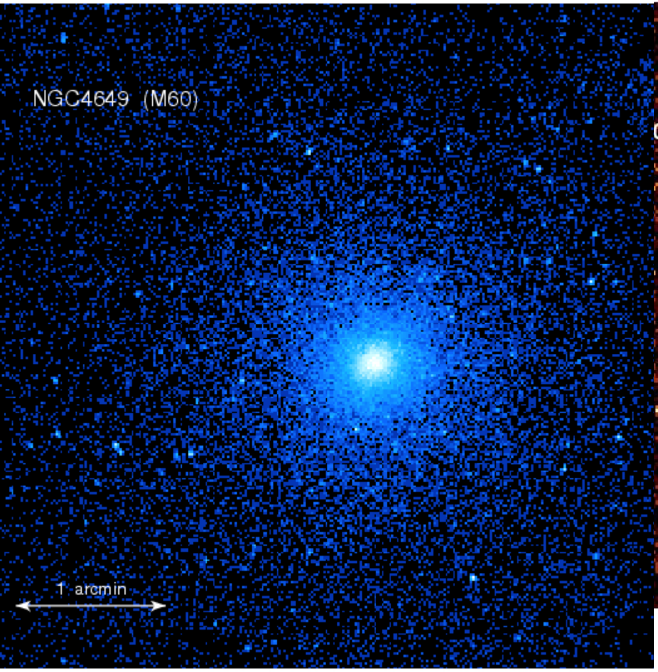
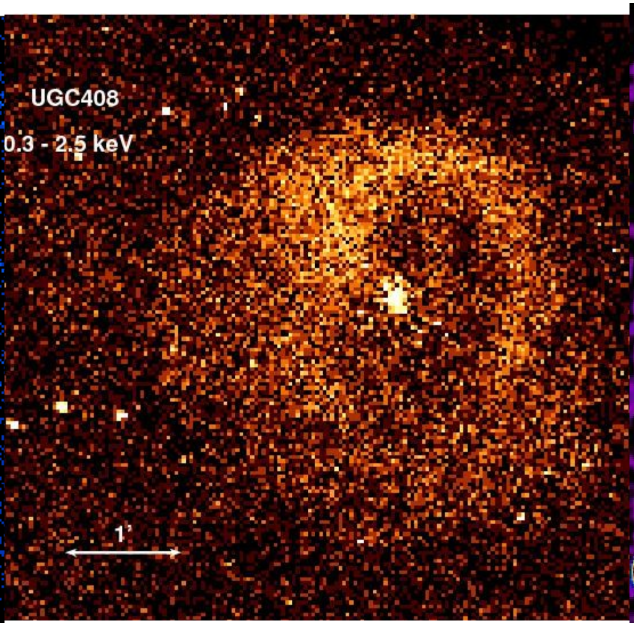
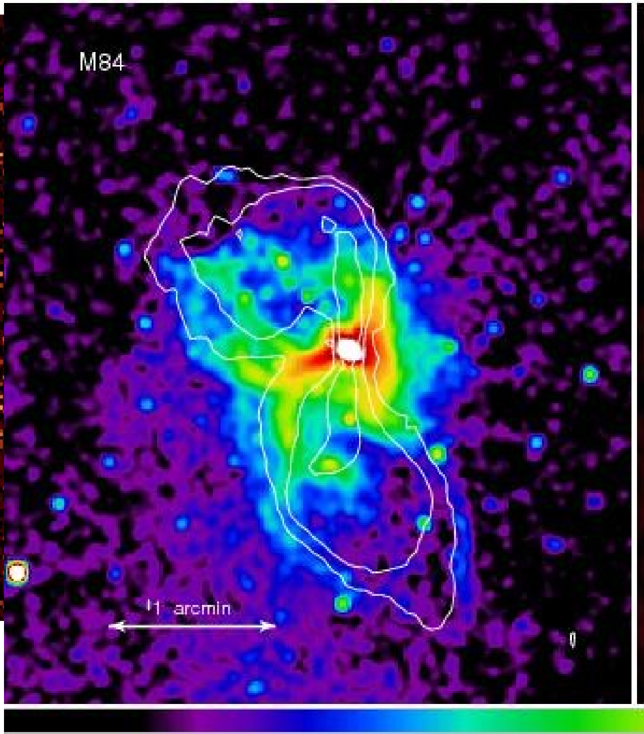
Nuclear Emission and Outbursts from SMBHs in Normal Galaxies

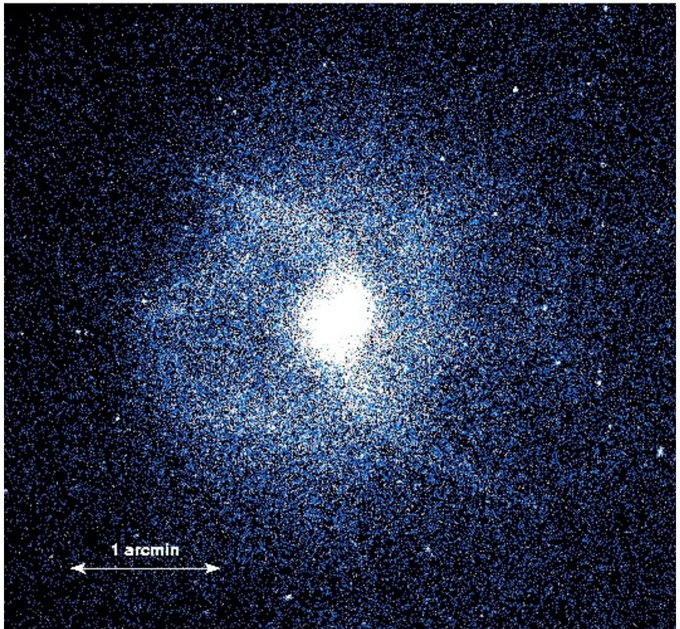
Jones, Forman, Churazov, Lal, Nulsen

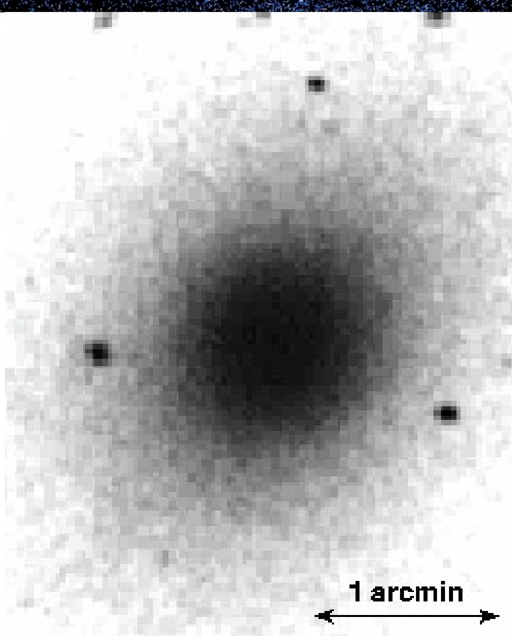






Cavities and shocks in the hot X-ray gas in galaxies and clusters provide a fossil record of AGN activity





NGC4636
Virgo elliptical

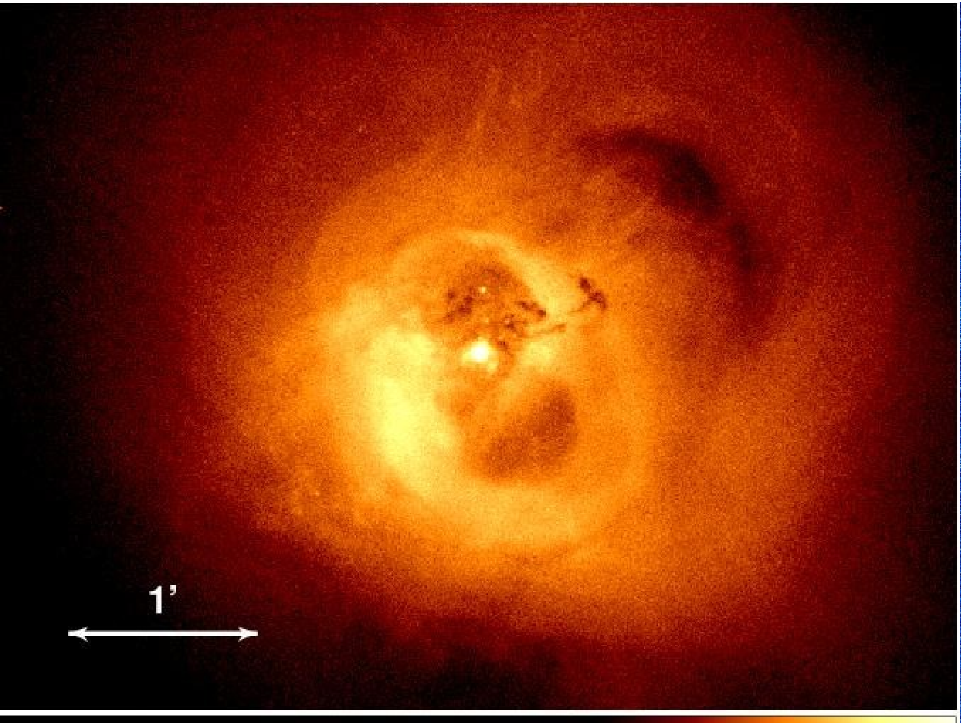
Hot X-ray atmospheres often provide the primary evidence of AGN activity

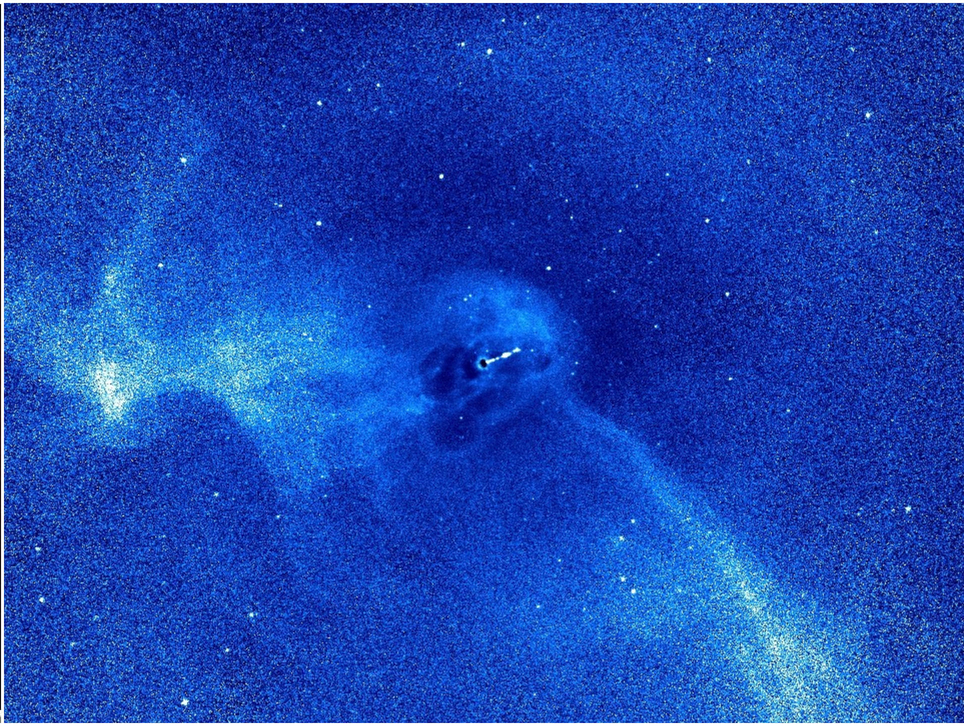
- Observe outburst frequency - common
  >50% clusters (Dunn,Fabian)>30% galaxies
- Measure total power - mechanical (cavities and shocks) >> radiative
- Measure outburst duration and age
- Understand interaction of outbursts with surrounding gas
- Insight into high redshift universe
    - Growth/formation of galaxies
    - Growth of SMBH
    - Feedback from AGN

X-ray cluster/group/galaxy studies are key
Extending to galaxies with lower mass black holes

Perseus Cluster core - Shocks and Ripples (Fabian et al. 2002, 2003, 2005)

M87/Virgo cluster core - Bubbles, shocks and filaments (Forman et al. 2005, 2007, 2009)



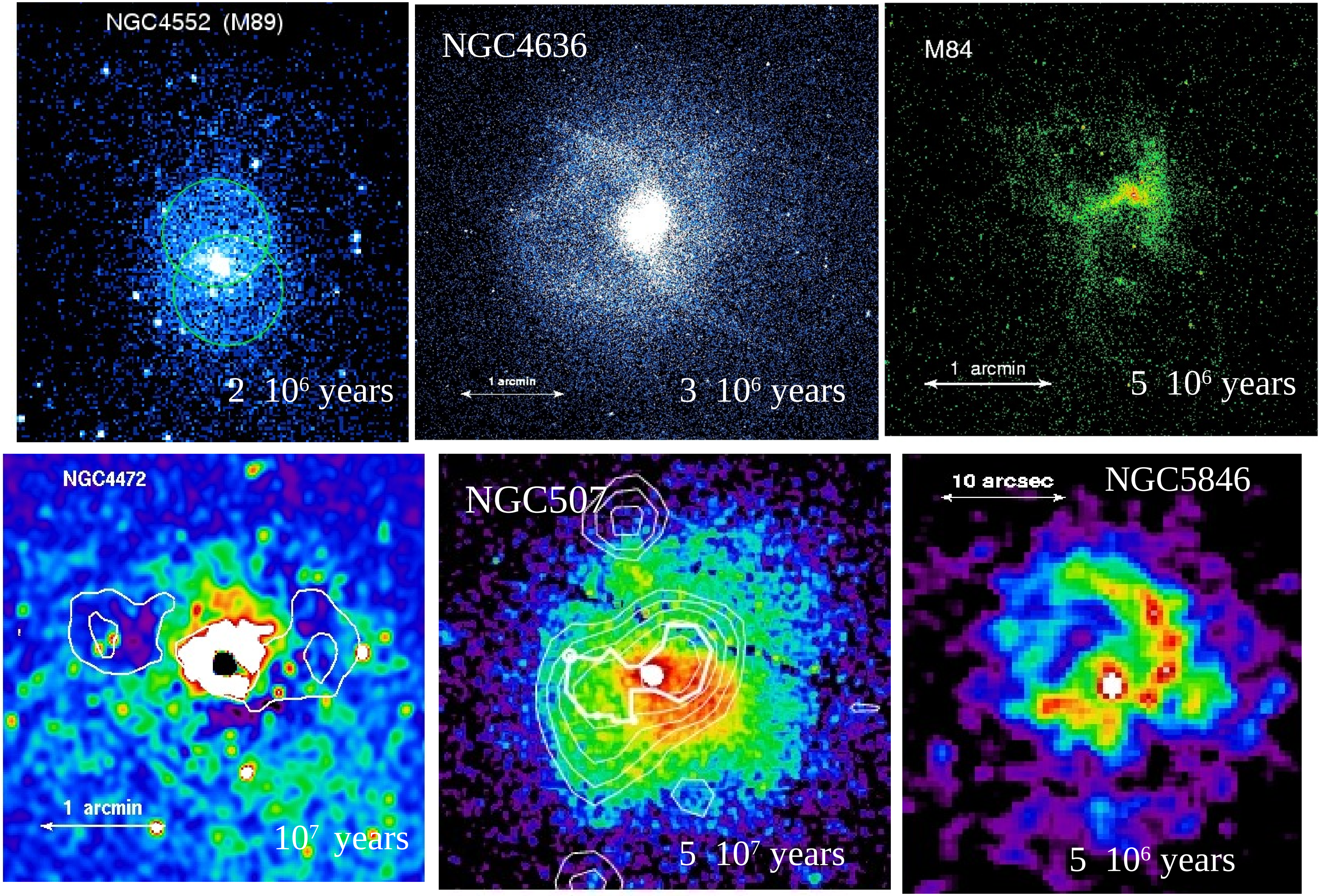


- **Chandra shows repeated outbursts**
- **Generally from X-ray observations, the outburst power is estimated from the size of the cavities and the surrounding gas pressure.**

Outburst age from buoyancy rise time.

- **(only with deep Chandra of bright clusters can one directly constrain outburst power, duration, and age from X-ray**

Normal massive Early-type galaxies – 30% have cavities

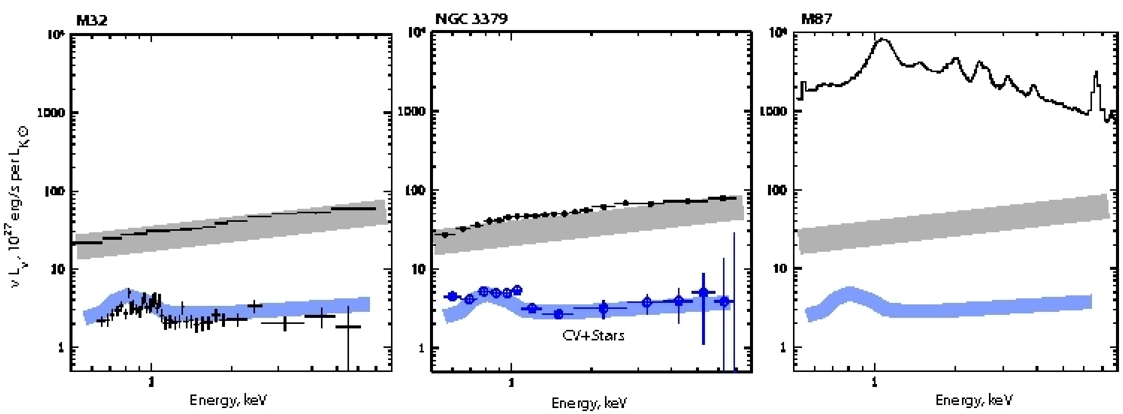


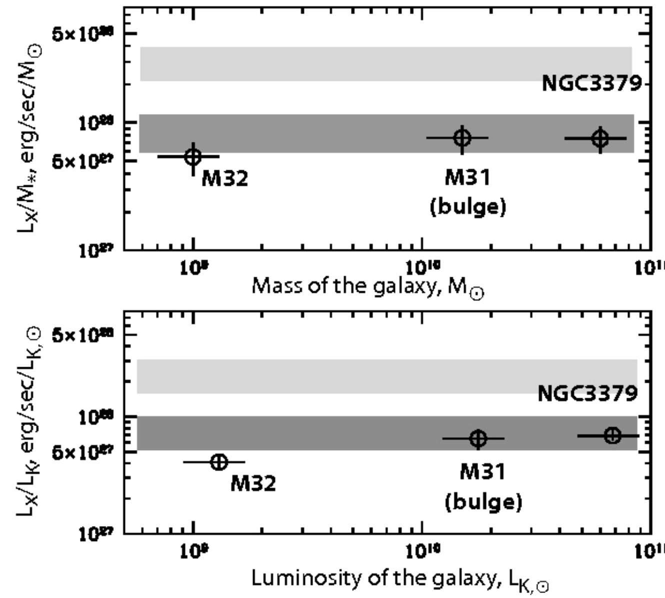
Outburst energies ~10^{55} - 10^{58} ergs Outburst ages 10^6 - 10^8 years

Components of X-ray Emission in Early type Galaxies

Hot gas dominates the emission in (most) massive galaxies
(unless gas blown out by outburst - see Lanz et al. poster on Fornax A)

In less luminous, gas-poor systems, LMXBs and coronally active stars dominate emission.
Much of LMXB emission can be resolved by Chandra, but emission from stars cannot be resolved.





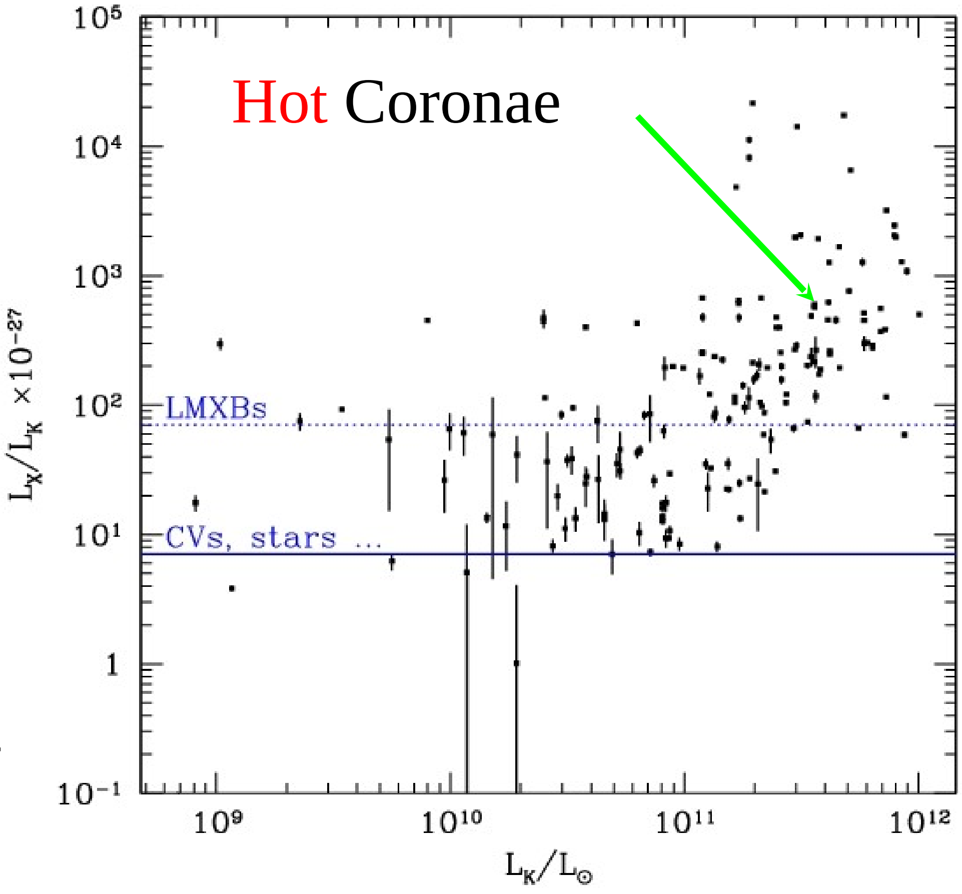
Stellar X-ray emission

Luminous (massive) E/S0 Galaxies have hot coronae and are **NOT** gas poor

~200 E/S0 nearby galaxies

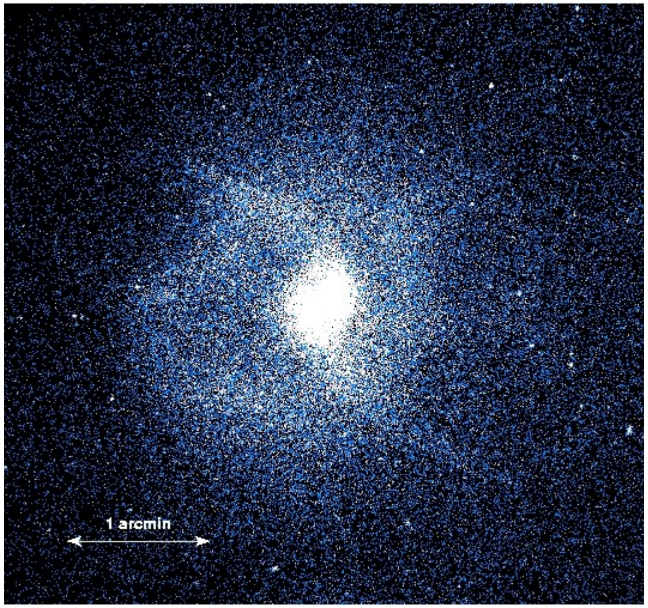
X-ray components

- LMXB's (some resolved)
- CV's and active stars
- Hot gas
  - kT~0.5-1.5 keV
  - Dominates at high mass
  - Provides fuel for SMBH
  - Captures energy from SMBH outbursts
  - 30% have cavities
  - Measure PV =AGN outburst energy



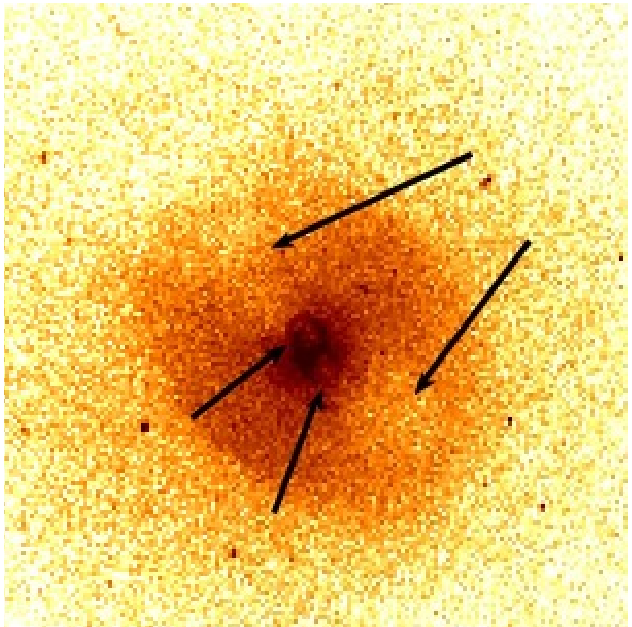
Measuring AGN activity in Early type Galaxies

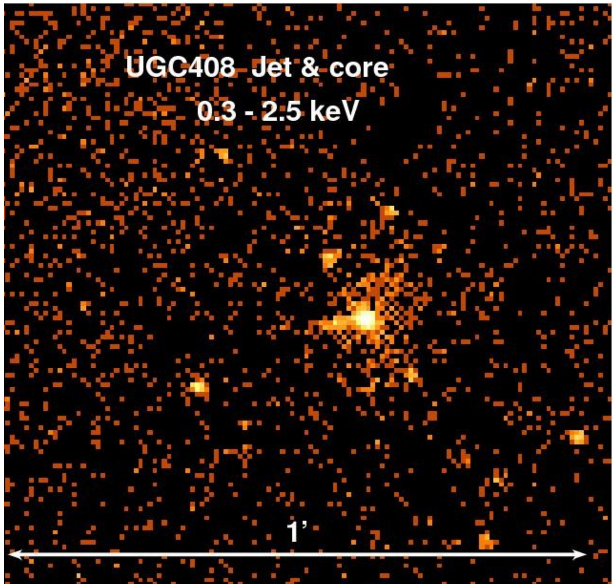
NGC4636 Virgo elliptical

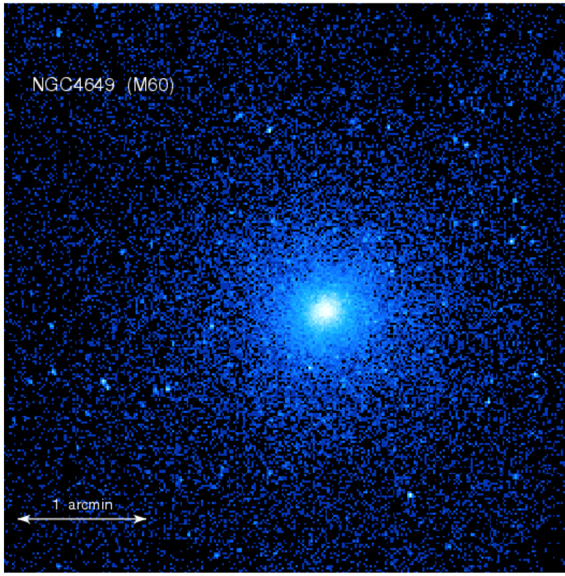


X-ray luminous, massive galaxies, measure X-ray cavities, shocks to determine AGN kinetic energy

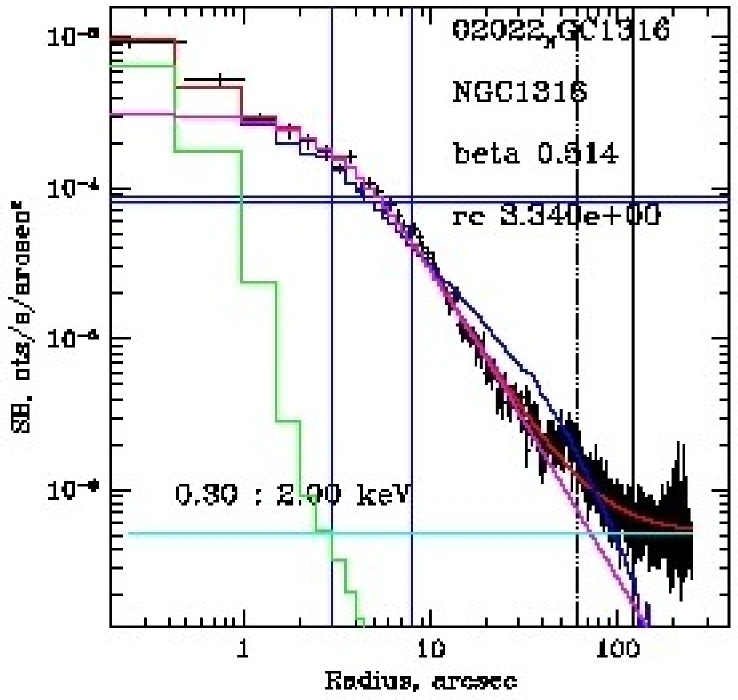
Less luminous, gas-poor systems, (or gas rich galaxies with no cavities/shocks) measure nuclear X-ray and radio emission to determine AGN radiative energy

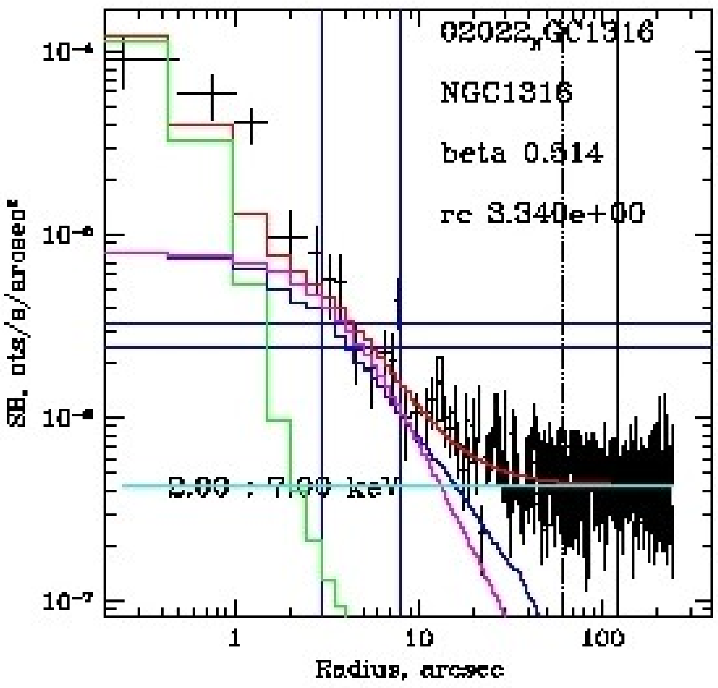






Measuring X-ray Components in E/S0 Galaxies



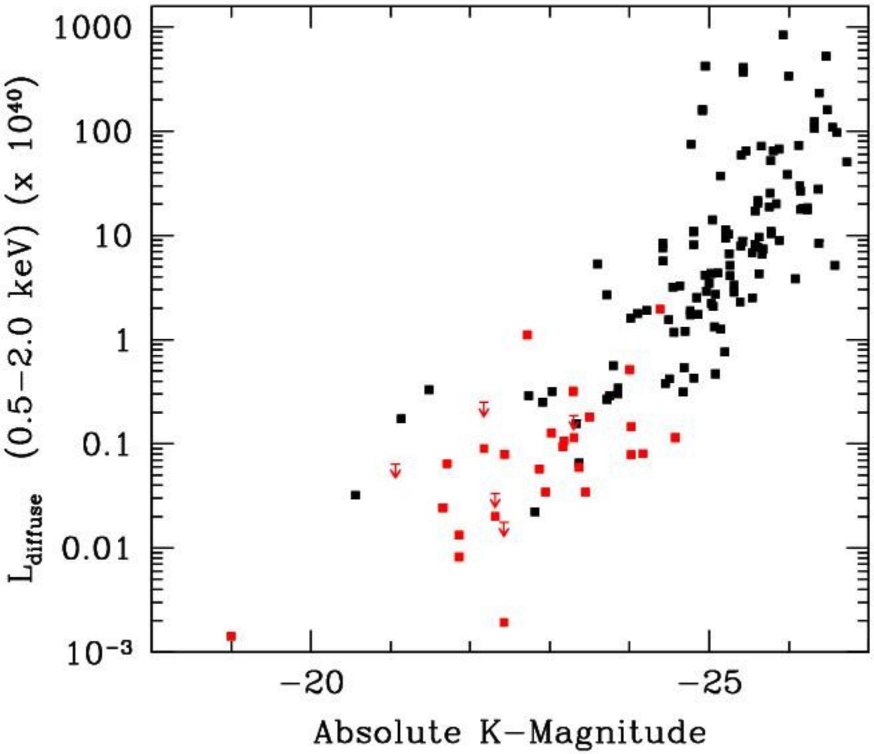


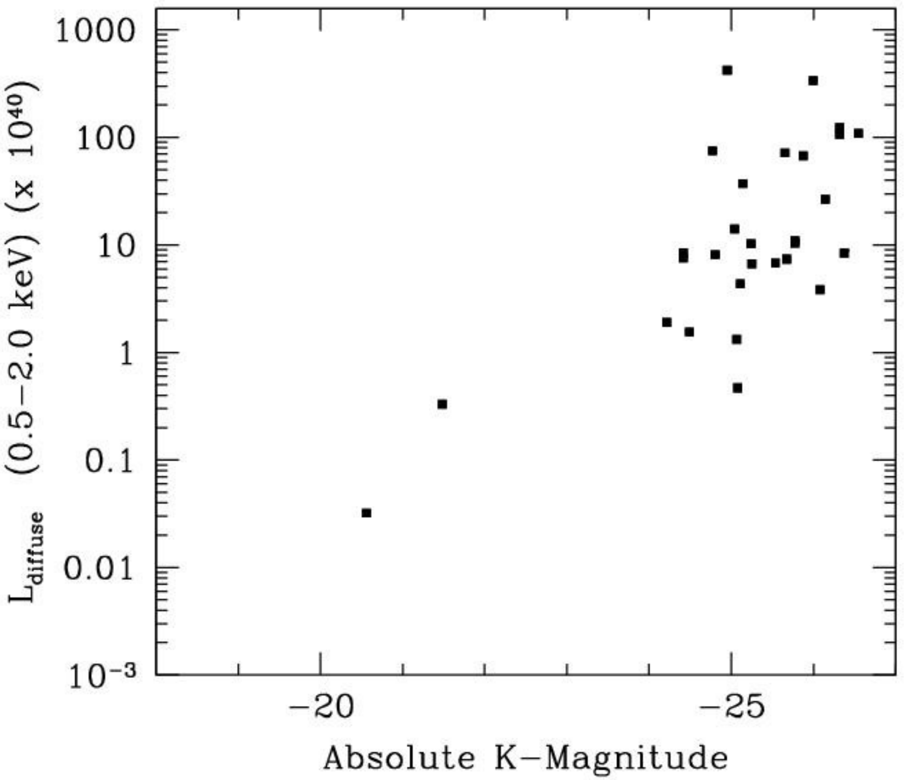
Fit diffuse ISM + point source in 0.3-2 keV (where ~1 keV ISM is bright)

Use 0.3-2 keV fit of ISM to measure hard emission (2-7 keV) from nucleus

Green = point source/AGN
Magenta = diffuse/hot gas
Red = sum
Blue=galaxy light

Measuring AGN emission in normal E/S0 Galaxies

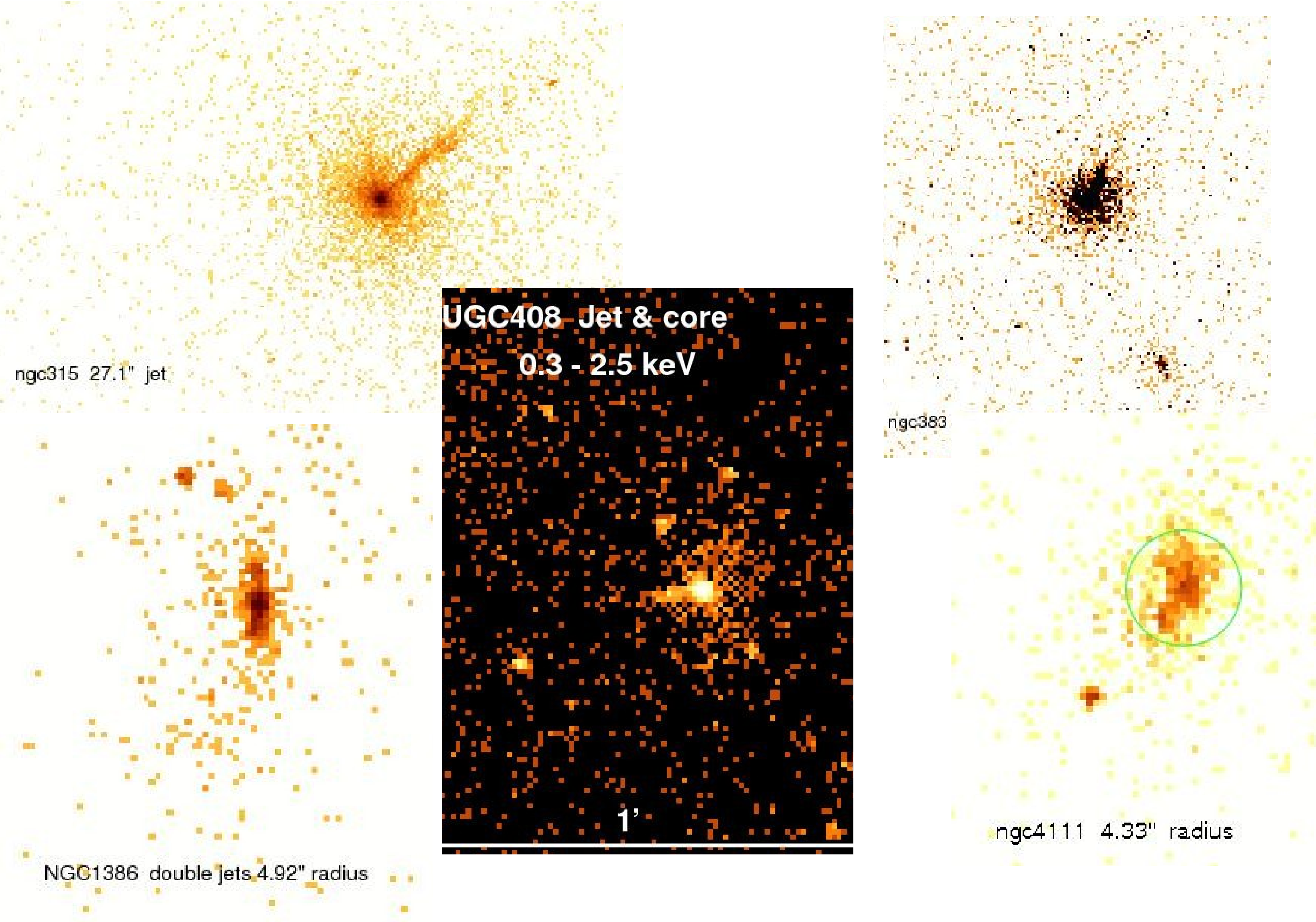




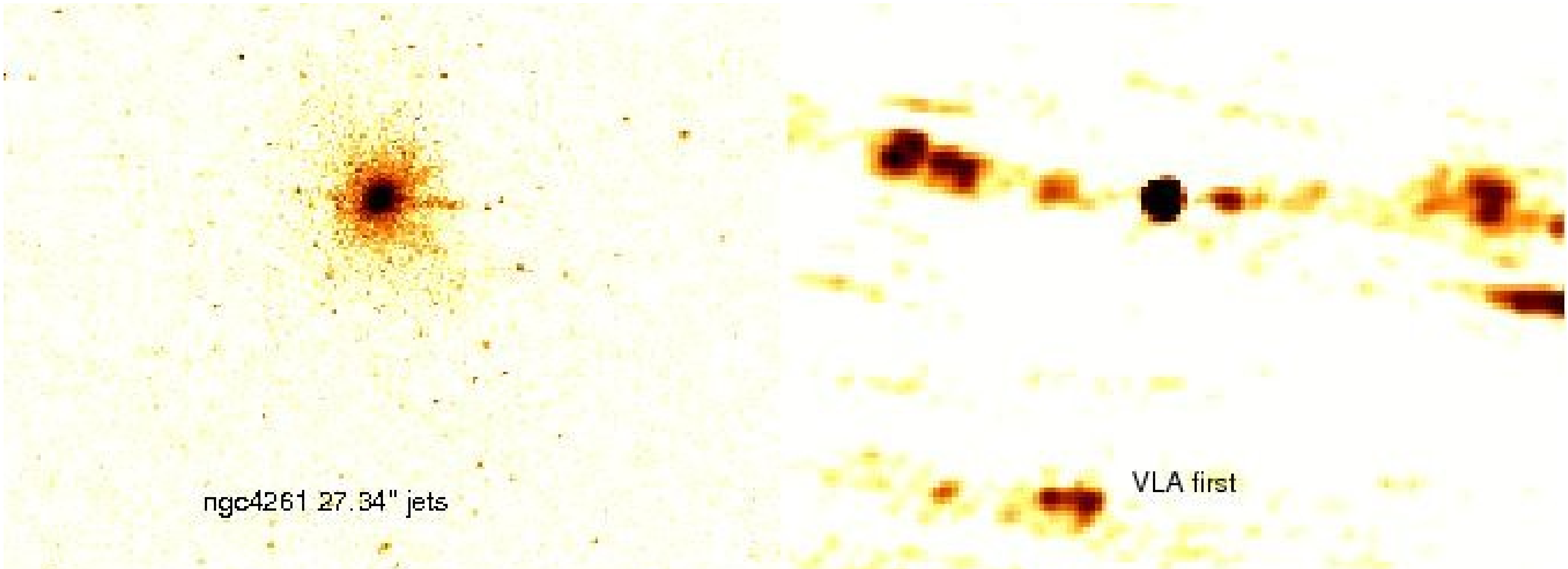
Red = LMXB's
Black = diffuse/hot gas

Galaxies with X-ray cavities
(30% of lumious systems)

Jets in Normal Gas-rich Early-type galaxies



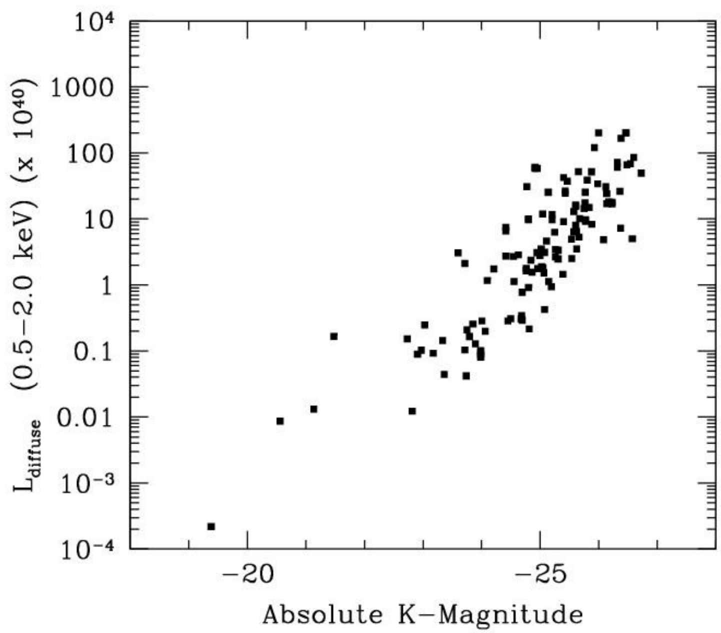
Often short, stubby X-ray Jets (compared to radio jets) in Normal Gas-rich Early-type galaxies

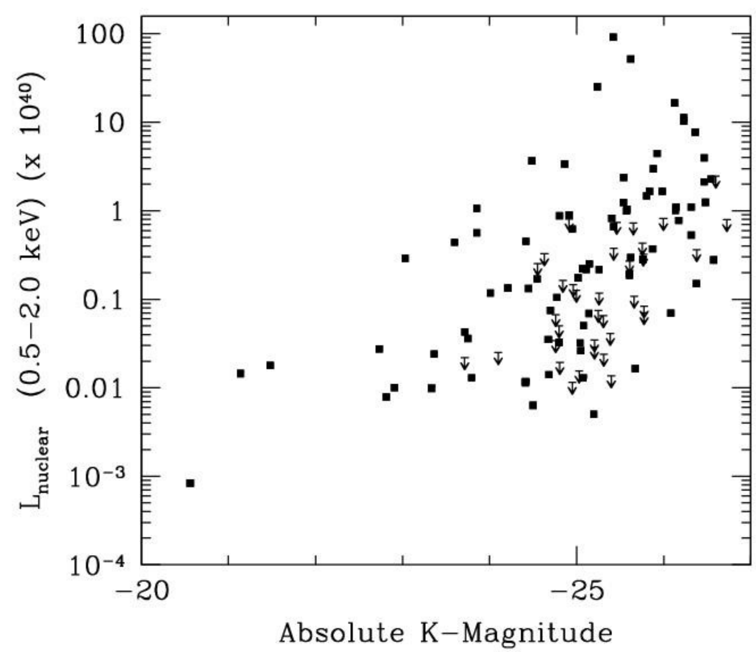


For 7 galaxies, X-ray jets are 0.24 to 4.2 kpc (ngc4261) in length

SMBH X-ray Luminosities in normal Early type Galaxies

Galaxies with hot gas

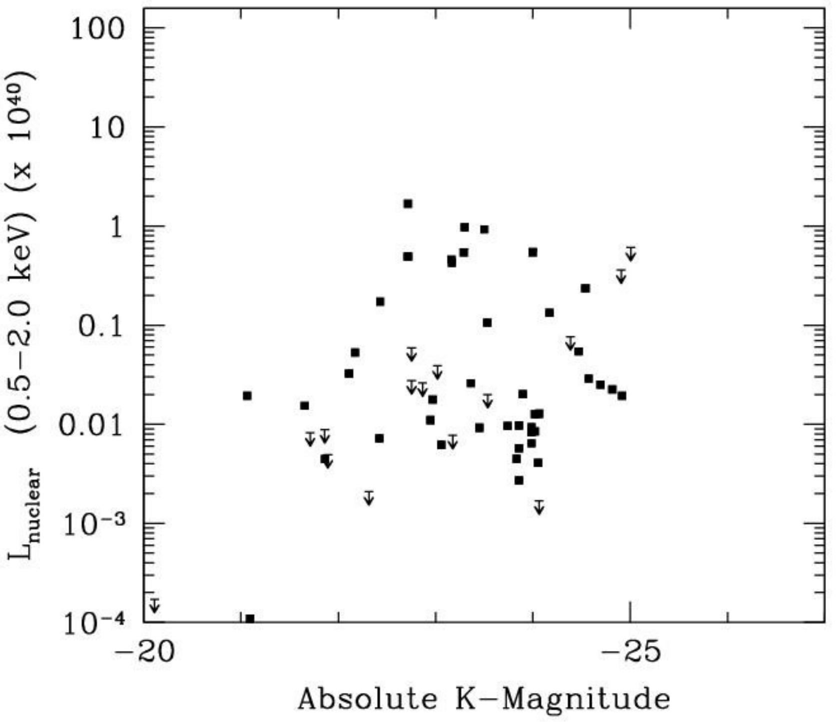




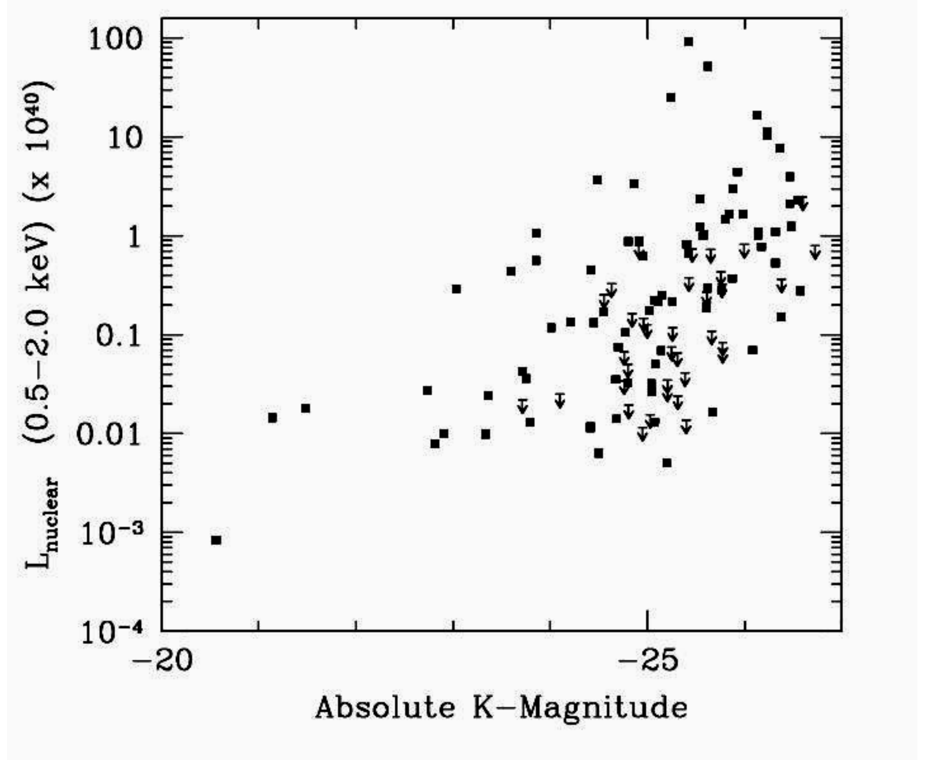
The most massive galaxies host the more luminous SMBH's

Luminosities range from ~10^{38} - 10^{42} erg s^{-1} (none > 10^{42} erg s^{-1})

SMBH X-ray Luminosities in normal Early type Galaxies



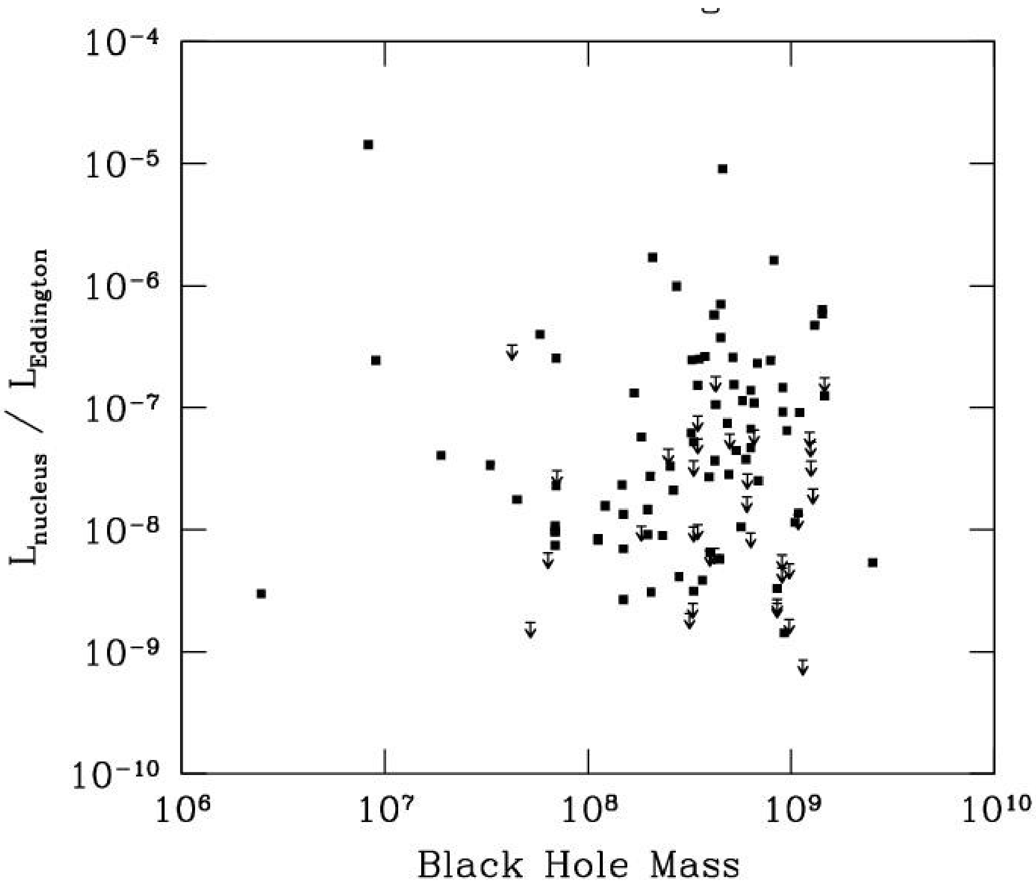
Galaxies with little/no hot gas



Galaxies with hot gas

Nuclear X-ray emission detected in 70% of SMBHs in galaxies with gas and from 75% of SMBHs in gas-poor galaxies

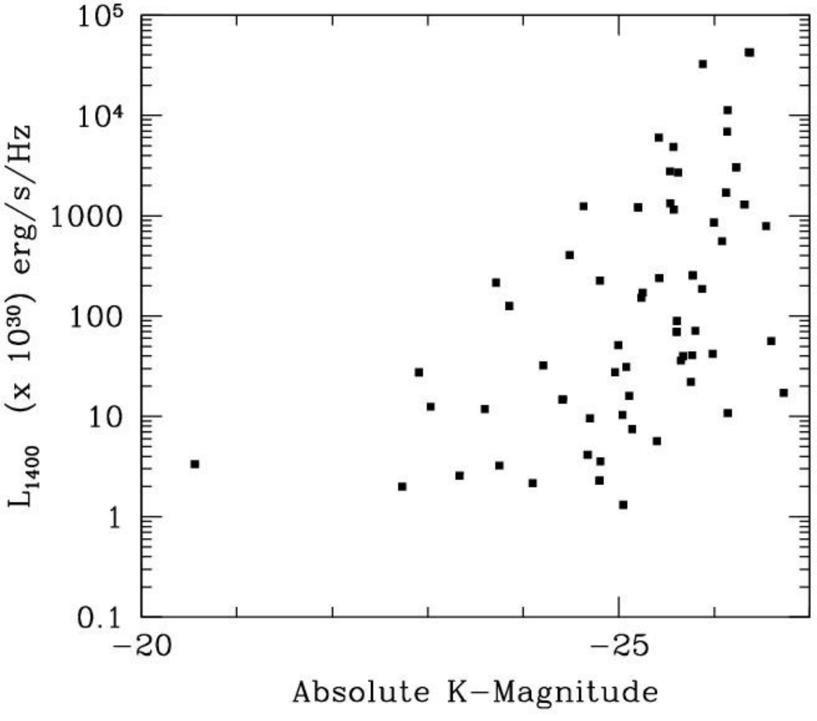
Eddington ratios for nuclear X-ray emission in normal early type galaxies

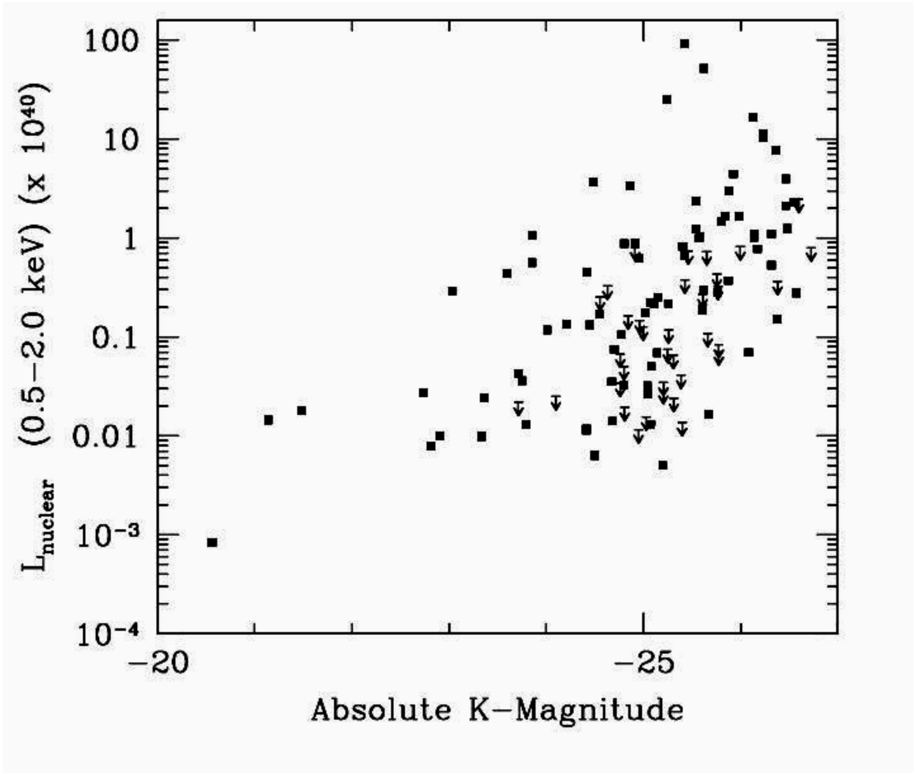


Eddington ratios ~10^{-5} to 10^{-9} in these low luminosity AGN

(for QSO's ~0.3)

SMBH X-ray and Radio Luminosities in normal Early type Galaxies



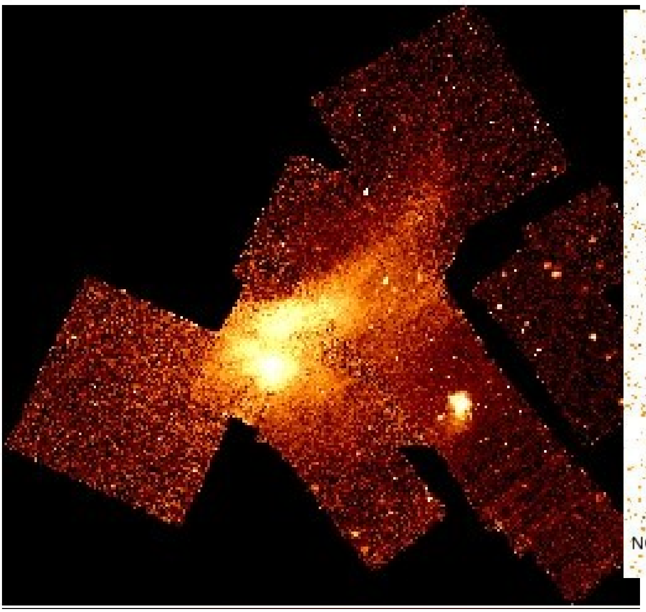


Nuclear X-ray emission detected in 70% of SMBHs in galaxies with gas

Radio emission (1400 MHz) detected in 83% of gas rich galaxies

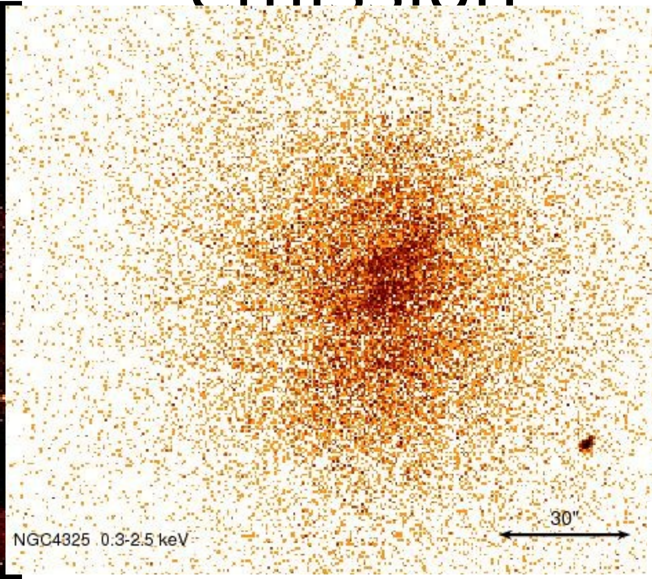
(only three galaxies brighter than -25 not detected in radio (or X-ray)

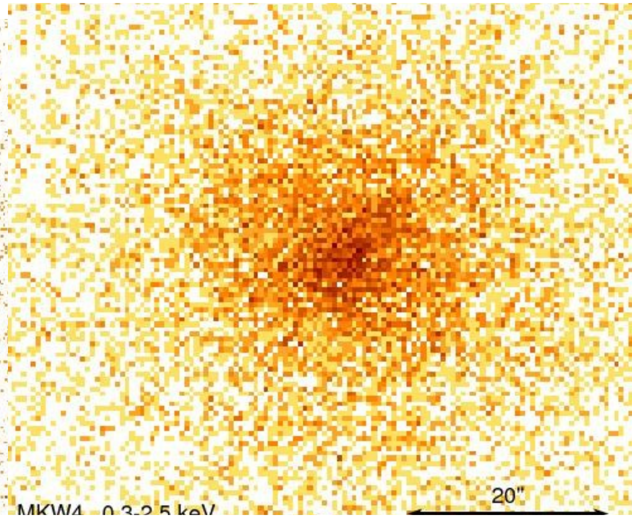
Three Luminous (Kmag <-25) ellipticals with no detected radio or X-ray nuclear emission

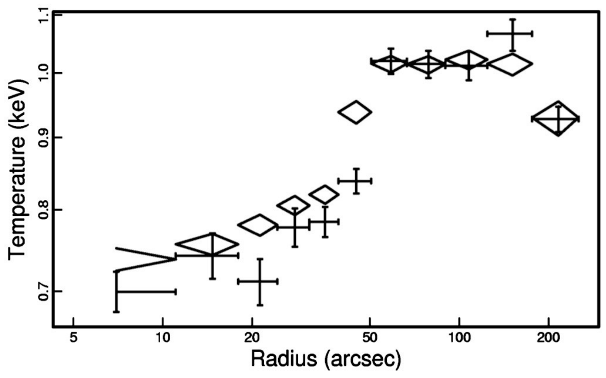


Randall et al. 2009

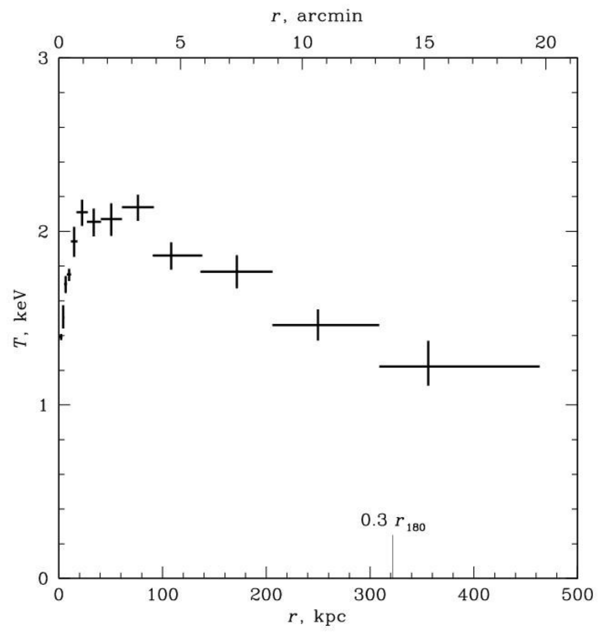
M86 falling into Virgo core with supersonic velocity.







Russell et al.



Vikhlinin et al.

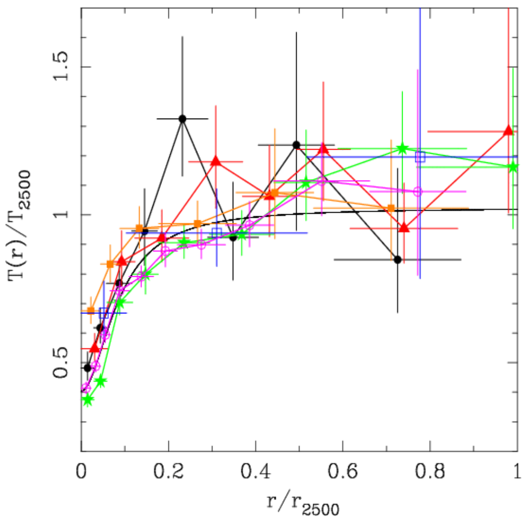
Summary - Emission and Outbursts from SMBHs in Normal Early type Galaxies

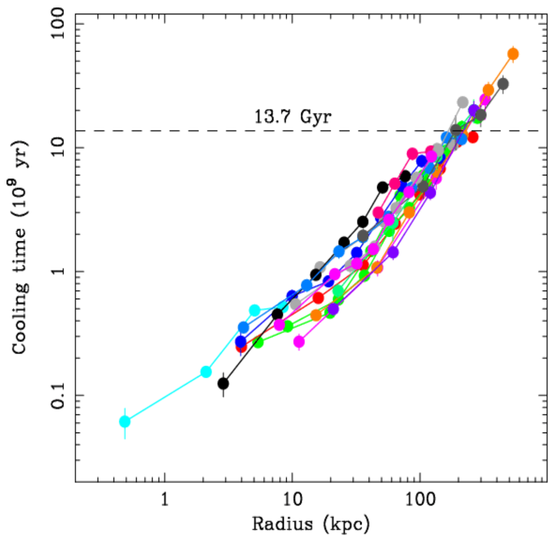
Kinetic energy from outbursts in galaxies 10^{55}-10^{58} ergs
(~ 5 10^{42} erg s^{-1})
30% of gas rich galaxies have had recent
(< few 10^{7} years) outbursts

Most gas-rich galaxies have nuclear X-ray (70% of galaxies) and
nuclear radio emission (83% of galaxies)
Nuclear X-ray emission 10^{38}-10^{42} ergs s-1

- **AGN feedback key to galaxy evolution - truncate star formation**

Problems that outbursts "solve"



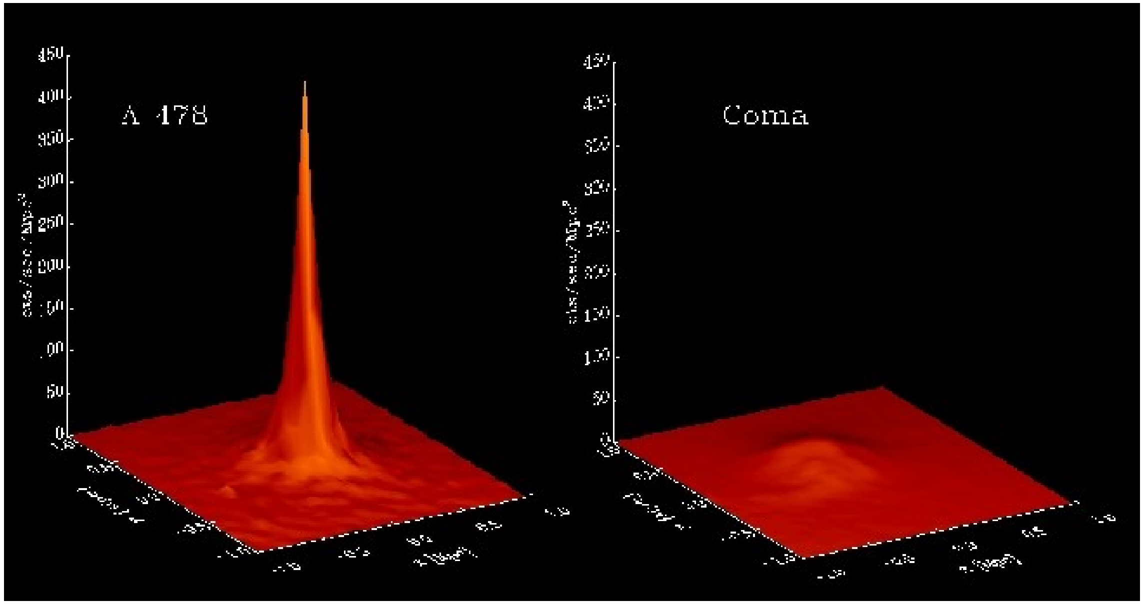


Cooling flow problem

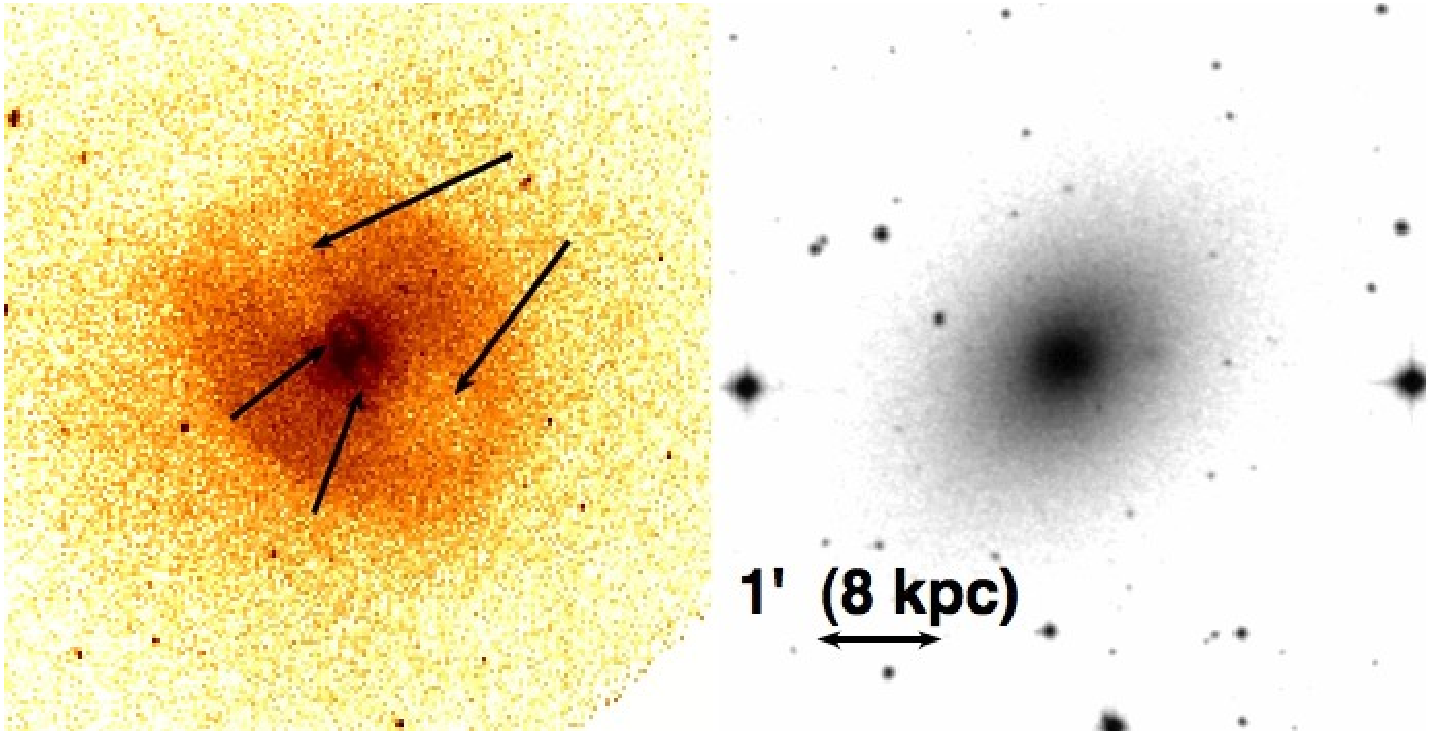
Radiative cooling times are short in cluster cores

➢Large mass cooling rates

AGN outbursts reheat cooling gas



AGN Outbursts in Groups and Galaxies



NGC5813 Multiple outbursts - 3 sets of cavities
plus sharp outer edge from shock (Forman et al 2009)

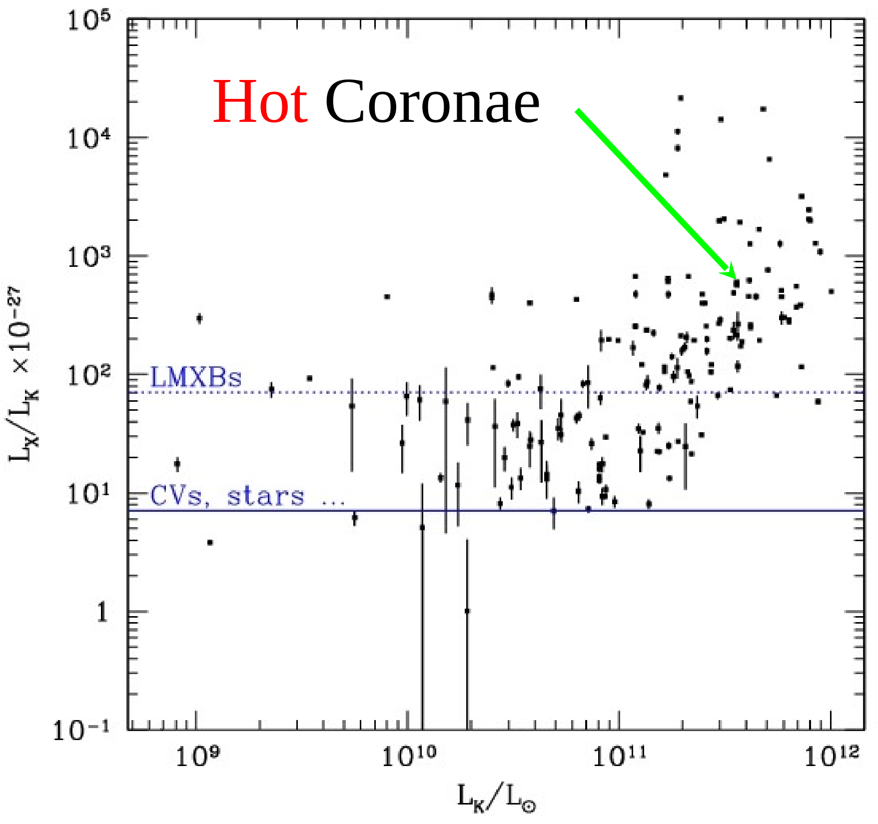
Shock velocity 480 km s^{-1} (M ~1.15).
~10^{55} ergs to produce middle cavities (~5 kpc diameter).

Outburst age 22 10^6 yrs

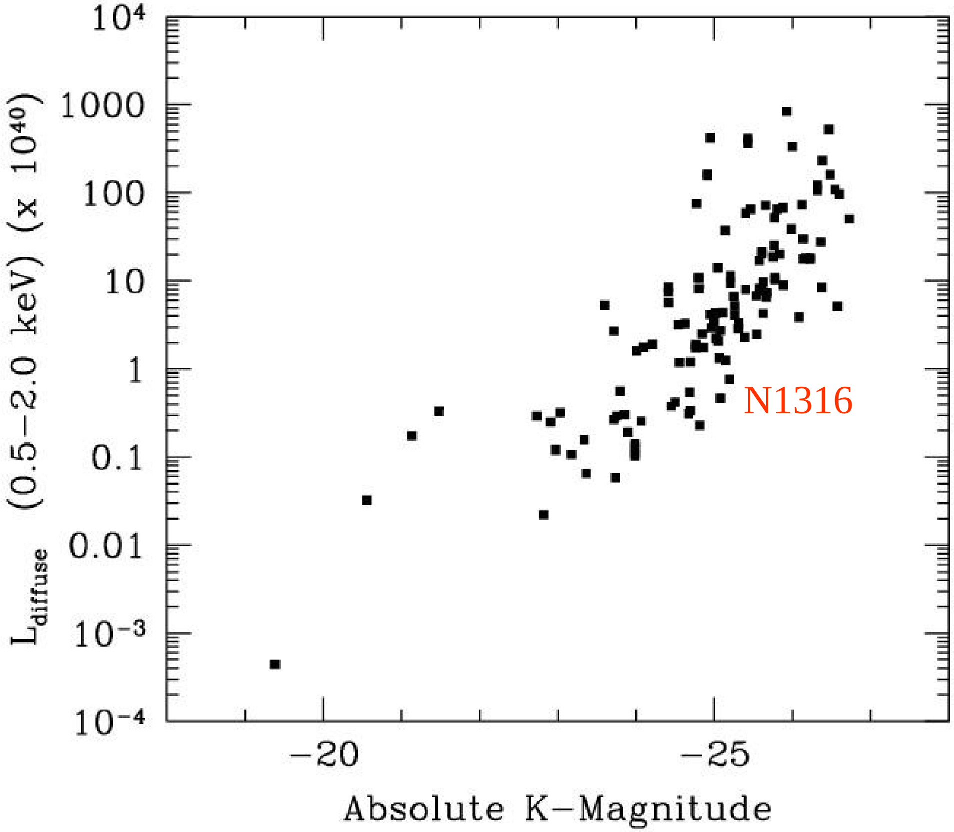
AGN Outbursts in Normal Early type Galaxies

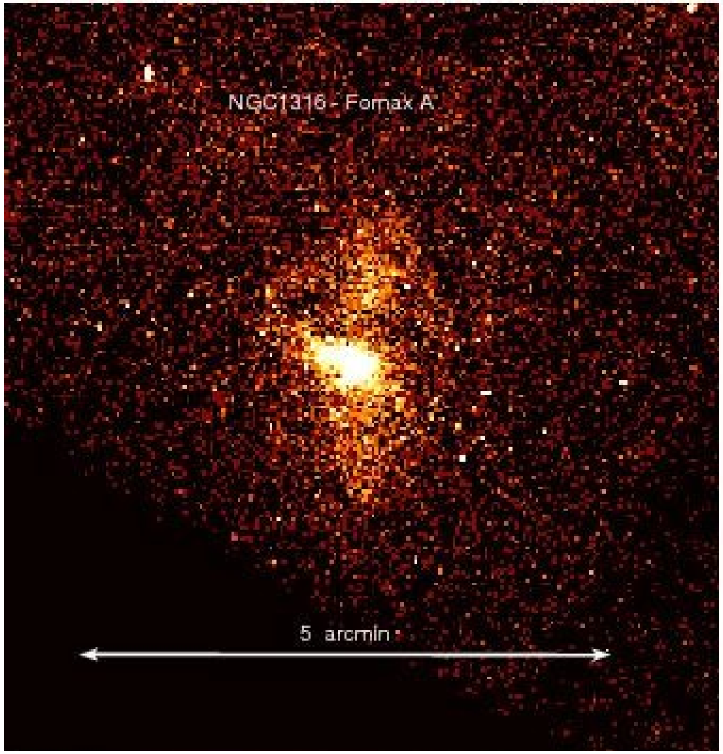
Luminous (massive) E/S0 Galaxies have hot coronae

X-ray components
- LMXB's (some resolved)
- CV's and active stars
- Hot gas
    - kT~0.5-1.5 keV
    - Dominates at high mass
    - Provides fuel for SMBH
    - Captures energy from SMBH outbursts



In galaxies, AGN outbursts can remove gas





NGC1316 = Fornax A

Scatter in L_X-opt mag relation is partly due to gas removal and partly due to environment (galaxies in the centers of groups

Outbursts from Clusters to Galaxies

SOURCE	SHOCK RADIUS (kpc)	ENERGY (10^{61} erg)	AGE (My)	MEAN POWER (10^{46} erg/s)	ΔM (**10^8 M_{sun}**)
MS0735.6	230	5.7	104	1.7	3
Hercules A	160	3	59	1.6	1.7
Hydra A	210	0.9	136	0.2	0.5
M87	14	0.0005	12	0.0012	0.0003
NGC4636	5	0.00006	3	0.0007	0.00003

Growth of SMBH by accretion in "old" stellar population systems with star formation to maintain M_{BH}-M_{bulge} relation

Mechanical outburst power balances radiative cooling
AGN outbursts deposit energy into gas through shocks and bubbles

M87 properties of outburst (2-5 10^6 yr duration and slowly expanding)