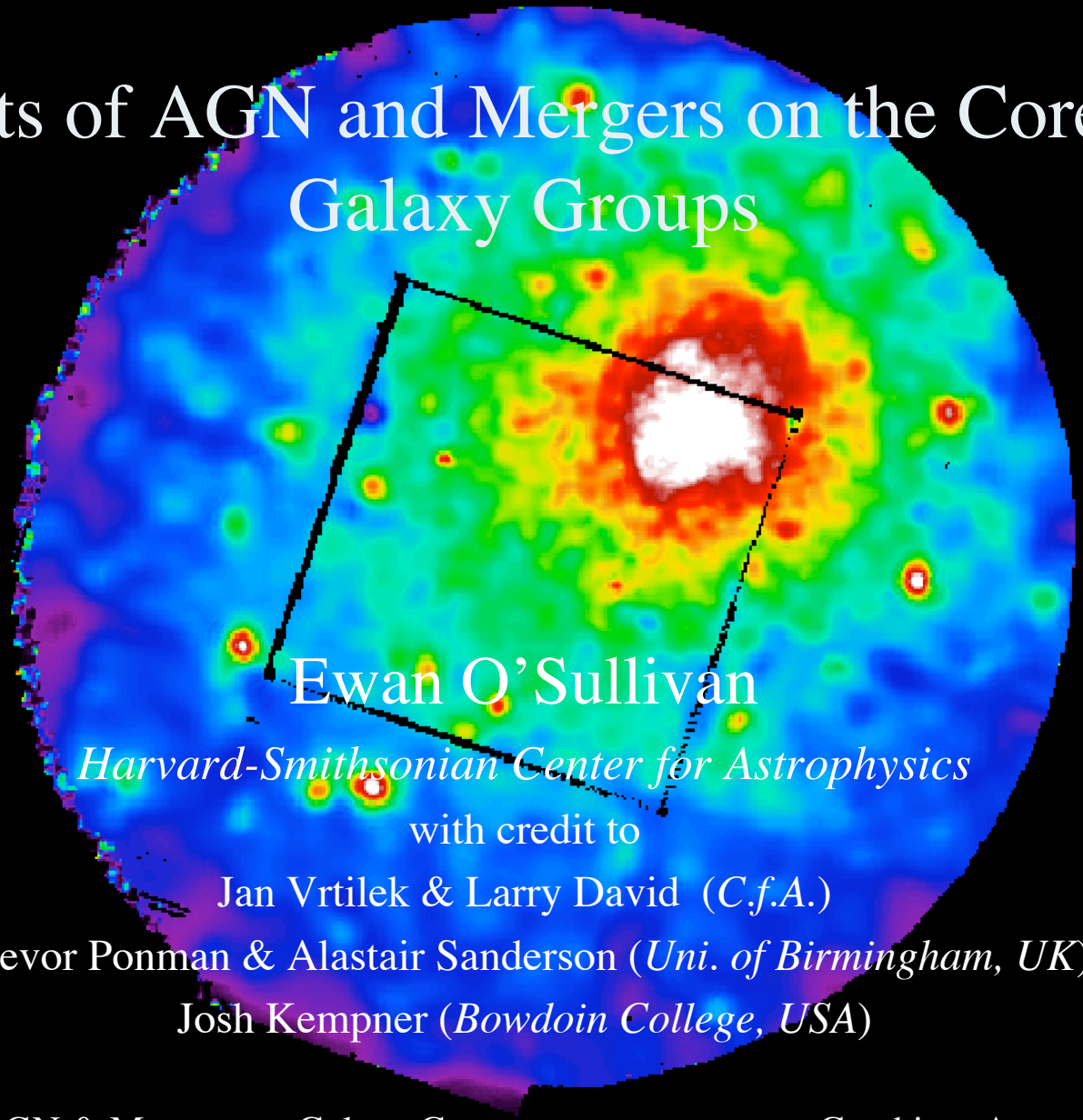
Effects of AGN and Mergers on the Cores of Galaxy Groups



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X-ray halos of galaxy groups

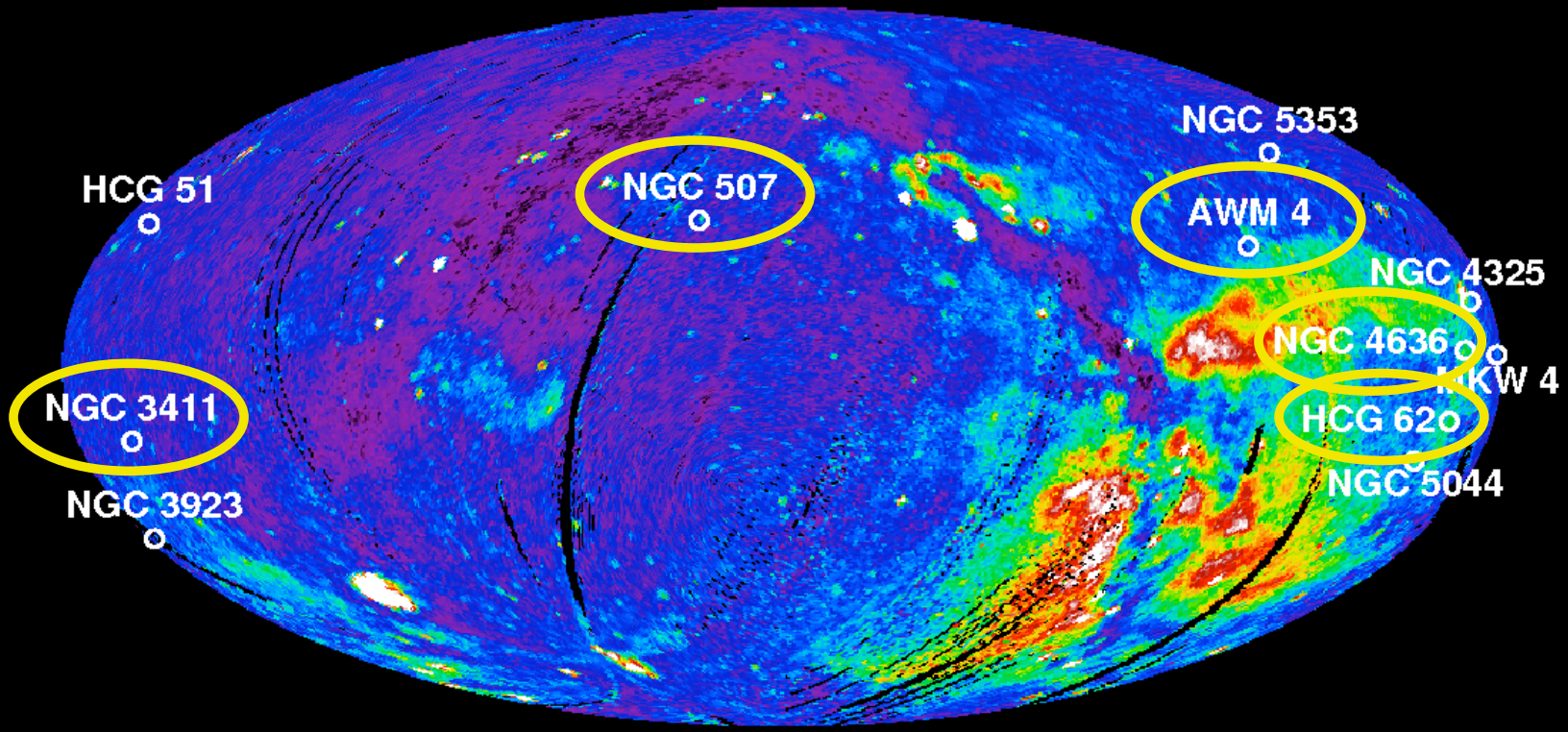
- Galaxy groups bridge the mass range between massive, bright, well-studied clusters, and individual galaxy halos.
- Shallow potential wells mean smaller energy inputs are required to produce disturbed structures.
- Rapid cooling times should fuel central AGN outbursts.

$\Rightarrow$ Groups with central radio galaxies known to fall below L_X:T relation - high kT or low L_X (Croston et al 2004)

- Galaxy infall and group mergers may also be important.

$\Rightarrow$ What kinds of interactions do we observe and how do they affect group properties (entropy, cooling time)?

Sample of X-ray bright groups

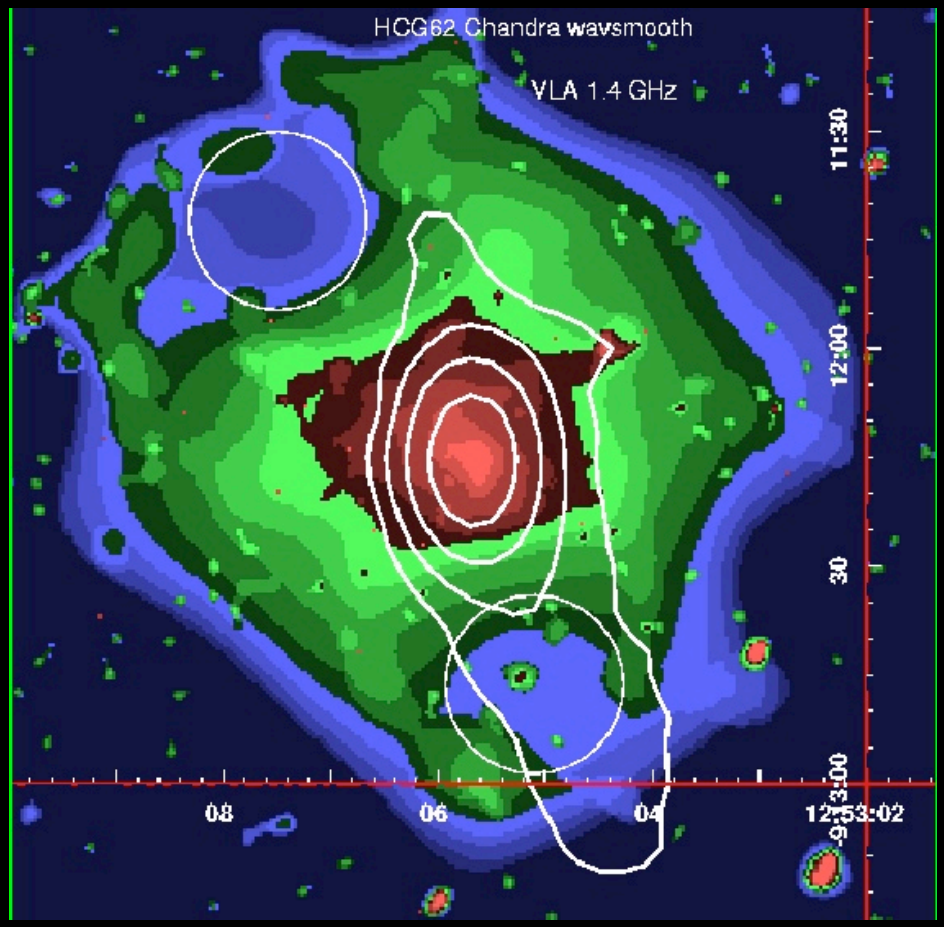


ROSAT 3/4 keV map with groups marked

- 23 Groups from XMM-Newton, 16 from Chandra
- 11 with high quality X-ray data, 5 have disturbed cores

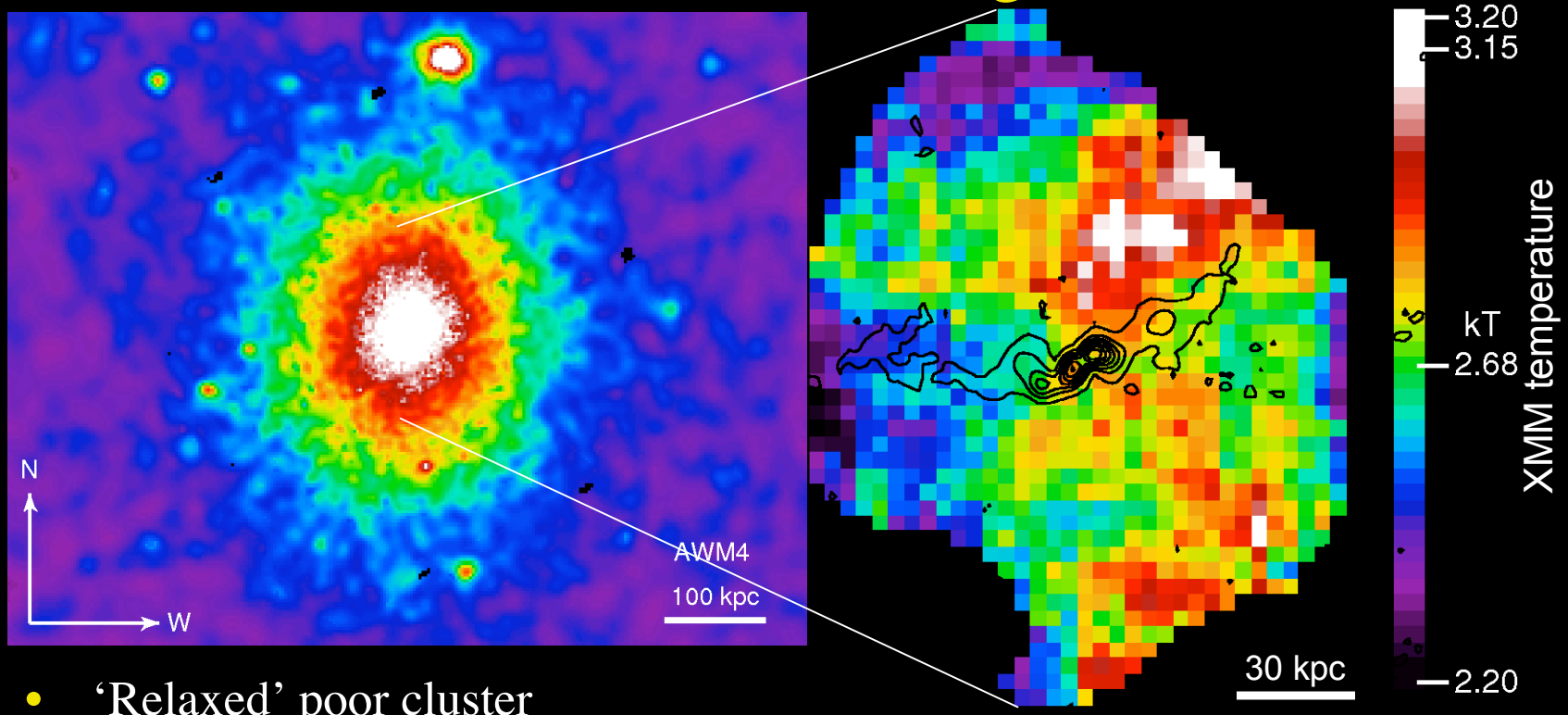
Ghost cavities: HCG 62

- Cavities clear in Chandra image (rare in groups)
- Energy required to inflate cavities (few 10^{56} erg) sufficient to stop cooling
- Radio source extends over southern cavity (at 1.4 GHz), but is weak, $L_R \sim 2 \times 10^{38}$ erg/s
- $\sim 10^{42}$ erg/s outburst $< 2 \times 10^7$ yr ago.
- See Morita et al (2006) + poster upstairs for more details



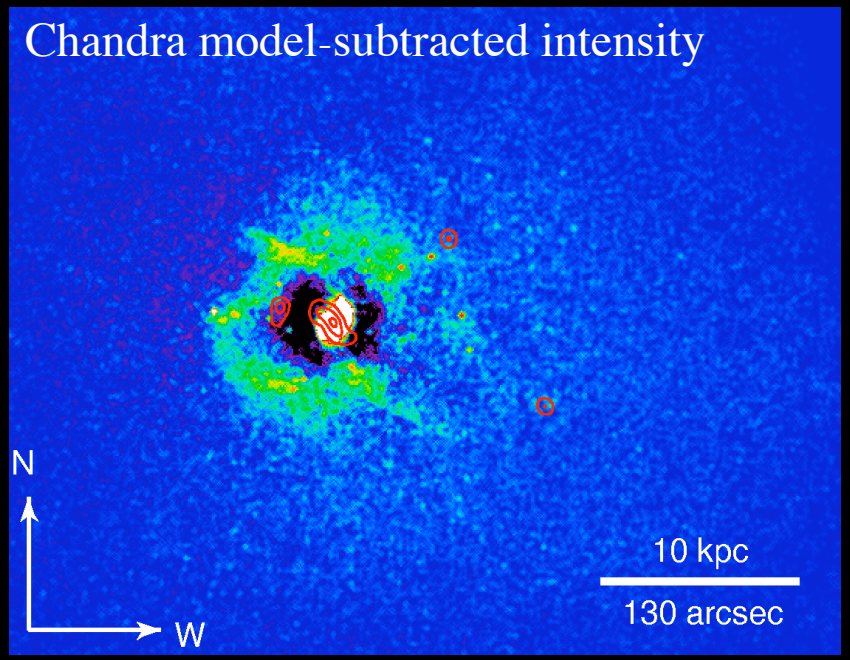
Smoothed Chandra image, VLA radio contours

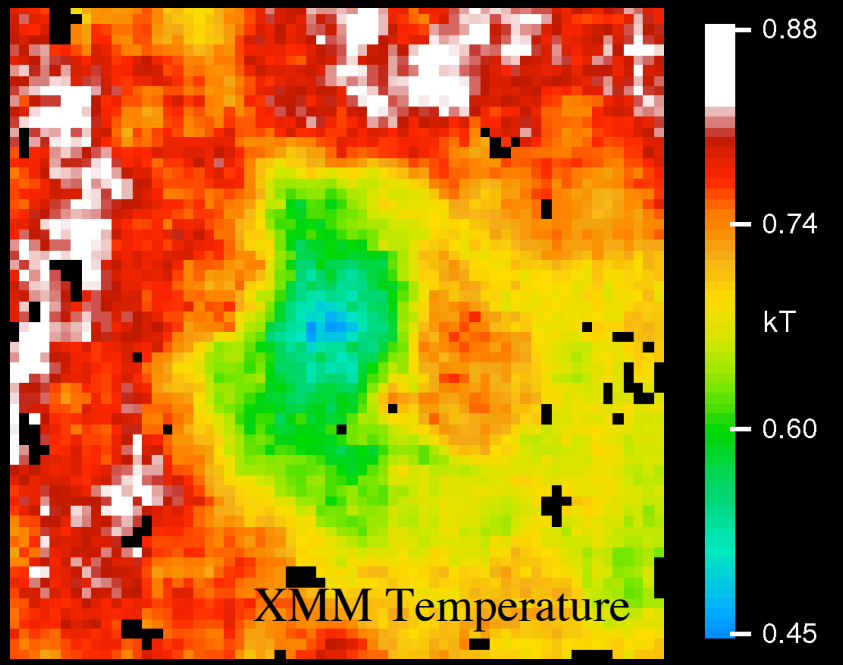
Jet-driven shock heating: AWM 4



- 'Relaxed' poor cluster
- Isothermal (2.6 keV) to >250 kpc radius. Not a post-merger system
- kT and Abundance maps reveal strong AGN interaction - shock NW of core coincident with highly enriched gas (O'Sullivan et al 2005a)
- 10^{59} erg required to produce isothermal core, but radio source very powerful ($L_{radio}=9\times10^{41}$, $L_{mech}=3\times10^{43}$ erg s^{-1}) for a group

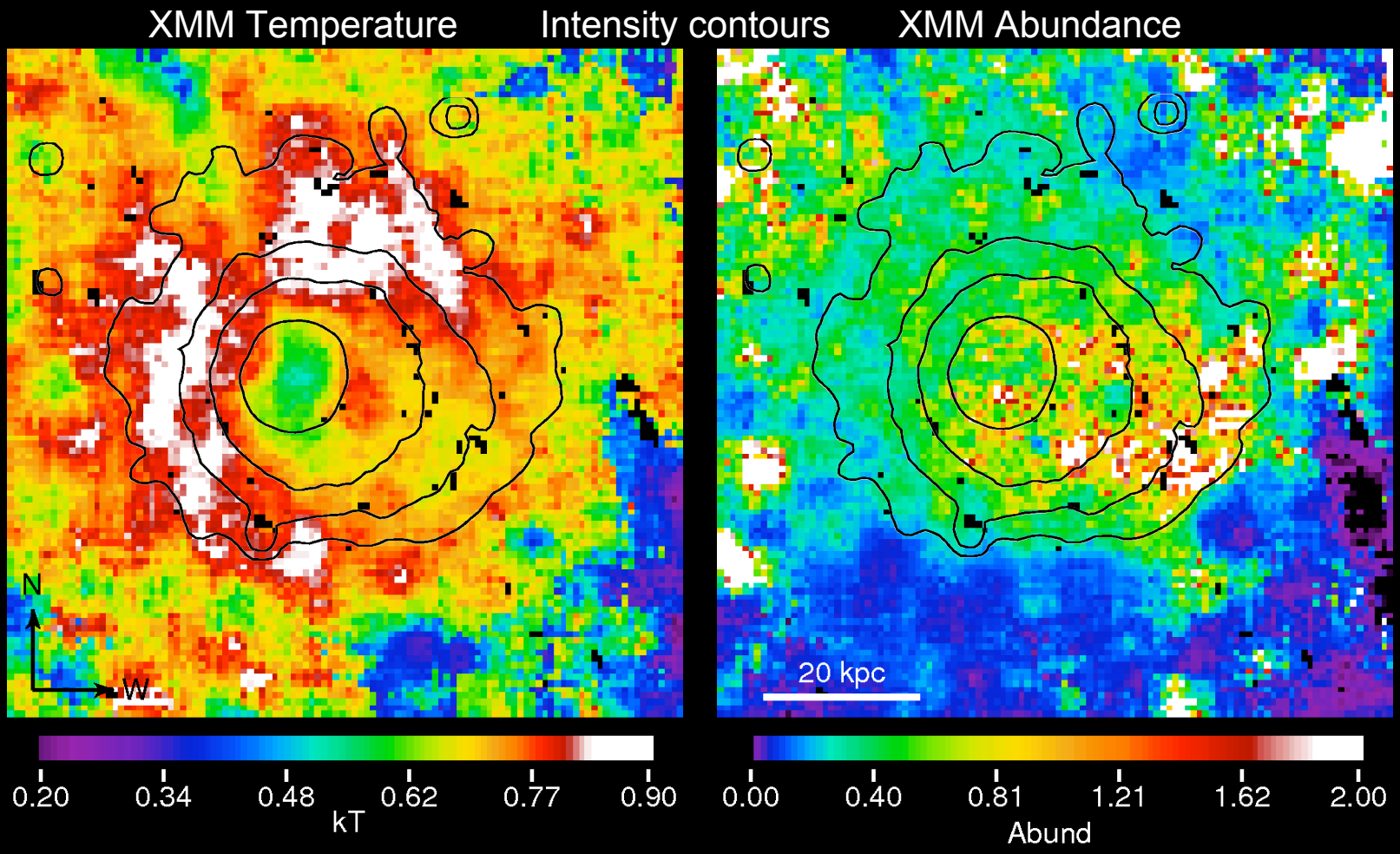
Shocks and cavities: NGC 4636





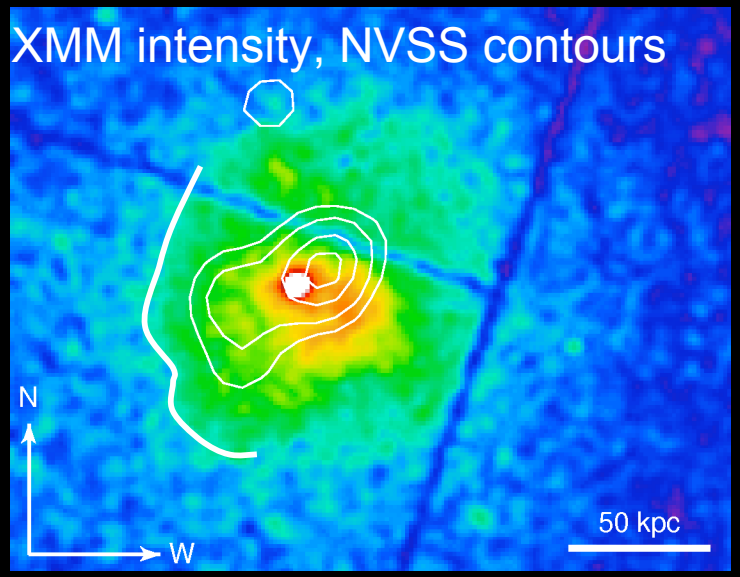
- Radio source only slightly extended, $L_{radio}=1.4\times10^{38}$ erg s^{-1}, jet power < 3×10^{41} erg s^{-1} (Bicknell et al 1997)
- 'Spiral-arms' are weak shocks with energy ~6×10^{56} erg from outburst few 10^6 ago (Jones et al 2002)
- Cavity to East visible only in temperature map, requires ~3×10^{57} erg to inflate over few 10^7 yr (O'Sullivan et al 2005b)

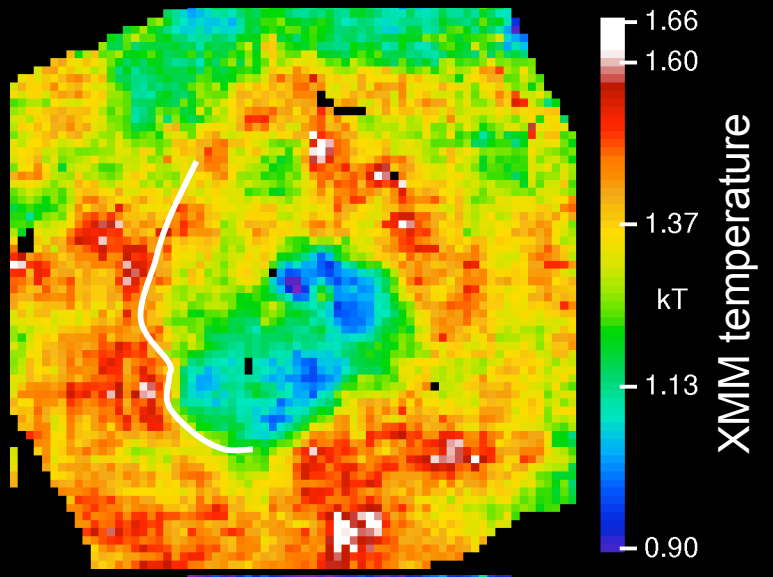
Gas mixing and IGM enrichment: NGC 4636

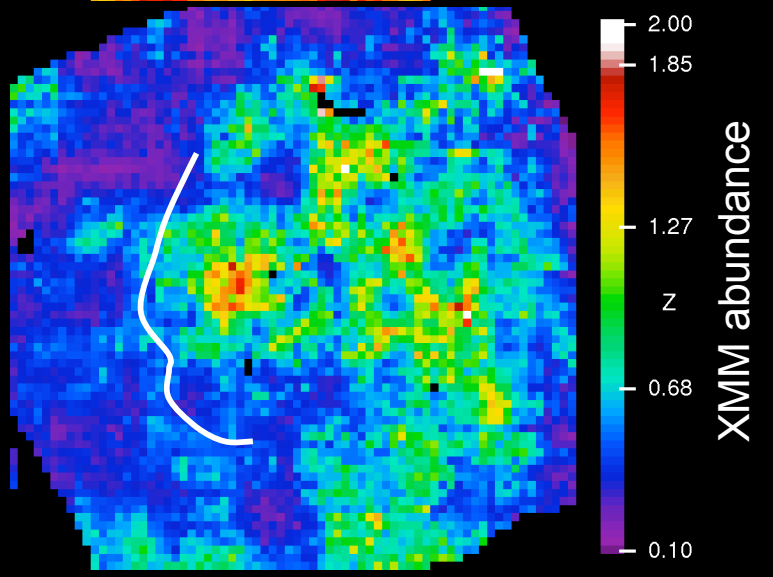


- ~3x10^8 $M_\odot$ of cool, enriched gas in plume extending 30 kpc

Gas motions in NGC 507







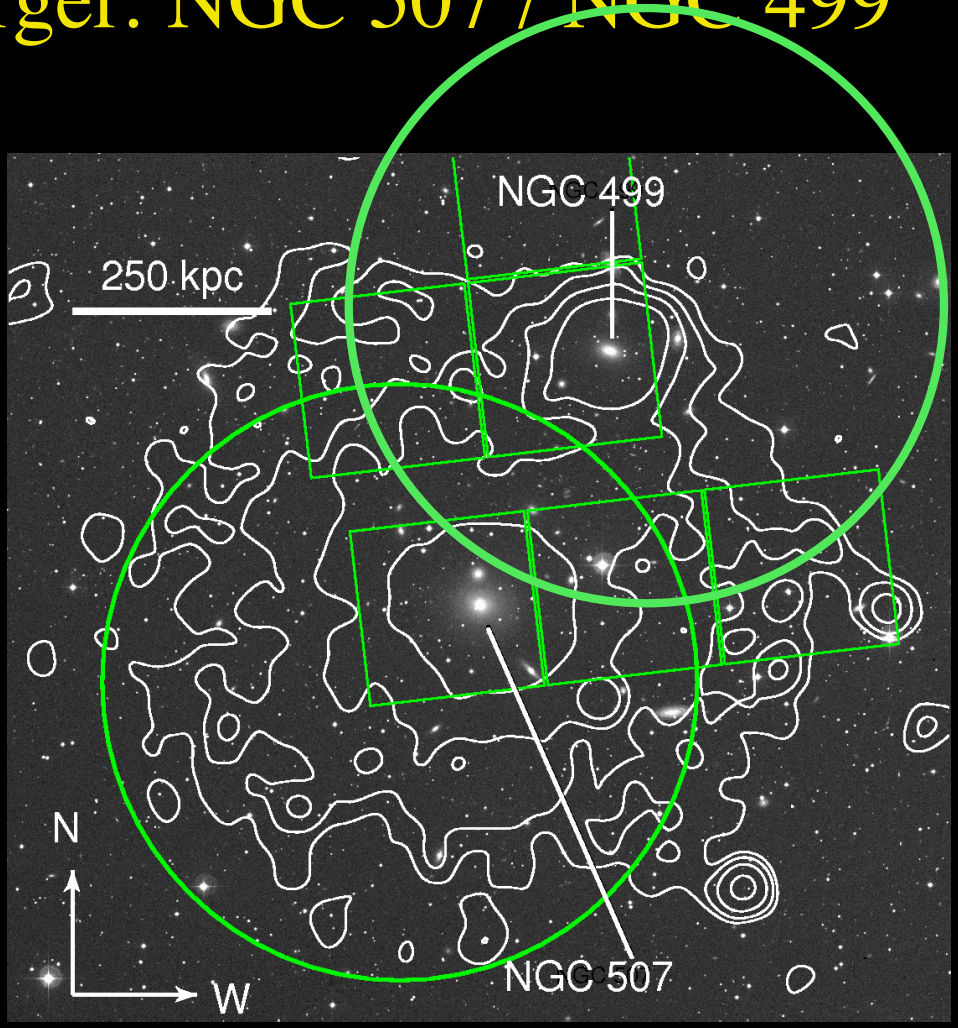
- FR-I radio galaxy (Parma et al 1996) with enough power to stop cooling (few10^{58} erg to inflate cavities)
- See also Tracy Clarke's talk
- Coolest and highest abundance gas displaced ~25 kpc from galaxy core.
- Surface brightness edge caused by combination of T and Z features (Kraft et al 2004)

Group / group merger: NGC 507 / NGC 499

- NGC 499 center of second peak in group X-ray halo

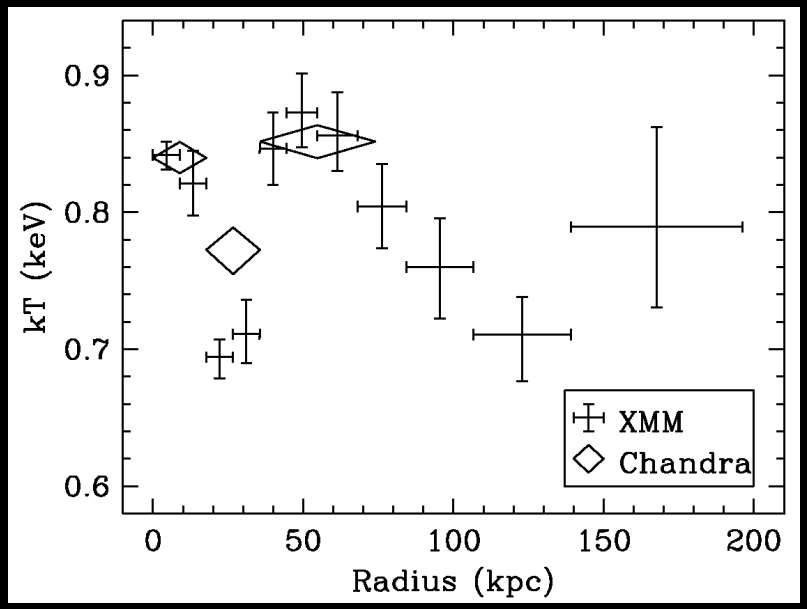
⇒ Likely group/group or galaxy/group merger, but is NGC 499 going North or South?

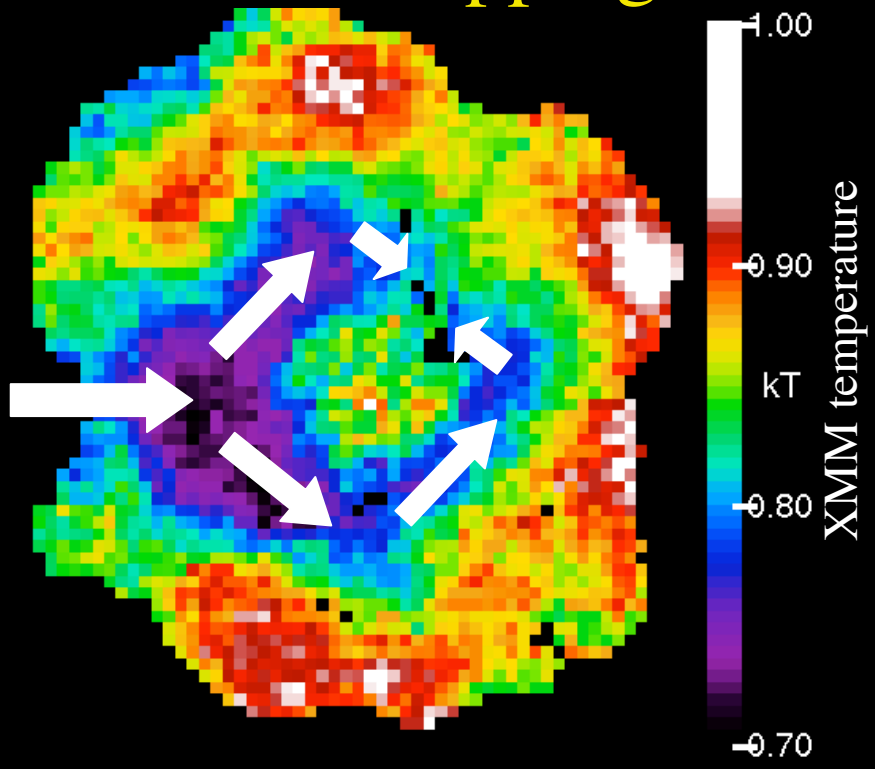
- Brief Chandra observation misses area between galaxies
- XMM observation only covers NGC 507, but new XMM observation coming…



ROSAT PSPC contours on DSS image

NGC 3411: Galaxy infall and stripping?

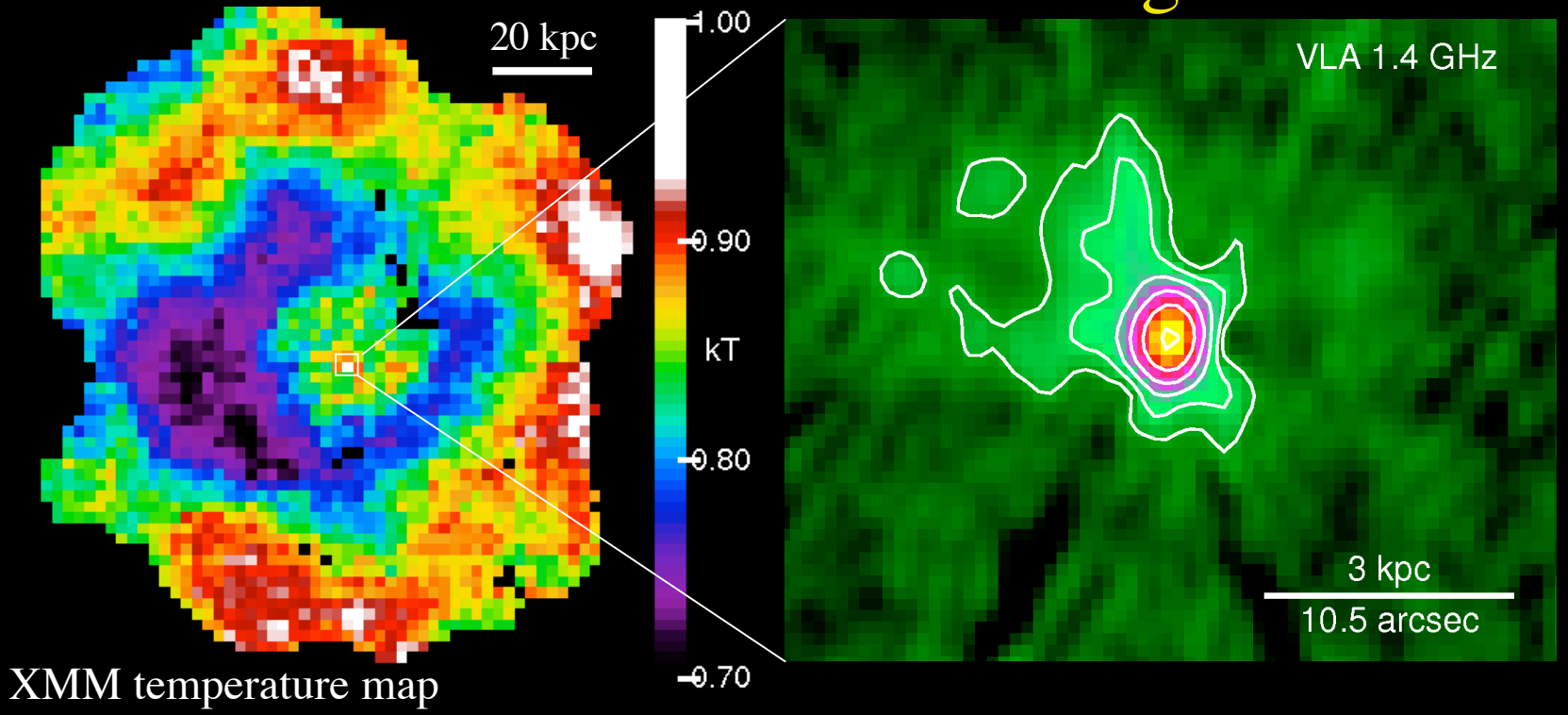




- Cool gas from infalling elliptical galaxy?
- Stripped gas sinks until point of equal entropy is reached, surrounds core
- $M_{gas}=3.4x10^9$ ✓

• Problems: nearby galaxies are spirals or S0s, why group core hot before infall?

NGC 3411: AGN heating?



XMM temperature map

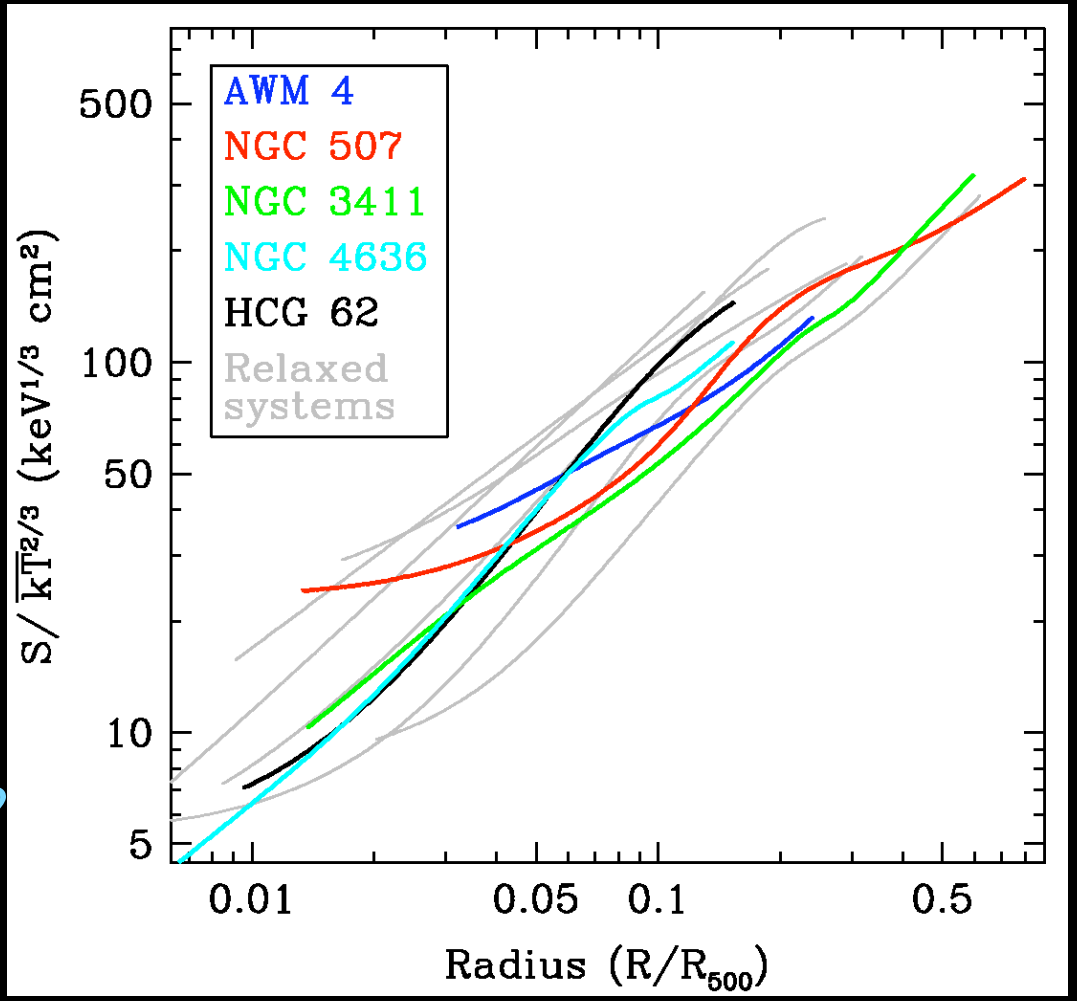
- ≥2x10^{57} erg required to reheat cool core over ~30 Myr
- VLA high resolution data reveals no jet, only small scale diffuse emission.
- L_{radio}=3x10^{38} erg s^{-1} but L_{cool}=10^{42} erg s^{-1} ⇒ core is cooling.

Summary of AGN activity

Group	Features observed	Energy (erg)	L_{radio} (erg s^{-1})	Age (yr)
HCG62	Ghost cavities	5×10^{56}	9×10^{37}	2×10^{7}
NGC 3411	Reheated core	2×10^{57}	3×10^{38}	3×10^{7}
NGC 4636	Weak shocks, cavities, gas motion (30 kpc)	3×10^{57} (3×10^{56})	10^{38}	5×10^{7} (10^{6})
NGC 507	Radio lobes, gas motion (25 kpc)	8×10^{58}	$\sim 10^{40}$	Now
AWM 4	Shocks, isothermal core gas motion (35 kpc)	9×10^{58}	9×10^{40}	Now

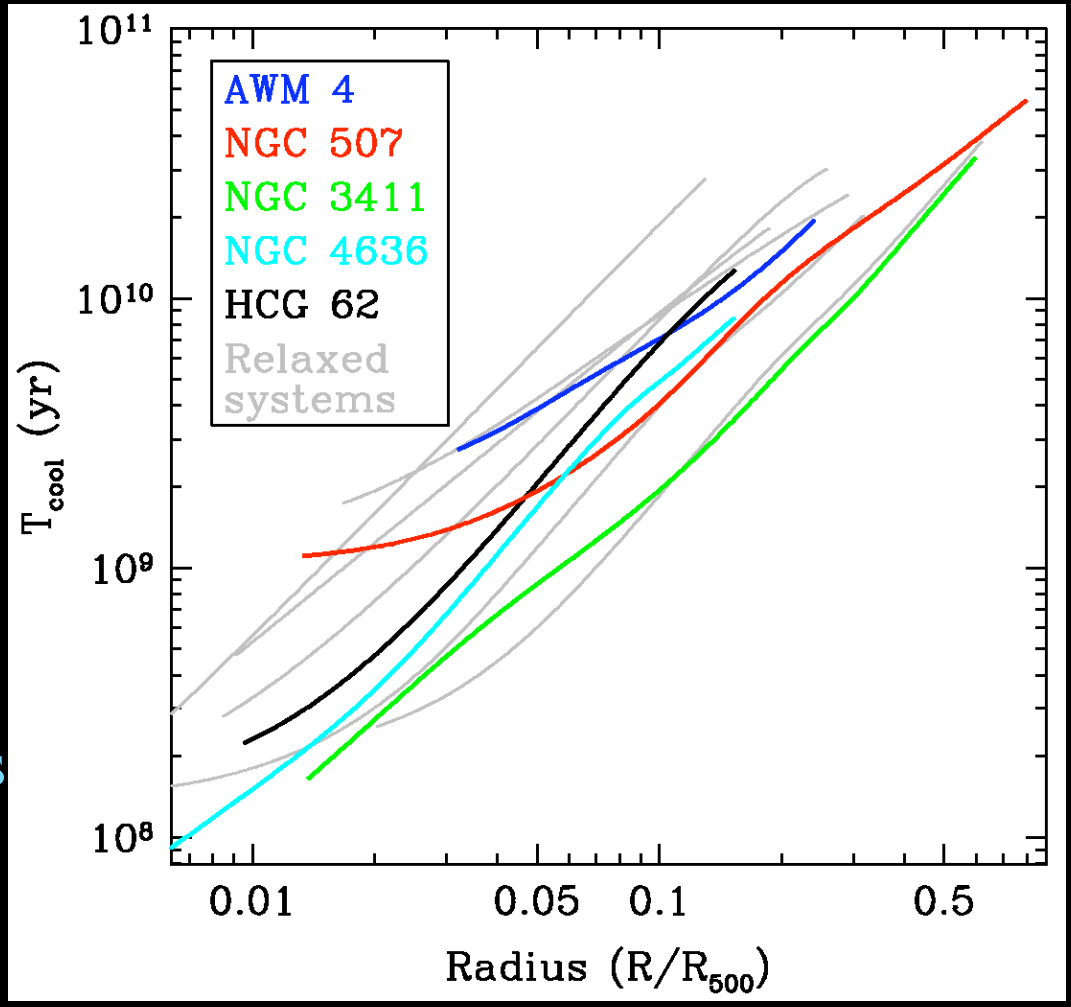
Entropy Profiles

- Most relaxed systems decline smoothly
- HCG 62, NGC 4636, NGC 3411 also decline in core
- AWM 4, NGC 507 have shallower gradients and higher entropy in core
- Small outbursts have little long-term effect on S ⇒Weak shocks?
- Ongoing, strong heating is visible



Cooling Time Profiles

- NGC 3411, NGC 4636, HCG 62 all have short central T_{cool} despite heating (and mixing).
- AWM 4 and NGC 507 have flatter profiles, $T_{cool} > 10^9$ yr at small radii.
- Mild AGN outbursts stop cooling but T_{cool} unchanged?



Conclusions

- Many of the best observed groups have disturbed structures in their cores (and there will be cases we cannot detect).
- AGN appear to provide enough energy to balance cooling.
- Wide range of total power from outbursts (10^{56}-10^{59} erg)

$\Rightarrow$ Low power heating process adiabatic (weak shocks?)

$\Rightarrow$ More powerful outbursts do affect core entropy, T_{cool}, and can erase cooling cores completely (AWM 4)

- AGN may also mix group gas, transporting metals out to enrich the halo or broaden central abundance peak.
- Group mergers and galaxy infall may cause heating and mixing of gas, but as yet few systems have been studied in detail. Watch this space…