Normal and Extreme Galaxies

What one might learn about gas from eROSITA

– *Christine Jones, CfA*

Why study groups?
Finding groups in the optical and X-ray
Examples of extreme galaxies
- *Fossil groups*
- *AGN outbursts*
- *Infalling groups*

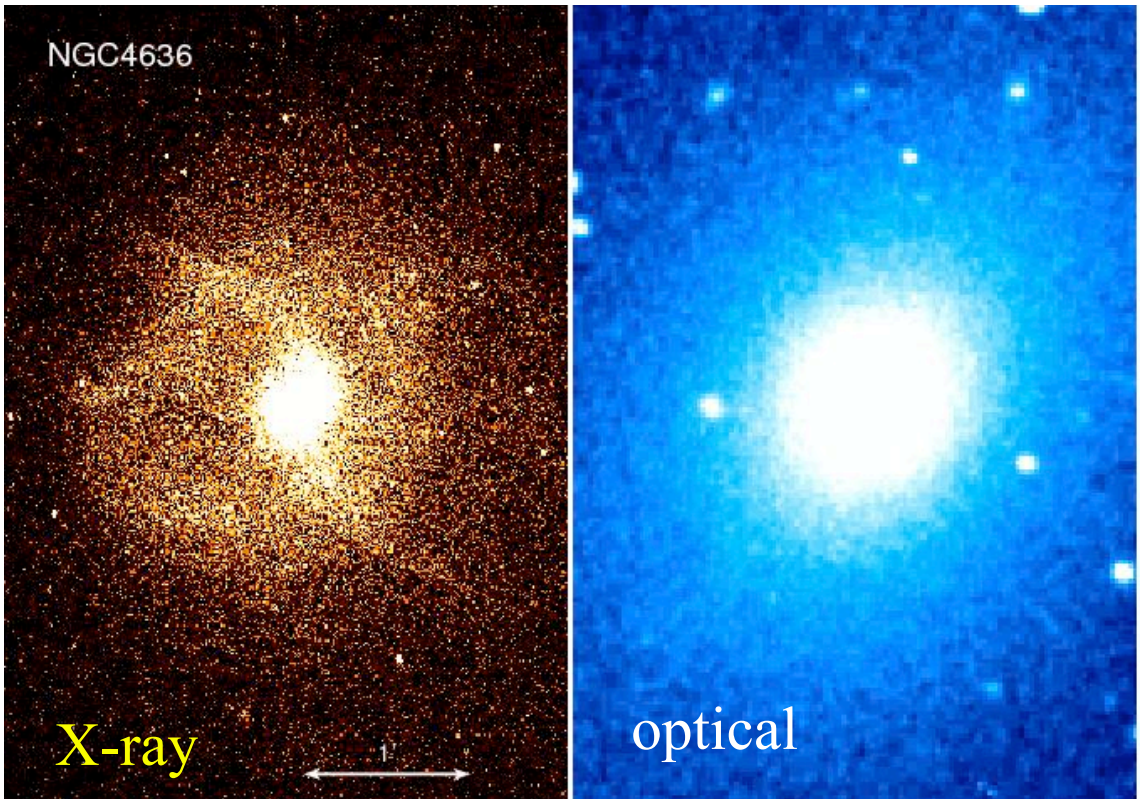
Why study groups?

Groups are not scaled down versions of clusters (following simple self similar relations) e.g. Voit 2005

Instead in groups, other processes (e.g. AGN feedback, cooling) and not just gravity, are important

Groups outnumber rich clusters by about two orders of magnitude

But have maximum luminosities of ~10^{43} ergs/s, while clusters reach 10^{45} ergs/s



More reasons to study groups

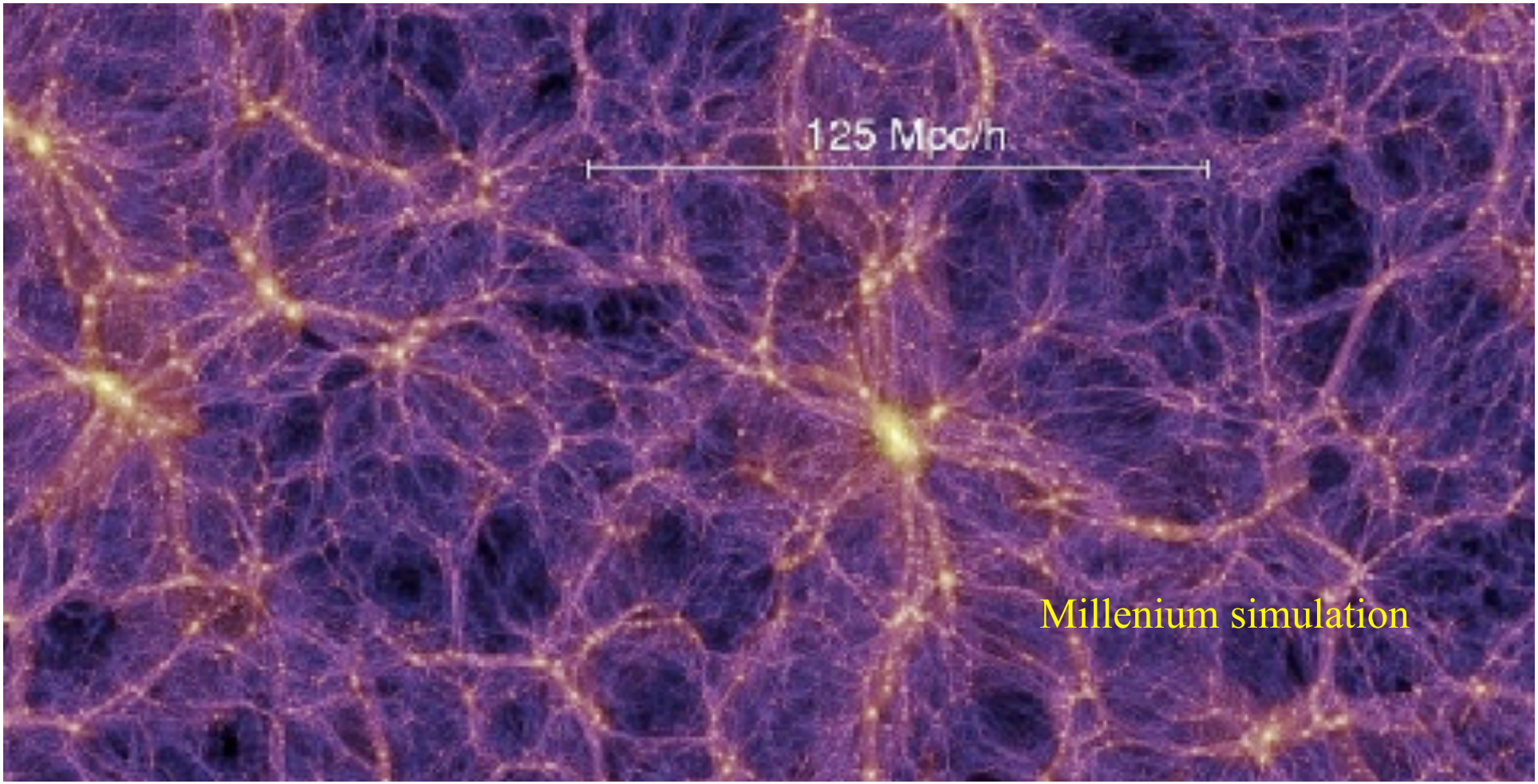
50-70% of all galaxies are in groups (probably bound groups) – Turner & Gott (1976), Geller & Huchra (1983), Tully (1987)

Study of local groups may provide clues to processes at high redshifts, when galaxy groups were the largest bound structures.

Half of the SZ power at $l = 3000$ comes from halos 10^{13} h^{-1} to $1.5\ 10^{14}$ h^{-1} M_{sun} and $z>0.5$ (Trac 2010)

Groups trace LSS

Like pearls on a necklace, groups trace large scale structure



"Small groups of galaxies are important cosmological indicators of the distribution and properties of the dark matter in the Universe" Carlberg et al 2001 ApJ.

Identifying groups – so far mostly optical

IMAGES

Stephan's Quintet, discovered in 1877 by Edward Stephan at Marseille Observatory

Shakhbazian and collaborators examined >200 POSS prints (18% of sky) and cataloged 377 compact groups.

Followed by Rose (1977) who examined plates 7.5% of sky found ~200 groups

Hickson (1982, 1993, 1994) from POSS prints - 100 groups in 67% of sky. (8 superpositions)

SPECTRA

Ramella et al (2002) found 1168 groups from Zwicky update and Southern Sky Redshift survey

Carlberg et al (2001) found ~200 groups from CNOC redshift survey

Cluster catalogs from photometric and spectroscopic SDSS data.
Max BCG - 13,823 clusters with velocity dispersions >400 km/s in 7500 sq deg $0.1<z<0.3$.
GMBCG - SDSS DR7 – follow-up to BCG extends to $z=0.55$

SDSS DR6 catalog of 69,173 clusters $0.045<z<0.78$ in 8420 sq deg
(Szabo et al ApJ 736, 21, 2011) threshold of ~ 4×10^{13} M_{sun}

X-ray identifications of groups

Important ROSAT studies of optically selected groups by Henry+ (1995), Ponman+(1996), Osmond and Ponman (2004; GEMS 60 groups)

X-RAY FOLLOWUP OF OPTICALLY SELECTED GROUPS

- RASCALS (from CfA redshift survey ROSAT All Sky Survey – (Mahdavi + 2000) 260 from redshifts with at least 5 galaxies – - 61 detected in X-rays covering 25% of sky – $<Lx> = 6 \times 10^{42}$ ergs/s
- Santos+ (2007) found 34 fossil groups by matching extended RASS sources with SDSS Luminous Red Galaxies
- Mulchaey+(2003) found X-rays from 61 of 109 optical groups

X-RAY DETECTIONS OF GROUPS

- Vikhlinin+(1999) found 4 fossil groups in 160 sq deg survey
- Mulchaey+ (2006) found 9 groups ($0.23<z<0.59$) RDCS (Rosati+)
- Eckmiller+ (2011) HIFLUGS, NORAS, REFLEX sample of 72 groups. 26 have $\sim 10^{42}$ – 3 x 10^{43} ergs/sec
- 45 groups in 9.3 sq deg Chandra Bootes survey

X-ray Properties of Groups

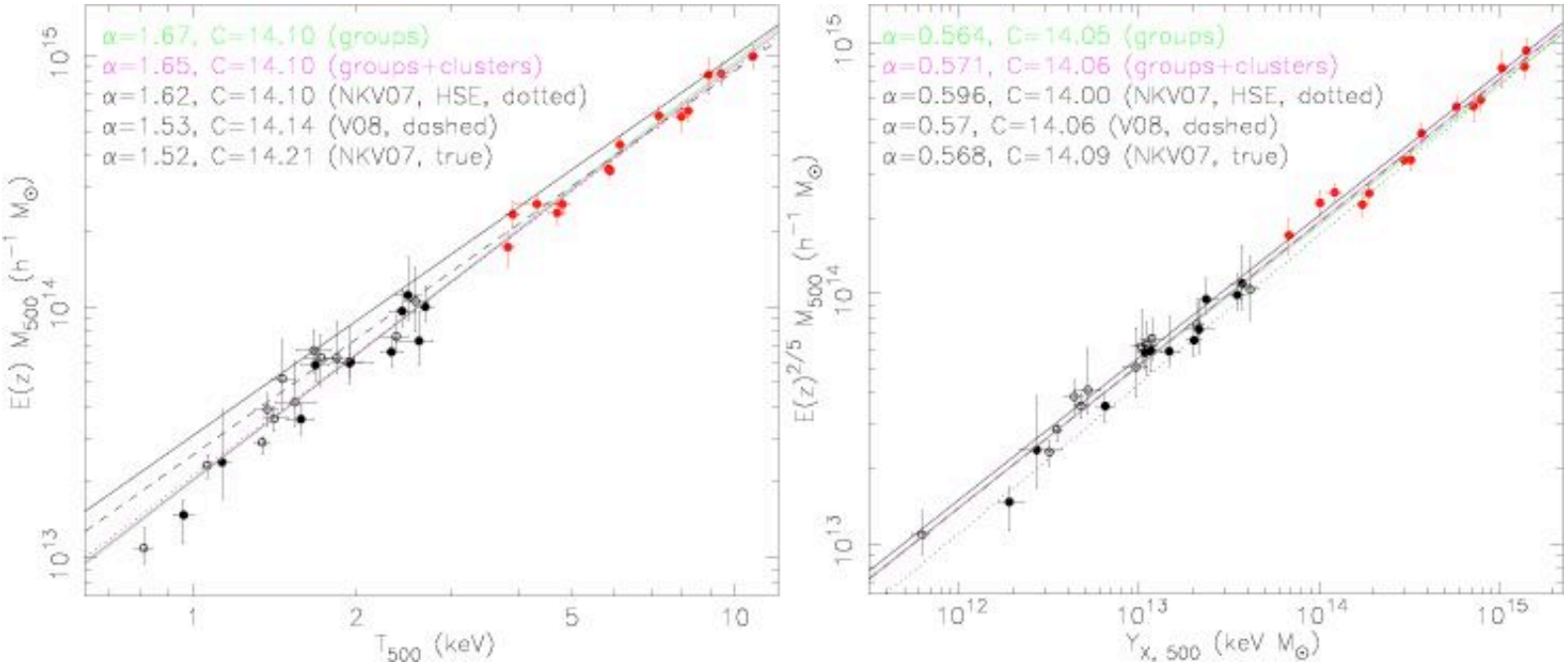
Extended X-ray emission (few hundred kpc to ~ 1 Mpc)

$5 \times 10^{40} < Lx < 10^{43}$ ergs/s

kT ~ 1 keV (0.5 ~ 2 keV) $M_{500} = 10^{13} - 10^{14} M_{sun}$

Spiral rich groups have lower X-ray surface brightness and cooler gas

X-ray luminous groups have a dominant central galaxy



Groups extend cluster mass relations Sun et al.2009

eROSITA SURVEY

- eROSITA all sky limit 6 to 8 x 10^{-14} ergs/cm^2/sec

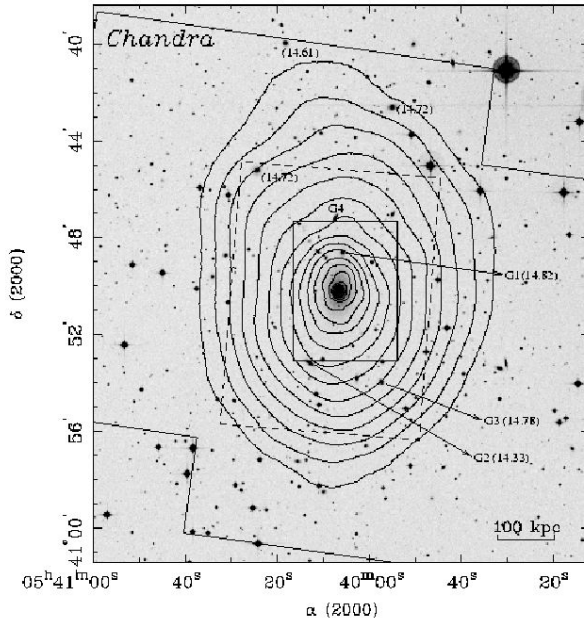
  eROSITA will detect all groups brighter than ~6 x 10^{40} ergs/s (0.5-2 keV) within 100 Mpc and brightest groups to ~1,000 Mpc (i.e. NGC5044 at 10^{43} ergs/s)

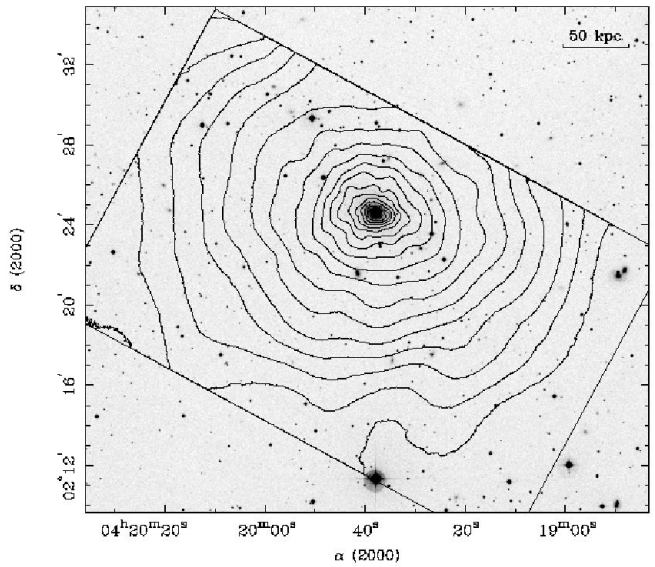
- sensitivity of Chandra 5ks Bootes field for extended sources flux limit ~4 10^{-14} ergs/cm^2/s Detected ~5 groups/sq deg

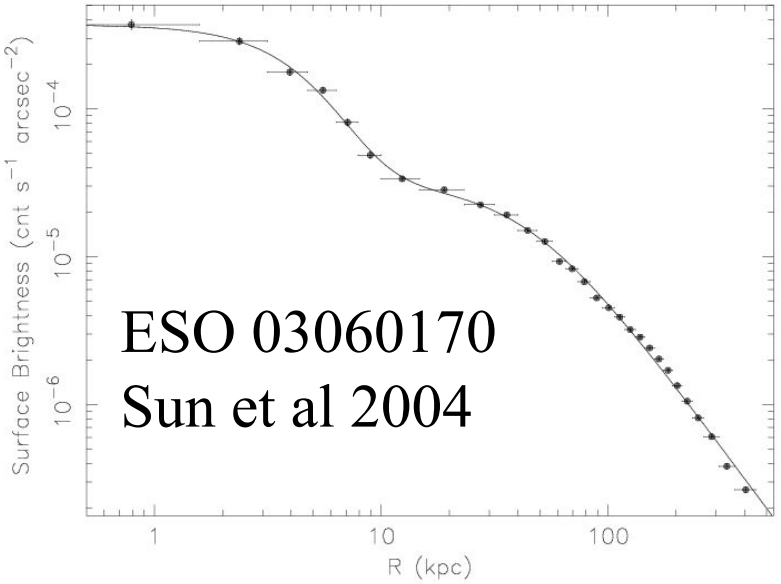
- Sixty to a hundred thousand groups will be found by eROSITA – full inventory of groups

- Among these will be fossil groups (OLEGS), groups with AGN outbursts and infalling/merging groups - some examples

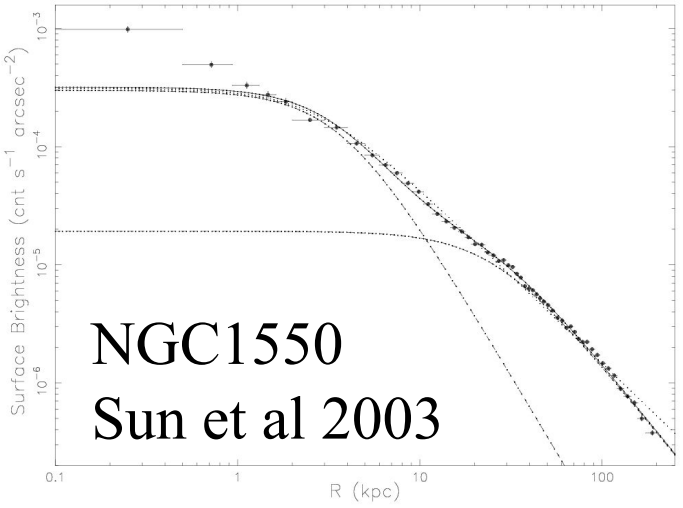
X-ray studies of fossil groups





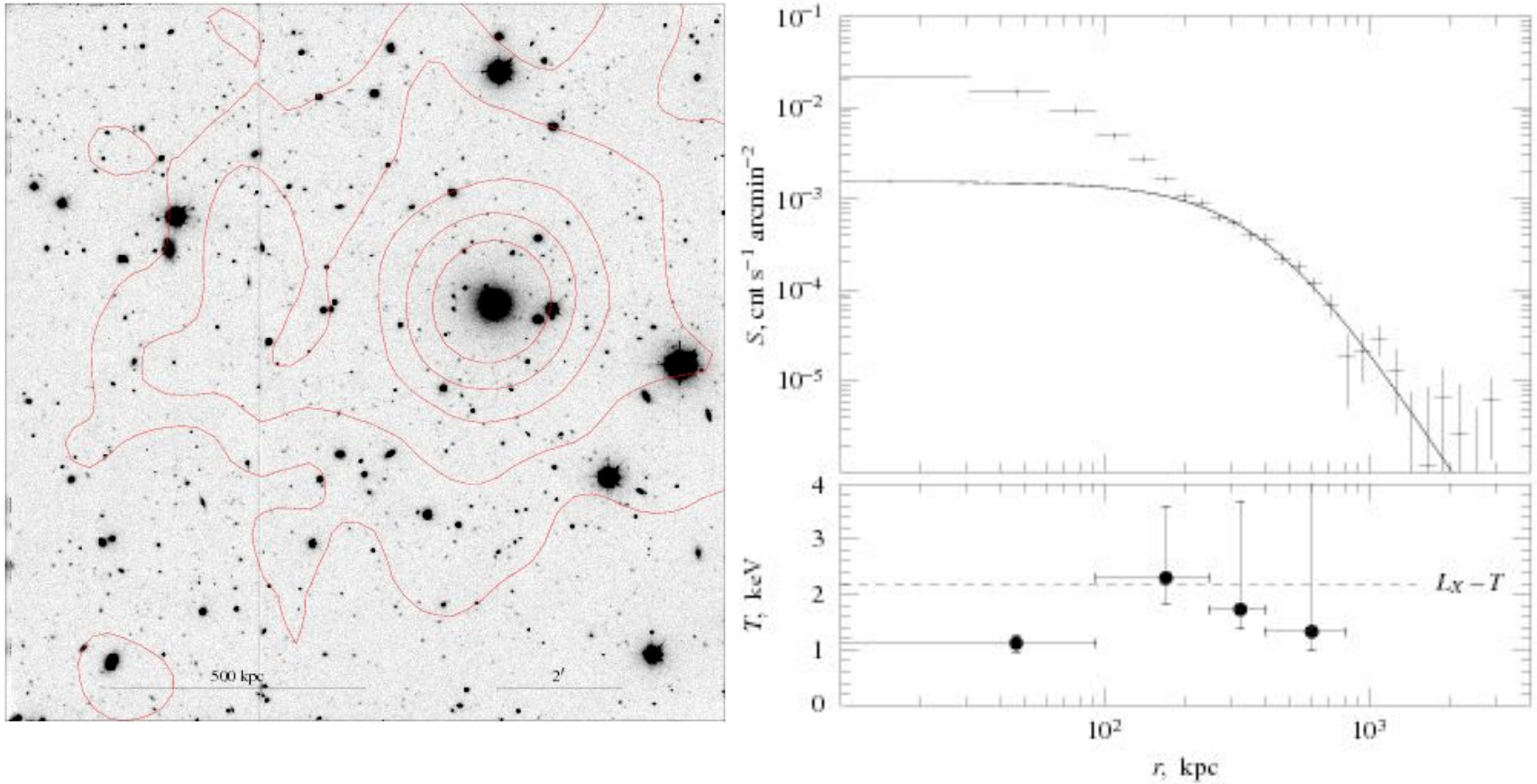


ESO 03060170
Sun et al 2004

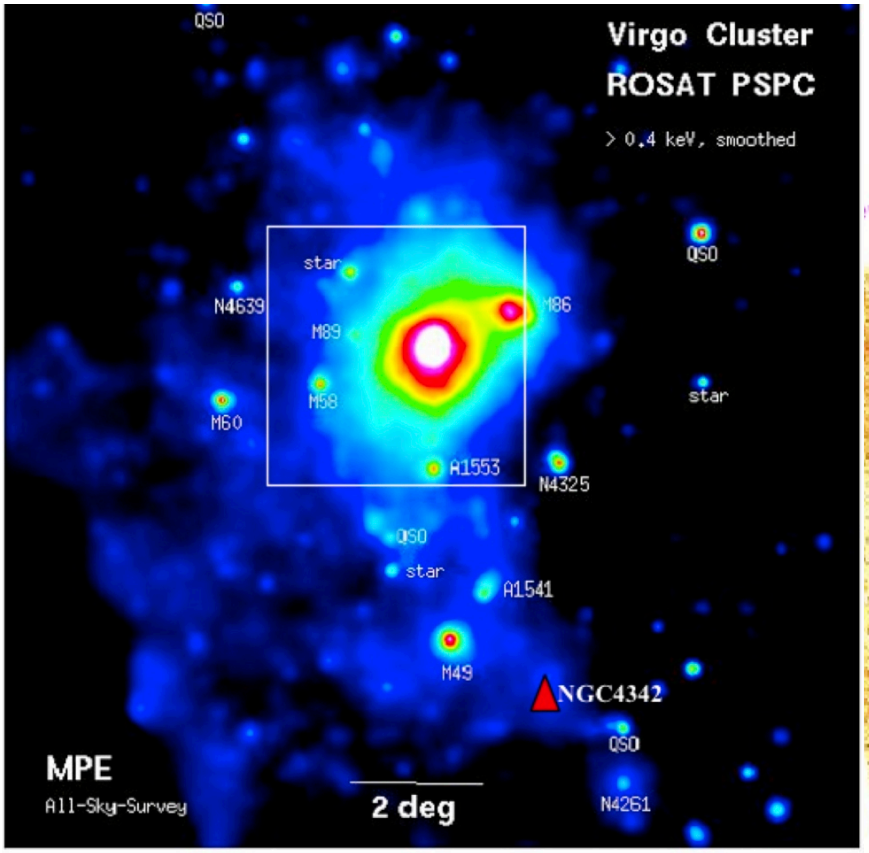


NGC1550
Sun et al 2003

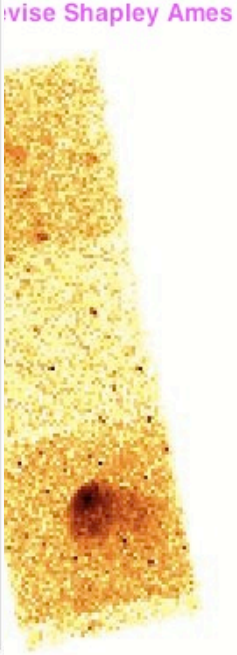
X-ray studies of fossil groups (OLEGS)

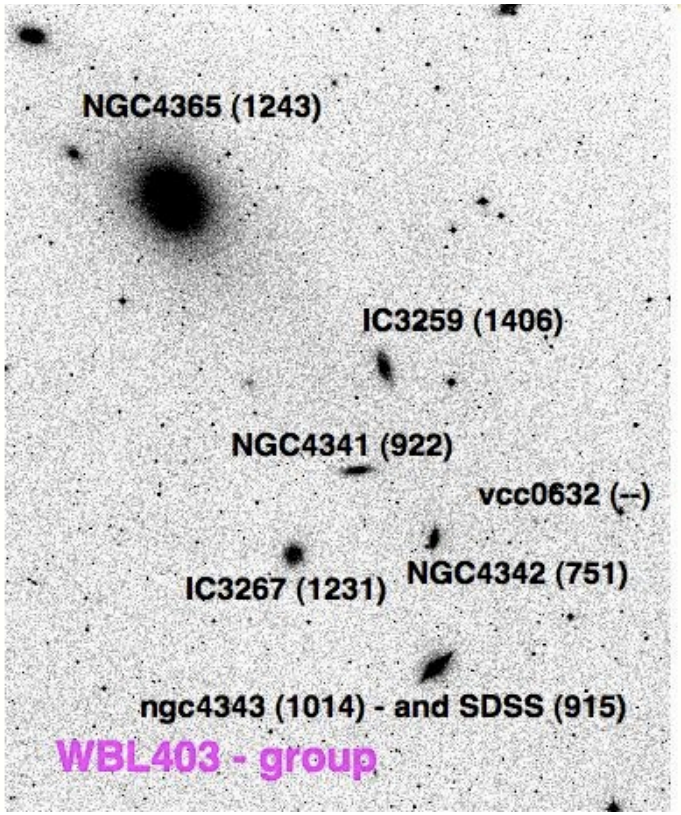


In 160 sq deg survey, Vikhlinin et al(1999) found 4 (10^{43} ergs/s); comparable space density to T > 7 keV clusters – eROSITA will provide full inventory of bright fossil groups within 1000 Mpc

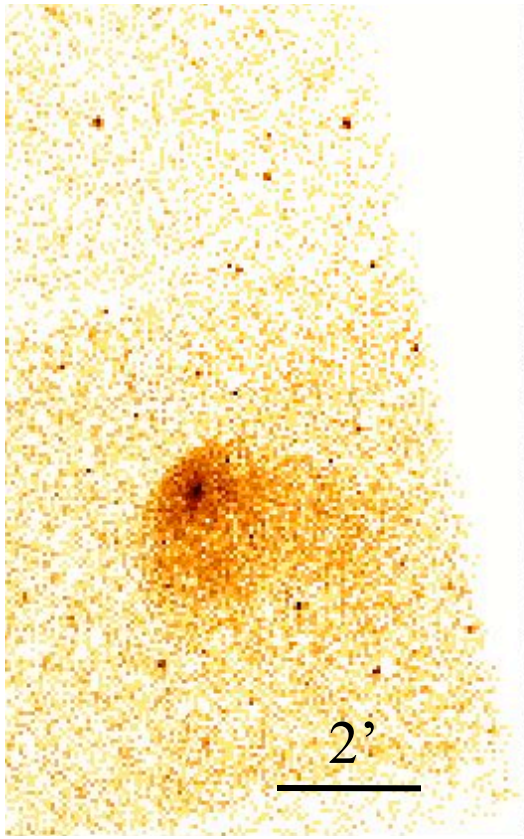


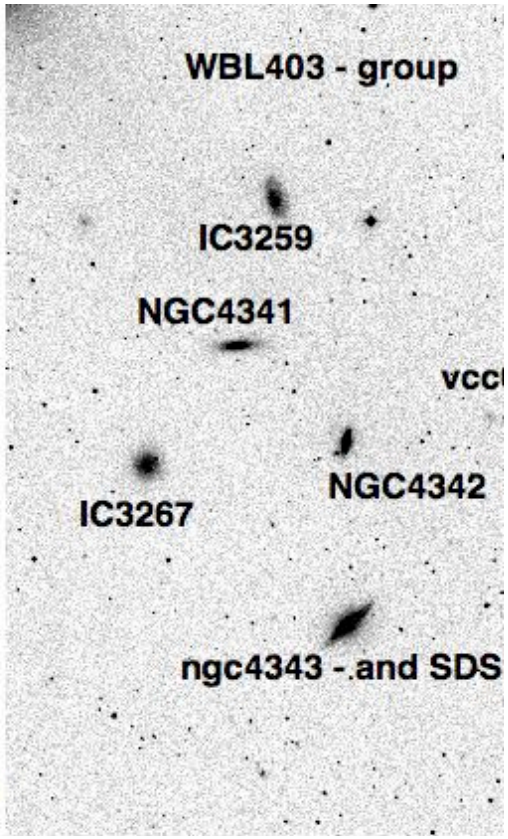
Another "OLEG" ?

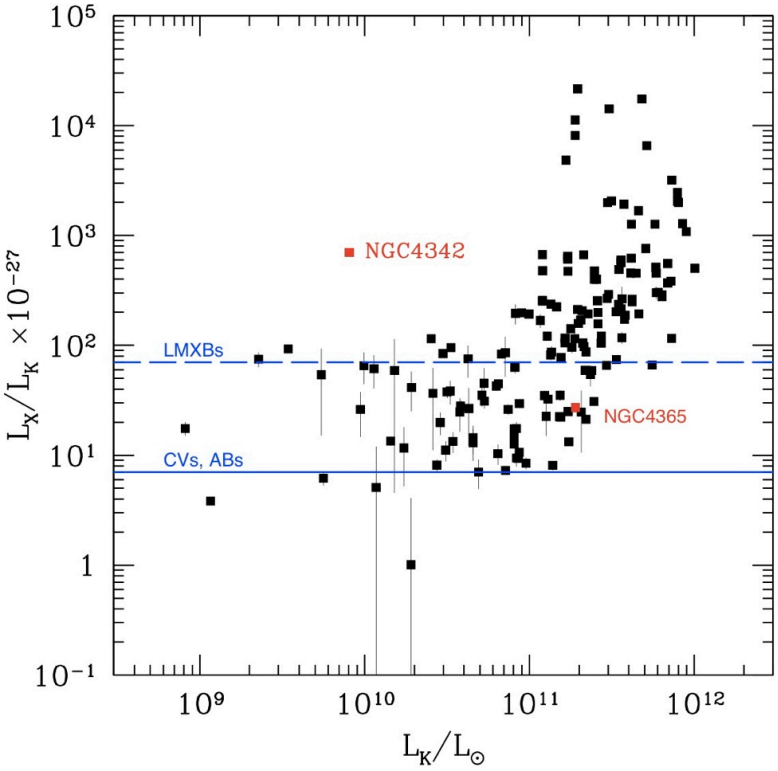




NGC4342 – optically faint, gas rich galaxy in Virgo outskirts (outside R_{vir}) probing filamentary environment







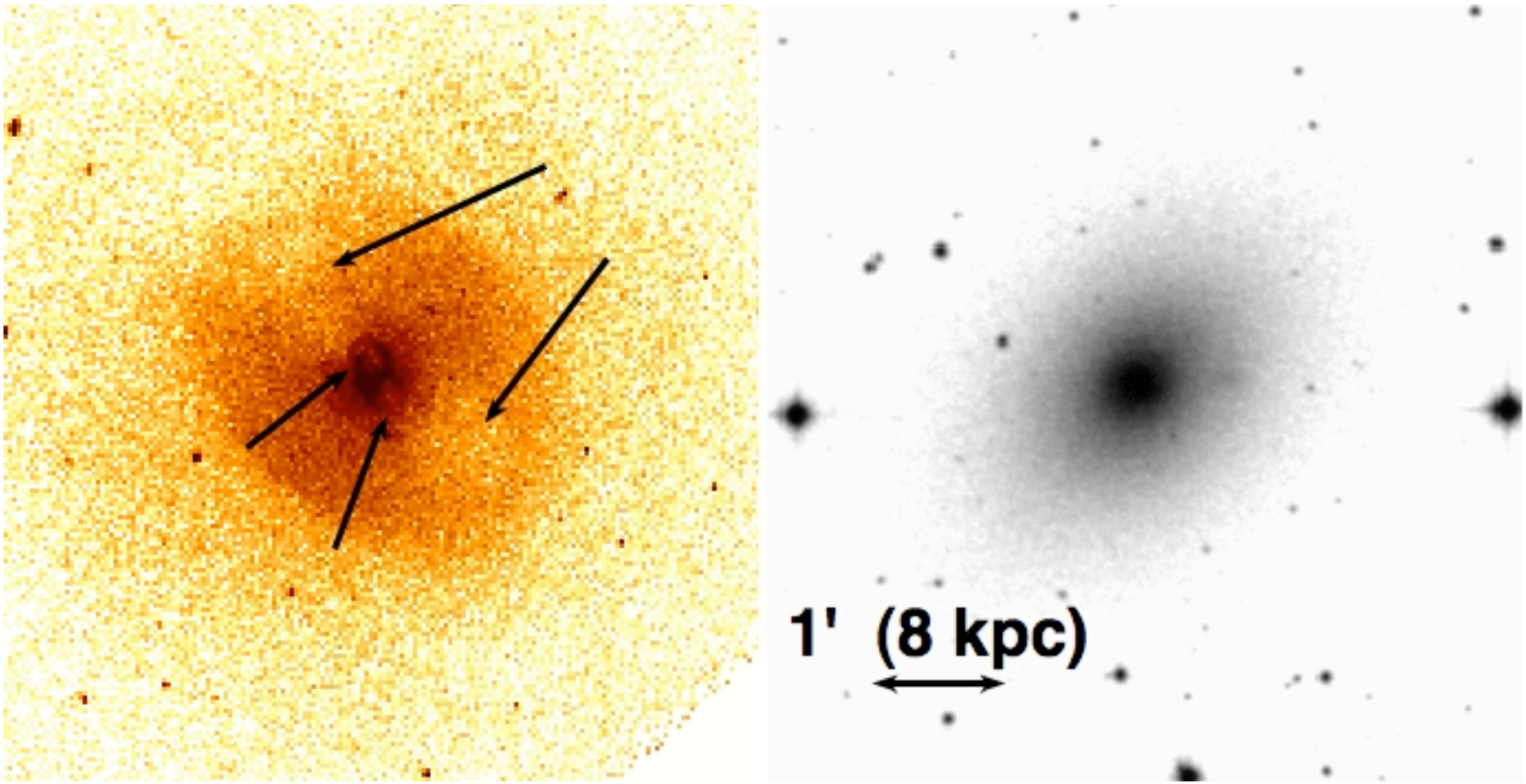
NGC4342 – gas rich galaxy not at center of group

eROSITA will find more of these unusual objects

B_T^0 ~13.5, most galaxies this faint not observed by Chandra or XMM

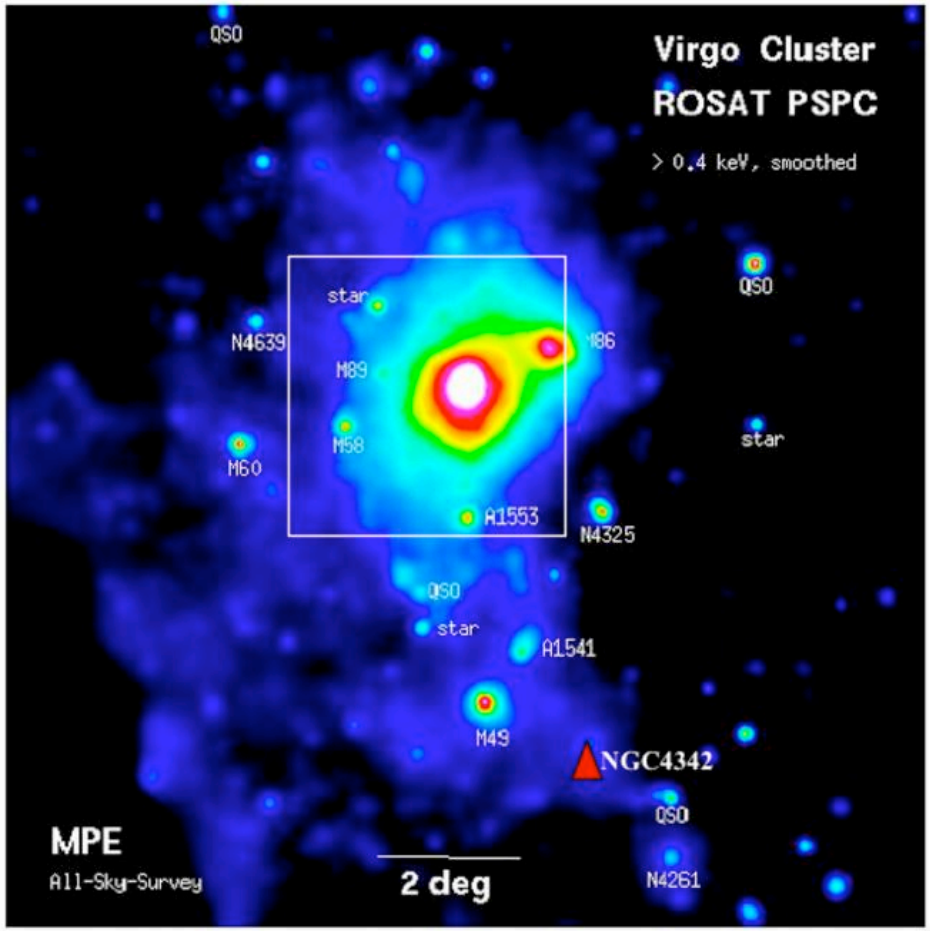
(see poster #54 by Bogdan, Forman et al)

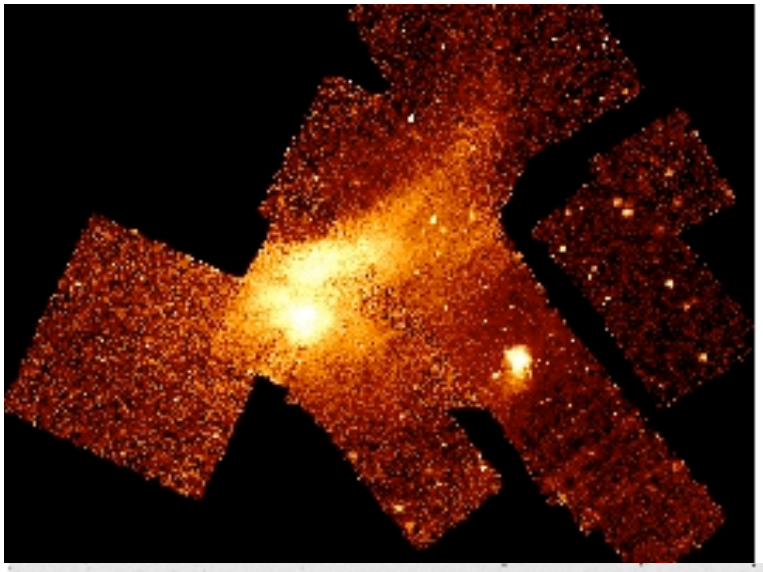
AGN outbursts in groups – eROSITA will provide inventory of SMBH outburst energies, frequencies, SMBH accretion rates…

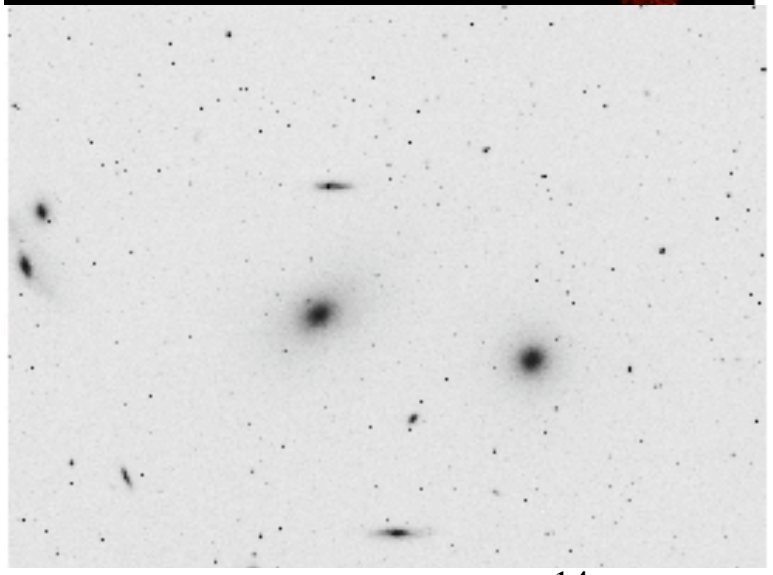


Outbursts in NGC5813 – central galaxy in group (Randall et al 2010)

Infalling groups -The infall of M86 into Virgo cluster





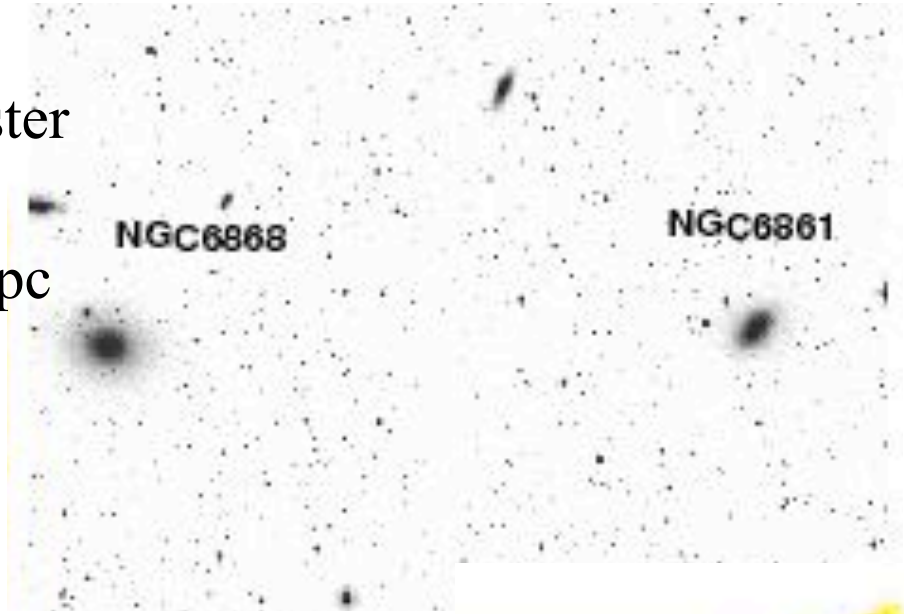


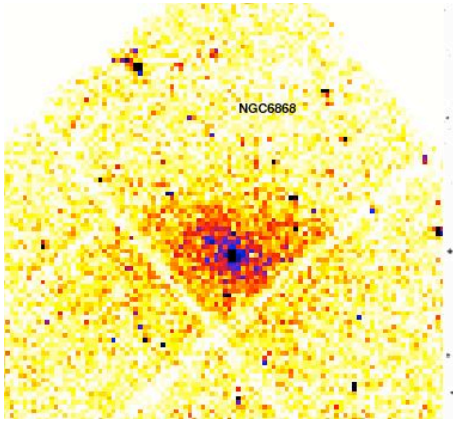
Virgo cluster from ROSAT (Bohringer & Schindler)
eROSITA will provide unlimited views of growth of LSS

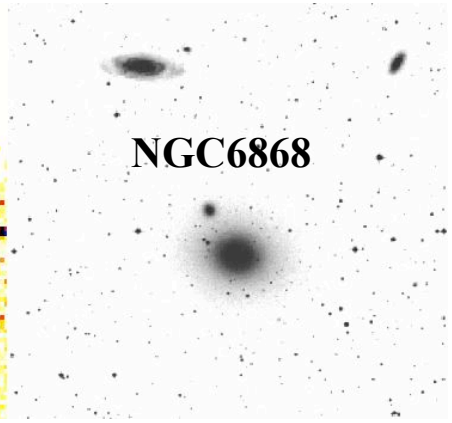
Found with Einstein (Forman et al. 1979)

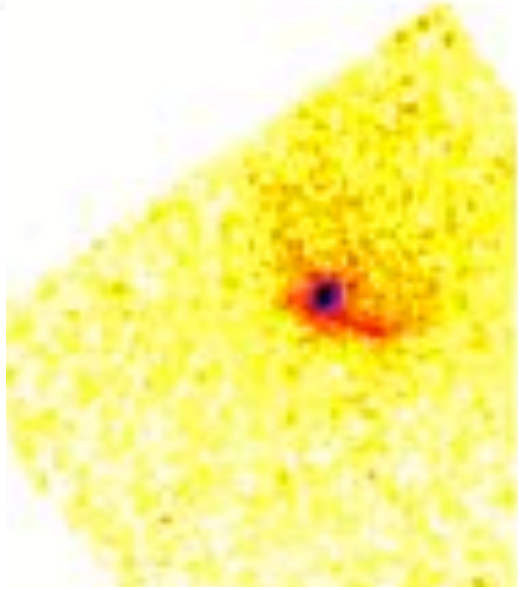
Abell poor cluster

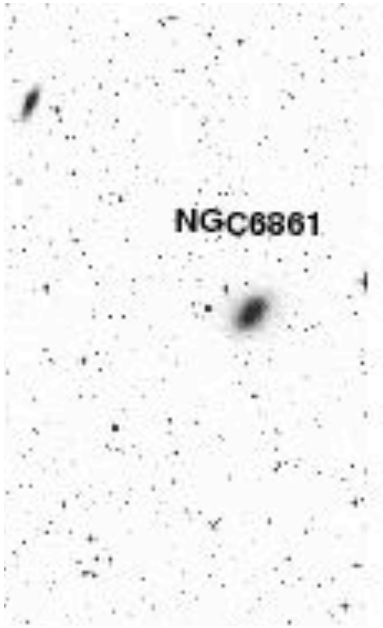
Separation 200 kpc





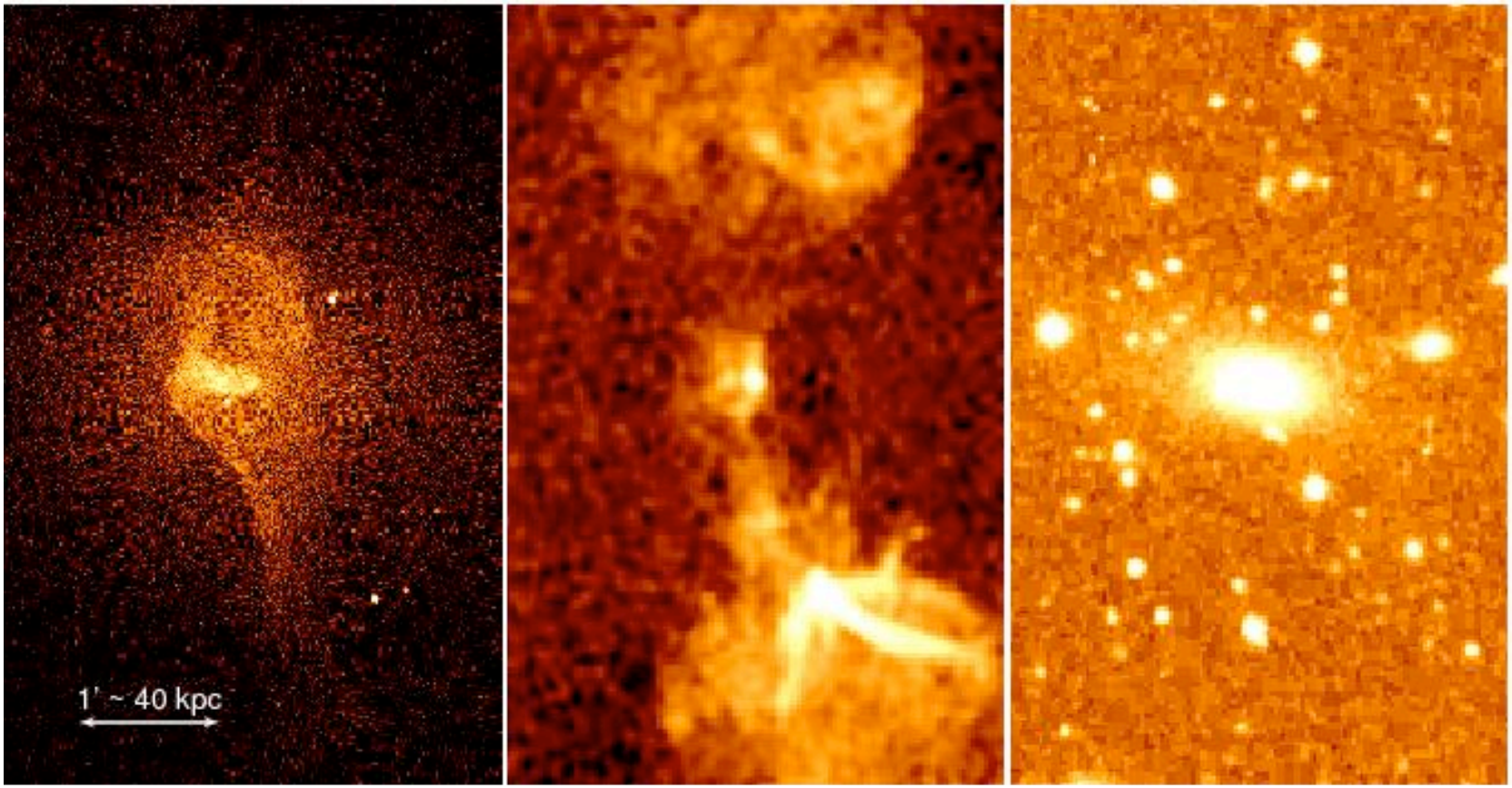






Merging groups – NGC6868 and NGC6861

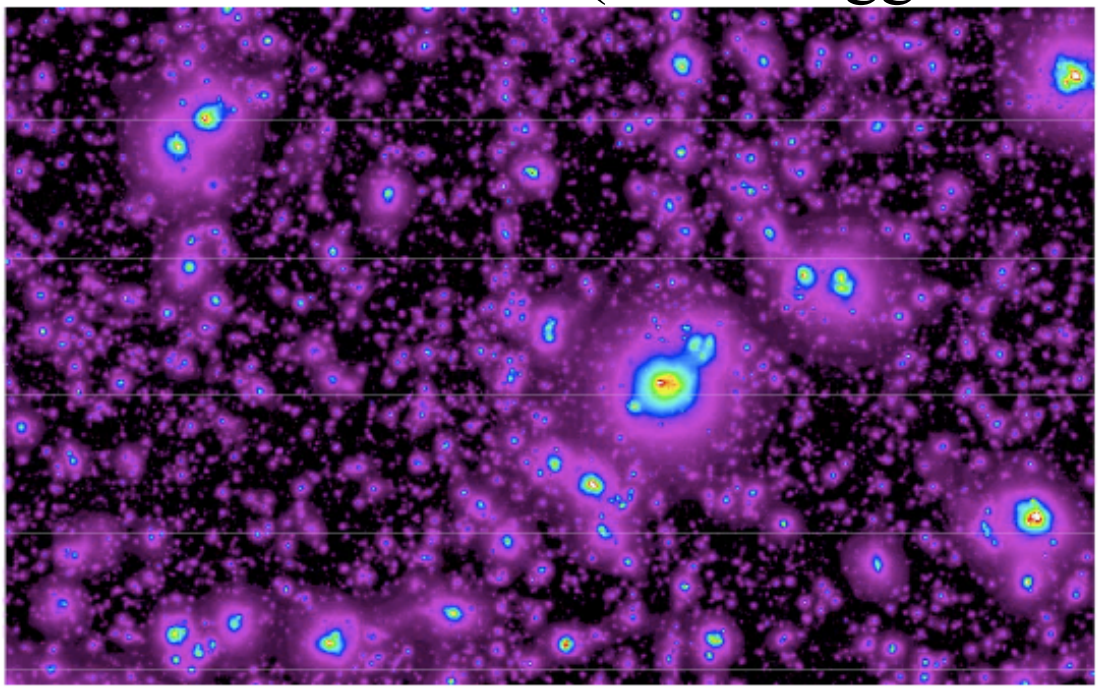
Chandra VLA optical



IC1262 AGN outburst and gas sloshing
X-ray luminosity 4 x 10^{43} ergs/s

(Forman et al. 2011)

eROSITA Simulations (Muehlegger 2010)



Surface brightness map (1° × 1,6°)

What is actually found will be "better" than the simulations!

Large (arcminute scale) structures from AGN outbursts & infall/stripping as clusters grow.

Groups will trace filaments – large scale structures

Identifying groups (SDSS)

- Sloan catalogs from photometric and spectroscopic SDSS data.
- Max BCG catalog of 13,823 clusters with velocity dispersions >400 km/s in 7500 sq deg $0.1<z<0.3$.
- GMBCG - sdss DR7 - followup to BCG extends to $z=0.55$

- SDSS DR6 catalog of 69,173 clusters $0.045<z<0.78$ in 8420 sq deg detected by adaptive match filter. (Szabo et al ApJ 736, 21, 2011)
- 95% complete for clusters >2 10^14 Msun $0.1<z<0.45$; 85% complete for >10^14 msun. Richness threshold of ~ 4 X 10^13 Msun;
- 5000 clusters above 10^14 h-1 msun

- 5447 matches with max BCG clusters; 15,214 matches with GMBCG

Chandra smoothed image