The Impact of Supermassive Black Holes on Massive Galaxies

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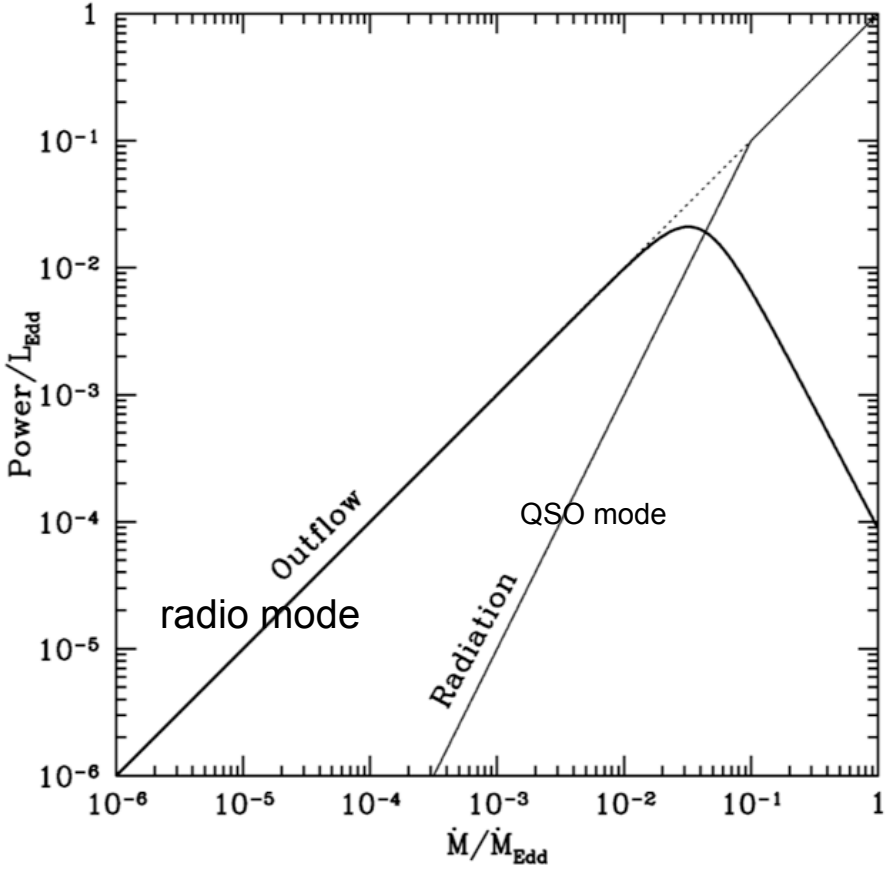
A very brief history of SMBH's

- Early epochs - SMBHs are luminous QSO's, radiatively bright, high accretion rates, rapid growth

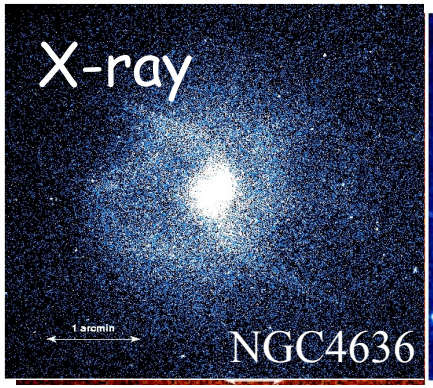
- Present epoch - SMBHs can be radiatively faint, large kinetic power (~1000 x radiative), low accretion rates

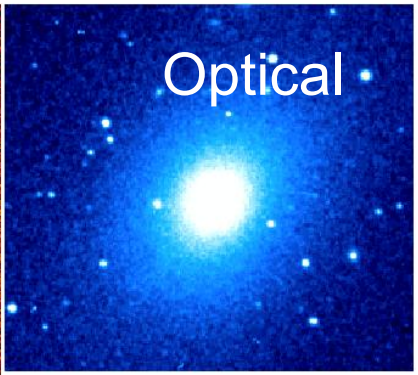
X-ray coronae provide mechanism to capture energy released from SMBH through bubbles and shocks

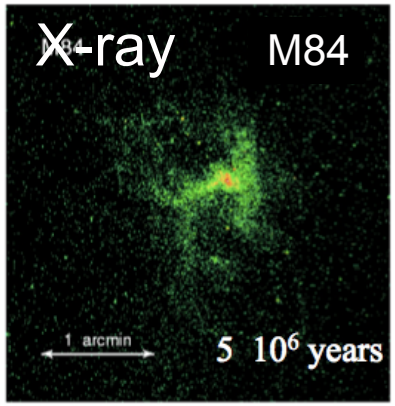


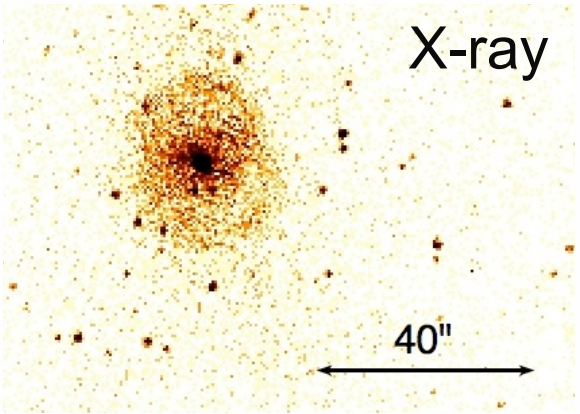
Churazov+ MNRAS 2005

Gas Rich Early Type Galaxies









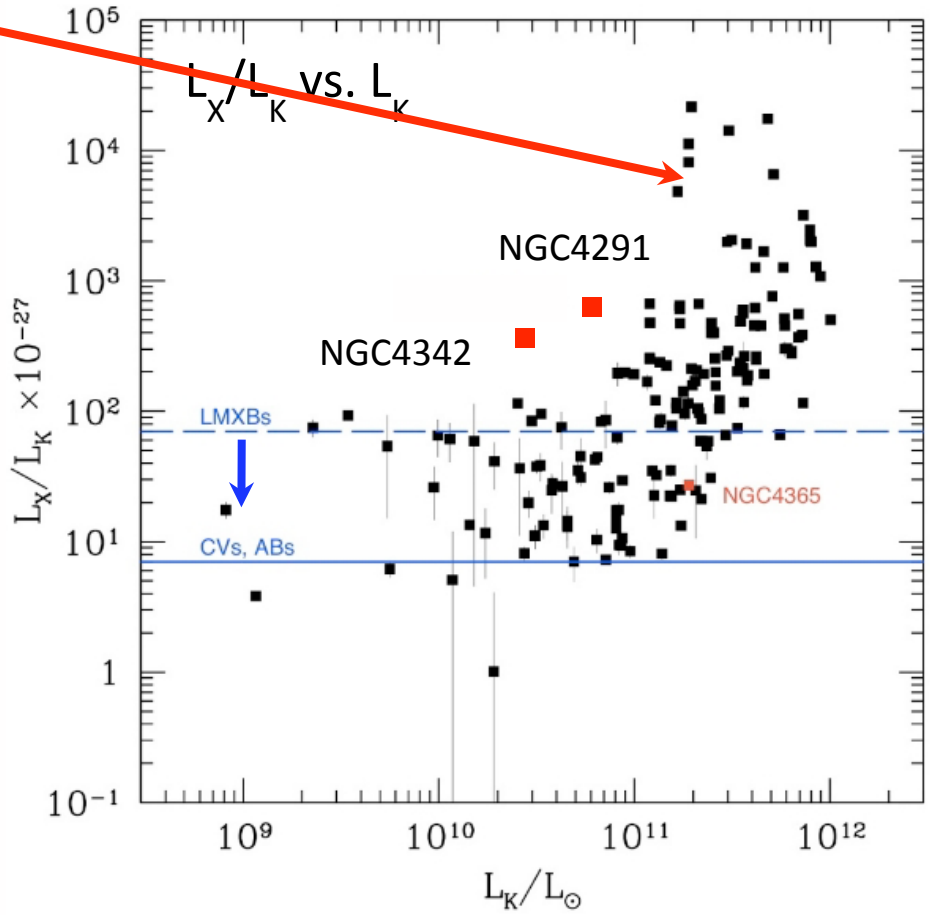
As a class, luminous early type galaxies ($L_K > 10^{11} L_{sun}$) have hot corona

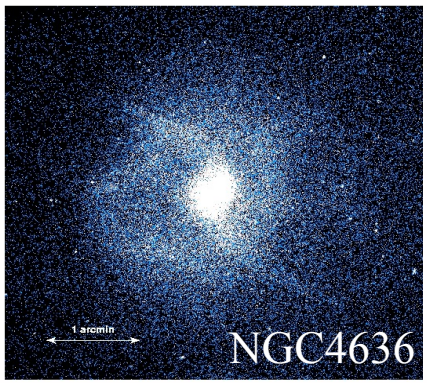
- AGN outbursts common
- Massive galaxies do NOT have "dry" mergers
- Complementary view from optical

- Not possible pre-Chandra
  - Requires high angular resolution
  - faint X-ray nuclei
  - can't exclude bright X-ray binaries

Coronal X-ray Emission in Early Type Galaxies

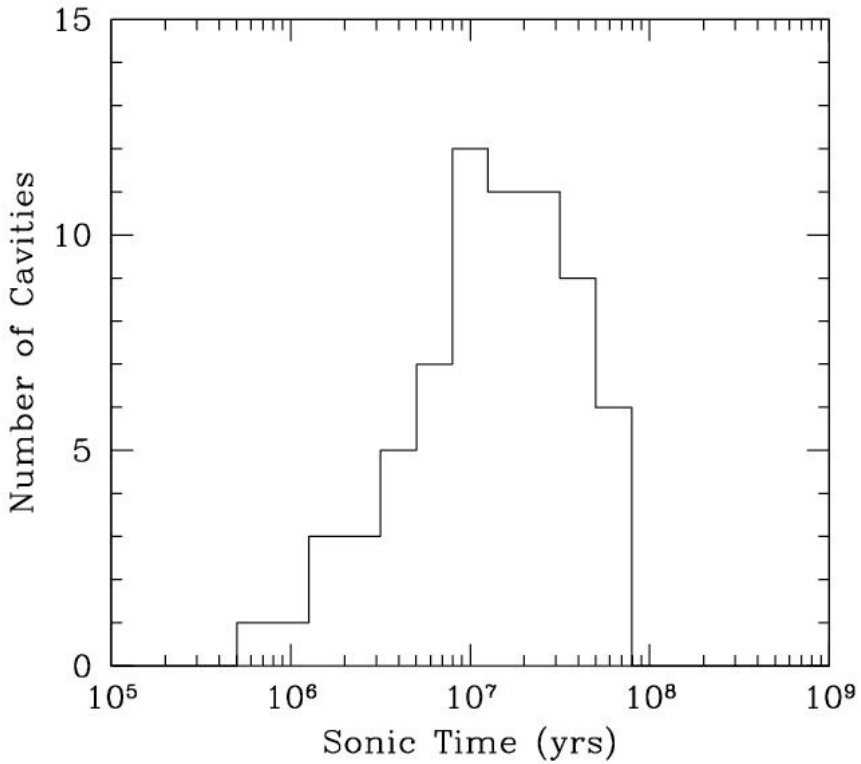
- Cavities
  - Common 30% of X-ray luminous galaxies; 50% in clusters with cooling cores)
  - power sufficient to balance cooling (e.g. Nulsen+09)
- AGN/SMBH
  - 70% detected in radio (see also Dunn+10 17/18 and 34/42)
  - Radiatively weak - radiated power < 10^{-3} of mechanical power

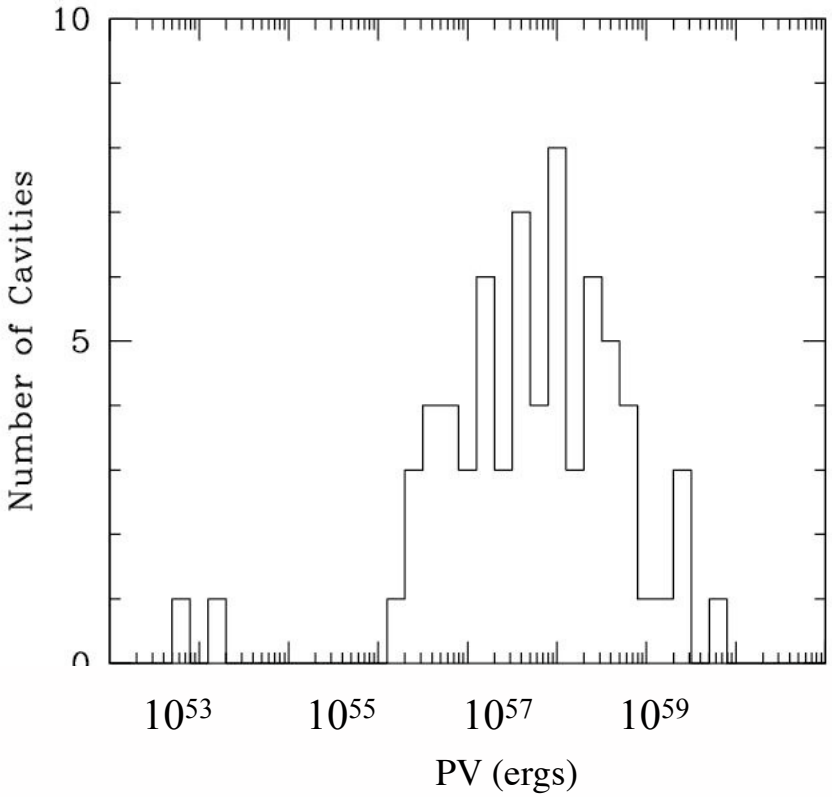




Cavities and shocks are best way to measure SMBH outburst history (measure energy and age)

In galaxies, outbursts are recent (=> frequent) and impart significant energy to the ISM - enough to balance cooling (e.g. Nulsen)



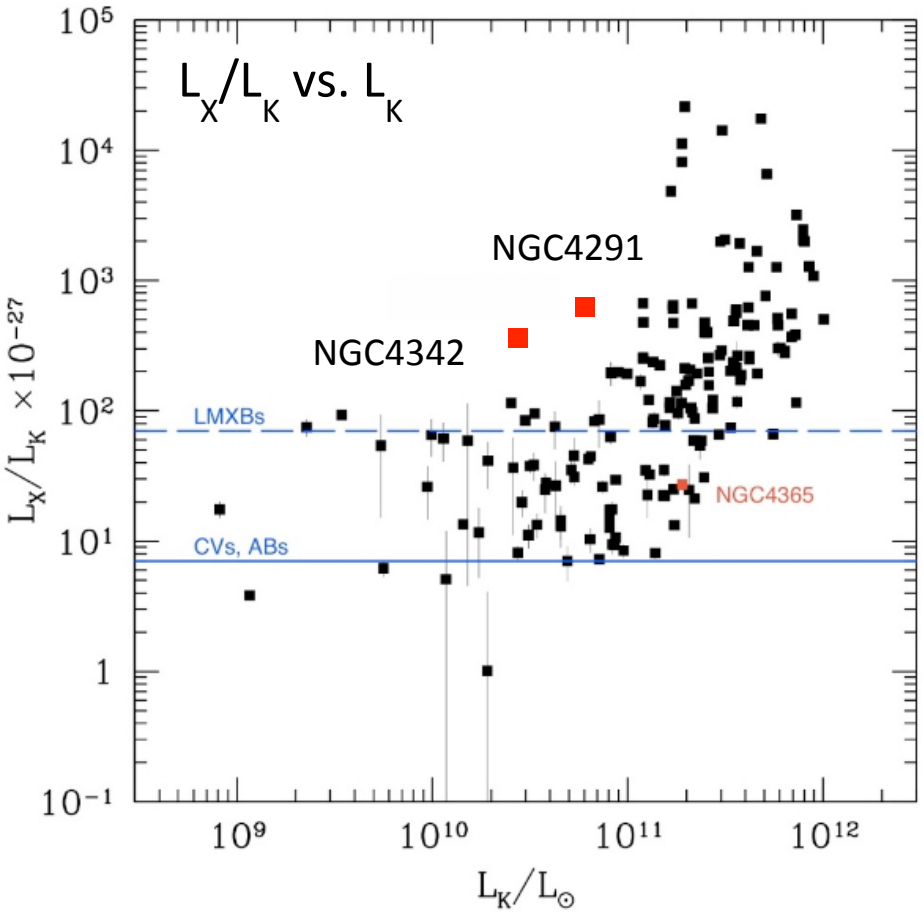


Time scales - 10^6 to 10^8 years (peak at ~10^7 years)

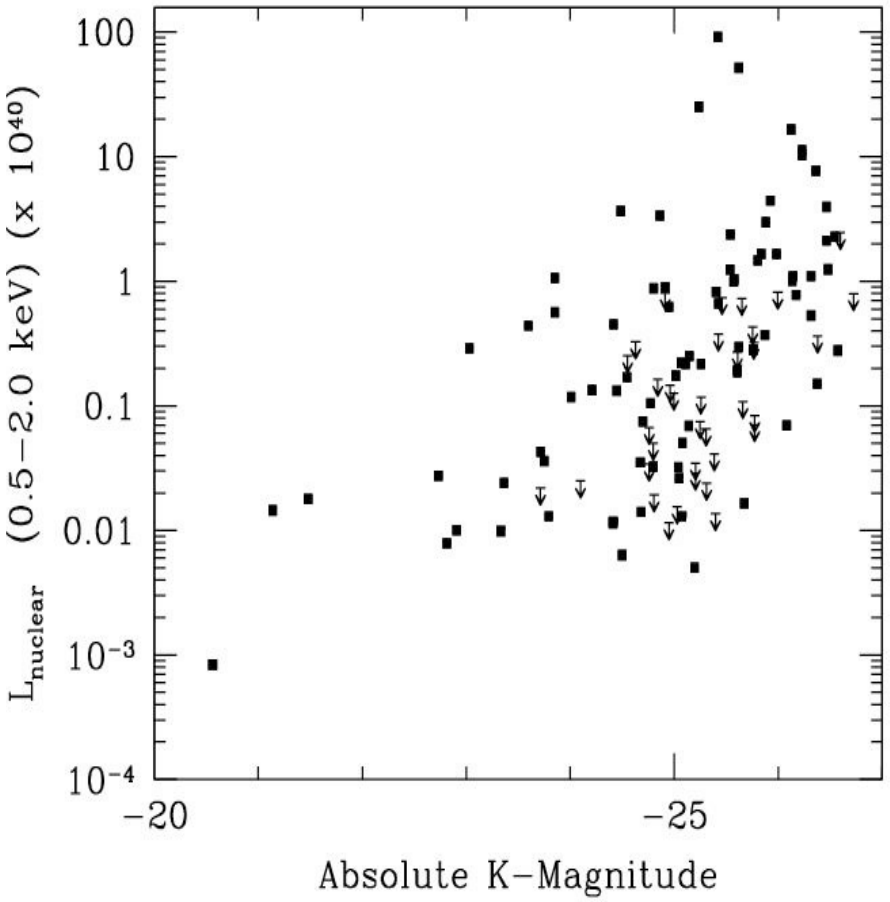
- PV = 10^{55} to 10^{59} ergs
- Combine outburst energy and time scale - yields power

Hot Gas and SMBH X-ray Luminosities in Normal Early type Galaxies

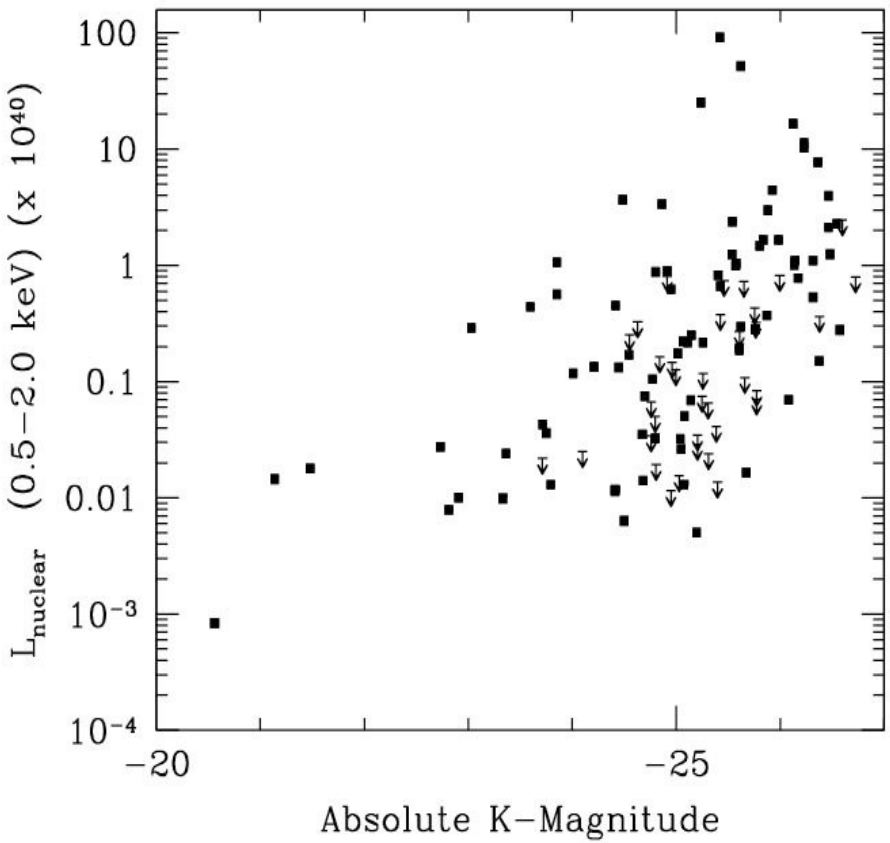
Hot Gas



SMBH



SMBH X-ray Luminosities and Eddington Ratios in Normal Early type Galaxies



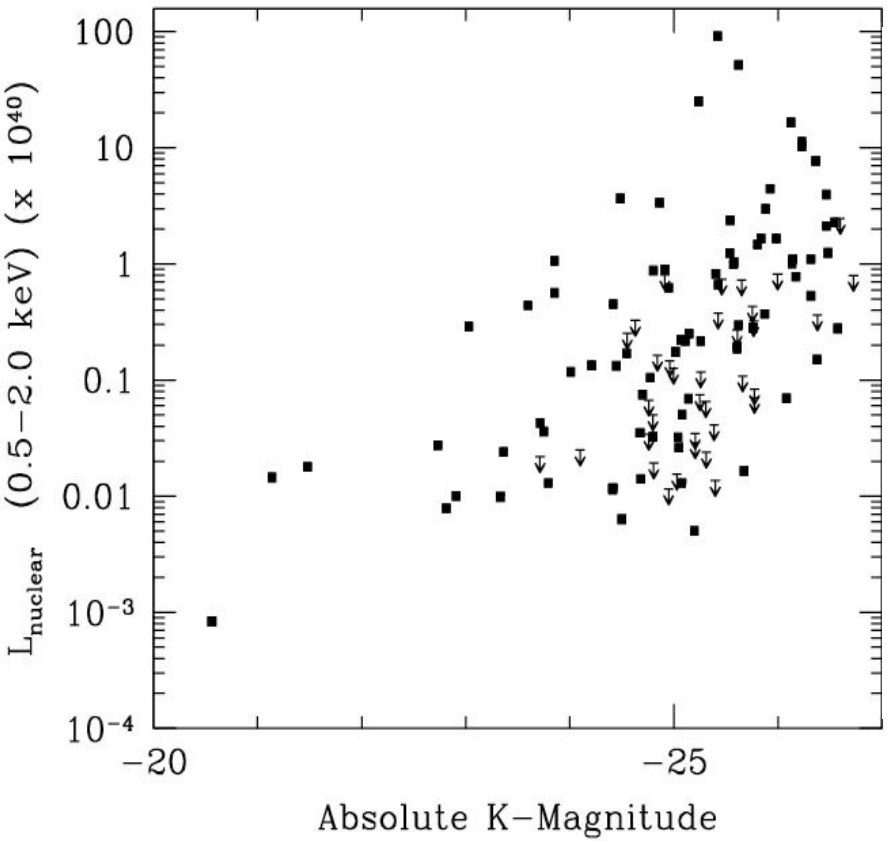
80% have X-ray detected SMBHs

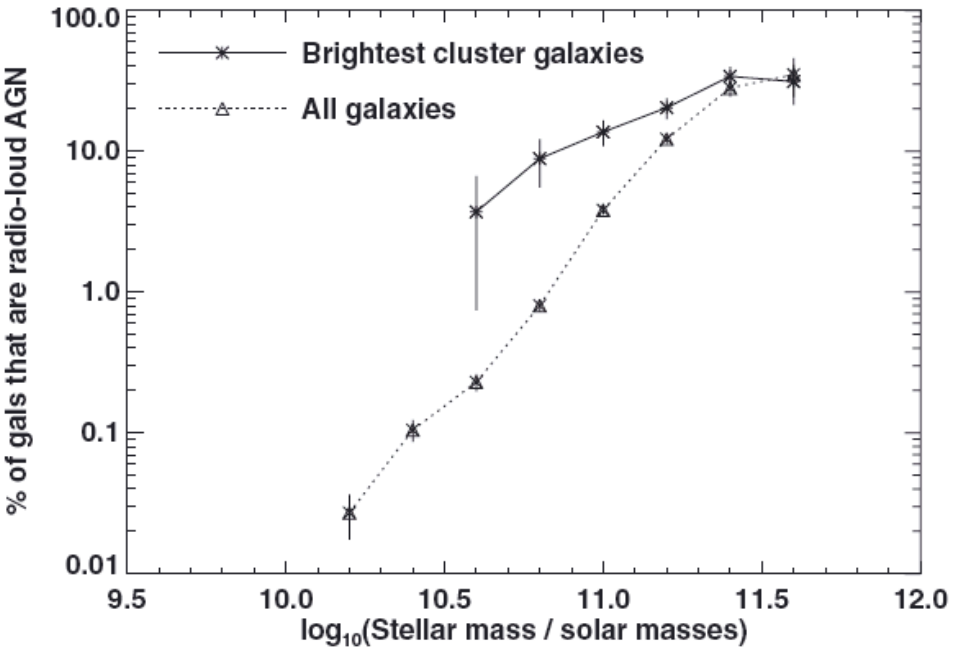
Luminosities range from $\sim 10^{38}$ - 10^{42} erg s^{-1}

70% detected in radio

- SMBH in normal galaxies have low Eddington ratios $\sim 10^{-5}$-10^{-9}
  - for QSO's ~0.3;
  - for Sag A = 10^{-9}
- ADAF/ADIOS/radio mode
  - Radiatively inefficient - radiated power ~ 1/1000 mechanical power

X-ray and radio emission from SMBHs in normal early type galaxies

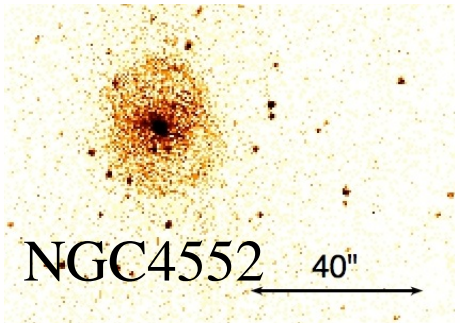




% of galaxies with radio loud AGN (Best+ 2007)

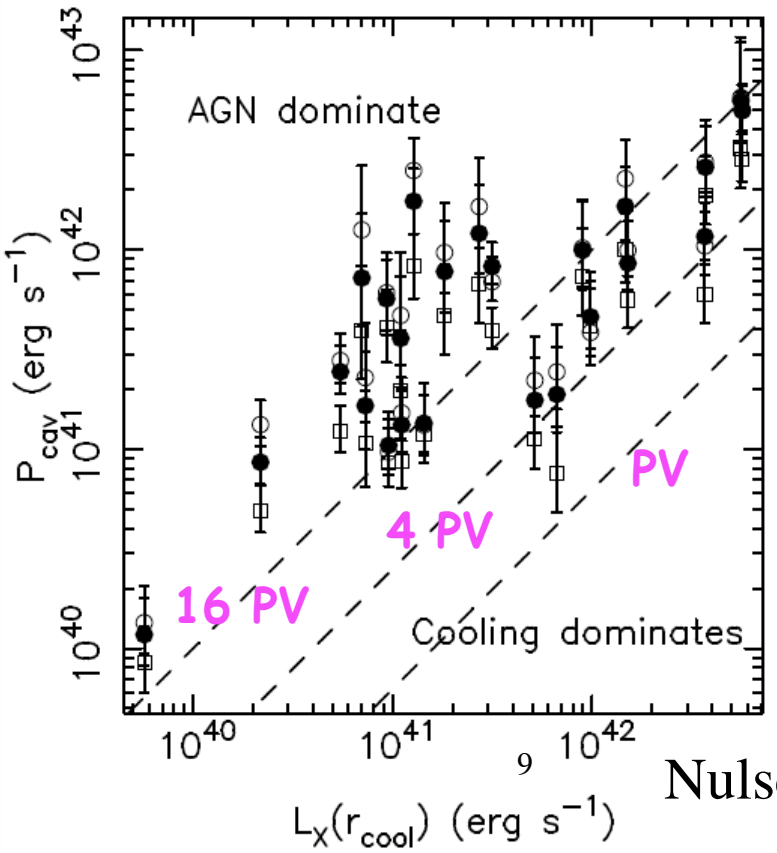
In galaxies, SMBH outbursts are recent (=> frequent) and impart significant energy to the ISM - **enough to balance cooling**

- Ages and outburst energy for 27 galaxies/groups with cavities (30% of optically luminous galaxies in the sample) - Nulsen, Jones, Forman, Churazov & friends)



- Time scales - 10^6 to 10^8 years (peak at ~10^7 years)
- PV = 10^{55} to 10^{59} ergs
- Combine outburst energy and time scale - yields power

- For 4PV, AGN mechanical power exceeds L_{rad} for all the galaxies (assuming an age given by the sound crossing time). (similar results for clusters e.g. Dunn/Fabian)

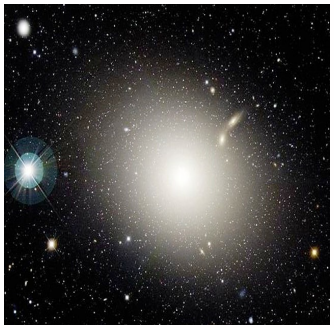


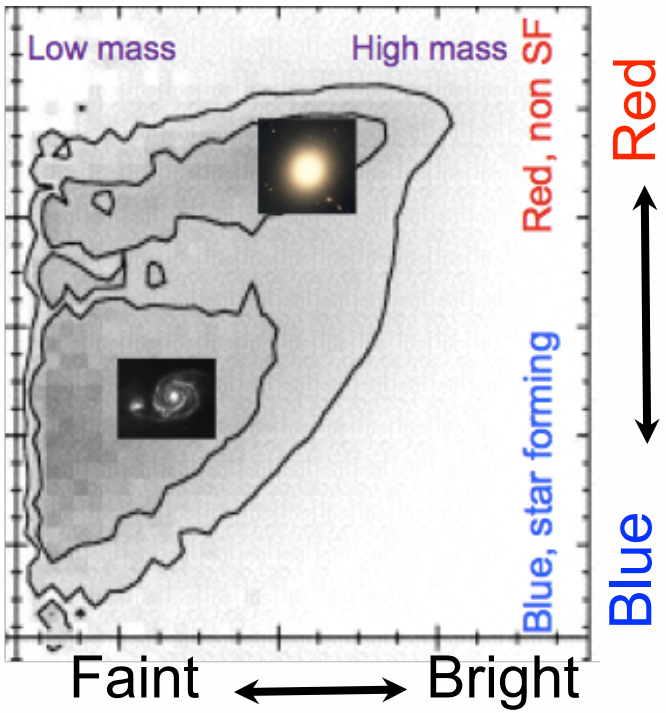
H = γPV/(γ-1) where γ=4/3 for relativistic plasma

Nulsen

Feedback from Supermassive Black Holes Explains Basic "Fact" of Astronomy - two kinds of galaxies

- Feedback
  - Supermassive Black Hole in galaxy nucleus accretes matter
  - Some energy returned (via jets/ cavities/shocks) to limit the formation of new stars
- Key component of galaxy evolution
  - red sequence/blue cloud (elliptical vs. spiral; old red, "dead" galaxies vs. blue/young ; hot gas rich vs. hot gas poor)
  - feedback suppresses and regulates star formation in red sequence

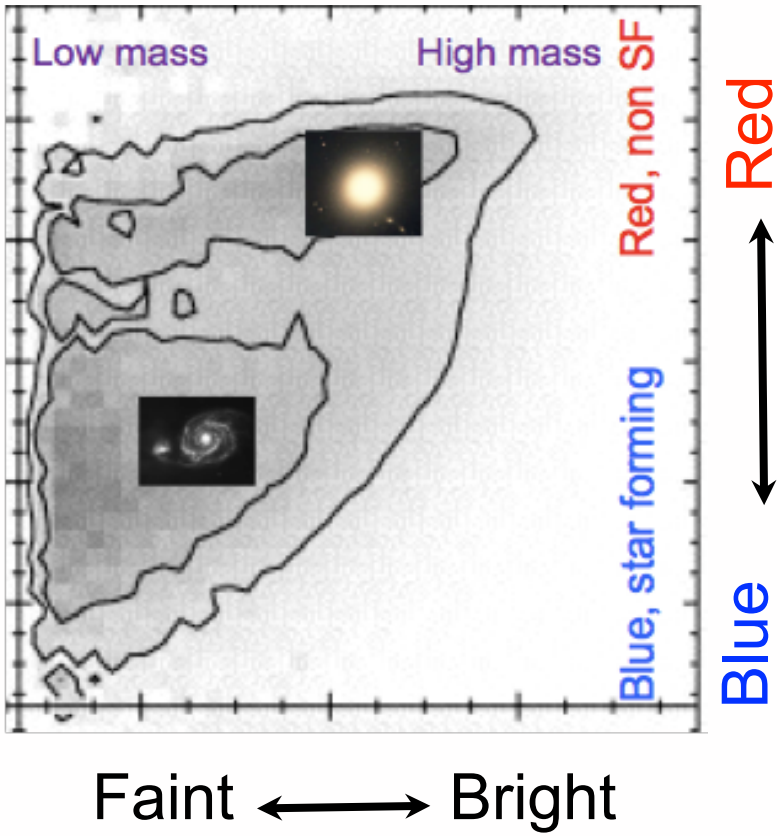




Conclusions

- Cavities (and shocks) - BEST way to measure black hole outburst history
  - Measure energy, age, duration
- For low luminosity AGN,

  mechanical power >> radiative power
- Mechanical Power Balances Cooling
- Feedback suppresses star formation
  - Maintains dichotomy of stellar populations
  - Old stellar populations with feedback from SMBH maintain hot atmosphere
  - feedback can alter the SMBH - bulge relation (e.g. NGC4342)



Feedback (black holes + hot gas) and Baseball

Early type (bulge) galaxies - like a baseball team

Batter = SMBH - sometimes hits the ball (outbursts)

- infrequent
- exact trigger unknown
- different sizes (walks, singles, … home runs)

Pitcher = provides ball/fuel (cooling gas for accretion)

Hot X-ray emitting gas = fielders

- capture AGN output

Fielders are critical

No fielders (no gas)

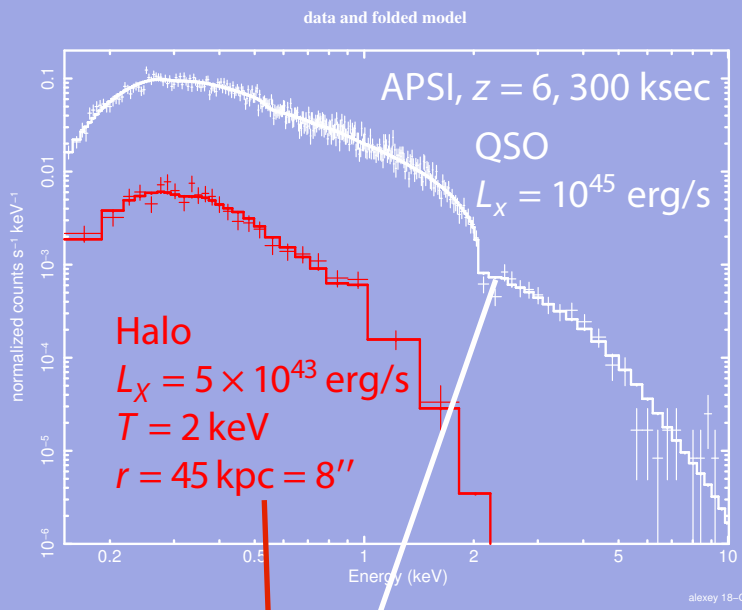
==> No energy capture

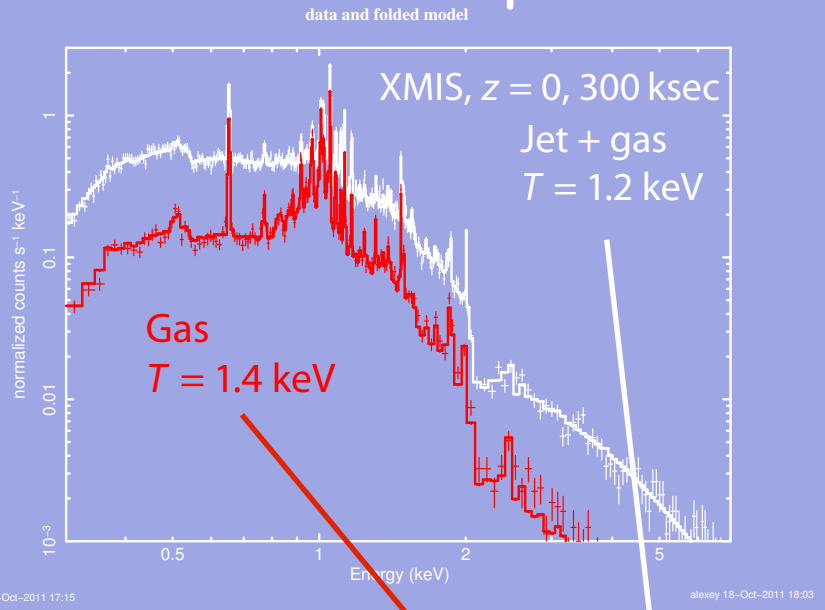
No feedback

Unifies SMBH, AGN activity,
Galaxy properties (red/blue)
X-ray cooling flows

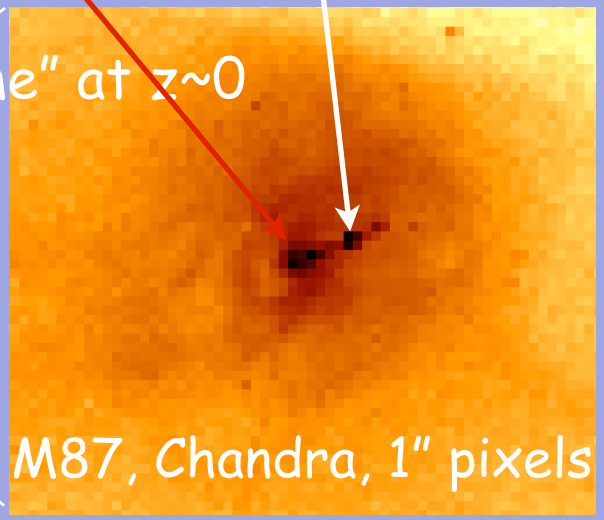
Gas Provides archive of AGN activity

SMBHs and LSS from z = 6 to the present



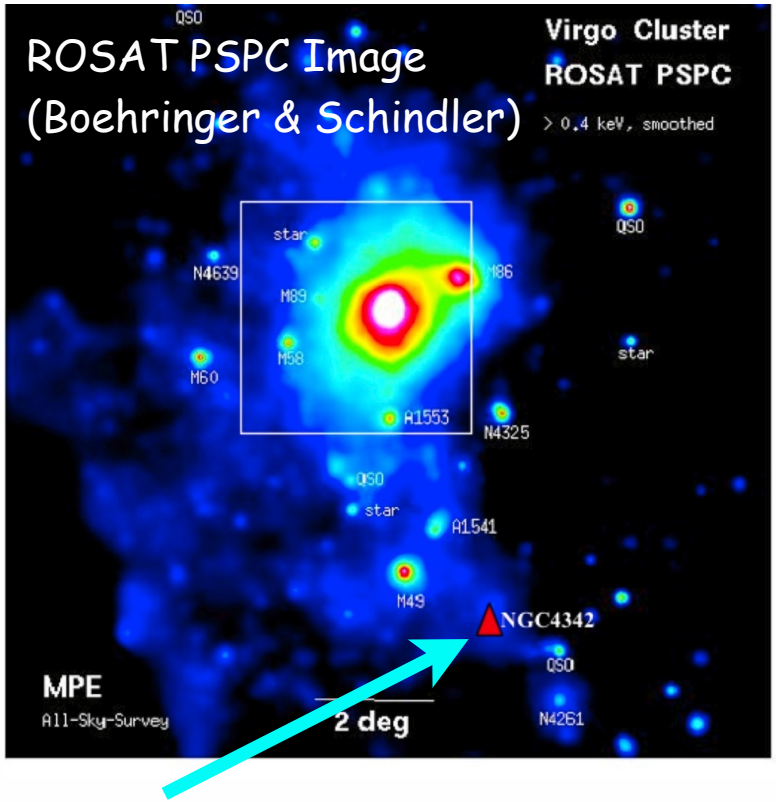


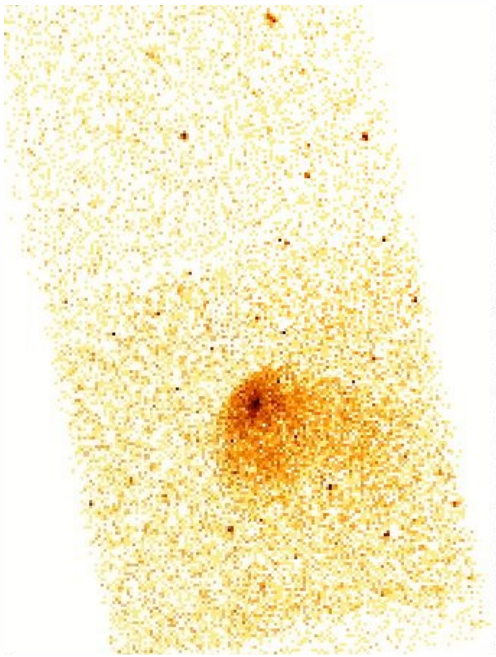
First quasar at z~6 to "nursing home" at z~0

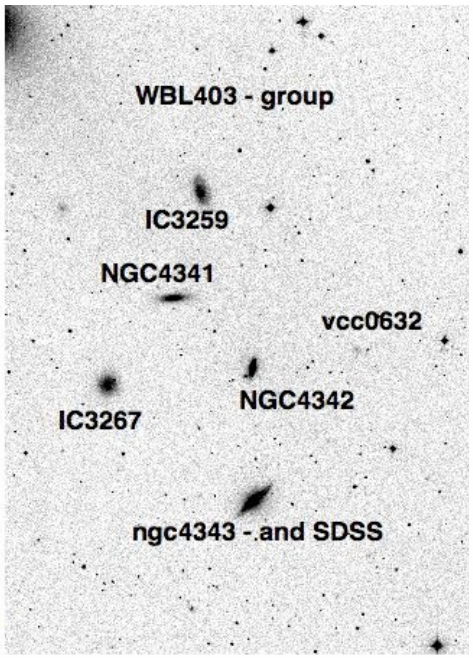


Study bright quasars at z~6 and emission from their coronae; high resolution spectroscopy of their radio mode descendants at z~0

Optically faint, gas rich galaxies - NGC4342







NGC4342 beyond r_{200} from M87
Only ~0.5 Mpc from NGC4472 (M49)
Virgo gas distribution - elongated N-S

Gaseous filament in Virgo outskirts?
Halo with cool gas?
NGC4342 encounters external gas for the first time?
Ram pressure stripping - clear