LOW LUMINOSITY ACTIVE GALACTIC NUCLEI

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LOW LUMINOSITY AGN, E.G.:

M87

M_{BH}~3 10^9 M_{Sun}
L_{Edd}~4 10^{47}erg/s
$L_{0.5\text{-}7kev}$~7 10^{40} erg/s
(Di Matteo+03)

Sgr A*

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$L_{2\text{-}10kev}$~2.5 10^{33} erg/s
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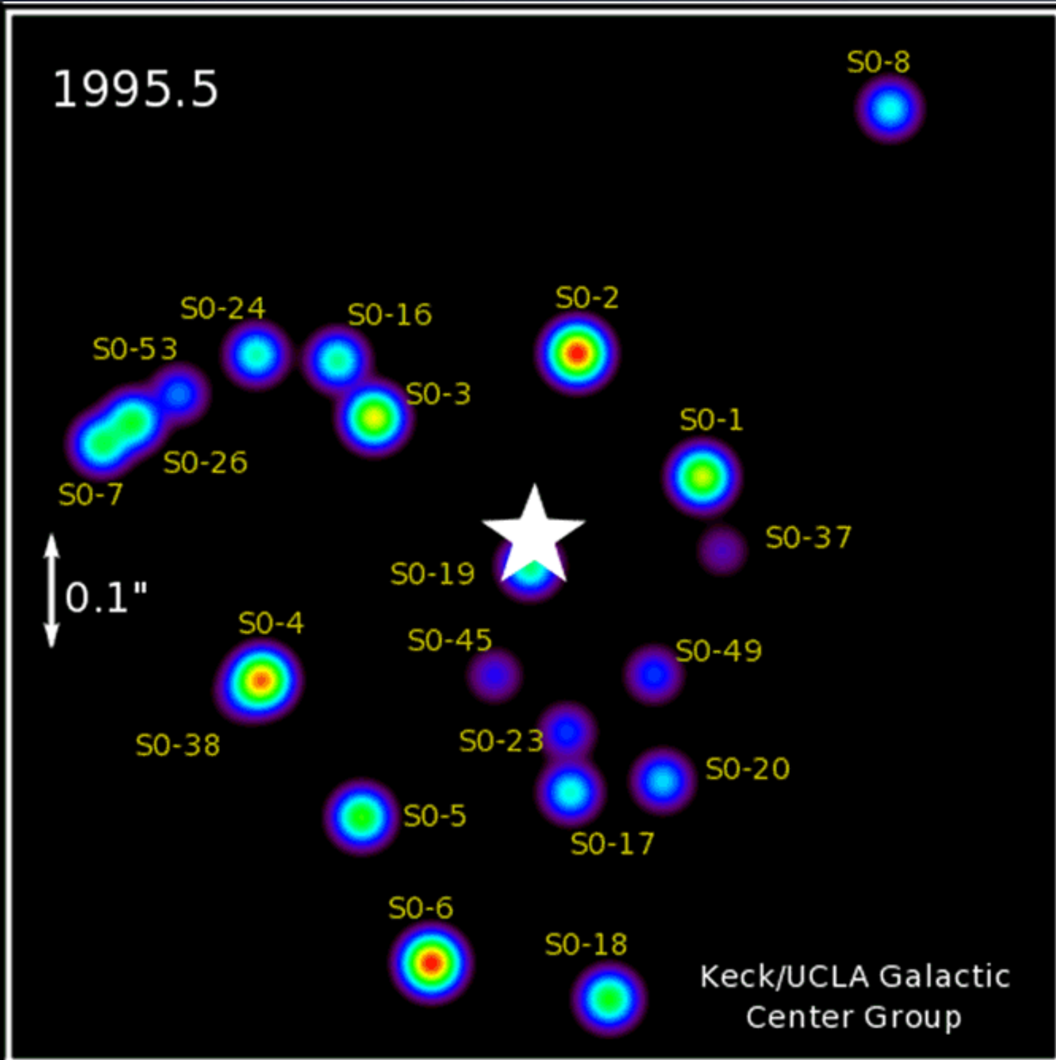

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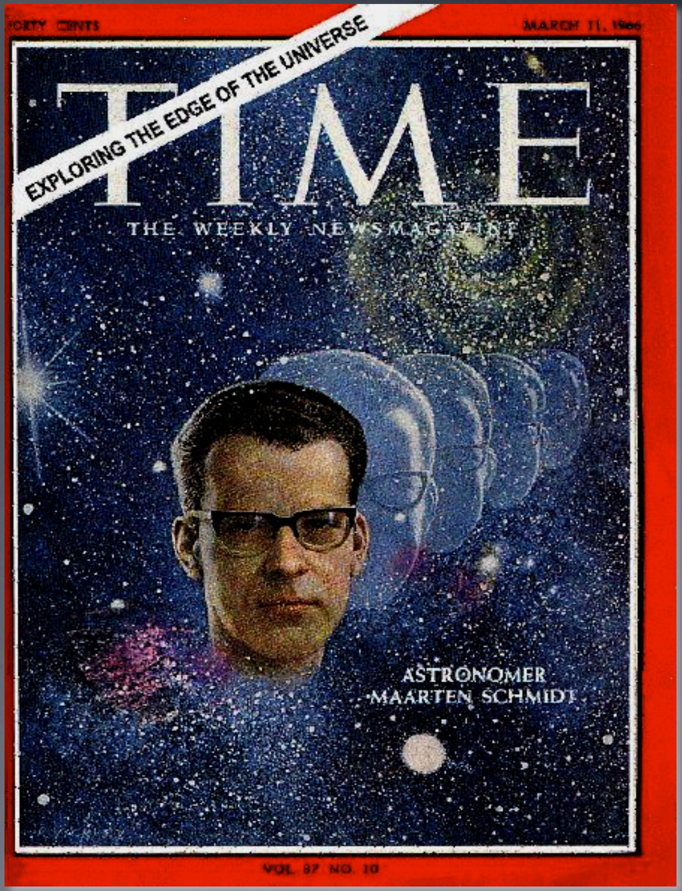
LOW LUMINOSITY AGN

- For the purpose of this talk:
  - Low Luminosity AGN = low Eddington ratios ($L_{acc}/L_{Edd}<10^{-3}$) not necessarily/only traditionally classified LLAGN, such as LINERS, ULIRGs etc.
- Outline
  - AGN: some history, classification
  - Ubiquity of super-massive black holes, feedback
  - Low luminosity AGN in the local universe: bridging the gap between AGN and ‘inactive’ galaxies, the AMUSE-surveys

Active Galactic Nuclei

- Discovered in the 60s' as quasi-stellar radio sources (a.k.a. quasars) with fuzzy optical counterparts & broad, unidentified optical emission lines
- The cosmological distances (first realized by M. Schmidt for 3C 273) implied nuclear luminosities as high as 10^{12} L_{Sun}
- Energy source: accretion onto a super-massive black hole (10^{6-9} M_{Sun})



- Strong link between nuclear black hole and host galaxy evolution (Greene's talk)

The power of accretion

- Engine: gravitational energy release through accretion of gas onto a super-massive black hole. Compactness (M/R) is key

E_{acc}= Gm(M/R) ~300 H bombs

η_{acc}~3 10^{21} erg/g >> $\eta_{nuclear\ fusion}$

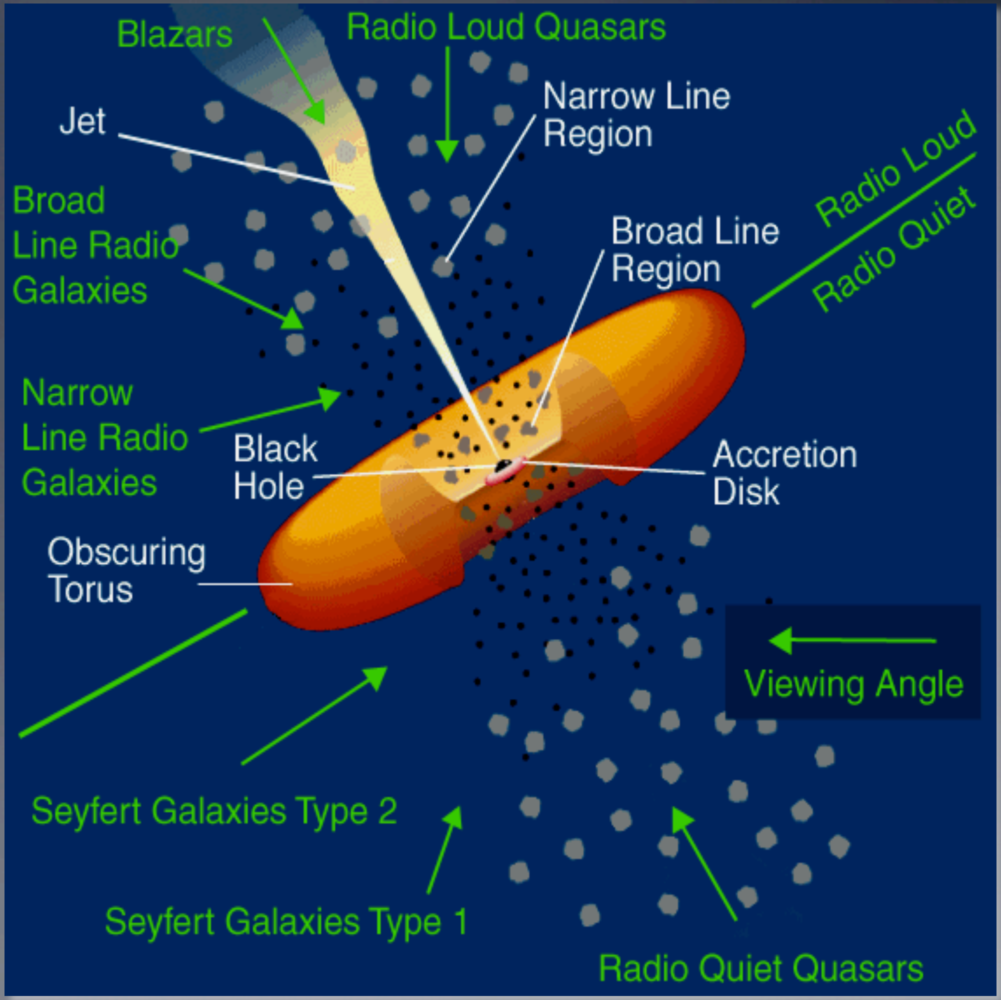
M= 1 M_{Sun}
R= 3 km

m=60 g

- Accretion energy released as thermal radiation (hν~kT) *AGN disk spectra peak in the optical/UV (big-blue-bump), stellar mass black hole disk spectra peak in the soft X-rays* (T_{peak}~$M^{-2/3}$ in standard Shakura-Sunyaev disks)

AGN Zoology

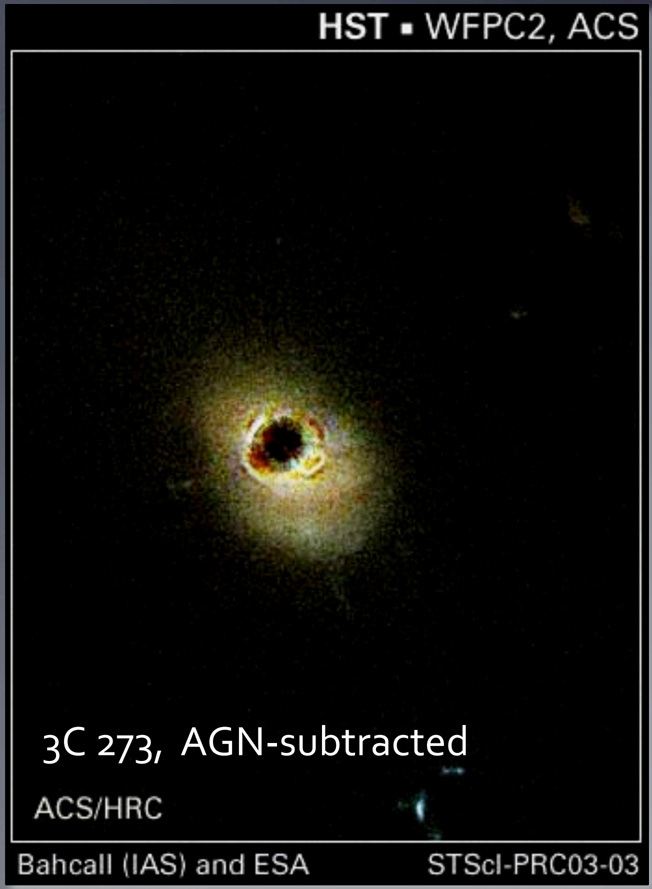
- AGN classification driven by 3 main factors
  - Bolometric luminosity
  - Radio loudness
  - Orientation
- Nomenclature can be confusing as it often reflects *historical* rather than physical differences



cf. Antonucci 93, Urry & Padovani 95

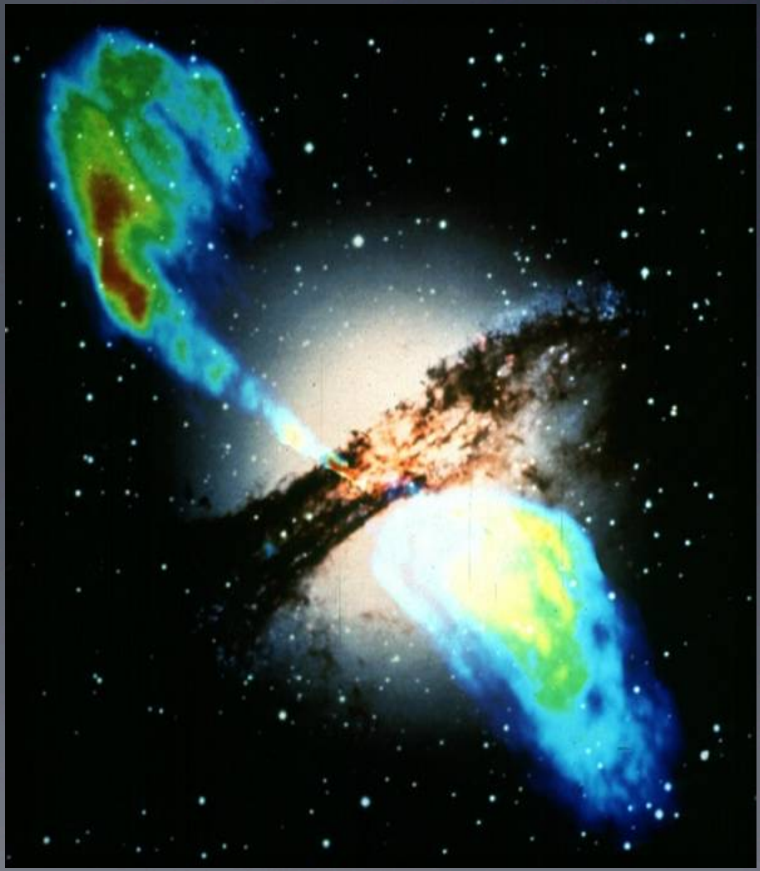
AGN luminosity classification

- Quasars: Very bright (M_B <23, L_{bol}~10^{46-48}) quasi-stellar objects: L_{AGN}>L_{host}
- Seyferts: less bright (M_B >23, L_{bol}~10^{43-46})
- *No major physical difference other than luminosity*, except perhaps for the host galaxies:
  - Seyferts are mostly in spirals
  - Quasars are in both ellipticals & early type spirals, though the brightest are found in the former class



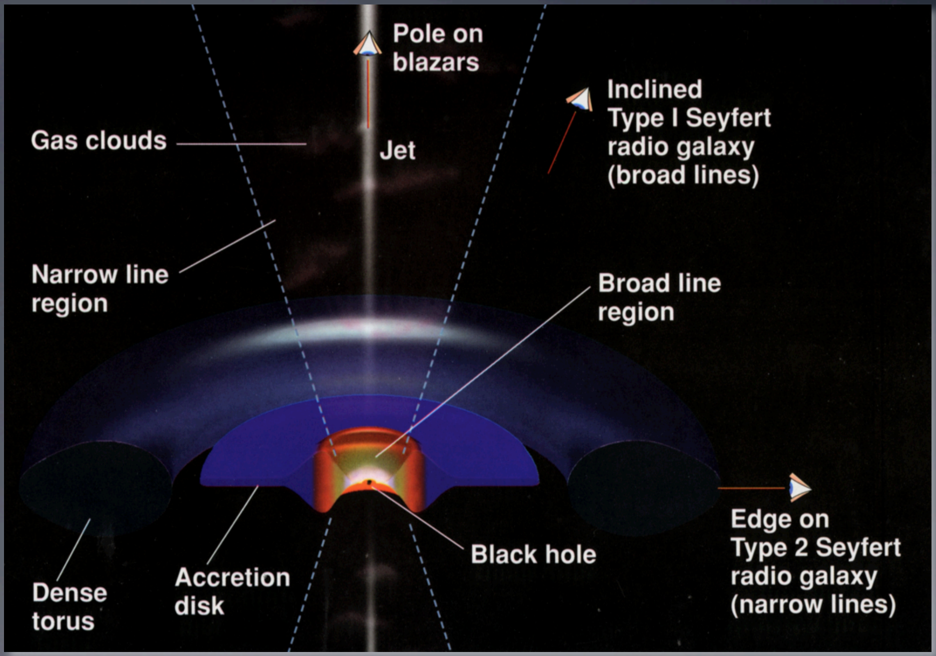
AGN radio loudness classification

- Radio-loud AGN: jet and jet lobes dominate the radiative output
  - Radio galaxies (viewed off-axis)
    - FRI core dominated
    - FRII more powerful, lobe-dominated
  - Blazars, BL Lacs, OVVs (viewed close to jet axis)
- Radio quiet AGN: *radiative* output from jets can be neglected



AGN orientation (unified model)

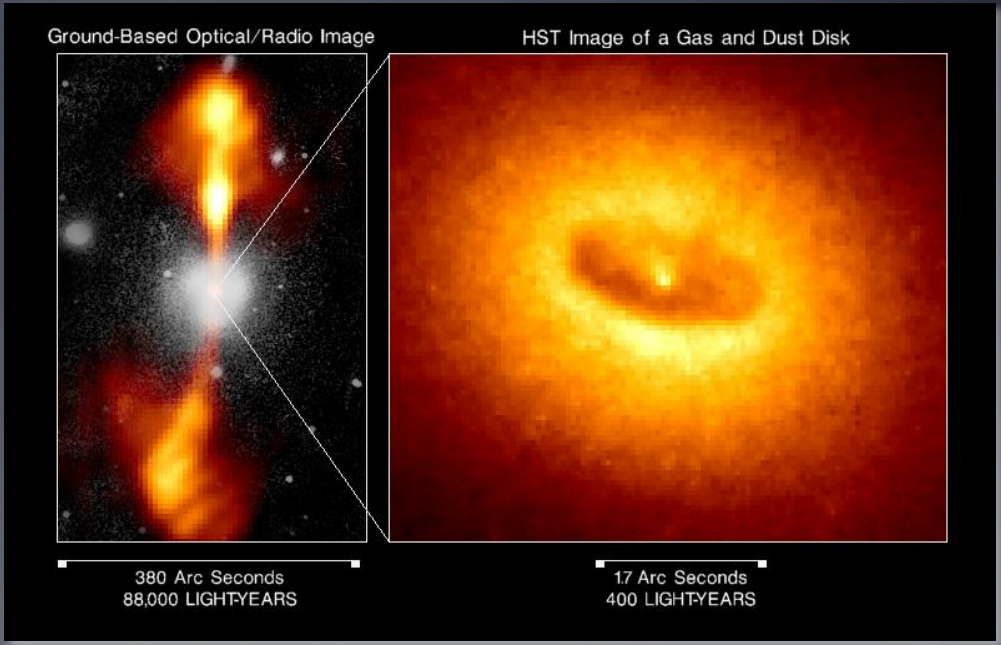
- Classification set by the observer's orientation relative to the torus and the jet
  - UV/Optical/soft X-rays & broad lines blocked by the torus
  - Hard X-rays may penetrate
  - IR from the torus and NLR emitted ~isotropically



- **Type 1 AGN**: shows both *broad & narrow emission lines* -> seen at higher angles w.r.t. torus
- **Type 2 AGN**: show *narrow lines only* -> seen through the torus

AGN orientation (unified model)

- Ratio of type1/type 2 AGN broadly consistent with torus covering angles
- Typical scales:
  - Broad Line Region
    - Size: ~10^{17} cm
    - Density: ~10^{9} /cm^{3}
  - Narrow Line Region
    - Size:~10^{19-21} cm
    - Density:~10^{3-6} /cm^{3}

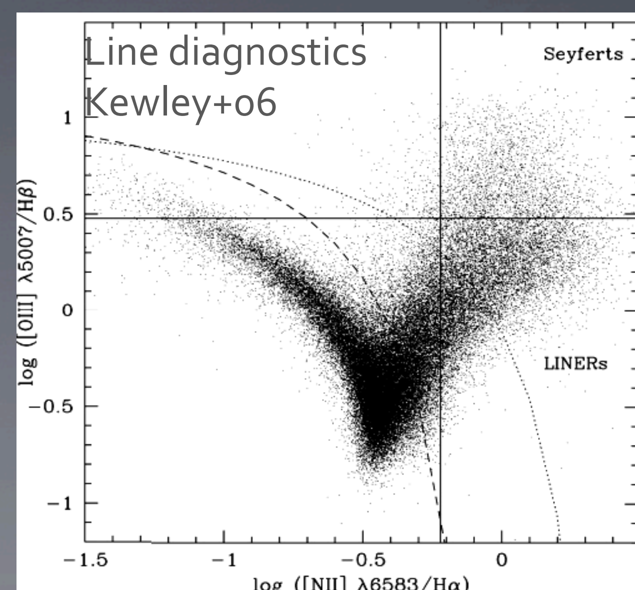


- Accretion disk size:~10^{14-16} cm
- Black hole size: ~ 10^{12} cm for 10^{8} M_{Sun}

Low Luminosity AGN (LLAGN) I.

- **LINERs** (Low Ionization Nuclear Emission Regions)
    - Narrow, low-excitation emission lines on top of weak continuum
    - (Common) associations with jetted nuclear radio sources (Nagar+02)
    - Mostly AGN (sometimes shocks/ winds from starburst galaxies)
    - When AGN, very low accretion rate / Eddington ratio

see Ho 99,08 for reviews



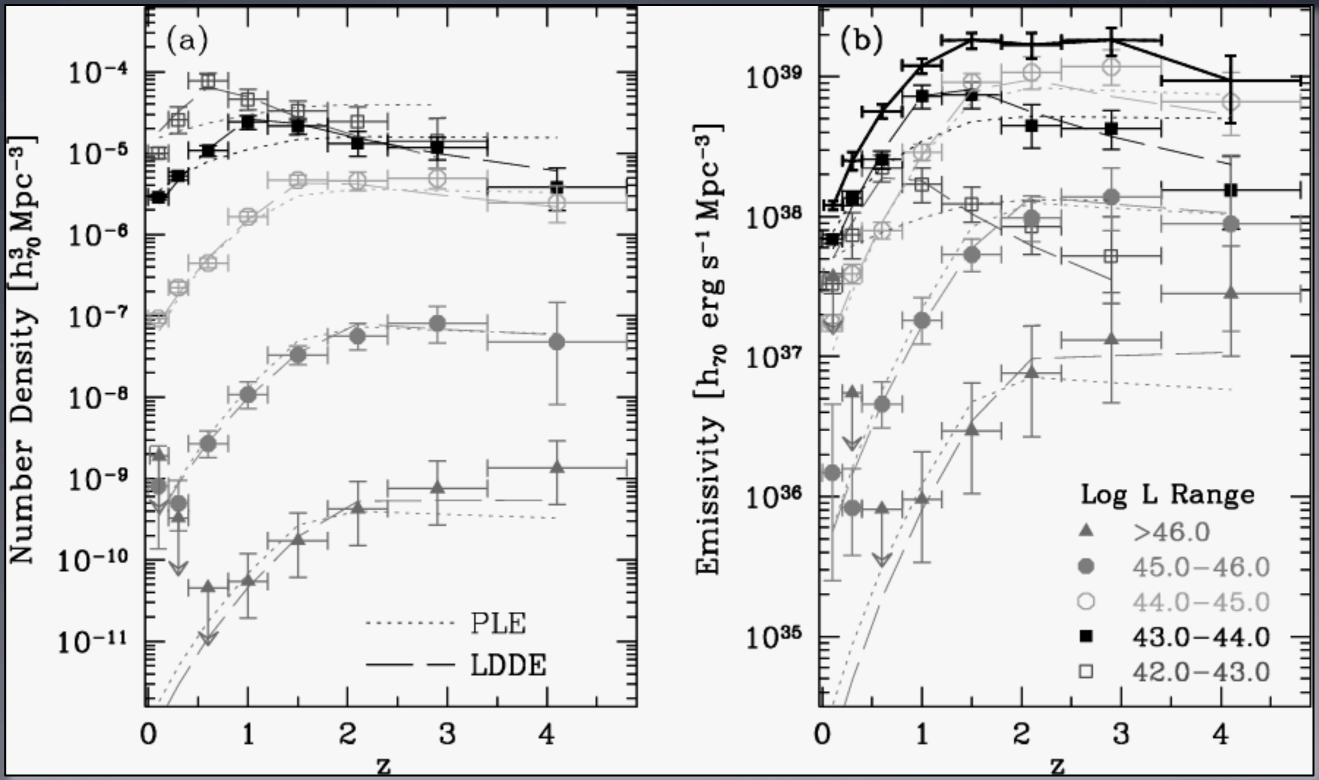
Low Luminosity AGN (LLAGN) II.

- **ULRIGs** (Ultra Luminous IR Galaxies)
  - Galaxies that emit most of their light in the IR: $L_{IR} > 10^{12}\ L_{sun}$
  - Few in the local universe; most at z>1
  - Nearly all are undergoing mergers
  - IR likely a combination of reprocessed AGN emission and starbursts

see Ho 99,08 for reviews

AGN number density & emissivity

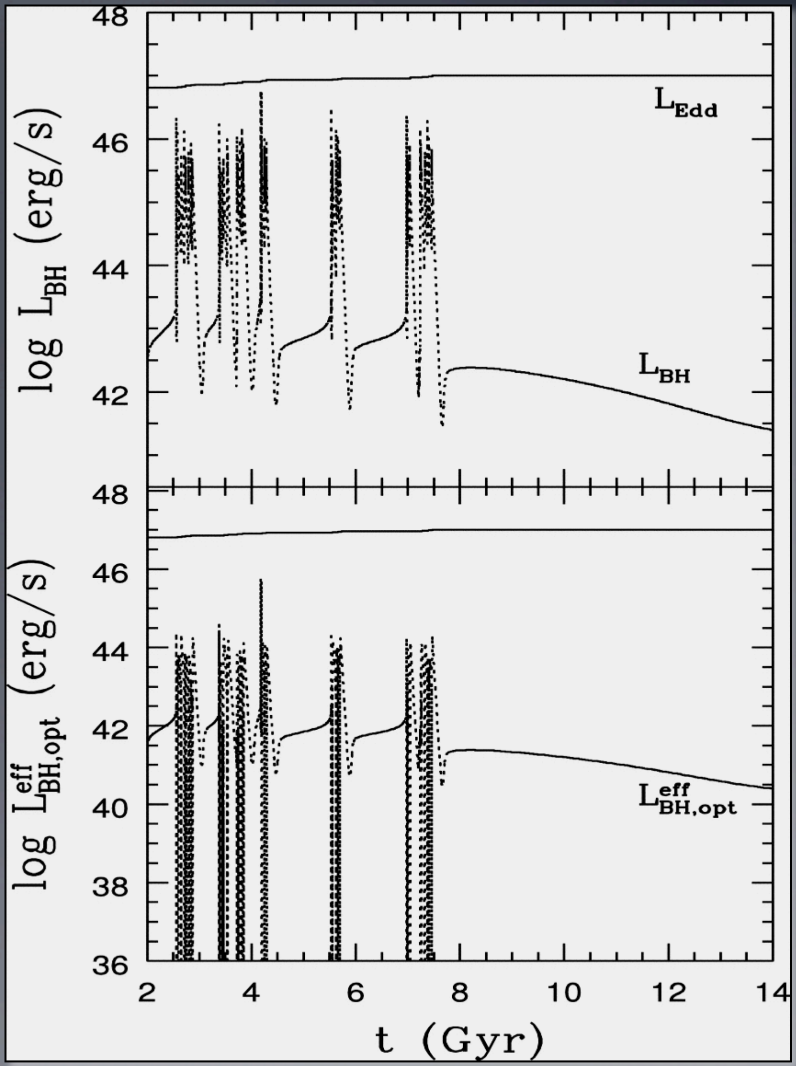
- Quasars density peaks near z~1.5, declines sharply at z<1-1.5
- Lower-luminosity AGN peak at lower z
- Sharper yet decline of quasar emissivity with z
- No *bona fide* AGN in the very nearby universe



Hasinger+05

Accretion luminosity evolution

- 1D hydro simulation of 1 elliptical galaxy hosting a super-massive black hole
- Several, short-lived (~10^8 yr) quasar phases (0.01-1 L_{Edd}) at high redshift
- Post-quasar phase: *highly sub-Eddington, radiatively inefficient phase* (possibly coupled with low-luminosity, high kinetic power outflow)

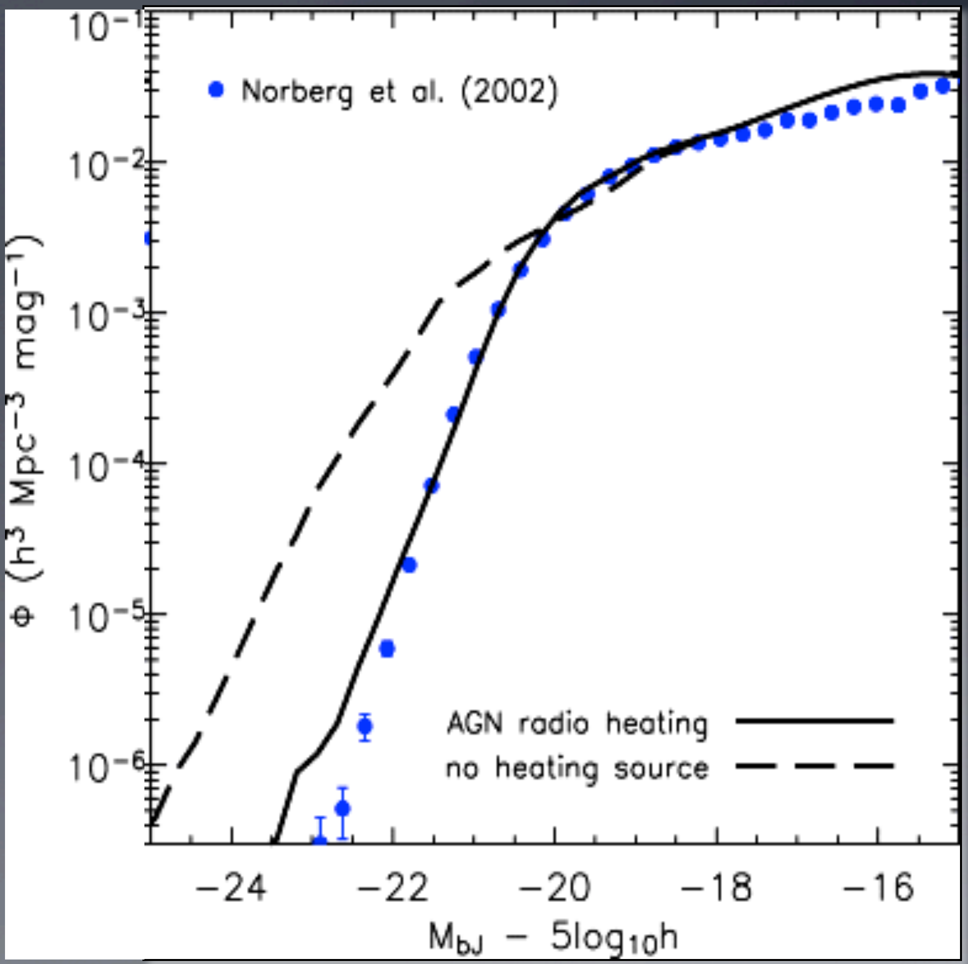


Ciotti & Ostriker 07

Low-level AGN activity & feedback

- "Radio mode" AGN feedback at low *z* required to quench cooling and inhibit star formation (to match the observed galaxy colors & luminosity function – Wise's talk)

- Lack of an additional energy source (e.g. low-power AGN) results in overproduction of massive, blue galaxies



Croton+06

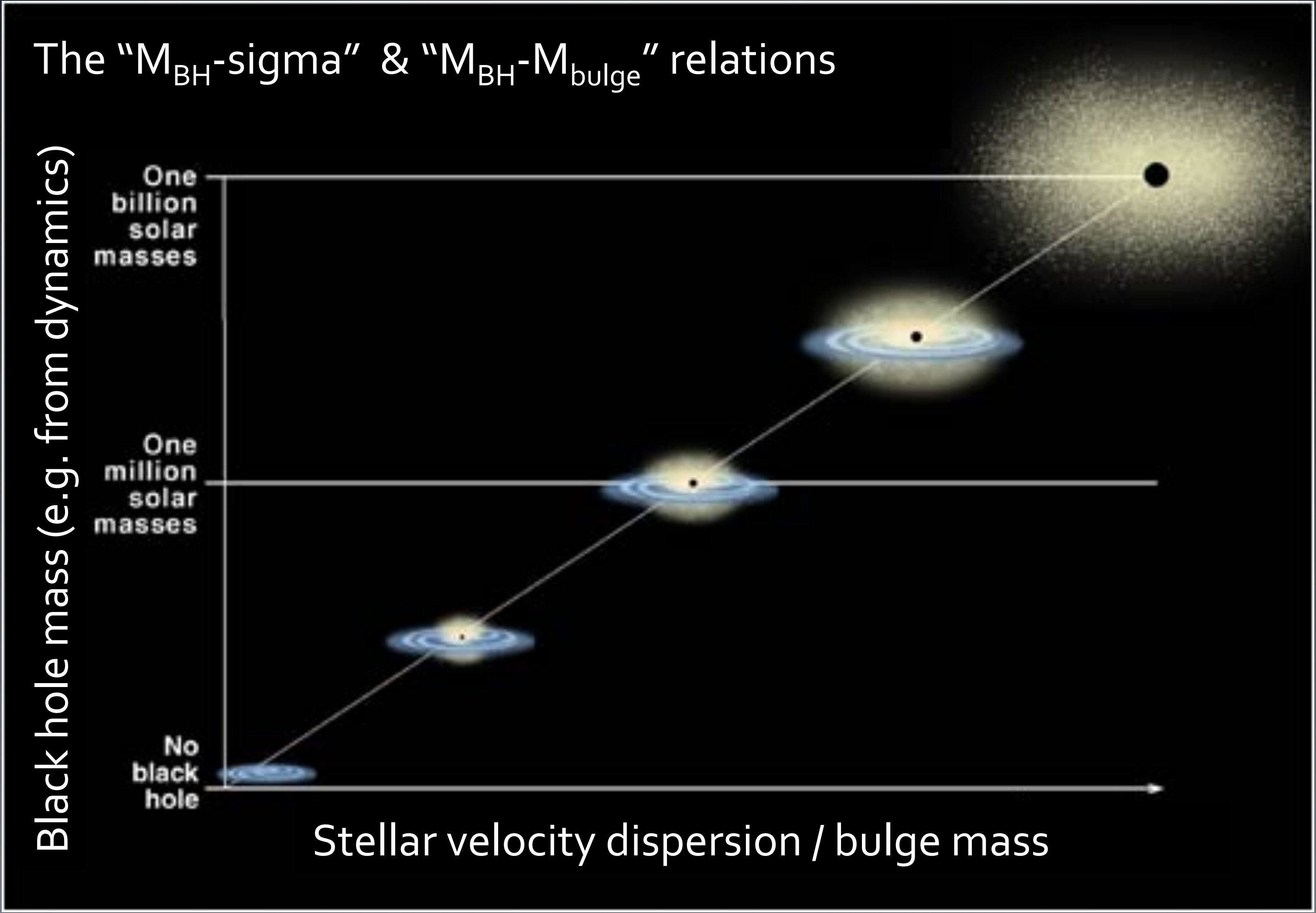
Low luminosity AGN accretion

- Sub-Eddington accretion rate
- No (or weak) big-blue-bump
- Highly sub-Eddington luminosity! Either:
    - very low radiative efficiency (via e.g. advection, convection..) cf. Narayan+94,99
    - mass is lost to an outflow (ADIOS) cf. Blandford & Begelman 99, Falcke & Markoff 00
    - a combination of the above e.g. Yuan+02

$$\dot{m} \leq 0.001$$

$$L/L_{Edd} << 0.001$$

Ubiquity of super-massive BHs



Kormendy & Richstone 95, McLure & Dunlop 02, Tremaine+ 02, Marconi & Hunt 03, Ferrarese & Merritt 00; Gebhardt+00; Haring & Rix 04; Gültekin+09

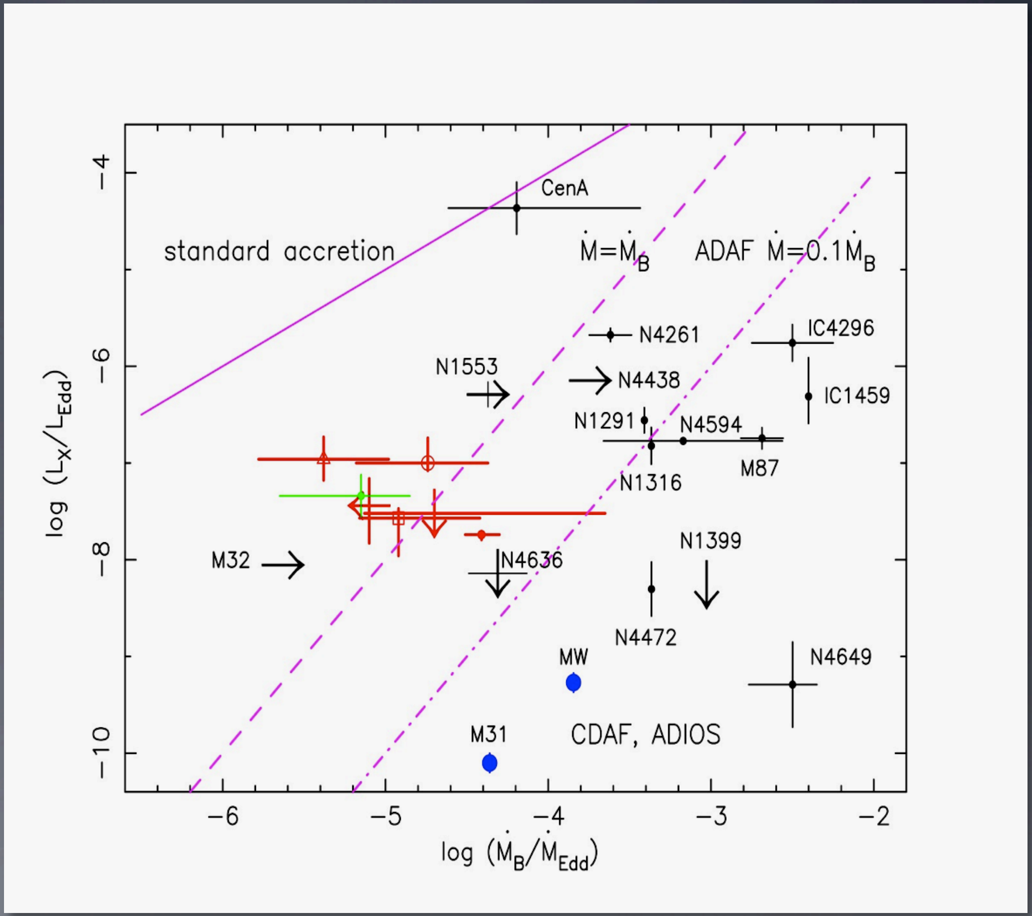
X-rays: AGN vs. ‘inactive’ galaxies

X-rays from “inactive” ($L_{nucl}>10^{-3}$ L_{Edd}) galaxies:

ROSAT effectively sensitive down to 10^{40} erg/sec for nearby galaxies

Chandra* bridges the gap between active and (formally) inactive galaxies

*Sub-arcsec angular resolution is crucial



Soria+ 06

The AMUSE surveys: science goals

- AGN MUlti-wavelength Survey in Early type galaxies: 2 Large Chandra Programs (~1Msec), plus HST & Spitzer, designed to:
- Investigate highly sub-Eddington ($L_x/L_{Edd}<1e-5$) accretion onto local super-massive black hole, & constrain their occupation fraction
- Control for *environmental effects* on nuclear activity AMUSE-Virgo & AMUSE-Field
  - Relative to their cluster counterparts, field early-type galaxies:
    - Have a lower incidence of past major mergers
    - Face reduced ram pressure stripping, but outflows less confined
    - Generally have more cold gas & younger stellar populations

Samples & Methodology

- Virgo sample: 100 early types from HST/ACS Virgo Cluster Survey (Cote'+04)
- Field sample: 97 HyperLeda E/E-S0 galaxies with M_B<-13, D< 30 Mpc, & |b|> 300 (not in Virgo or Fornax)
- Both samples span 4 orders of magnitude in host galaxy mass
- **Chandra surveys' sensitivity: ~6e38 erg/sec, i.e. close to the Eddington limit for a few solar masses**
- Major challenge: control & correct for bright low mass X-ray binaries contamination via known low-mass X-ray binary X-ray luminosity functions (Gilfanov 04, Sivakoff+07)

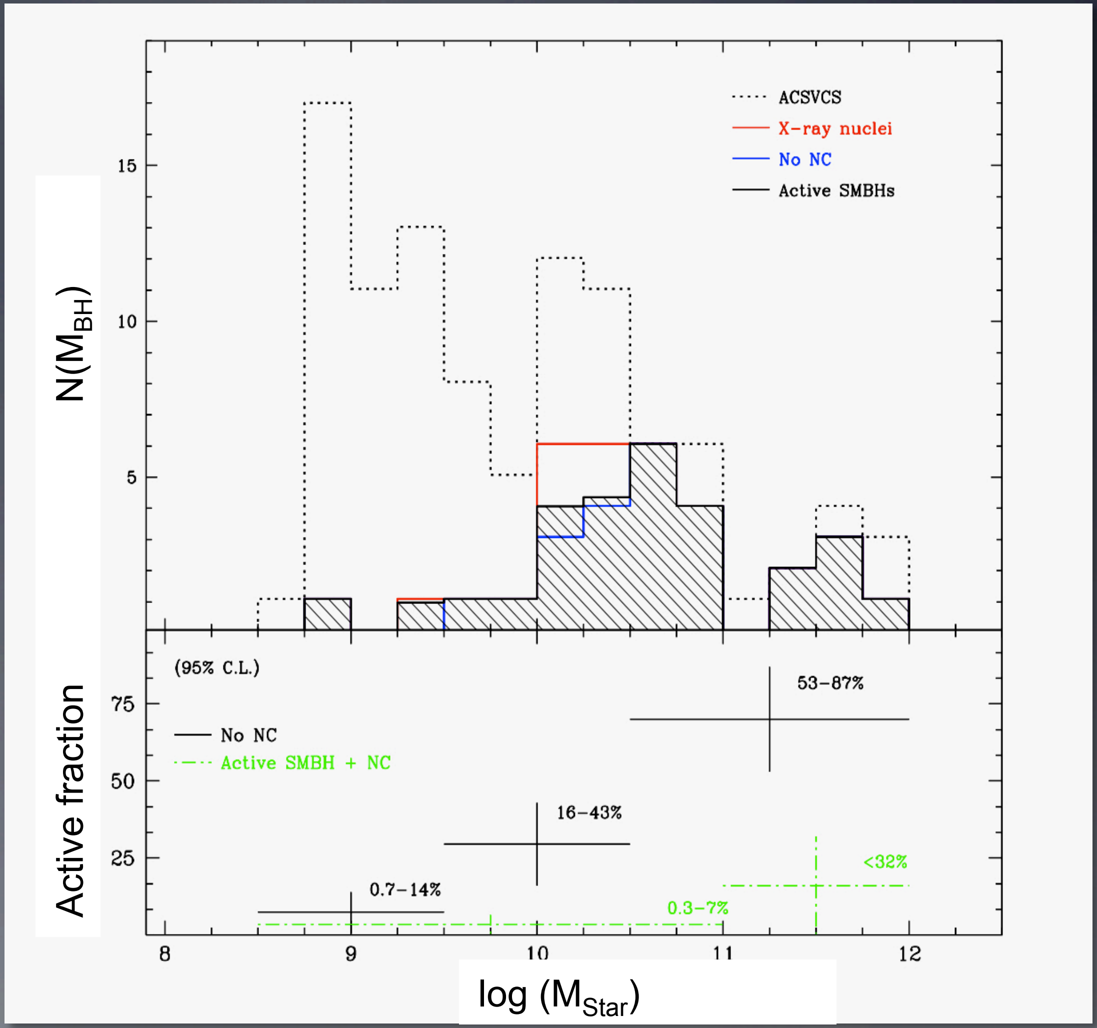
AMUSE-Virgo: Active fraction

Active fraction: 28±6%

Raises with host stellar mass

(see Ho+97, Kaufmann+03, Decarli+07, Seth+08,10)

Mostly due to 'Eddington incompleteness': Dealing with `Eddington-limited' sub-samples results in no evidence that the fraction depends on host mass



(Gallo+08,10)

AMUSE-Field: Active fraction

Active fraction: 46±8%

Raises with host stellar mass

(see Ho+97, Kaufmann+03, Decarli+07, Seth+08,10)

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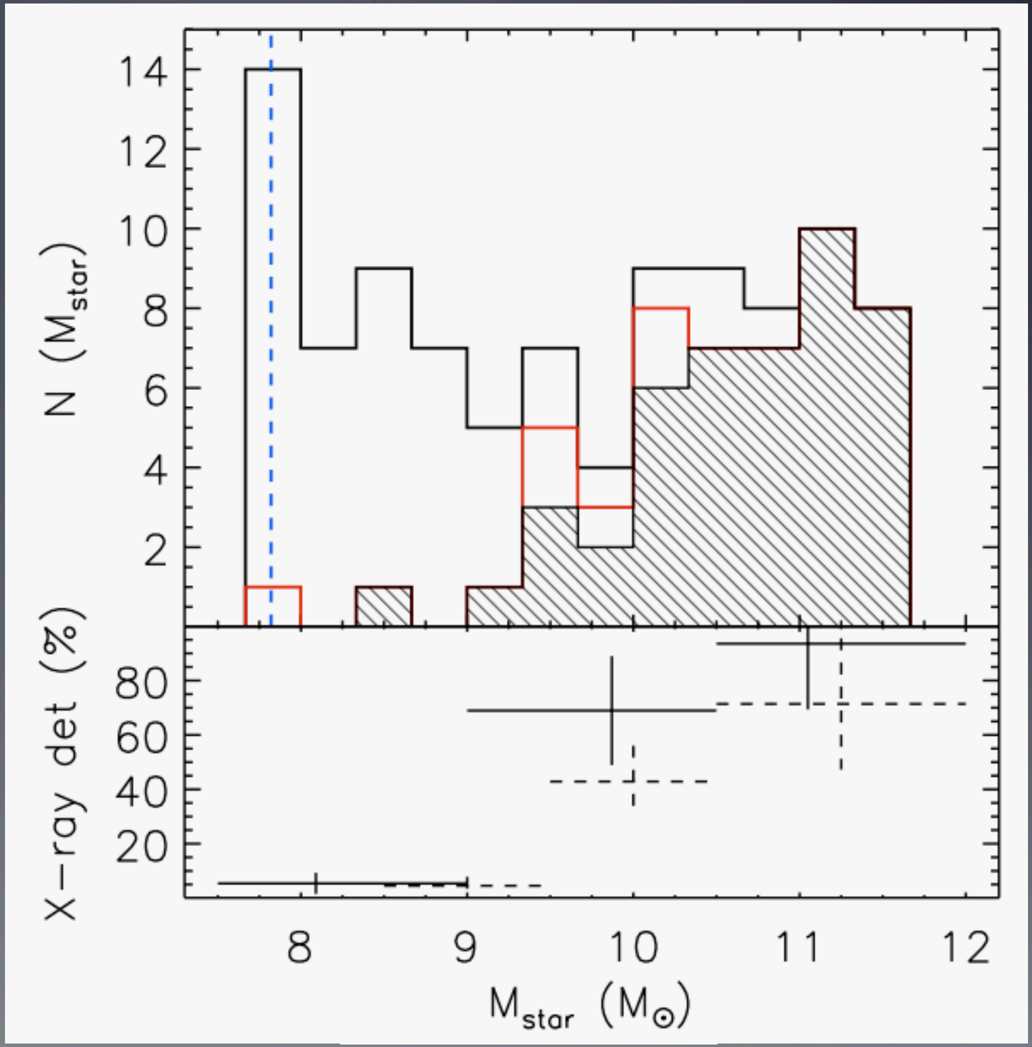
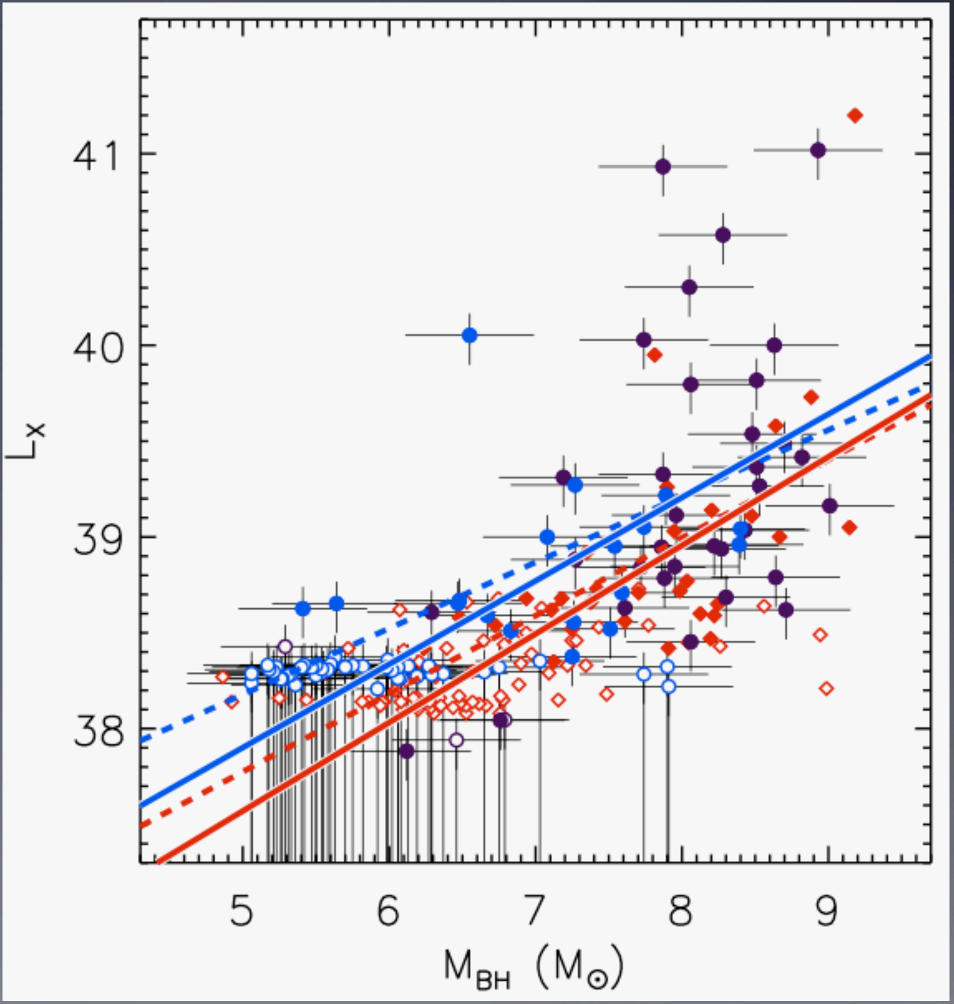


(B. Miller+, in prep)

Black hole accretion down-sizing

- Nuclear X-ray luminosity increases with increasing stellar mass (Red & Purple: Virgo; Blue: Field; Filled: detections; Open: limits; Solid lines: whole samples ; Dashed lines: exclude $\log(L_x) > 40$)
- Lower mass black holes shine closer to their Eddington limit (local 'down-sizing')
- Field galaxies only marginally X-ray brighter (nuclear activity not responsible for reddening cluster members)



(B. Miller+, in prep)

Summary

- The boundary between active & inactive galaxies is set by our ability to be able to detect accretion-powered emission
- Low luminosity AGN are *ubiquitous* (so long as there is a black holes)
- The high luminosity end of this population (M87-like) is likely responsible for the observed luminosity function of galaxies in the local universe, via prolonged, low level feedback to quench star formation
- The active fraction and X-ray luminosity at very low Eddington ratios ($-9 < L_x/L_{Edd} < -4$) are only marginally higher in the field compared to cluster environment B. Miller+ in prep

Influence of environment

- Relative to their cluster counterparts, local field early-type galaxies tend to:
  - Have a lower incidence of past major mergers
  - Face reduced ram pressure stripping, but outflows less confined
  - Generally have more cold gas (e.g., higher HI content) along with younger stellar populations