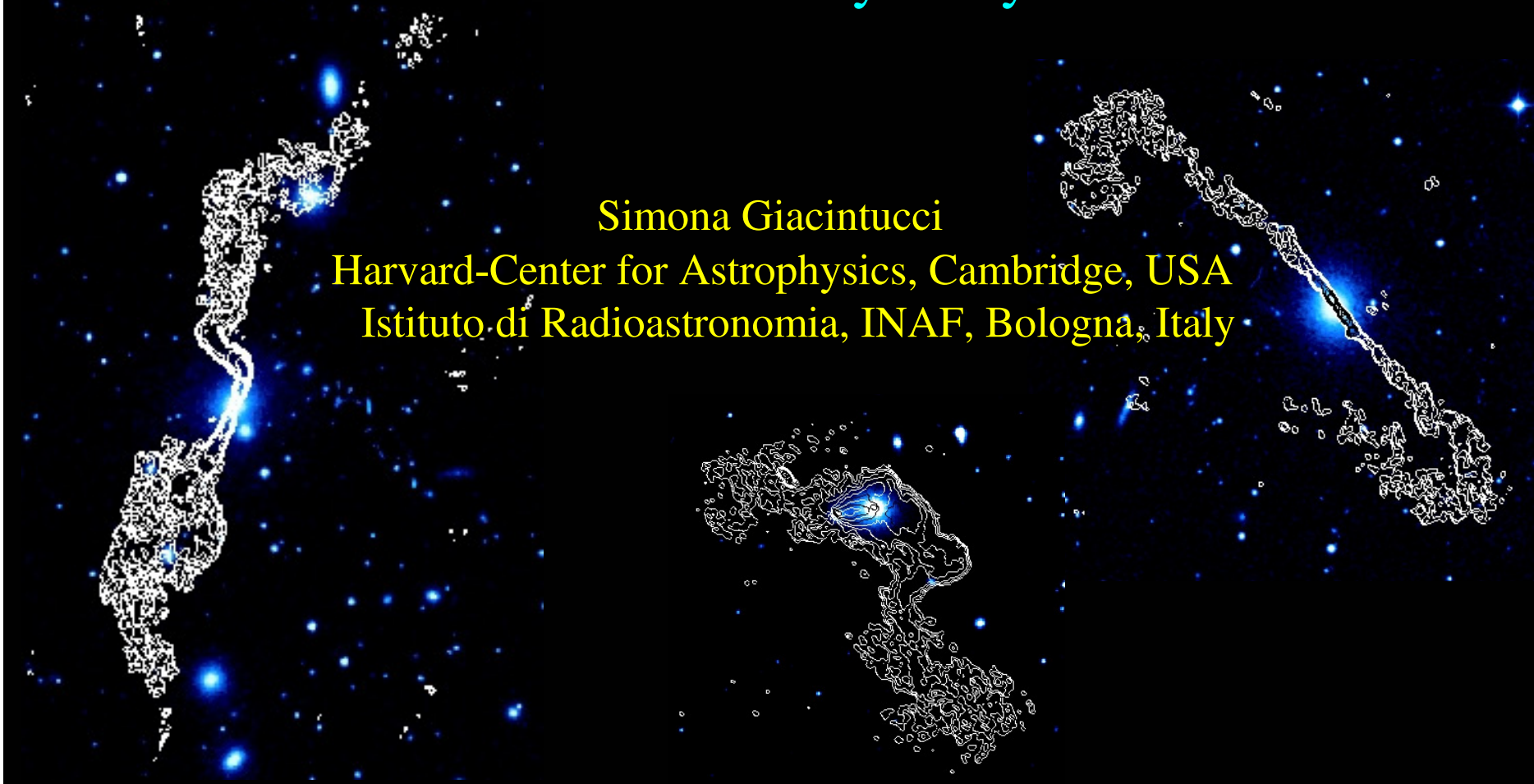
AGN feedback in galaxy groups: a joint GMRT / X-ray study



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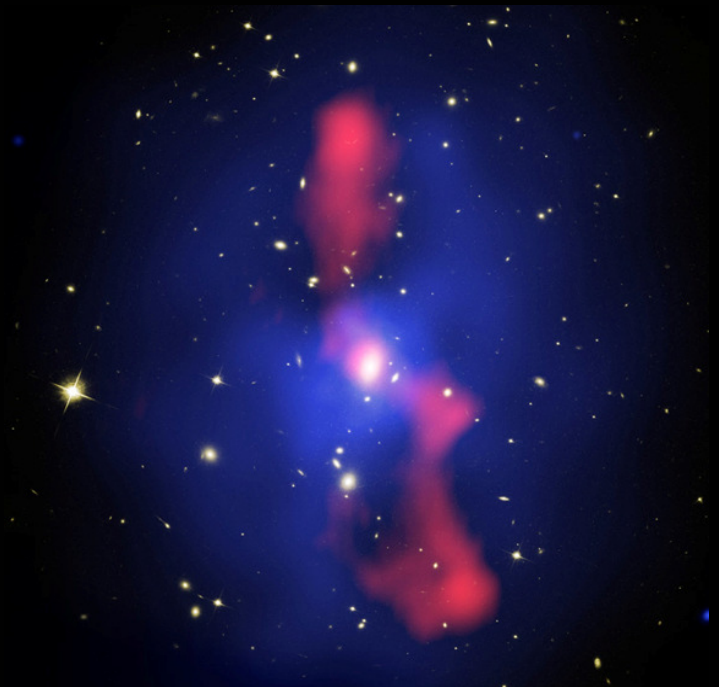
Cooling flow regulation in galaxy clusters and groups

Possible *feedback* mechanisms:

- Sub-cluster mergers
- Supernovae
- Thermal conduction
- AGN-driven outbursts



MS 0735.6+7421 (McNamara et al. 2005)

Rich clusters:

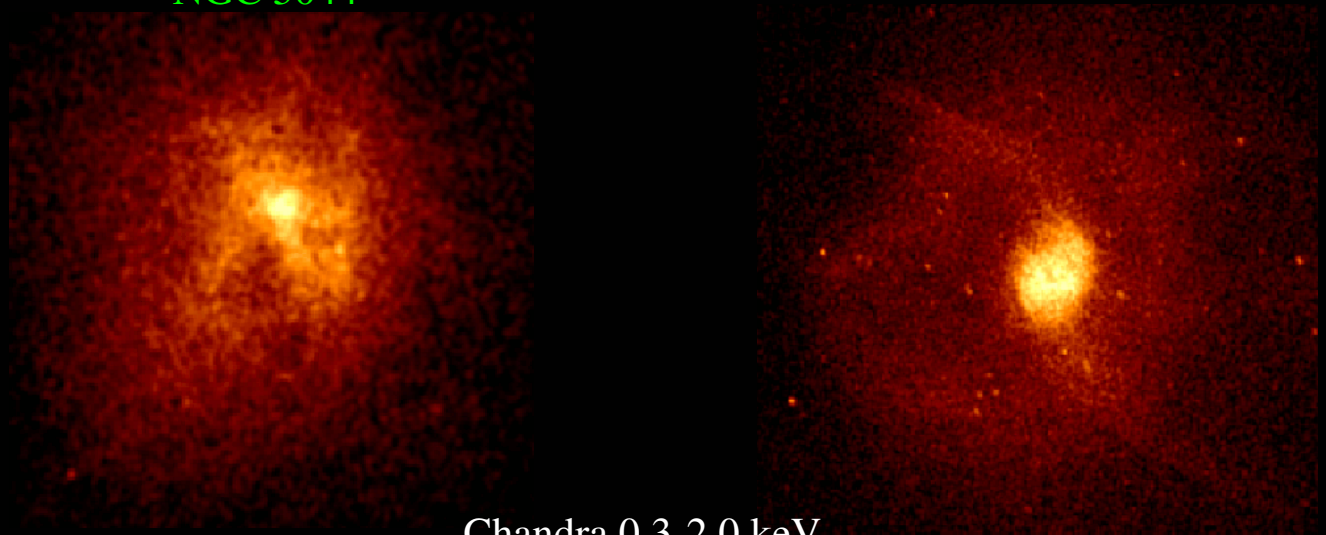
detection of X-ray cavities and AGN-driven shocks -> dominant contribution from (repetitive) outbursts from the central AGN, harboured in the central galaxy at the centre of every cool core cluster.

Why do galaxy groups matter?

Groups are the location of most galaxies in the Universe (Eke et al. 2004)

NGC 5044

NGC 4636



Chandra 0.3-2.0 keV

Examining outbursts in systems smaller than the well-studied rich clusters is valuable for a number of reasons:

- shallow group potential $\Rightarrow$ large impact on intragroup medium;
- low pressure environment $\Rightarrow$ more apparent radio/thermal gas interaction;
- significant influence on galaxy evolution

The project

For a sample of 18 X-ray bright groups:

Low-frequency GMRT obs. at 150, 235, 327 & 610 MHz (+ archival high frequency data)

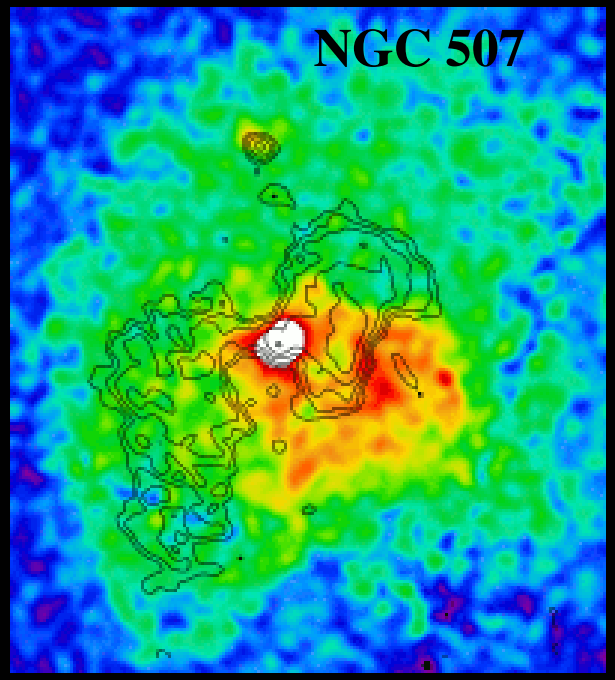
X-ray data from *Chandra* and/or XMM-Newton

* How do X-ray and radio structure correlate?

* What are the properties of the central radio source and what do they imply for ages, outburst cycles..?

* What are the effects of AGN at various phases of activity?

* What are the mechanisms of energy injection?



GMRT 610 MHz on Chandra

Targets and status of the GMRT observations

Group Name	235 MHz	610 MHz
UGC 408	X	X
NGC 315	X	X
NGC 383	X	X
NGC 507	X	X
NGC 741	X	X
HCG 15	X	X
NGC 1407	X	X
NGC 1587	X	X
MKW 2	X	X

Group Name	235 MHz	610 MHz
NGC 3411	X	X
NGC 4636	X	X
HCG 62	X	X
* NGC 5044	X	X
NGC 5813	X	-
NGC 5846	-	X
* AWM 4	X	X
NGC 6269	X	X
NGC 7626	X	X

All have *Chandra* and/or *XMM* data

- Temperatures 1-3 keV
- All have at least NVSS 1.4 GHz data initially
- Presence of X-ray or radio structure indicative of AGN interaction with hot gas

observed at 150 MHz
observed at 327 MHz

Targets and status of the GMRT observations

Group Name	235 MHz	610 MHz
UGC 408	X	X
NGC 315	X	X
NGC 383	X	X
NGC 507	X	X
NGC 741	X	X
HCG 15	X	X
NGC 1407	X	X
NGC 1587	X	X
MKW 2	Giacintucci et al. 2007	

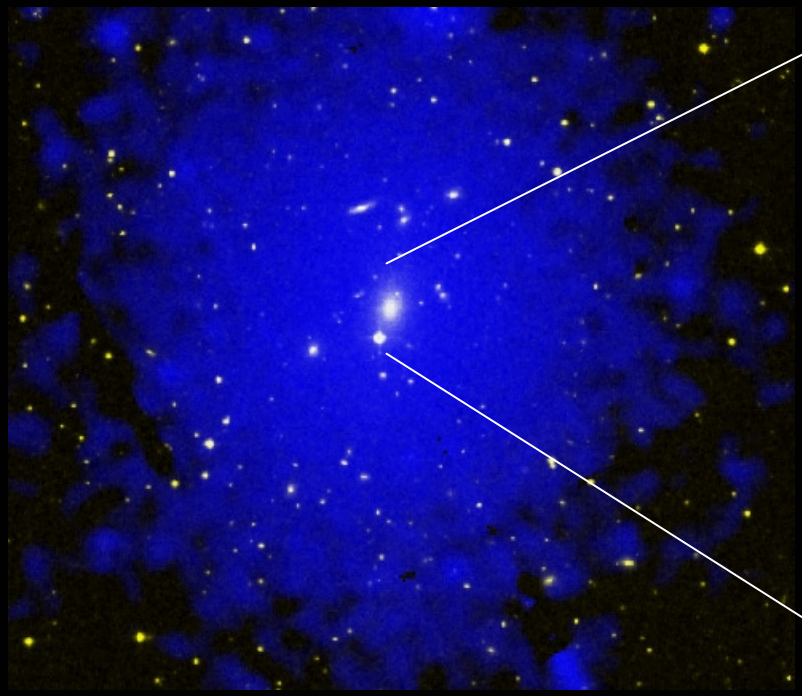
Group Name	235 MHz	610 MHz
NGC 3411	X	X
NGC 4636	Baldi et al. 2009	
HCG62	M. Gitti's talk	
NGC 5044	David et al. 2009	
NGC 5813	X	-
NGC 5846	-	X
AWM 4	Giacintucci et al. 2008	
NGC 6269	X	X
NGC 7626	X	X

Data for all groups will be presented in Giacintucci et al. in preparation

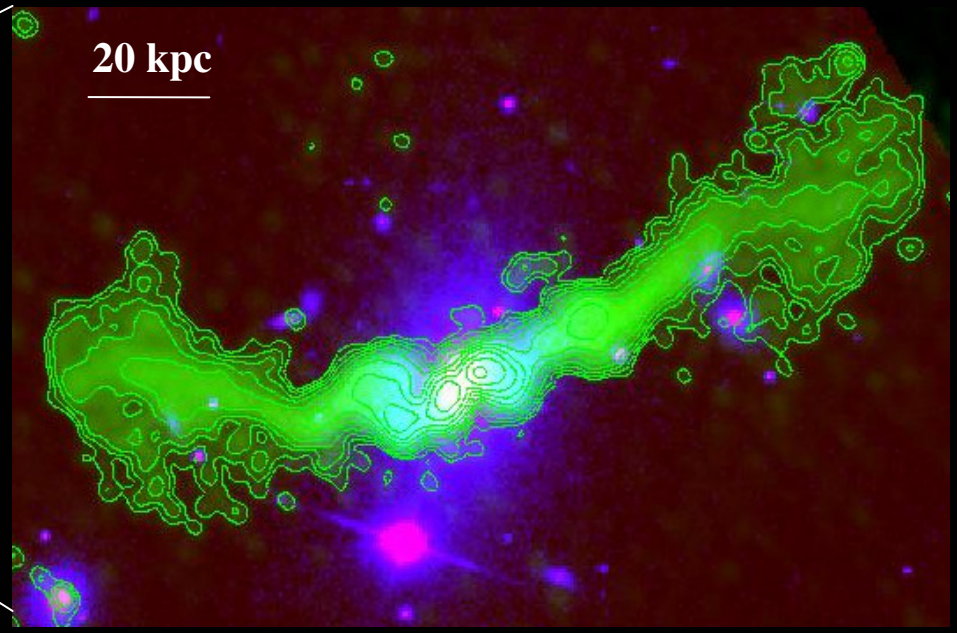
New Chandra data
O'Sullivan et al. in prep.

The poor cluster of galaxies AWM 4

Composite XMM - optical image



4C +24.36 GMRT 610 MHz on SDSS



Giacintucci et al. (2008)

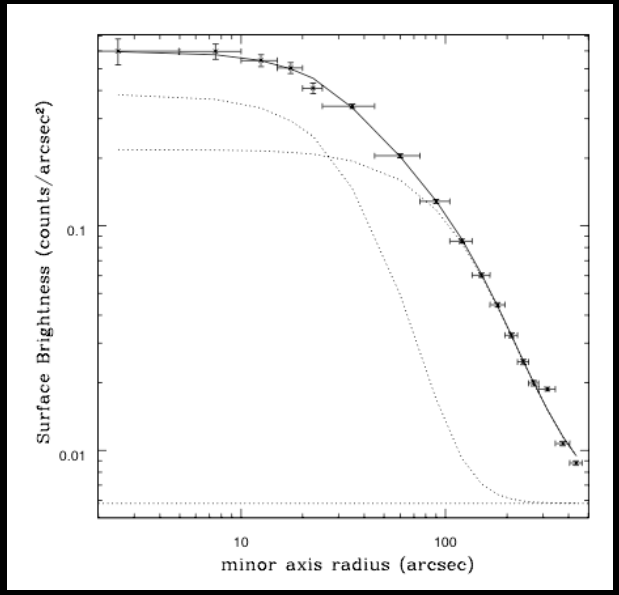
- Fossil group centered on giant elliptical NGC 6051
- No optical substructure (Koranyi & Geller 2002)
- X-ray bright (~ 2 x 10^{43} erg s^{-1}) , T~ 3 keV
- Relaxed X-ray morphology

- GMRT 235, 327 and 610 MHz
- WAT
- $\theta = 81 \div 88^{\circ}$
- Radiative age : ~ 160 Myr

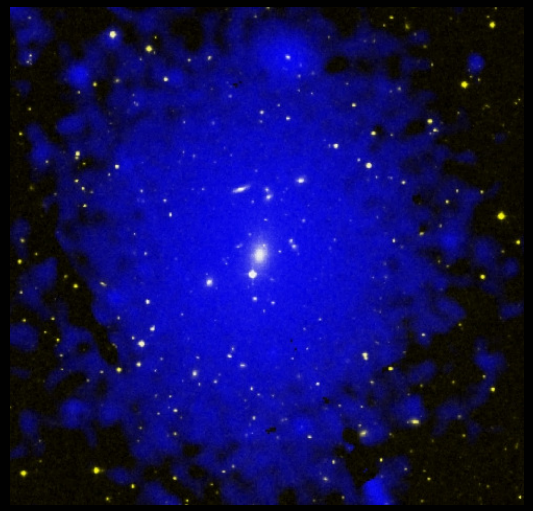
X-ray overview: old XMM-Newton results

AWM 4 occupies an unusual place among groups and clusters

X-ray brightness profile

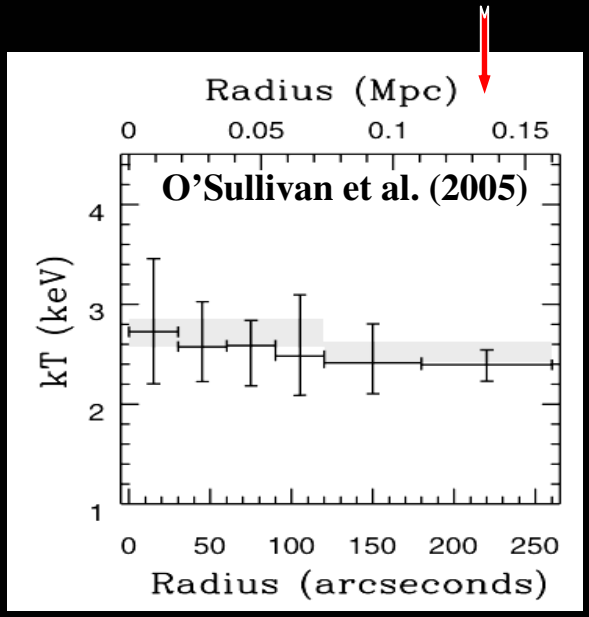


- Regular X-ray emission
- Monotonic increase of brightness toward the centre
- Cooling time ~ 2 Gyr
- Metallicity decline from the centre to large radii



Relaxed cluster with a well-established cool core

BUT



see also Gastaldello et al. 2008

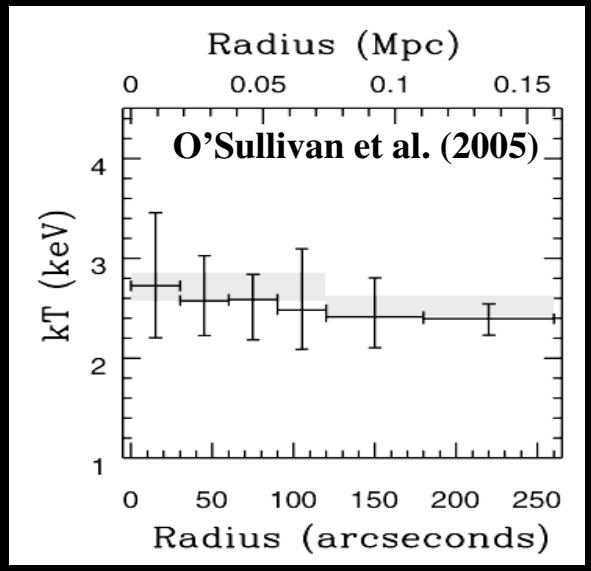
Gas heating at the core?

Gas (re-)heating by the central AGN

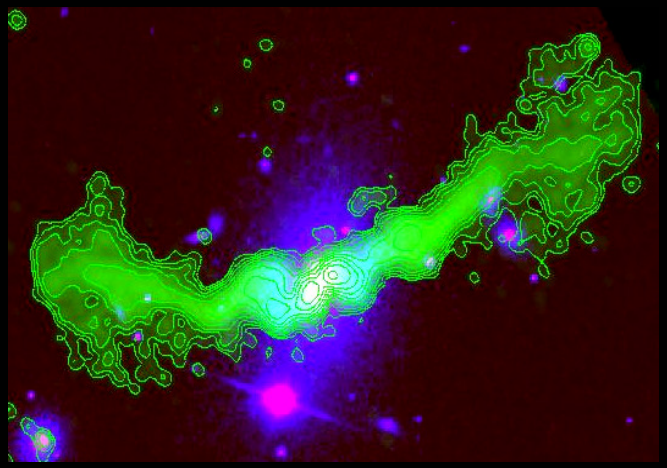
* Required energy ~ 9 x 10^{58} ergs

Giacintucci et al. 2008:

* $E_{tot,\ RADIO}$ ~ 2.9 x 10^{57} ergs (t ~ 160 Myr)



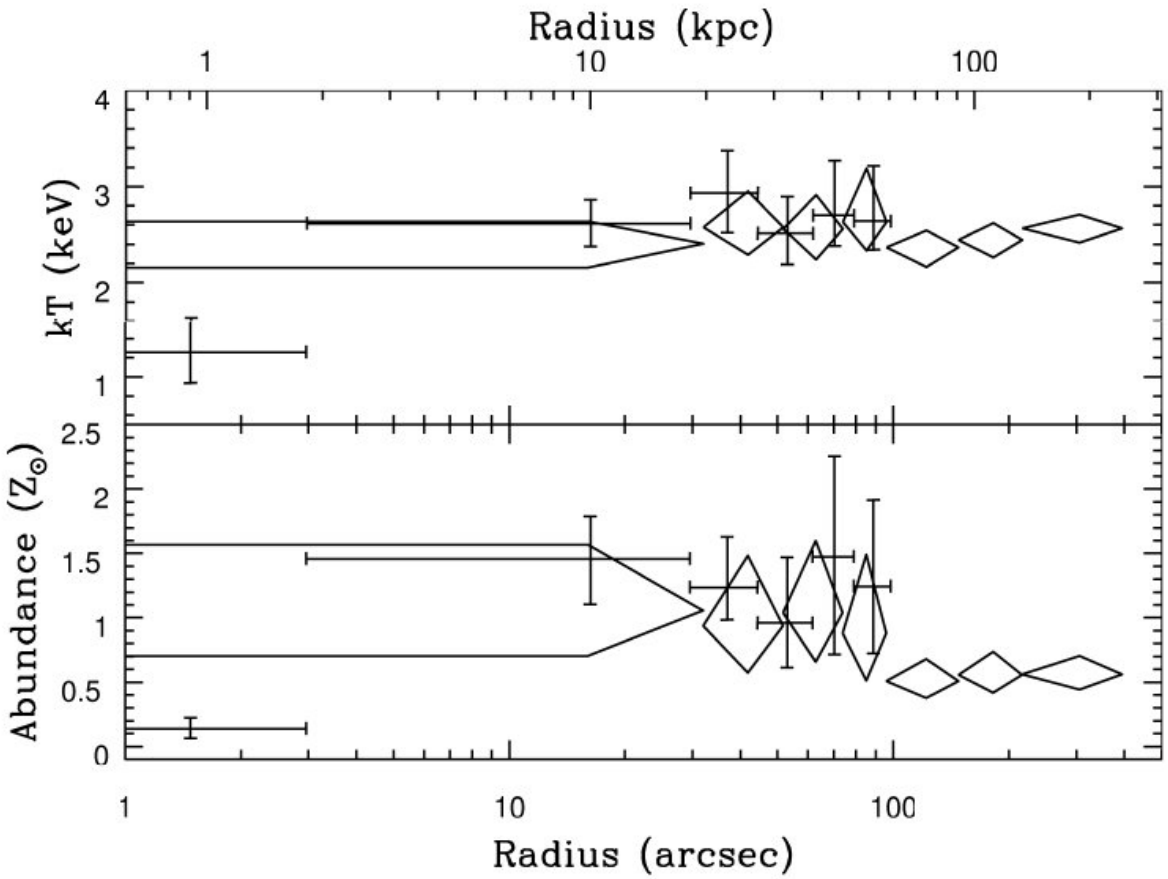
see also Gastaldello et al. 2008



Mechanical energy → 10-100 kpc radius bubbles

But no X-ray cavities in the XMM image!

New 75 ksec Chandra observation: kT and Z profiles



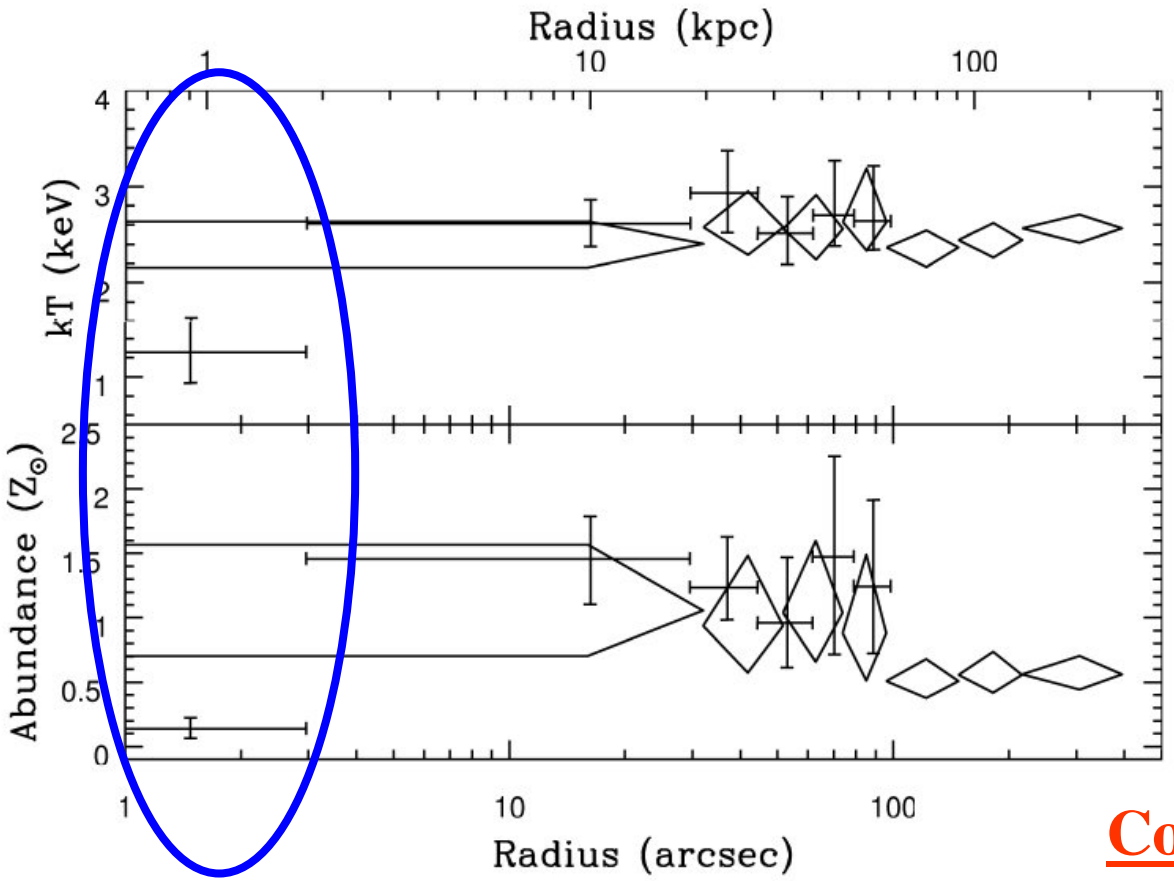
Deprojected profiles

Crosses:
8000 cts/spectrum
(central bin ~ 370 cts)

Diamonds:
12000 cts/spectrum

O'Sullivan et al. in prep.

A cool corona in AWM4



Deprojected profiles

Crosses:
8000 cts/spectrum
(central bin ~ 370 cts)

Diamonds:
12000 cts/spectrum

Size: 3- 4" (1.8-2.4 kpc) radius
kT= 1.26 (+0.37, -0.32) keV,
Z=0.14 (+0.08, -0.07) Zsolar
Lx(0.5-2.0)=2.76e40 erg/s

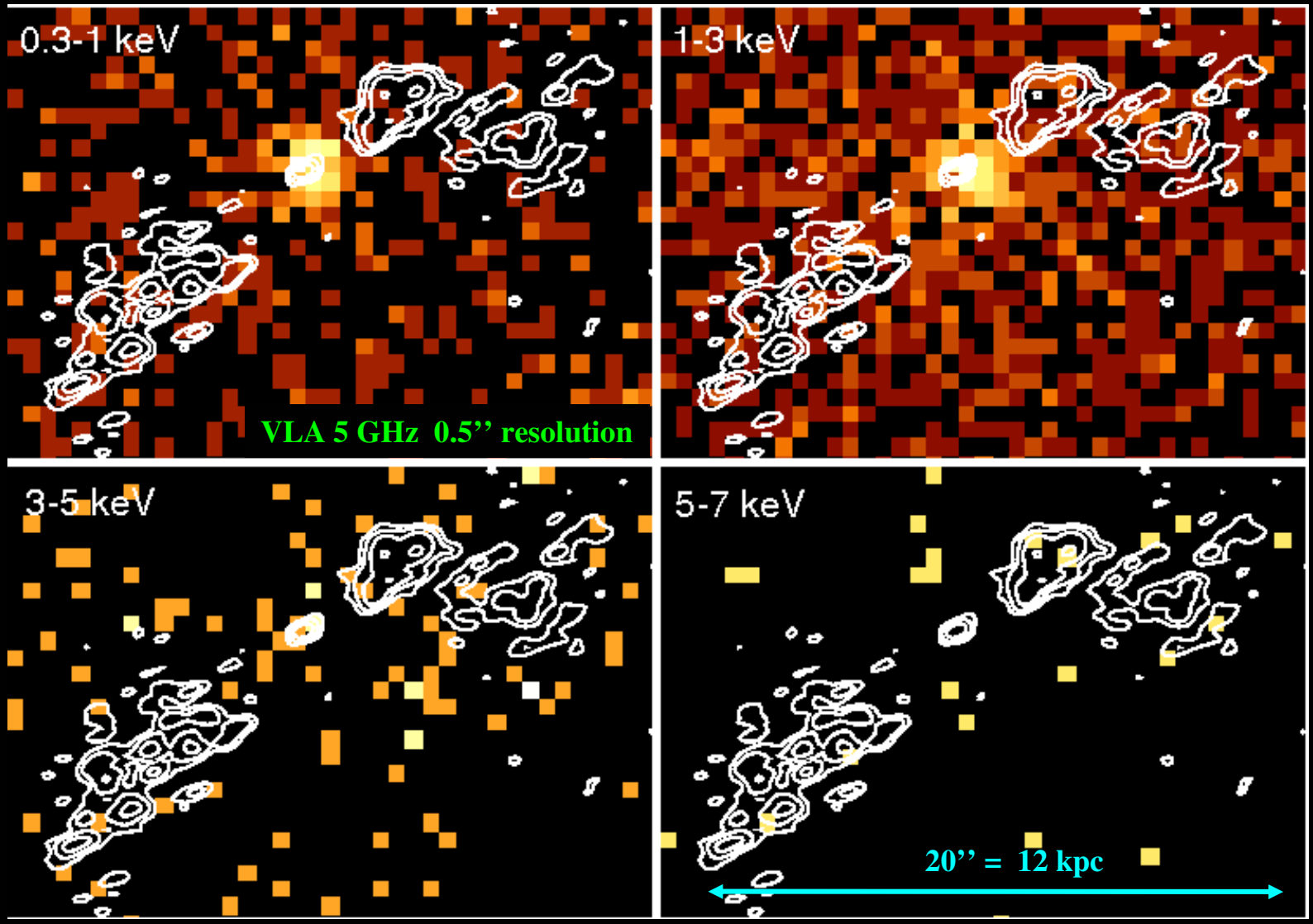
Cool corona

t_{cool} = 441 Myr at 2 kpc
(compared to ~ 2 Gyr at 10 kpc)

M_{dot} = 0.11 M_{sol}/yr

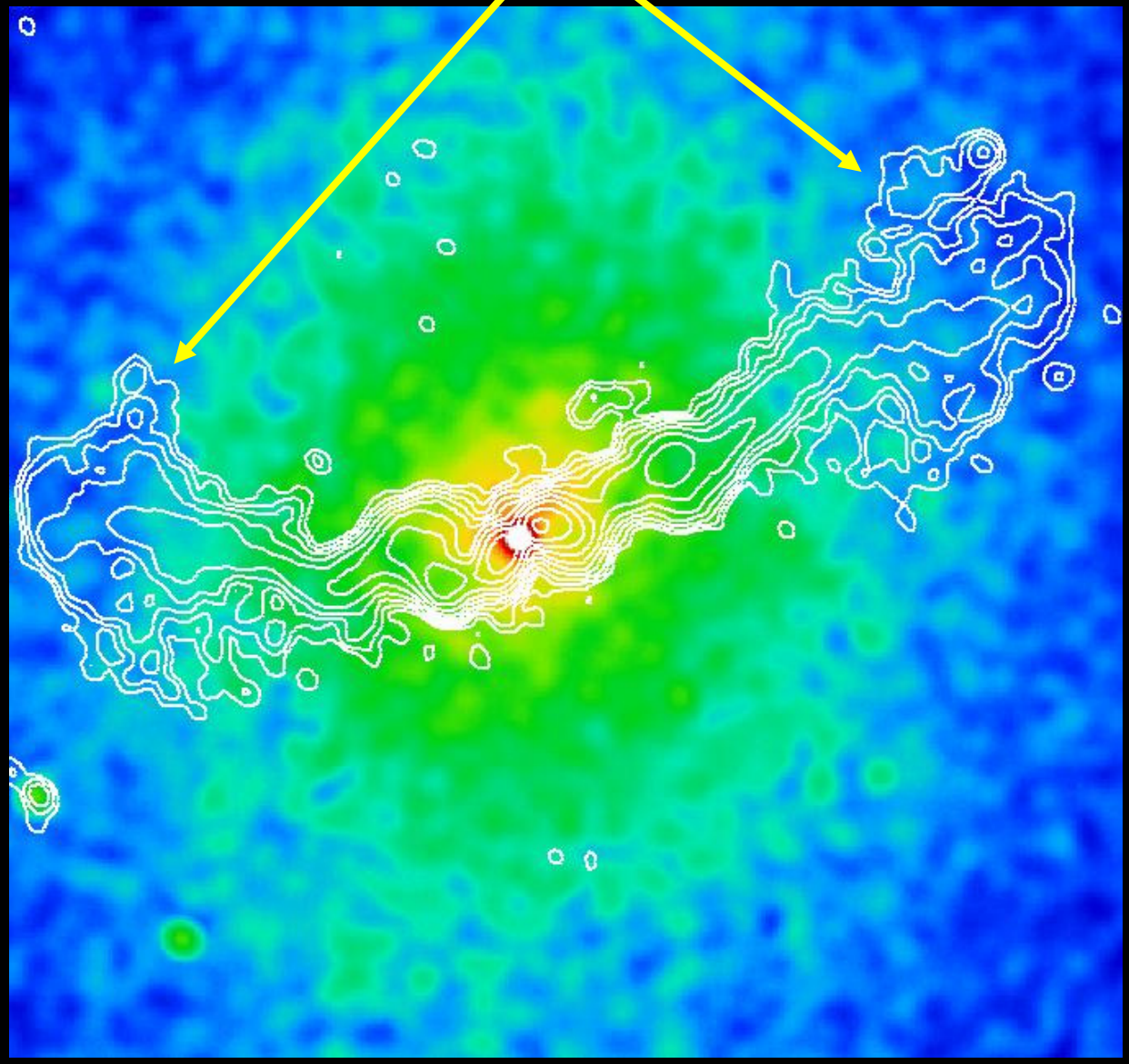
O'Sullivan et al. in prep.

A cool corona in AWM4 - Chandra images



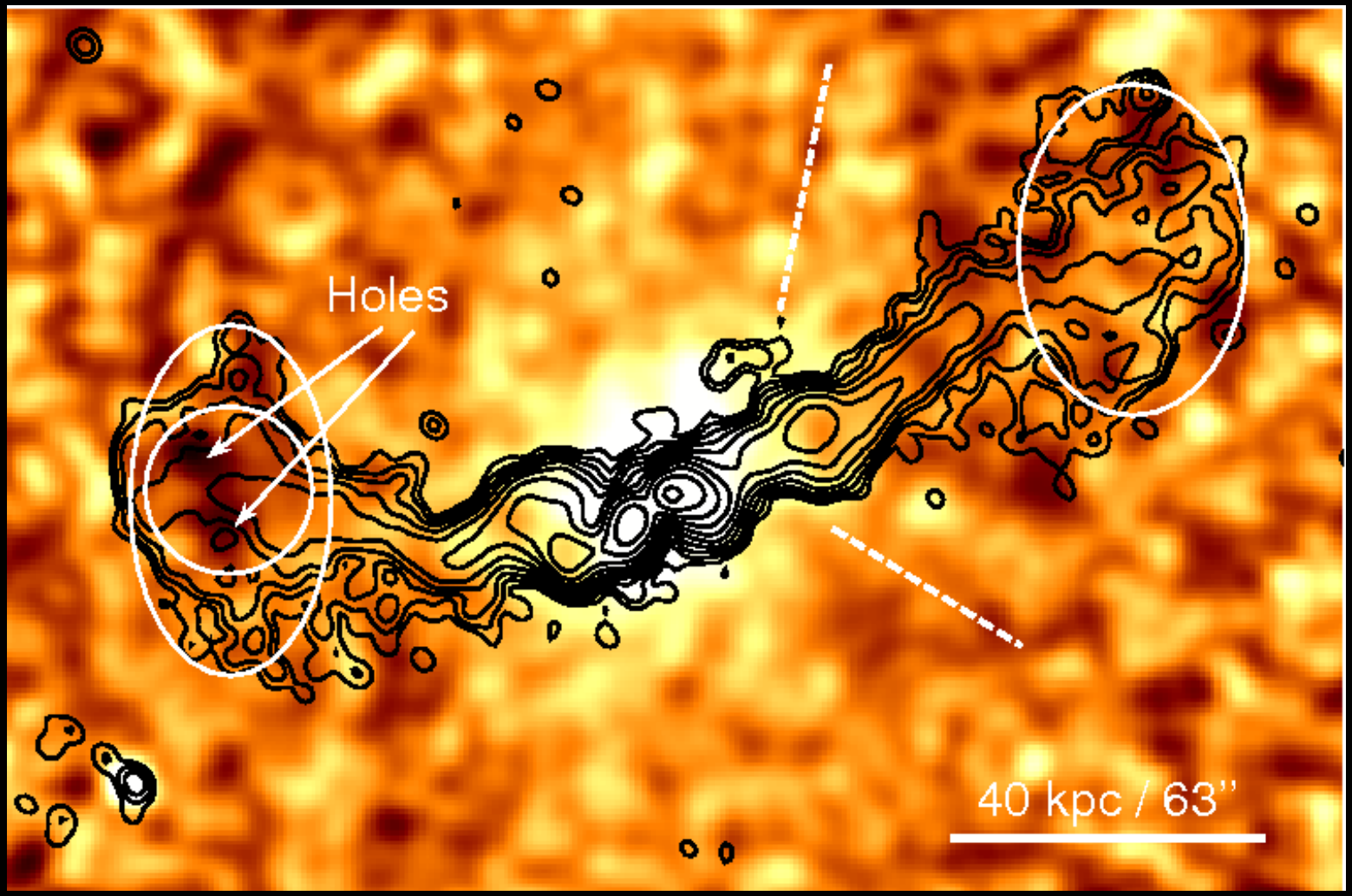
The radio jets flare after the corona/ICM boundary
(e.g., NGC 3842, NGC 4874 - Sun et al. 2005)

No cavities?



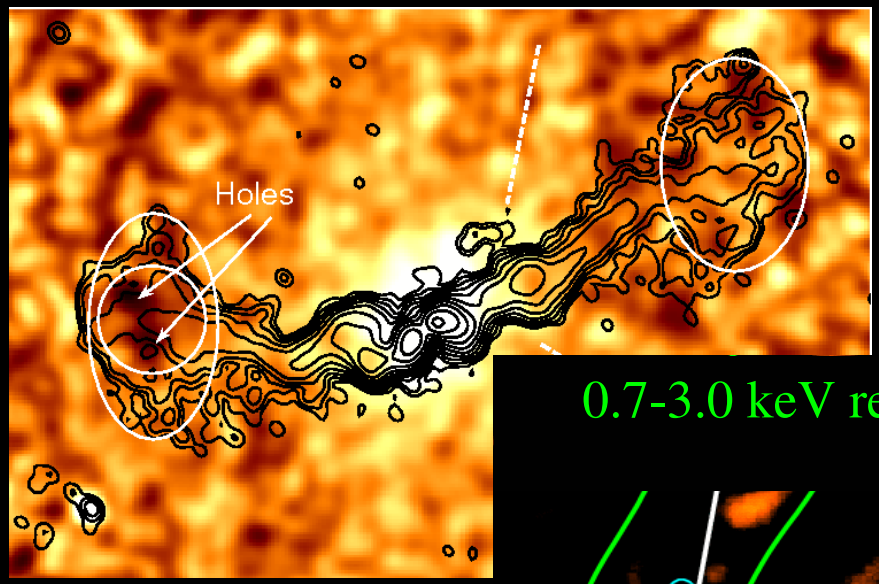
GMRT 610 MHz on the 0.3-2 keV smoothed Chandra image

Chandra 1-3 keV unsharp mask image



"Holes" in the eastern lobe correspond to a 3.7 σ deficit -> cavity?

Chandra 1-3 keV unsharp mask image



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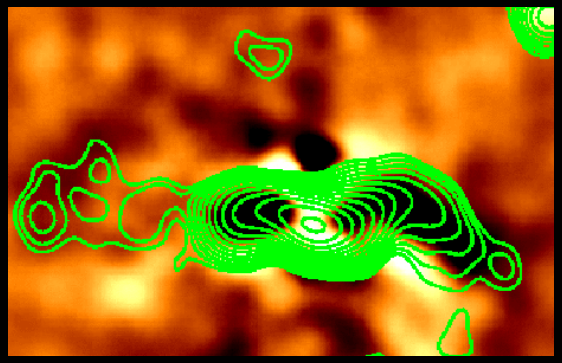
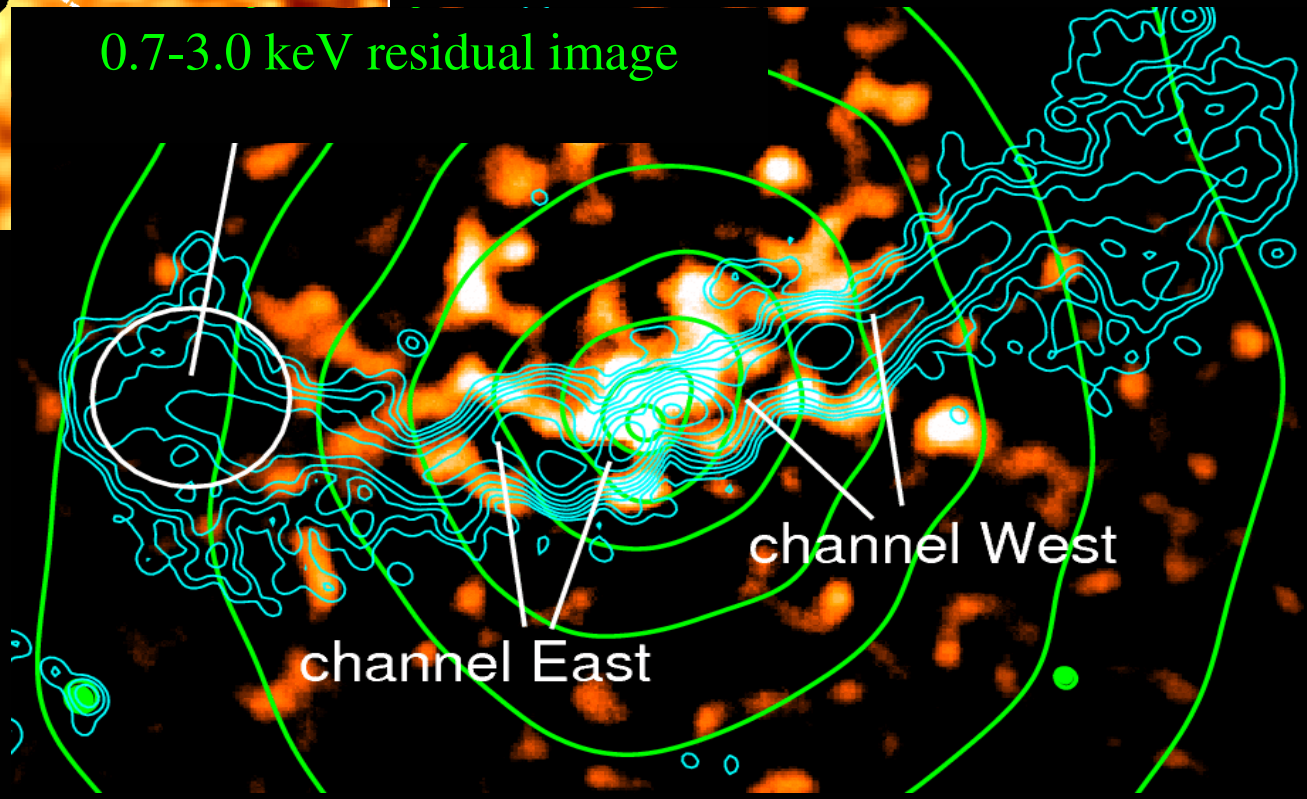
Clarke et al. 2009



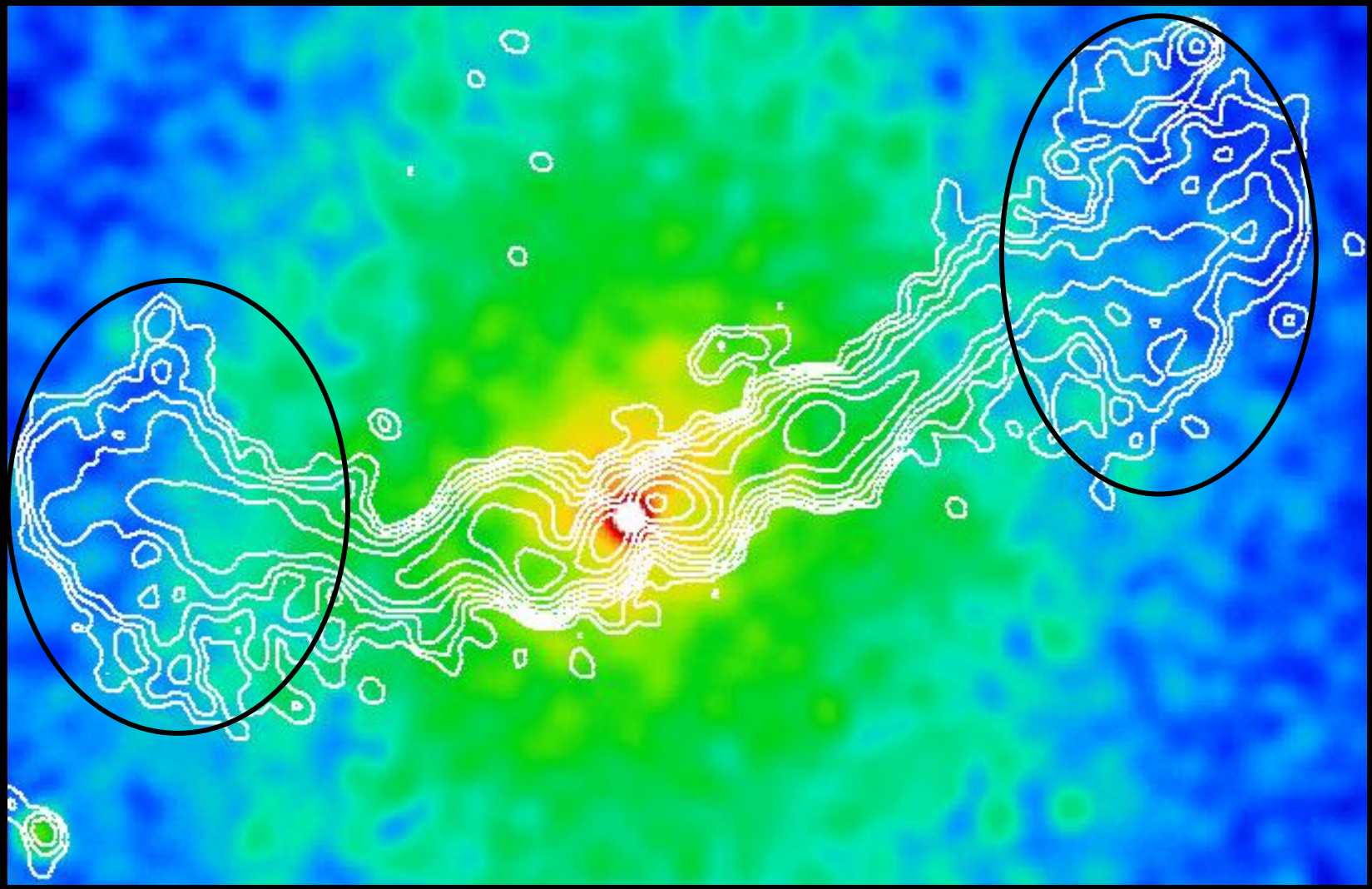
0.7-3.0 keV residual image



West jet knot: 2.5 σ deficit

Lower significance for all the other structures -> deeper observations are needed

Based on the density profile of the ICM, we would expect a deficit of
184 cts (West lobe) and 251 cts (East lobe)

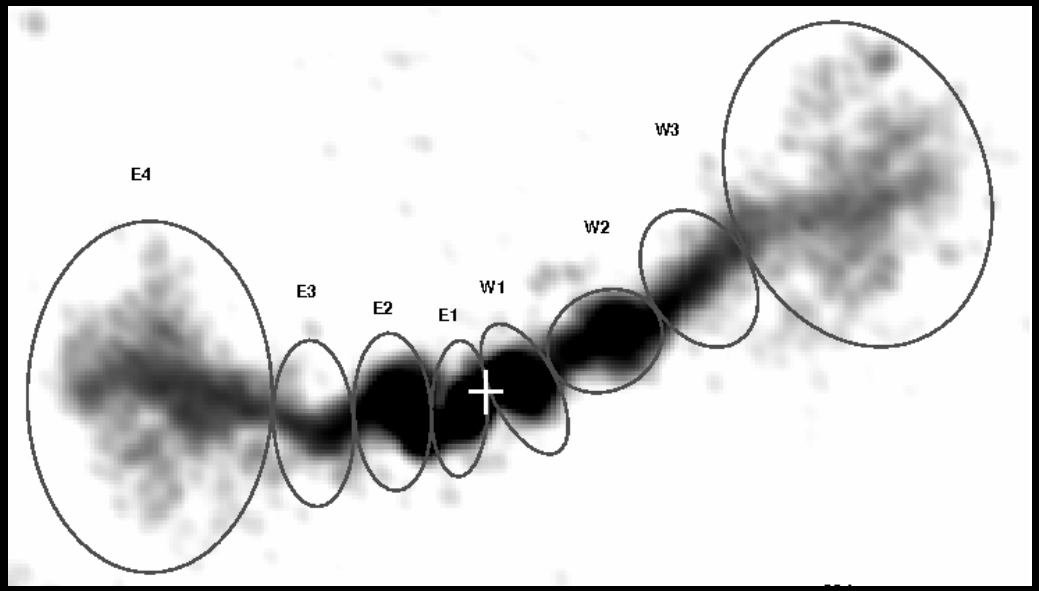


X-ray cavities at 4-5 σ, if the lobes are empty of thermal plasma

Content of the lobes... work in progress

- The lack of clear cavities might suggest filling factor of the radio plasma $\Phi < 1$: mixing with the ICM gas?

- Radio images shows the relativistic component to be clumpy and filamentary: still separated from the ICM? Role of the magnetic field?



Mixing only in the lobes or entrainment of material in the jets?

O'Sullivan et al. in preparation

Summary

- Elliptical-dominated galaxy groups are an ideal laboratory to investigate AGN-driven feedback:
  - Groups show generally similar phenomenology to clusters, with many radio and X-ray features the direct result of AGN activity
  - Groups are an important/dominant locus for evolution of baryonic material
- Our analysis of AWM4 shows that the combination of high sensitivity multi-frequency radio data and X-ray observations offers useful insight into AGN/hot gas interactions, timescales, and energetics in the central region
- A similar study will be carried out for other individual interesting groups in the sample (e.g., NGC 3411, NGC 1407, NGC 741..)
- Statistical analysis and comparison with the X-ray properties for the whole sample (in progress)