ClG J1205+4429, the most distant fossil group at z=0.59

Ulmer, Adami, Covone, Durret, Lima Neto,
Sabirli, Holden, Kron & Romer
2005, ApJ 624, 124

A distant cluster candidate in the Bright Sharc Survey

638 ROSAT PSPC observations with |b| > 20° and exposure time > 10,000 seconds

Bright SHARC covers 178.6 deg^2, with flux > 1.4 10^{-13} $erg/s/cm^2$ [0.5-2.0keV]

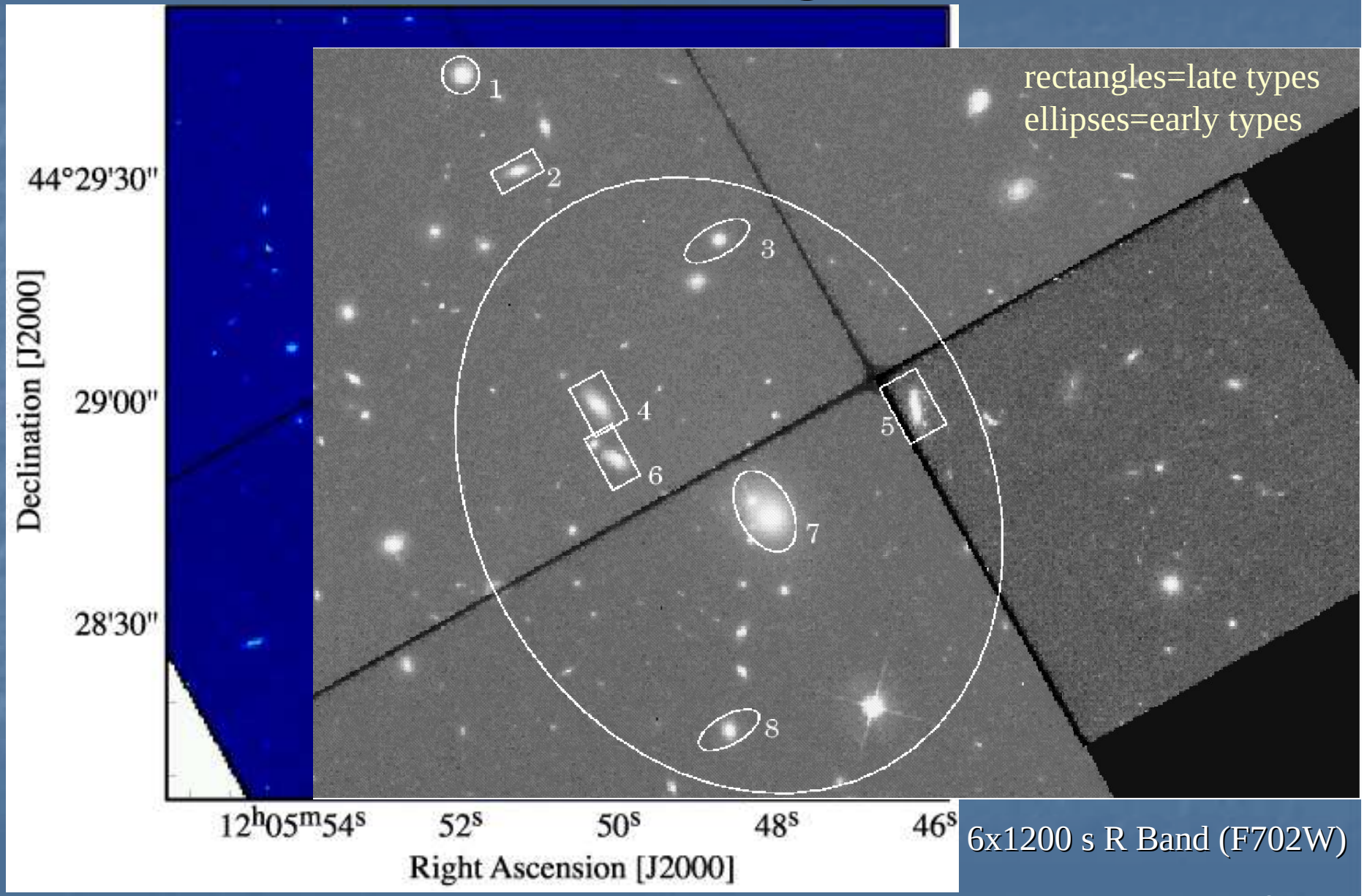
see Adami et al. 2000; Romer et al. 2000, 2001

ClG J1205+4429 selected for "follow-up":

- Astrophysical Research Consortium (ARC) 3.5 m (Apache Point Observatory)
  photometric redshift suggested $z \sim 1$

- Chandra (our data)
- XMM (our data)
- HST & VLA (archives)

HST image



6x1200 s R Band (F702W)

The group and probable group members

Group redshift: z=0.5915 (Mulchaey, private communication)

ID(Class)[a]	Ra	Dec	F702w	i′	Ks
1(AGN)[b]	181.474	44.4960	19.27	18.23	16.30
2(S)	181.472	44.4938	21.04	20.80	17.54
3(E)	181.466	44.4923	21.38	21.19	18.05
4(S)	181.470	44.4885	20.73	20.43	17.29
5(S)	181.460	44.4885	21.84	20.65	17.63
6(S)[c]	181.469	44.4873	21.01	20.99	18.57
7(D)	181.464	44.4860	19.27	18.50	15.44
8(E)	181.465	44.4812	21.22	20.85	17.85

main galaxy

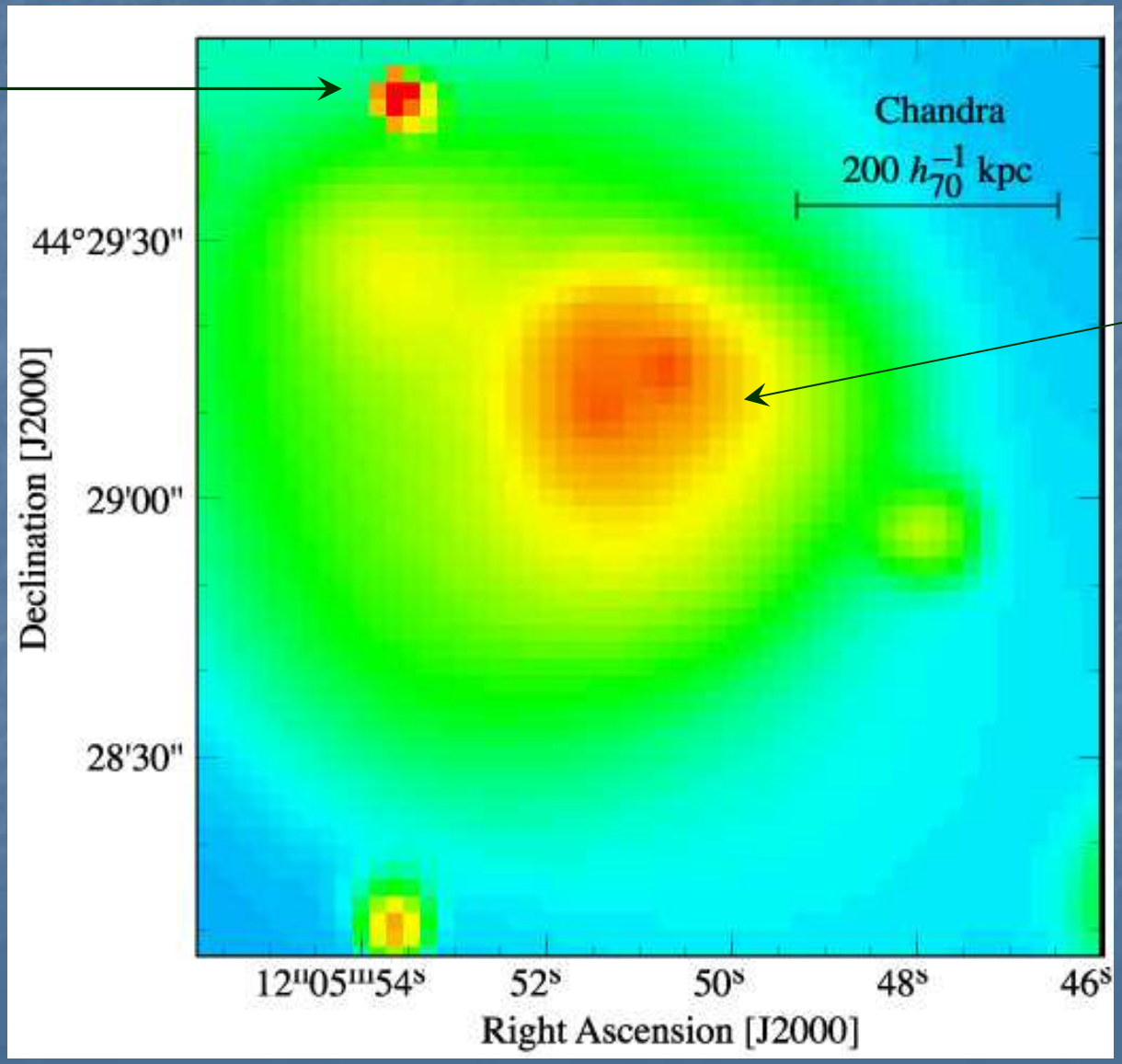
8 possible group members among which 6 very probable group members

b: probably not in group (would be dominant, but far from centroid of X-ray emission)
c: possibly not in group

$m_{G7} - m_{G4}$ ~ 2 magnitudes

X-ray information: Chandra map

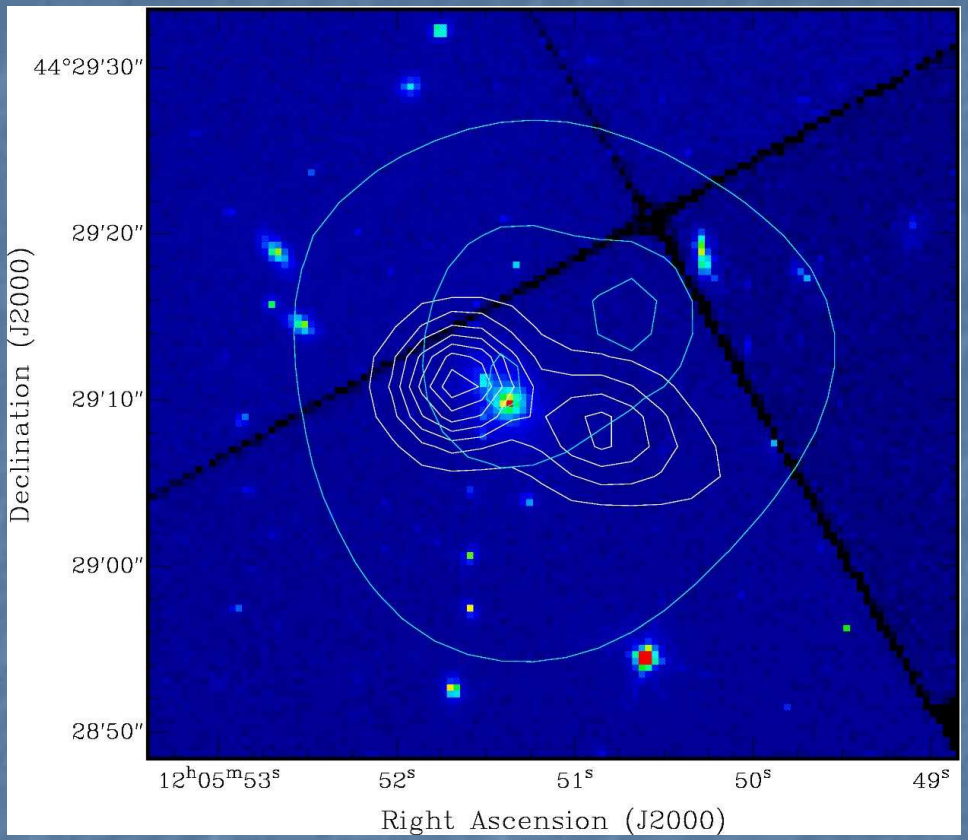
AGN
(=1)

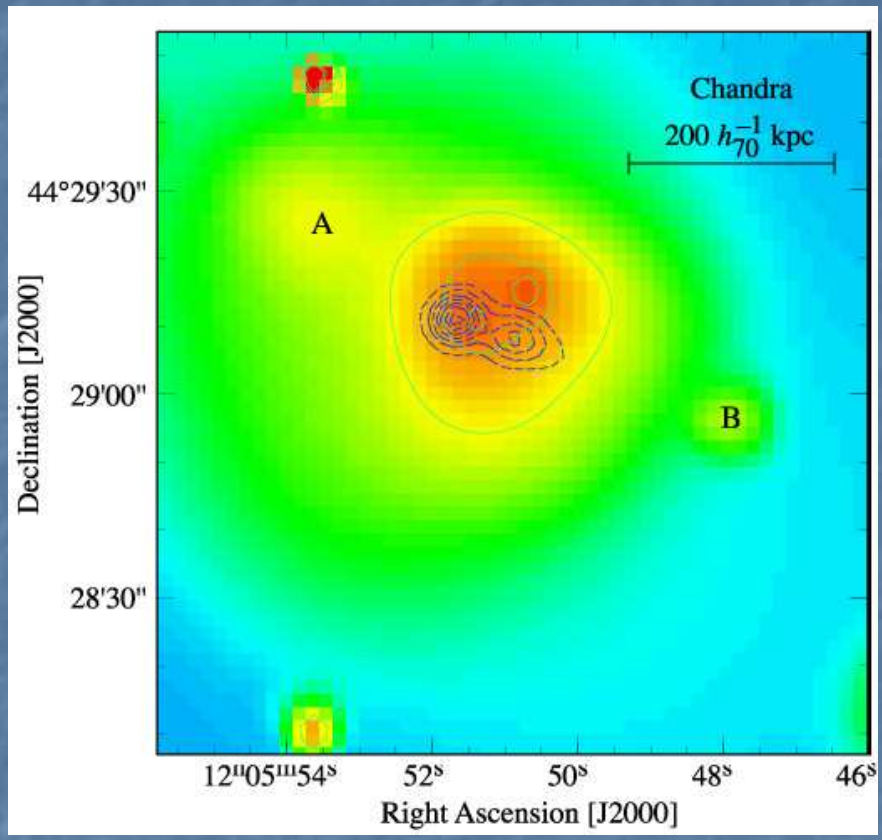


bi-modal?

Exposure time
29,711s

Radio/X-ray images



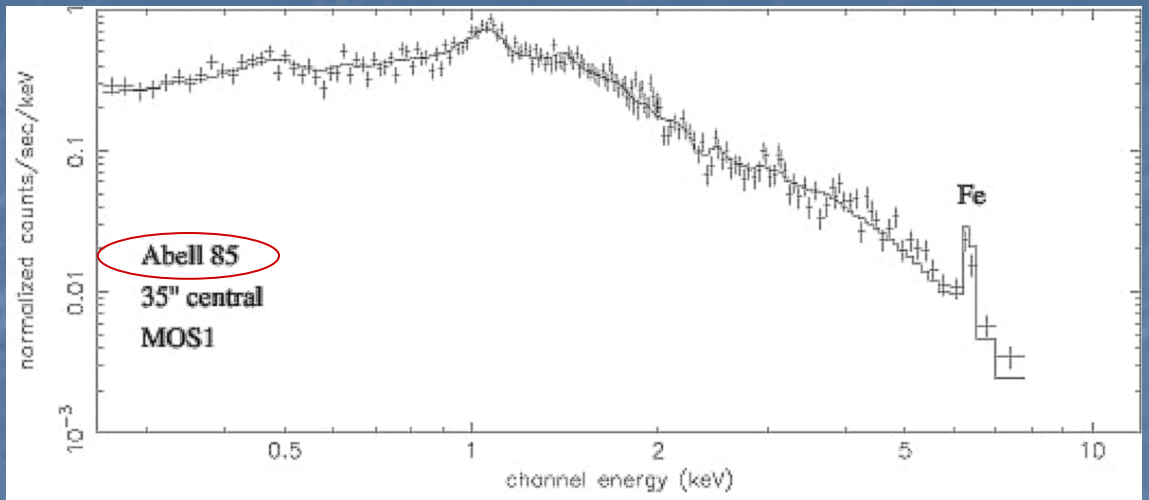


Double lobed radio source

Possible alignment of radio source with ill-defined elongation of X-ray emission, but no obvious relation between radio and X-ray emission

XMM-Newton spectrum

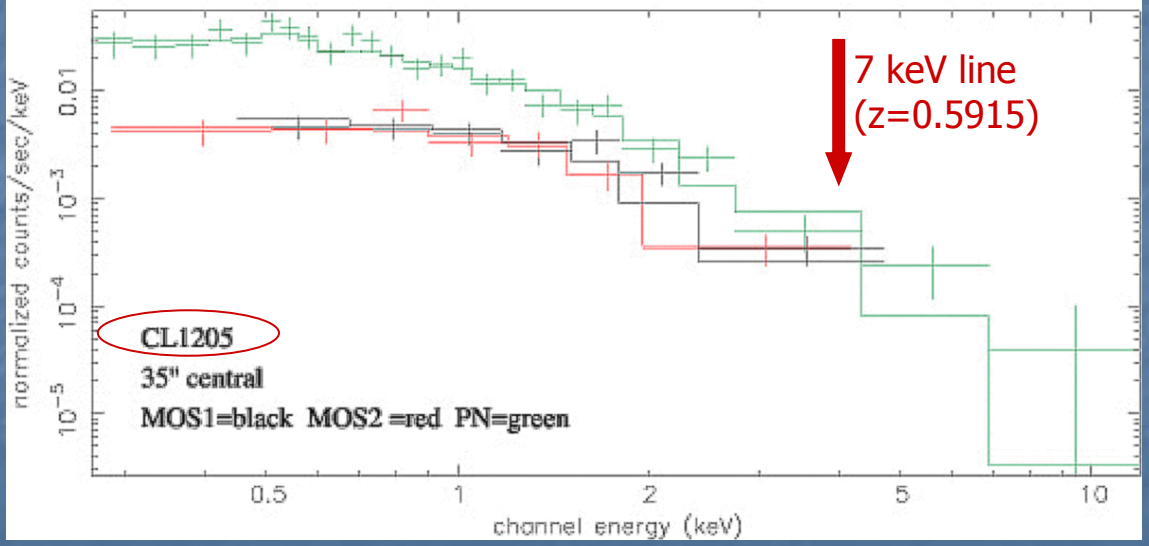
What we would like to have…



Exposure times
MOS: 12,400s
PN: 9,000s

z=0.055

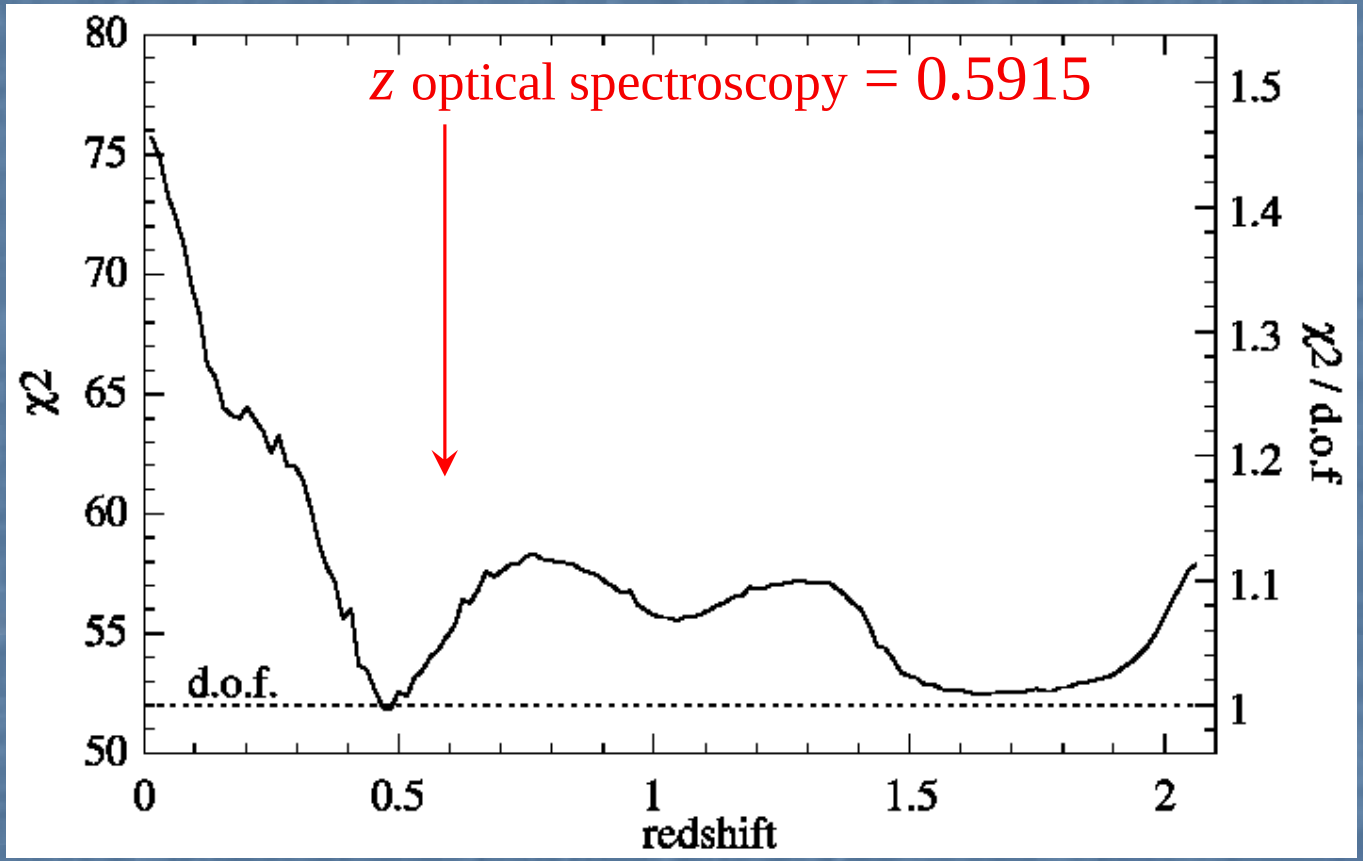
What we have!



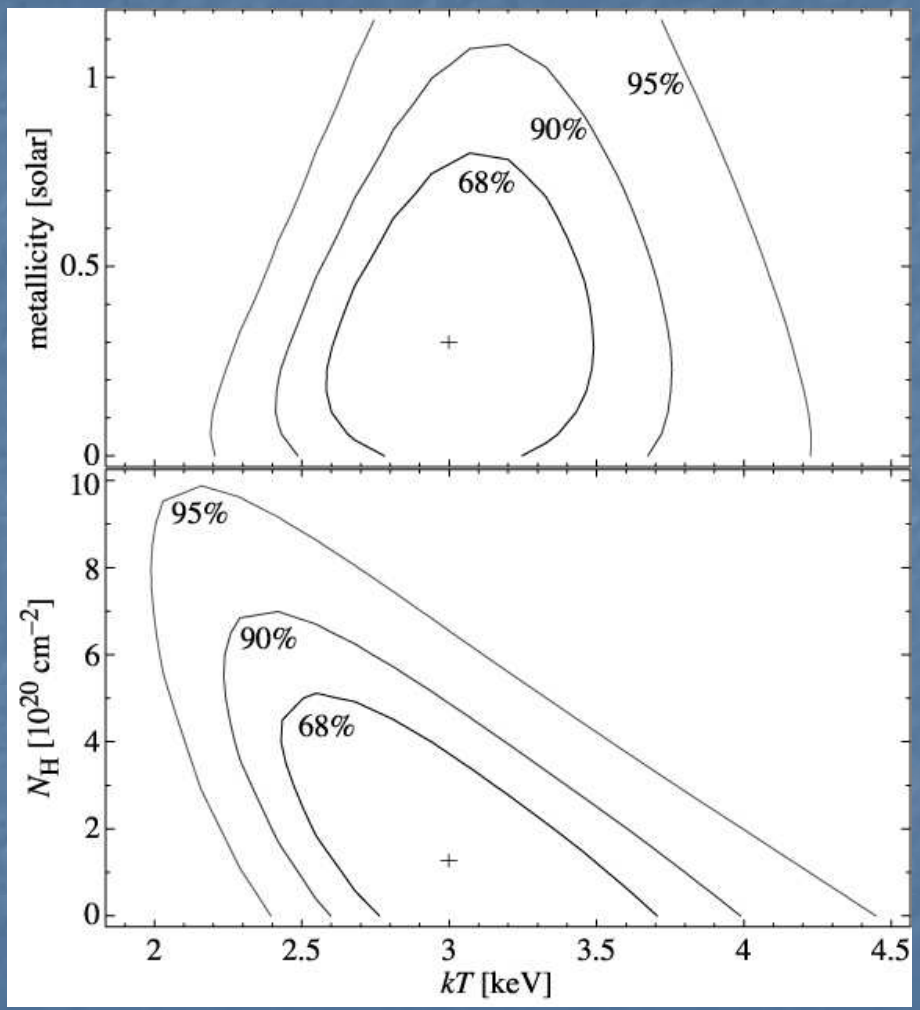
Exposure times
MOS1: 21,223s
MOS2: 20,861s
PN: 16,478s

Initial: 52,200s!

X-ray flux makes a difference!



Redshift determination from X-ray spectral fit



Thermal bremsstrahlung fit assuming z = 0.5915

kT = 3.0 ±0.3 keV

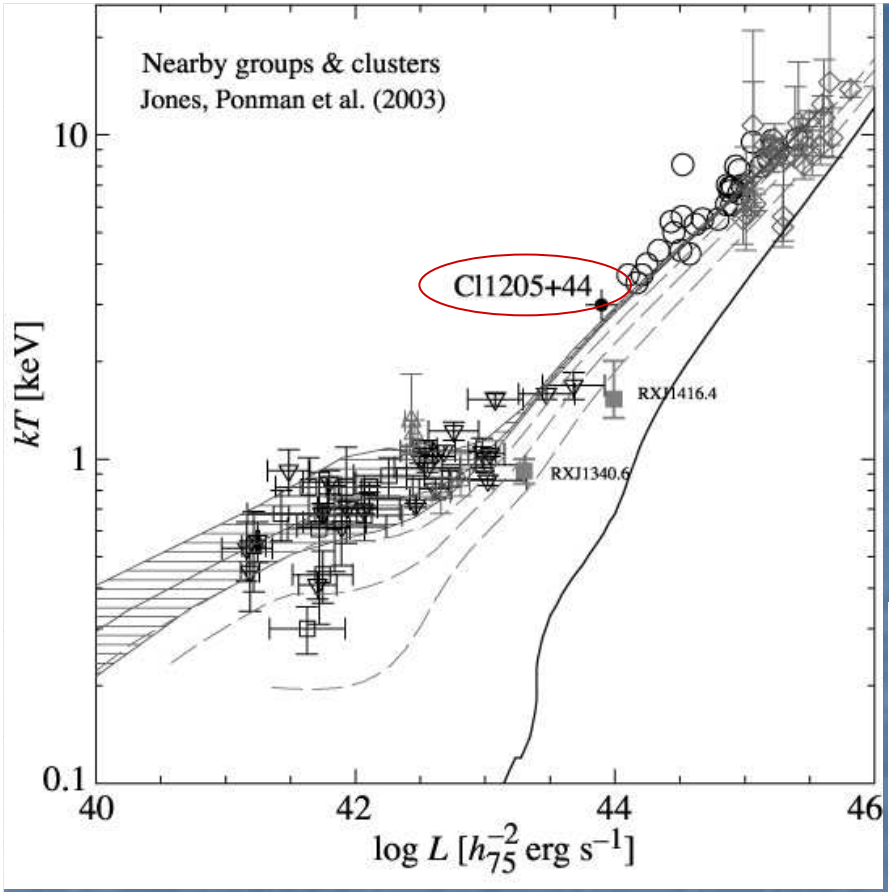
Z = 0.3 ± 0.3 Z_{solar}

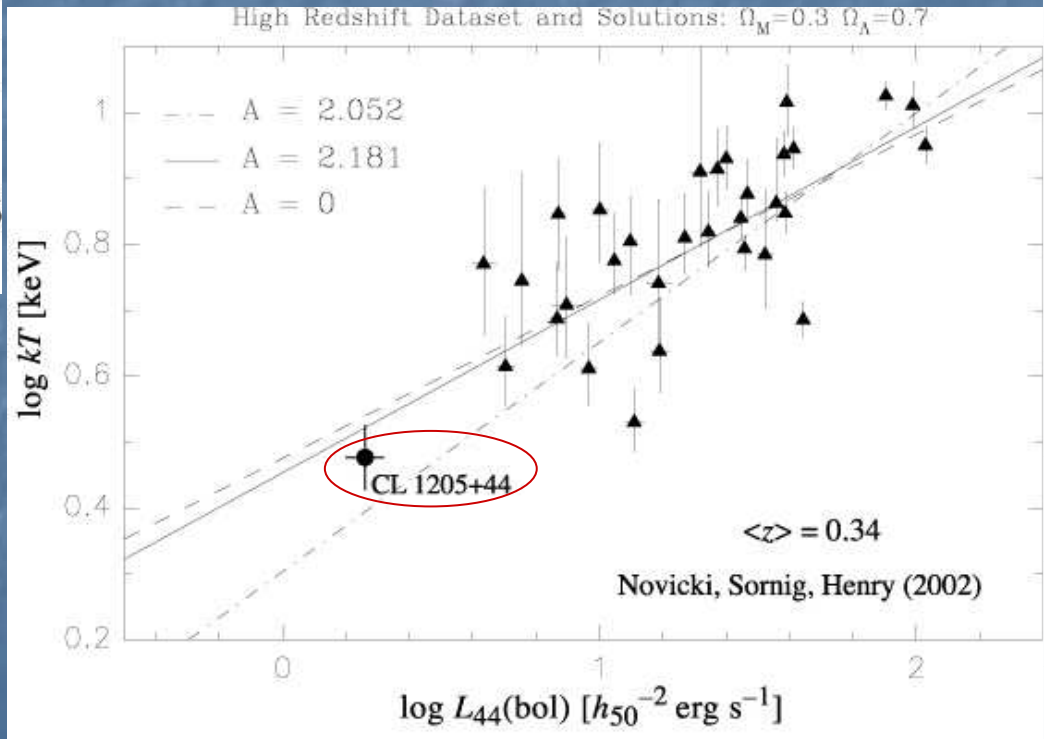
$L_{X,bol}$ = (9.2±0.7) 10^{43} erg/s

M_{gas} = 1.9 10^{12} M_{solar}

M_{tot} = 1.0 10^{13} M_{solar}

Cl 1205+44 in the L_X-T_X relation





- Between poor clusters and groups
- Follows the L_X-T_X relation of $z \approx 0.4$ clusters

Results

"Normal" X-ray emission:

- Follows the L_X-T_X relation of $z \approx 0.4$ clusters
- No strong substructures
- X-ray emission centre coincides with dominant galaxy
- Hotter than fossil groups at smaller z: probably not because other fossil groups have cooled between z=0.6 and z=0
- $L_X > 10^{42}$ erg/s

Optical properties:

- Central dominant galaxy:
  $M_R \sim -24.1$
  much more luminous than second brightest galaxy (m1 ~ m2 – 2)
- L_{opt} (F702W) = 1.5×10^{11} L_{solar}

→ **Fossil Group**

(following Ponman et al.1994; Jones et al. 2003)

Predictions of numerical simulations

A merged group can relax to form a single elliptical galaxy

- Barnes 1989, Nature 338, 123
- Governato, Bhatia & Chincarini 1991, ApJ 371, 15
- Bode, Coch & Lugger 1993, ApJ 416, 17
- Athanassoula, Makino & Bosma 1997, MNRAS 286, 825

Timescale for brightest group members < Hubble time so merging of groups into ellipticals expected to be observed (Zabludoff & Mulchaey 1998)

A scenario for Cl 1205+44

- initial potential well of dark matter
- energy injection (supernovae, radio galaxies, ULIRGs…)
- group "fossilizes" at z ~ 2
- from z ~2 there is little infall of bright galaxies
- gas rich galaxies that eventually fall may lose gas by ram-pressure stripping
- galaxies are cannibalized by central D galaxy
- star formation in late-type galaxies is suppressed
  and these galaxies are almost as red as early-types
- entire evolutionary sequence ~ 4 Gyr

Other fossil groups

TABLE 4

15 FOSSIL GROUP GALAXIES KNOWN TO DATE

(1) Name	(2) RA (2000)	(3) DEC (2000)	(4) z	(5) $L_{X,bol}$ (10^{42} h_{50} $^{-2}$) ergs s^{-1}	(6) Reference
NGC 1132	02 52 51.8	-01 16 29	0.0232	1.9	Yoshioka et al. (2004)
RX J0454.8-1806	04 54 52.2	-18 06 56	0.0314	1.9	Yoshioka et al. (2004)
ESO 306- G 017	05 40 06.7	-40 50 11	0.035805	129	Sun et al. (2004)
RX J1119.7+2126	11 19 43.7	+21 26 50	0.061	1.7	Jones et al. (2003)
RX J1159.8+5531	11 59 51.4	+55 32 01	0.0810	22	Vikhlinin et al. (1999)
CL 1205+44	12 05 53.7	+44 29 46	0.59	180	Ulmer et al. (2005)
RX J1256.0+2556	12 56 03.4	+25 56 48	0.232	61.	Jones et al. (2003)
RX J1331.5+1108	13 31 30.2	+11 08 04	0.081	5.9	Jones et al. (2003)
RX J1340.6+4018	13 40 33.4	+40 17 48	0.1710	25	Vikhlinin et al. (1999)
RX J1416.4+2315	14 16 26.9	+23 15 32	0.137	220.	Jones et al. (2003)
RX J1552.2+2013	15 52 12.5	+20 13 32	0.136	63	Jones et al. (2003)
NGC 6034	16 03 32.1	+17 11 55	0.0339	0.75	Yoshioka et al. (2004)
NGC 6482	17 51 48.8	+23 04 19	0.013129	2.17	Khosroshahi et al (2004)
RX J2114.3-6800	21 14 20.4	-68 00 56	0.1300	20	Vikhlinin et al. (1999)
RX J2247.4+0337	22 47 29.1	+03 37 13	0.199	41	Vikhlinin et al. (1999)

Mendes de Oliveira, Cypriano & Sodré 2005, astro-ph/0509884

The first fossil galaxy group:

RX J1340.6+4018

Optical

z=0.171

M_V=-23.5

X-rays (ROSAT)

T_X=0.92±0.08 keV
Z=0.36±0.13 solar
L_X=4.5 10^{43} erg/s
t_{cool}=9 10^9 yr
M_{tot}=2.8 10^{13} M_0
M/L=130

RX J1340.6+4018

- is not a normal elliptical galaxy
- is not in the centre of a cluster
- has X-ray properties comparable to the brightest compact groups

Probably the merged remains of the galaxies which previously constituted the group

Ponman et al. 1994, Nature 369, 462

The isolated elliptical NGC 1132: evidence for a merged group of galaxies?

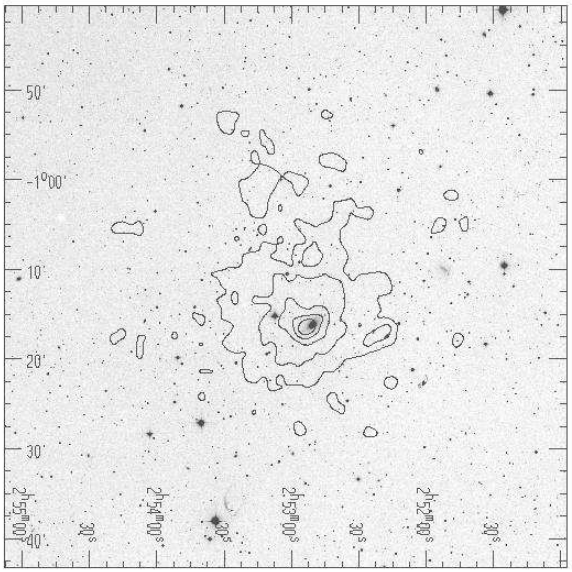
Catalogue of nearby isolated ellipticals:
z<0.03, no bright galaxy within 1 Mpc
and within velocity ±2000 km/s

NGC 1132:
X-ray halo ~ 250 kpc radius
T~1 keV
L_X ~ 2.5 10^{42} erg/s
M_{tot} ~ (1.0 ±0.7) 10^{13} M_0 ~ 10xM_{N1132}
Comparable to poor groups
Number density and spatial distribution of dwarf galaxies comparable with those of X-ray groups, but lack of other bright galaxies in the group

→ **NGC 1132 is a merged poor group**

Mulchaey & Zabludoff 1999, ApJ 514, 133

NGC 1132



ASCA contours on DSS
Field 1°x1°

Similar systems possibly found by Matsushita et al. (1998) and Matsushita (2001)

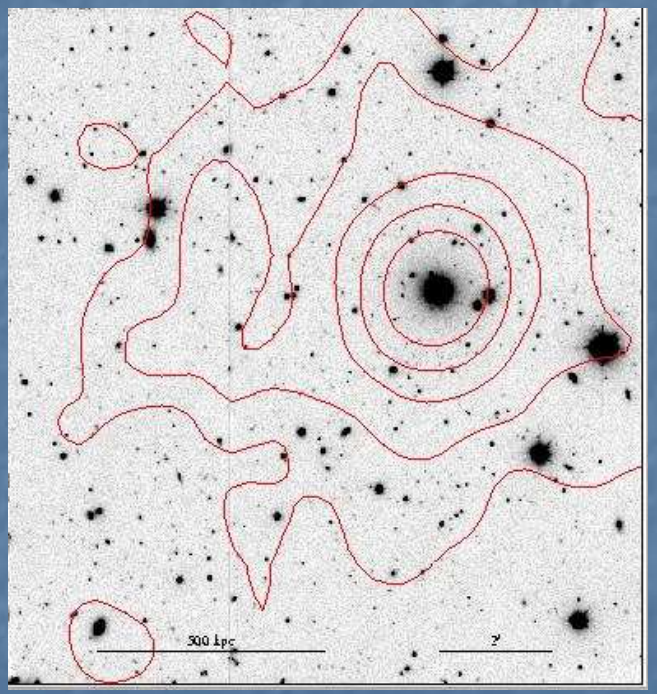
OLEGs (X-ray OverLuminous Elliptical Galaxies)

Four objects from ROSAT survey similar to the Ponman et al. (1994) fossil group.

Criteria:
- bright elliptical with no corresponding concentration of faint galaxies
- $z<0.2$
- $L_X>2\ 10^{43}$ erg/s (poor Abell clusters)

Results:
- Two objects are elliptical galaxies in the Einstein survey
- One is the Ponman et al. (1994) fossil group
- One is new: 2247+0337

1159+5531



Vikhlinin et al. 1999, ApJ 520, L1

OLEGs (continued)

Optical

z=0.081-0.199

M_V=-23.1 (1159+5531)

X-rays (ROSAT)

T_X=2.1-2.8 keV

L_X=(2.0-4.1) 10^{43} erg/s

M_{tot}=(0.8-1.7) 10^{14} M_0

M/L=270-430

f_{gas}=0.07-0.08

- Central galaxies dominate
- Space density of OLEGs comparable to that of compact galaxy groups or field ellipticals
- OLEGs represent 20% of clusters and groups with L_X>2 10^{43} erg/s
- OLEGs outnumber HCGs of similar X-ray luminosities by 3.5 and are as luminous as HCGs of similar optical luminosity
- OLEGs have high values of M/L

→ OLEGs can be merged compact galaxy groups

Also see Yoshioka et al. (2004), ADSR 34, 2525, IOLEGs (Isolated OLEGs)

The nature and space density of fossil groups of galaxies

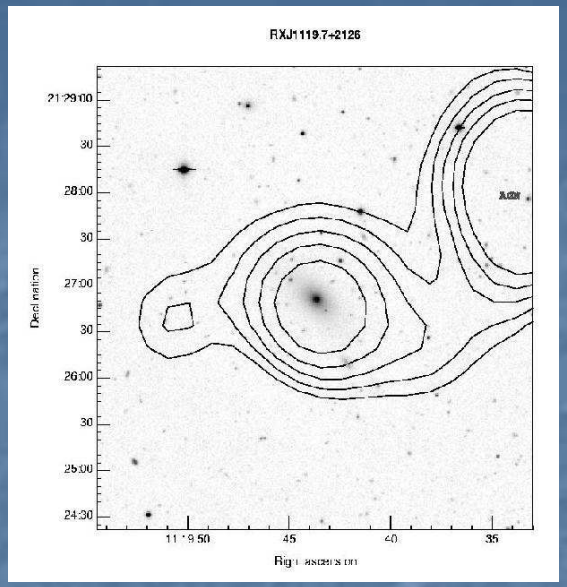
Definition of a fossil system:

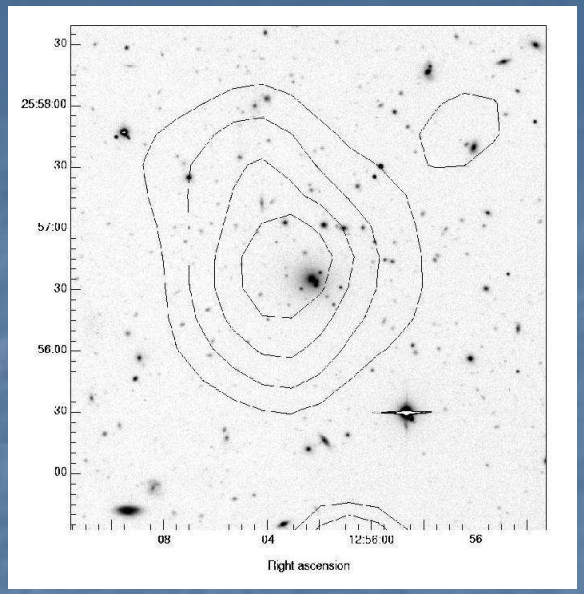
- Spatially extended X-ray source with

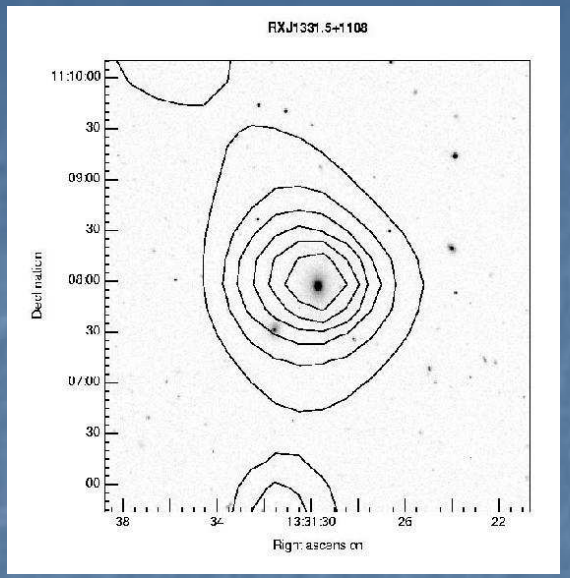
$L_{X,\,bol} > 10^{42}$ erg/s (excludes normal ellipticals)

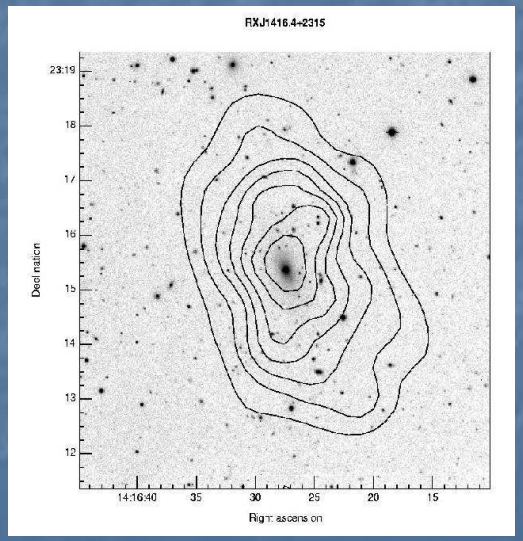
- Optically: bound system of galaxies with $\Delta m_{12} > 2.0$ mag (mag in R within $0.5 r_{vir}$; excludes « normal » poor clusters), dominated by central luminous elliptical galaxy with no cD halo
- Sample of 5 new fossil systems (not included in the OLEG sample)

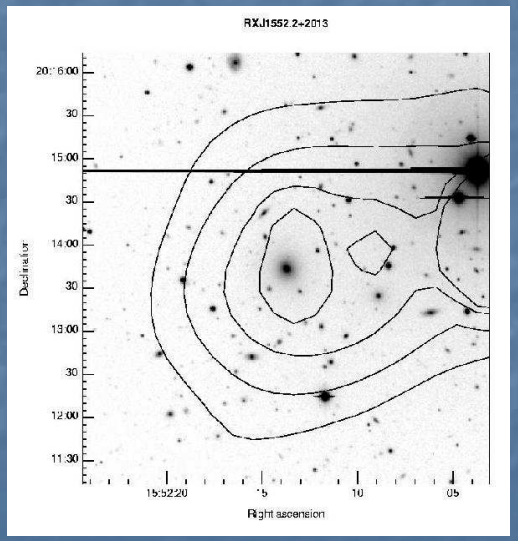
Jones, Ponman, Horton, Babul, Ebeling & Burke 2003, MNRAS 343, 627











Optical images and ROSAT contours

Jones, Ponman, Horton, Babul, Ebeling & Burke 2003, MNRAS 343, 627

Properties of these 5 fossil systems

Optical

z=0.061-0.232

M_R=-22.8 to -25

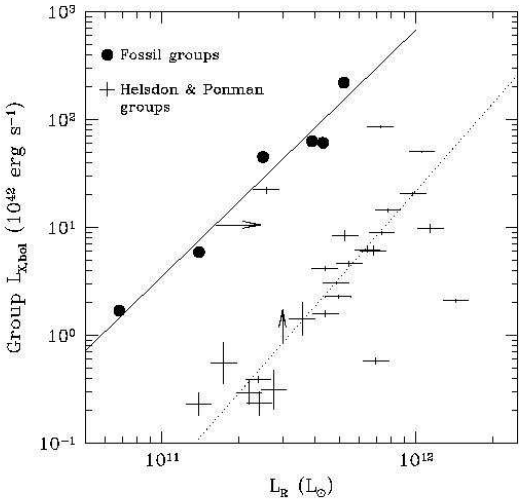
X-rays (ROSAT)

T_X=1.5 keV (one gal.)

L_X=(0.1-10) 10^{43} erg/s

- Correlation of L_{opt} with L_X implies a link between central galaxy properties and X-ray properties of the group
- Fossil group X-ray luminosities higher by a factor of 5 compared to normal groups

L_{opt} vs. L_X relation



- Rough agreement with space density estimated from OLEGs
- Fossil groups are more numerous than HCGs

- In favour of merging hypothesis:
  - gap in luminosity function at L*
  - high L of central galaxy
  - low probability of obtaining $\Delta m_{12}>2$ by chance (numerical simulations)
  - strong correlation between L_X of groups and L_{opt} of central galaxy

- Merger 4 Gyr ago (no traces of merging in morphology)
- At least a fraction of very luminous elliptical galaxies formed via mergers in galaxy groups
- High L_X could be due to cool gas in the centre and/or to low central gas entropy

Also see NGC 6482 in Khosroshahi, Jones & Ponman (2004), MNRAS 349, 1240

Conclusions: why are fossil groups interesting?

- If merger interpretation is correct, fossil groups have seen little infall of galaxies since their collapse
- Thus they can be important for studying the formation and evolution of galaxies and the intragroup medium in an isolated system
- They may be a link between ellipticals and compact galaxy groups
- More high redshift clusters, groups and fossil groups badly needed!