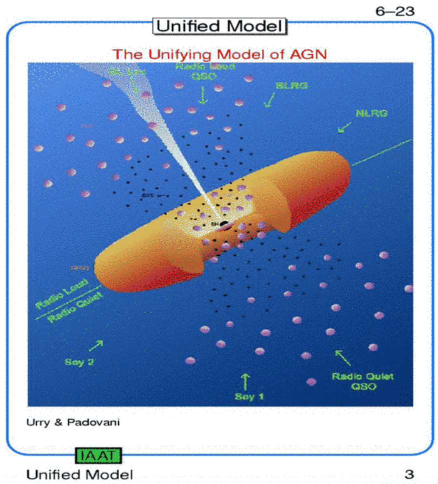
Radial Mass Profiles

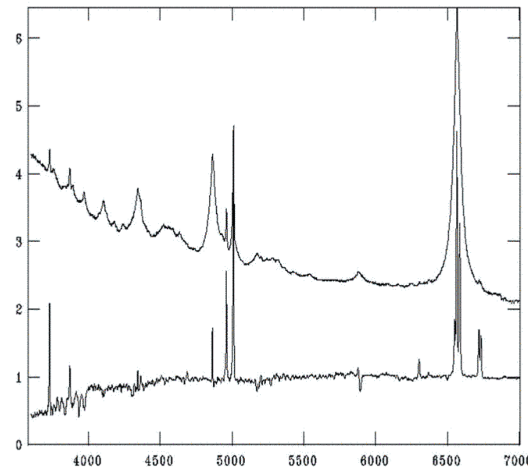




- Color gives M/L
- Color + Light profiles transformed to mass profile

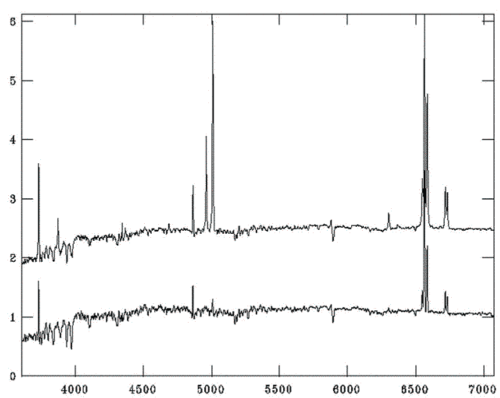
AN AGN PRIMER

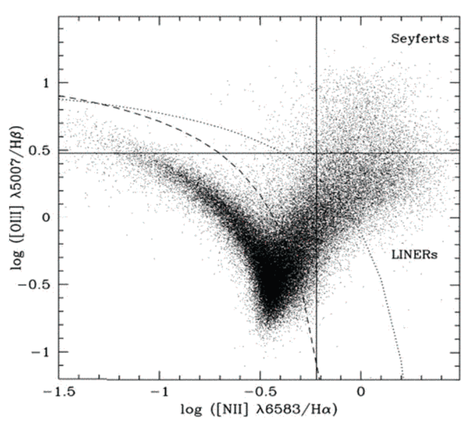




- View "central engine" directly in Type 1 AGN
- Central engine occulted in Type 2 AGN
- Powerful jets in Radio Galaxies

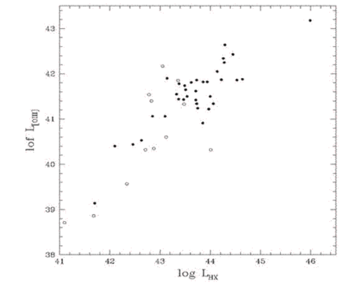
EMISSION-LINE AGN

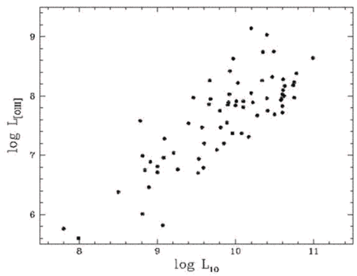


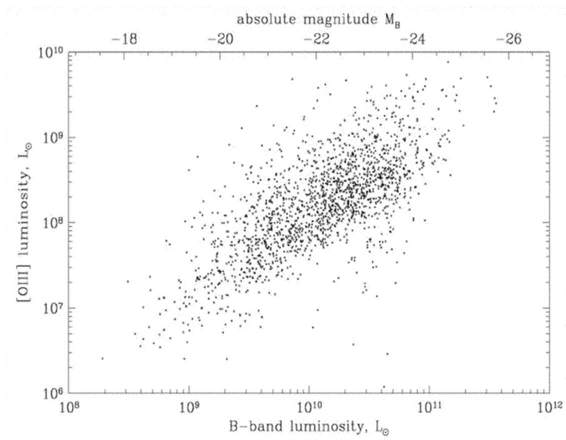


Classification AGN vs. SF: emission-line ratios
[OIII]5007 as AGN tracer
Strongest AGN line and minimal contribution from SF

THE [OIII] LINE AS A PROXY FOR THE BOLOMETRIC LUMINOSITY





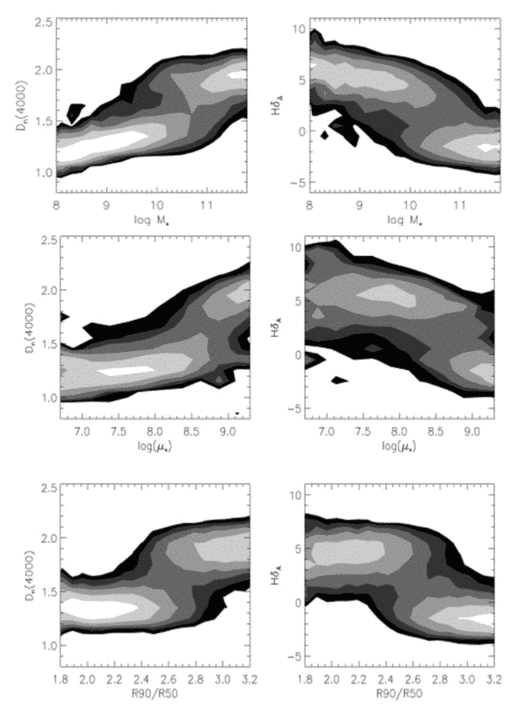


THE BIMODAL SDSS GALAXY POPULATION

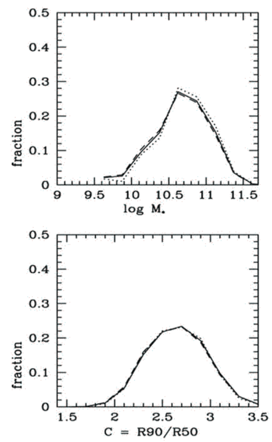
Characteristic scales for transition from old to young:

- $M_* \sim 3 \times 10^{10}\ M_\odot$
- 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)

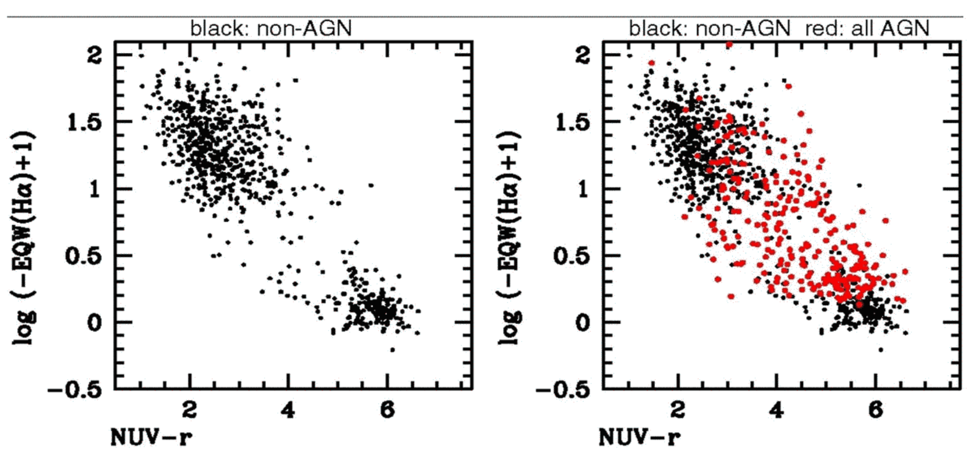


Where do emission-line AGN live?



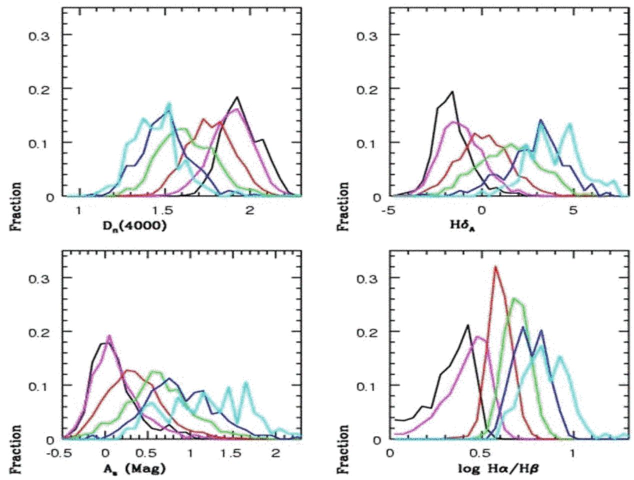
- The production of [OIII] emission by AGN is dominated by “hybrid” galaxies
- Near the boundaries between the bimodal population
- Structures/masses of early-type galaxies
- Bulges: young stellar population

THE GALEX PERSPECTIVE



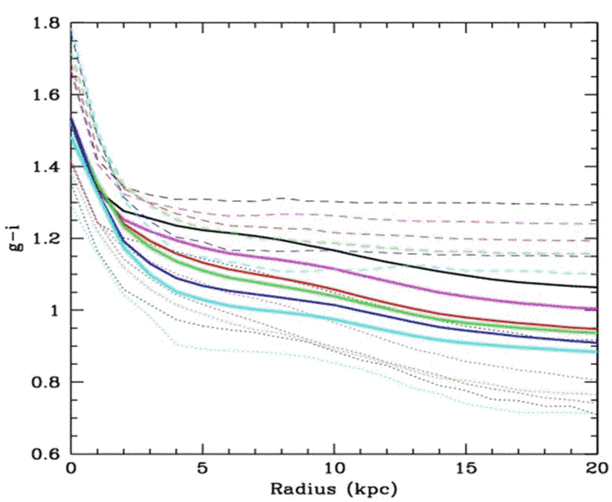
- The bimodality in the galaxy population is even more apparent
- The emission-line AGN live in “no-man’s land”!

Luminosity Dependence: Bulge



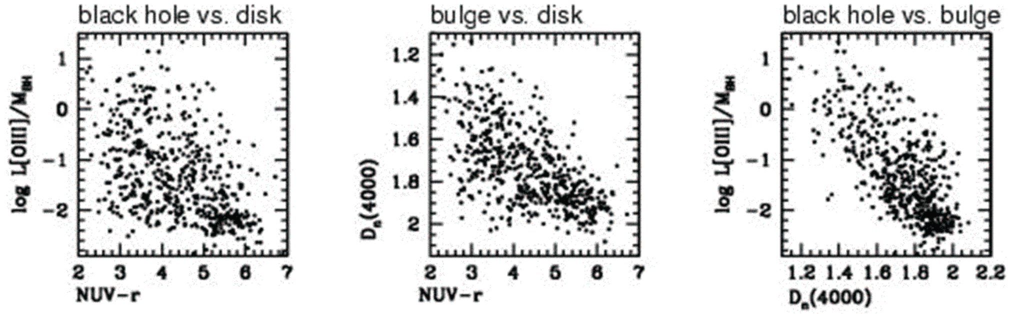
- As the AGN luminosity increases the stellar population in the bulge becomes younger
- And the amount of dust/cold-gas increases

Luminosity Dependence: Disk



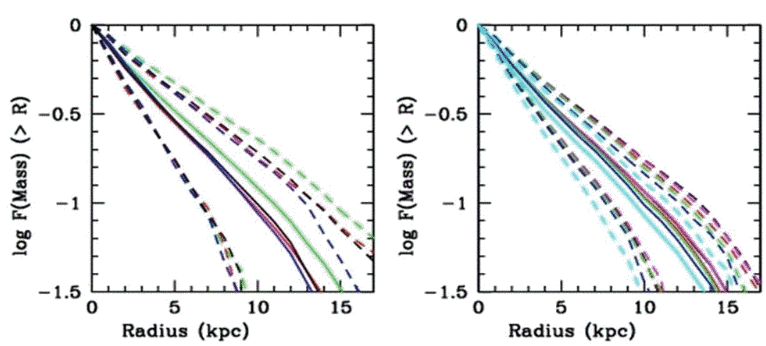
- More luminous AGN occur in galaxies with younger disks

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

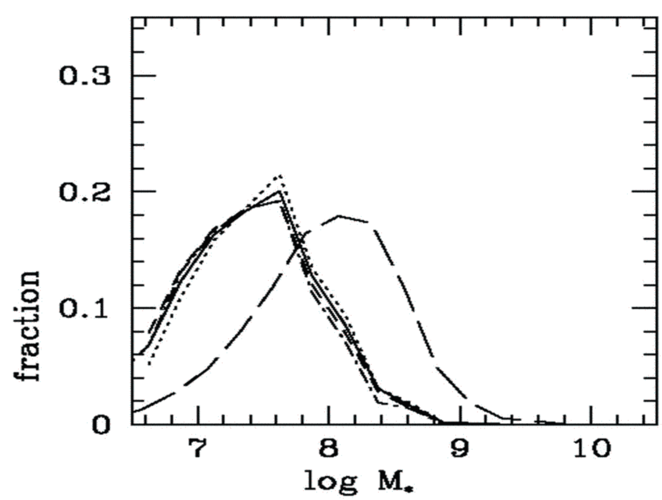


- Galaxies with rapidly growing black holes and bulges have very similar stellar mass profiles to red/dead galaxies with same velocity dispersion
- The trigger does not involve a major "event"

BLACK HOLE DEMOGRAPHY

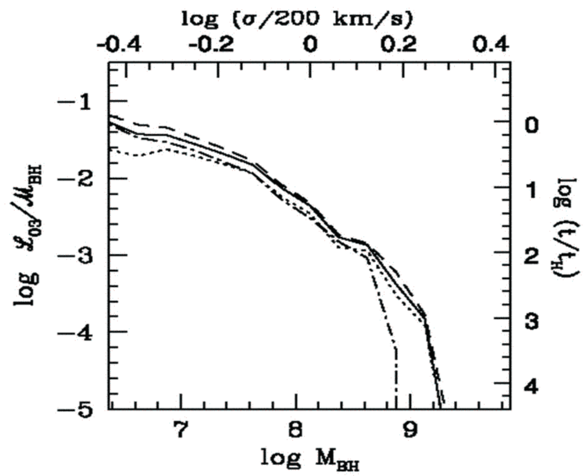
- Estimate black hole masses using the stellar velocity dispersion (AGN hosts are bulge-dominated)
- Estimate the accretion rate using the bolometric luminosity derived from [OIII]
- Perform volume averages over SDSS

WHICH BLACK HOLES ARE GROWING?



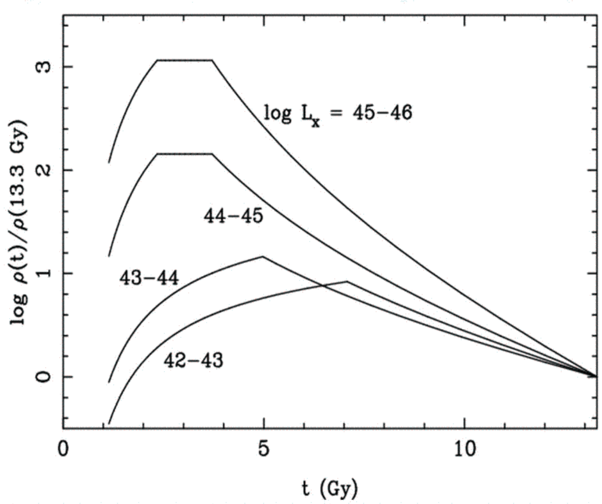
- Mass resides in the more massive black holes
- Growth dominated by less massive ones

MASS-DOUBLING TIMES



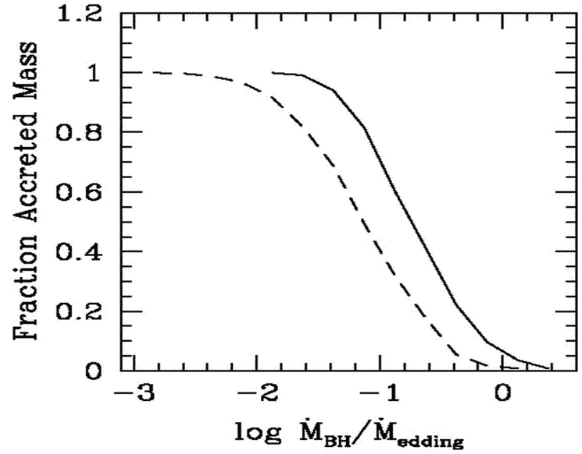
- Only ~ Hubble Time for lower mass black holes
- Orders-of-magnitude longer for the most massive black holes ("dead quasars")

BLACK HOLE DOWNSIZING



- Consistent with observations of the cosmic evolution of the AGN X-ray luminosity function (Hasinger et al.)

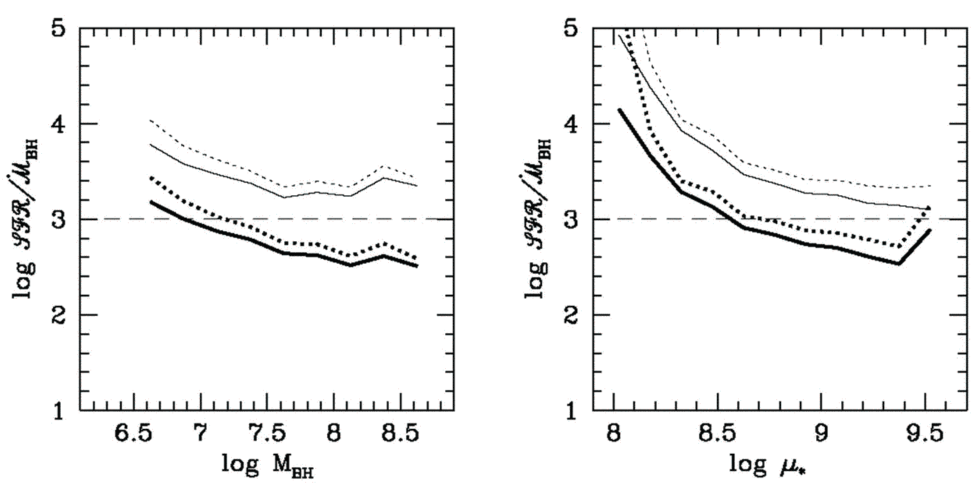
EDDINGTON RATIOS



AGN do not exceed the Eddington Limit!

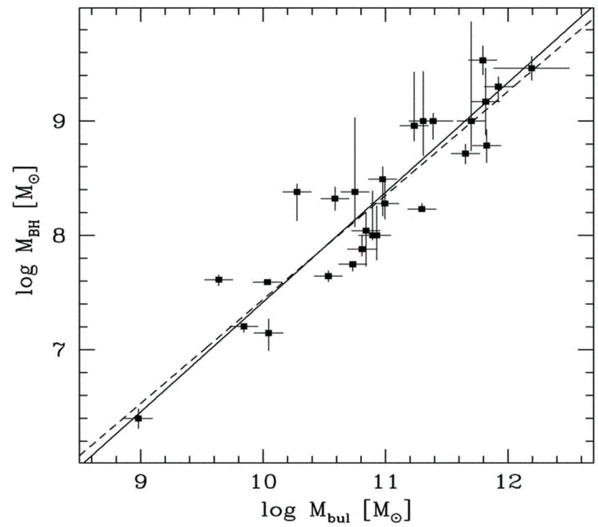
- Lower mass black holes characteristically accrete at higher rate (in Eddington units)

BLACK HOLES & BULGES



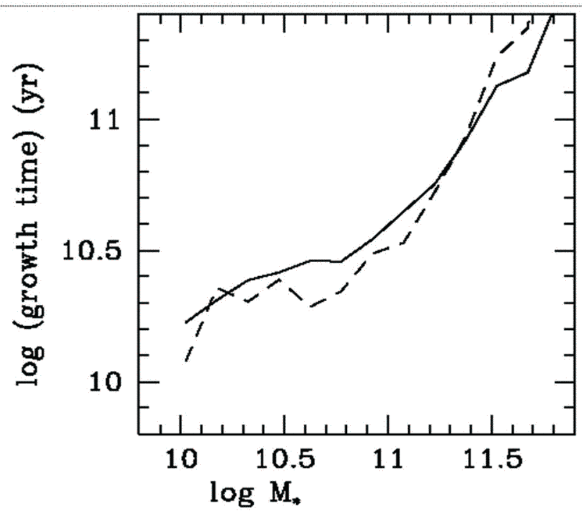
Ratio of SF/black-hole-growth: volume average over early-type galaxy population is ~1000

FOSSIL RECORD



- Same ratio!

MORE DOWNSIZING



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

SUMMARY

- The galaxy population is bimodal
- Strong AGN are hosted by hybrid galaxies: early-type w/ young stars (disk & bulge)
- Black hole growth occurs just above the transition mass in the bimodal galaxy population
- A gas-rich disk intermittently fuels growth of the bulge and black hole. The trigger is unclear
- The global ratio of black hole growth and star formation in bulges is similar to the past average
- Cosmic downsizing is occurring in parallel in the growth of bulges and black holes