AGN FEEDBACK IN GALAXY GROUPS

— THE CASE OF HCG 62 —

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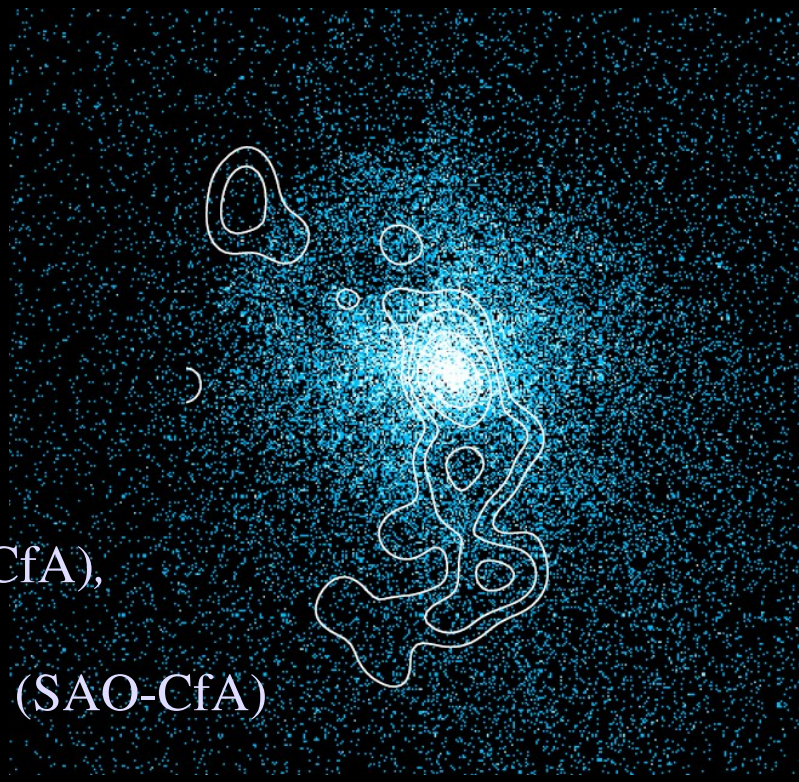
(SAO-CfA)



In collaboration with:
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With thanks to:
C. Jones (SAO-CfA), *W. Forman* (SAO-CfA), *T. Ponman* (Univ. Birmingham)

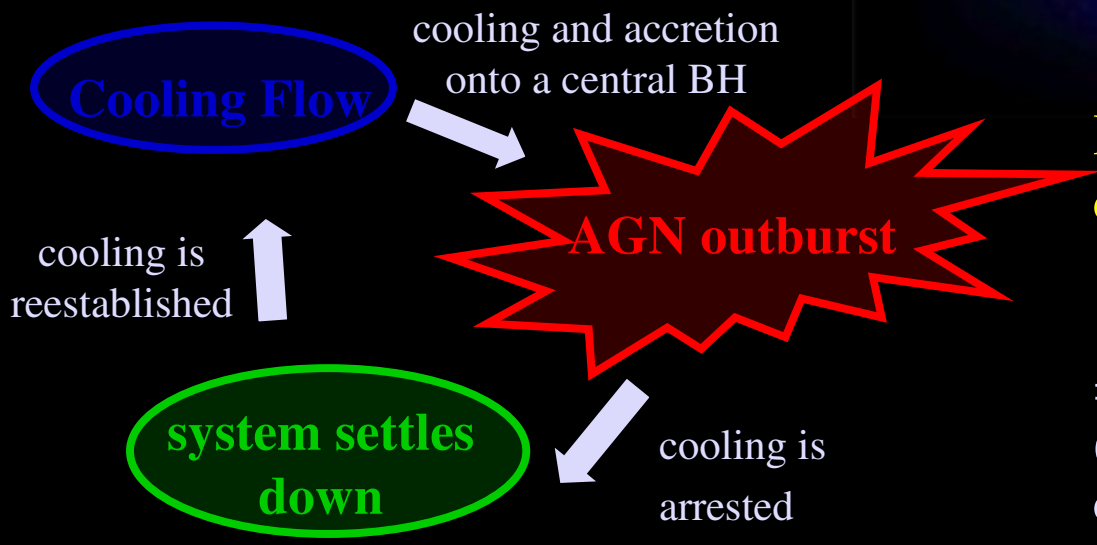
Cooling flow regulation in galaxy clusters and groups

Main candidate to solve the "Cooling Flow Problem":

Feedback by central AGN

MS0735.6+7421

McNamara et al. 05, 09
McNamara & Nulsen 07
Gitti et al. 07

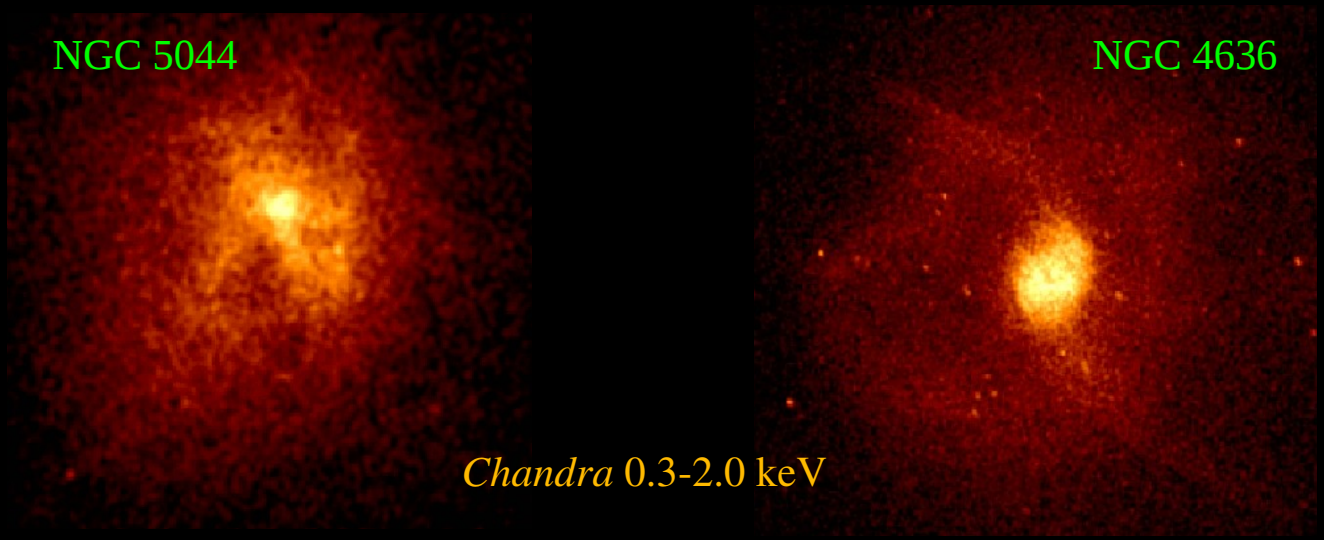


Rich clusters: detection of X-ray cavities and AGN-driven shocks

⇒ dominant contribution from (recurrent) outbursts from the central AGN, hosted by the cD galaxy at the center of (almost) every cool core clusters

Why do galaxy groups matter?

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



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: a joint X-ray / radio study

For a sample of 18 X-ray bright groups of galaxies:

X-ray data:
archival *Chandra* and/or *XMM-Newton* observations

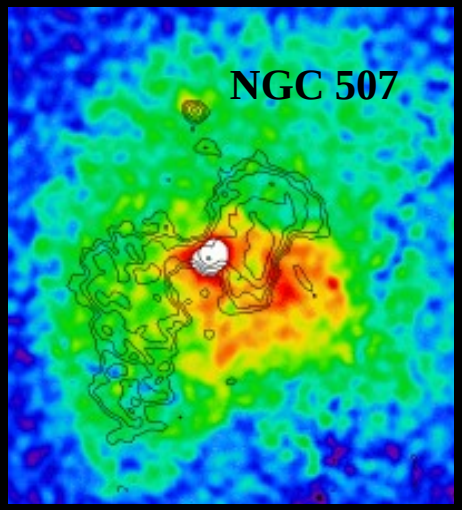
⇓

geometry, physical state, and energetics of the hot gas

Low frequency radio data:
GMRT observations at 150, 235, 327 & 610 MHz

⇓

loci of energy injection, history of AGN outbursts through spectral aging of electrons



* How do X-ray and radio structures 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?

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	
HCG 62	**Gitti et al. in prep.**	
* **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

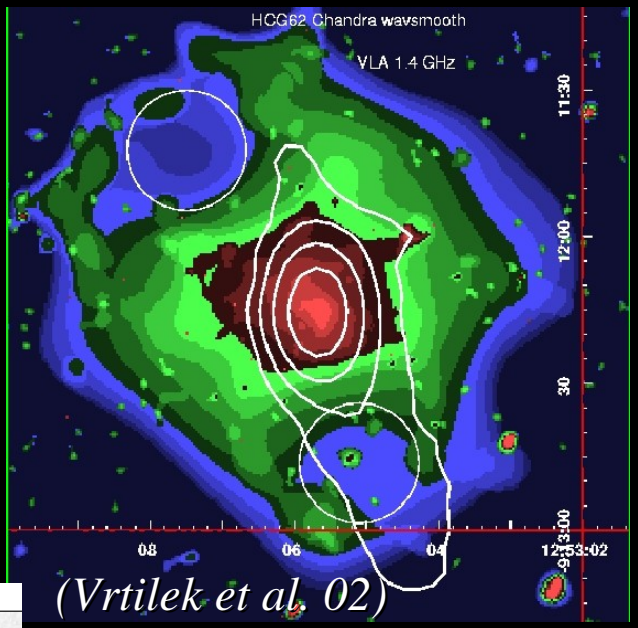
Data for all groups will be presented in Giacintucci et al. in prep.

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

*** see posters !**
David et al.
Giacintucci et al.
Vrtilek et al.

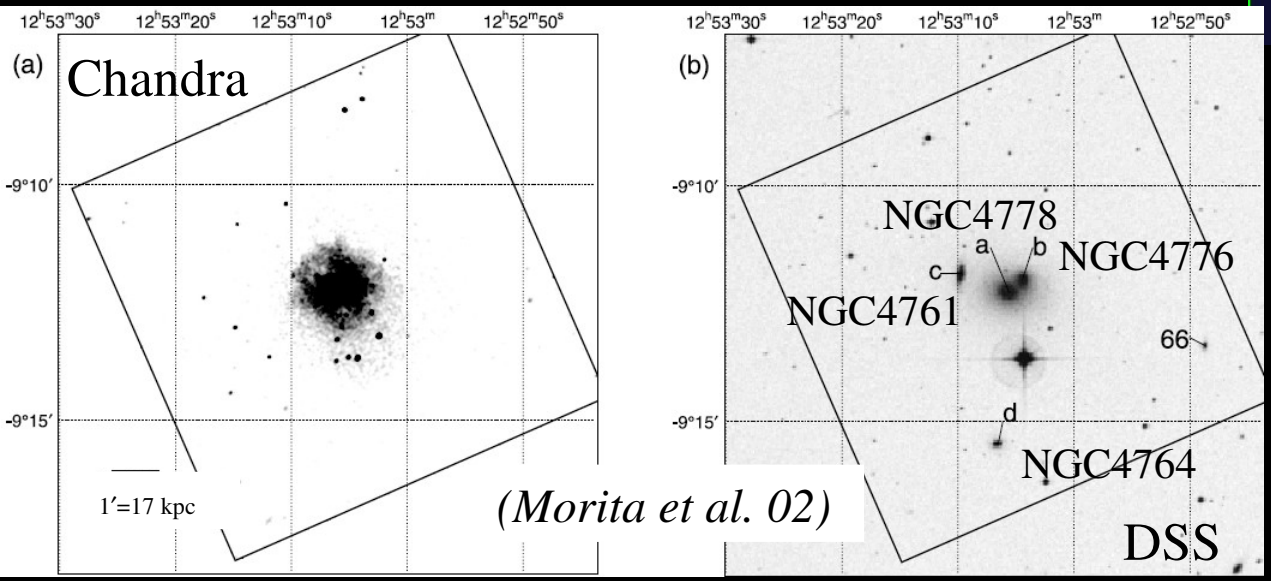
The compact group of galaxies HCG 62 (z = 0.014)

- One of the most intrinsically luminous of the 100 Hickson compact groups: $L_X \approx 10^{43}$ erg s^{-1}
- VLA 1.4 GHz : S = 6.6 mJy
- Very clear, small X-ray cavities (radio ghost) — first detection in a galaxy group



(Vrtilek et al. 02)

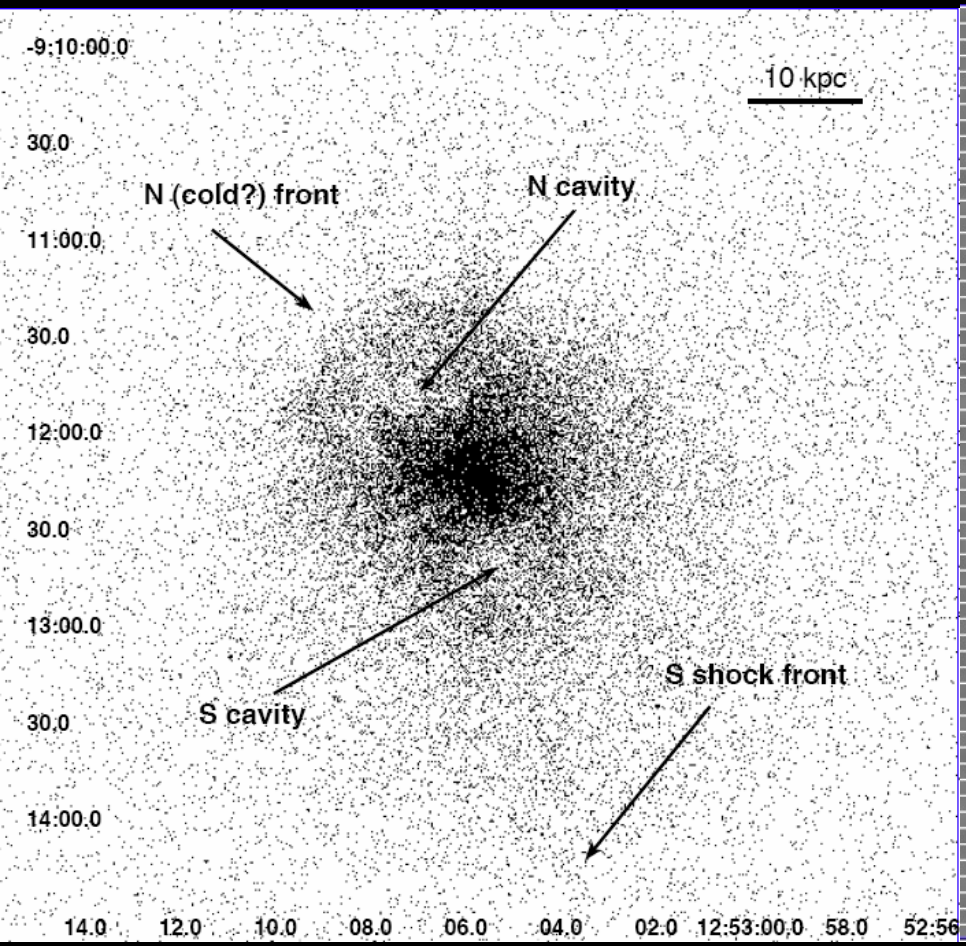
beam=18″×12″
lowest contour at 0.3 mJy/beam



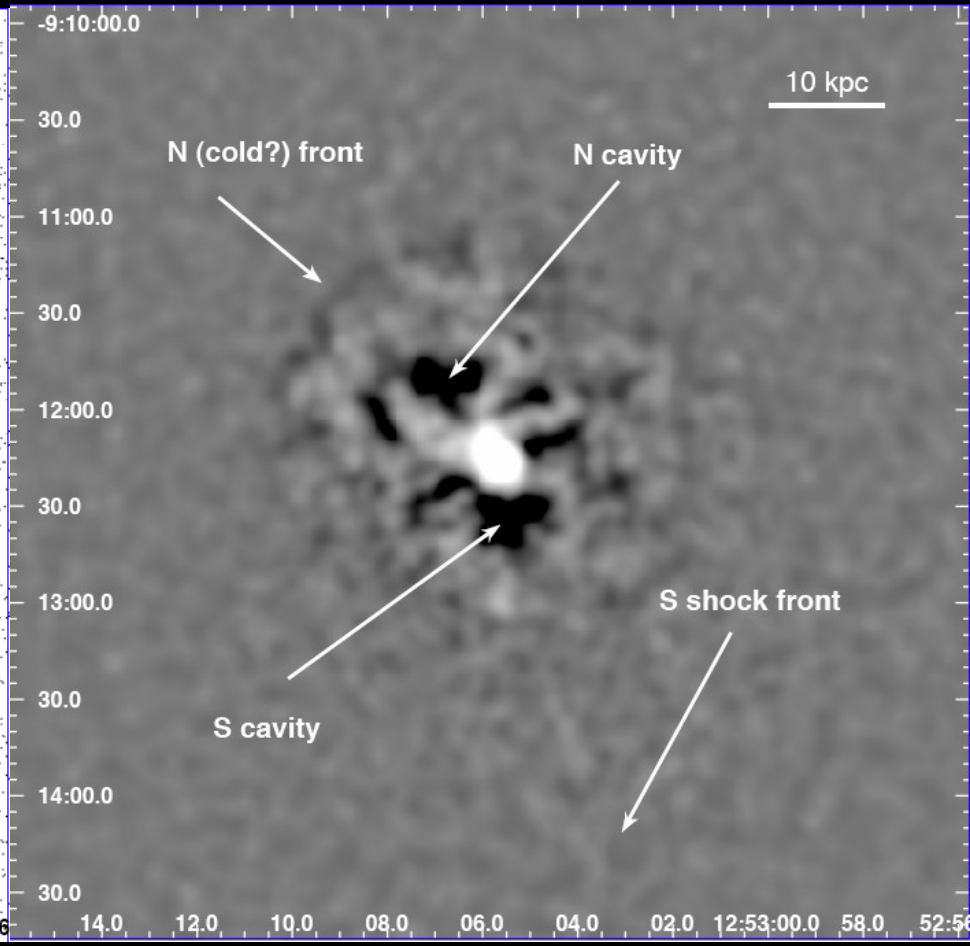
(Morita et al. 02)

- central region dominated by 4 early-type galaxies
- NGC 4778 possibly interacting with NGC 4761 *(Spavone et al. 06)*

X-RAY DATA: *Chandra* 50 ks (2000)



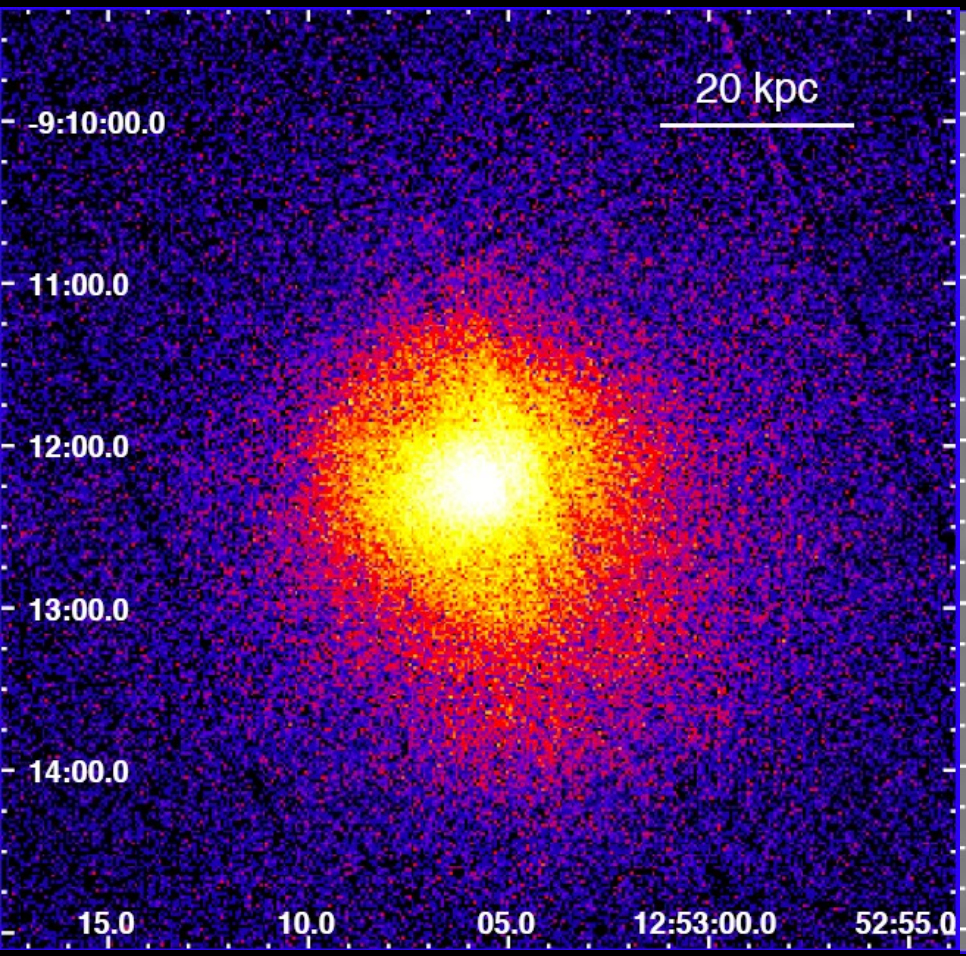
raw 0.5-2.0 keV ACIS



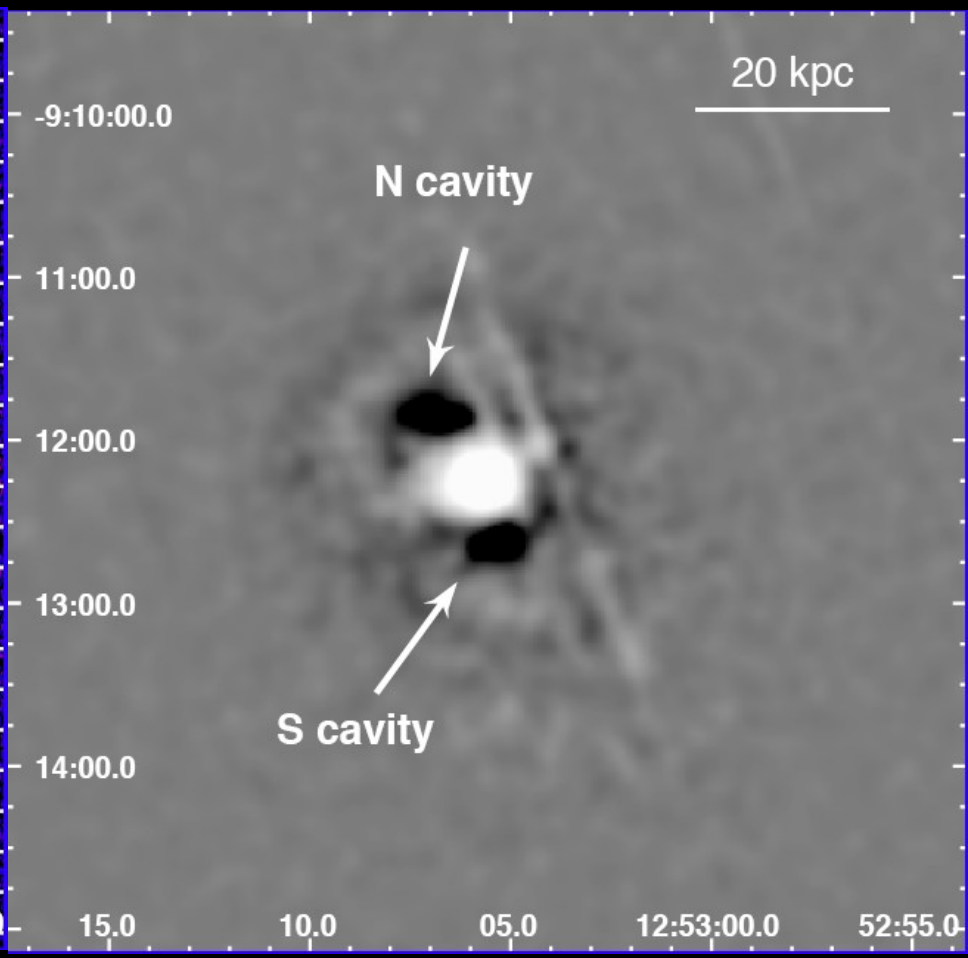
Unsharp masked image

(Gitti, O'Sullivan, Giacintucci et al., in prep.)

X-RAY DATA: *XMM* 90 ks (2007)



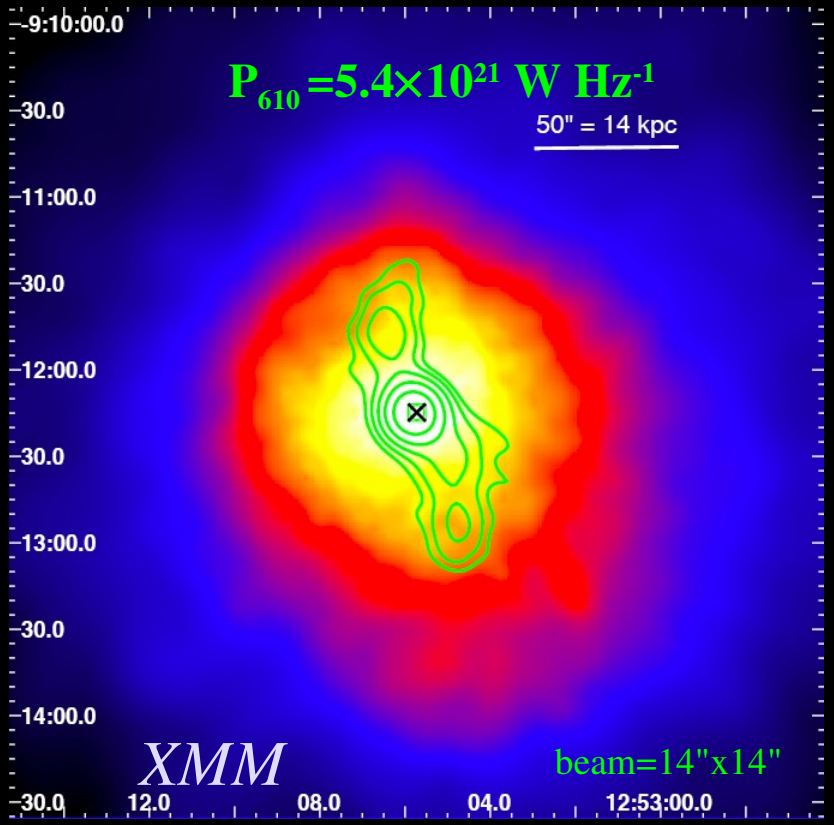
mosaic 0.5-2.0 keV MOS+PN

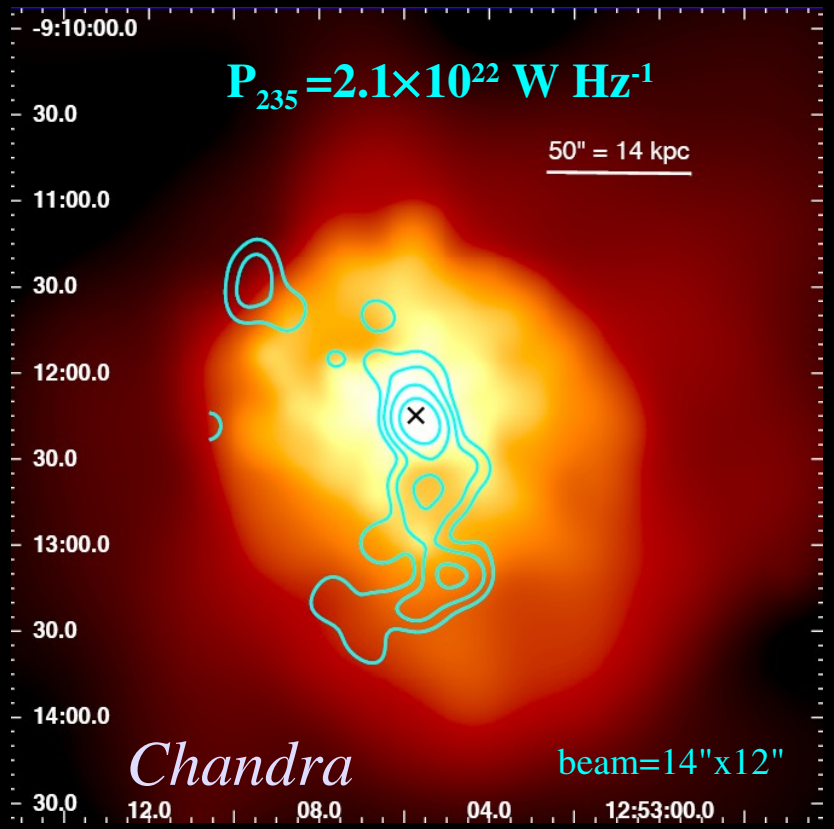


Unsharp masked image

(Gitti, O'Sullivan, Giacintucci et al., in prep.)

(new!) RADIO DATA: GMRT 2h (2008)





610 MHz:

r.m.s. = 65 μJy/beam

S = 12.8 mJy (6.9 mJy core)

$\alpha^{235}_{610} = 1.42$

235 MHz:

r.m.s. = 230 μJy/beam

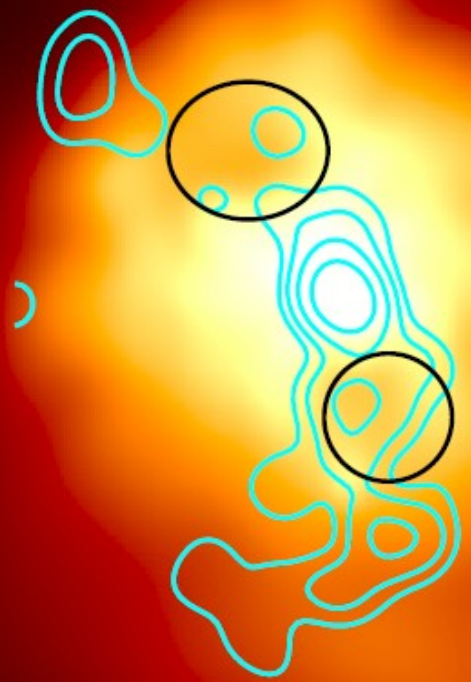
S = 49.6 mJy (15.1 mJy core)

(Giacintucci et al., in prep.)

X-RAY / RADIO INTERACTION

– Energy budget –

$$E = \frac{\gamma p V}{\gamma - 1}$$



P_{cav} = **3.9×10^{42}** erg s^{-1}

L_{ICM} = **1.8×10^{42}** erg s^{-1}

(Rafferty et al. 06)

The AGN outburst is currently supplying about twice the power lost by radiation within the cooling region

$L_{[10MHz-10GHz]}$ = **4×10^{38} erg s^{-1}**

The radio luminosity is much less than the mechanical power

⇒ radiative efficiency ~ 10^{-4}

X-RAY / RADIO INTERACTION

– Pressure –

Cavity N:

$P_X / P_{radio} \sim 4$

Cavity S:

$P_X / P_{radio} \sim 2$

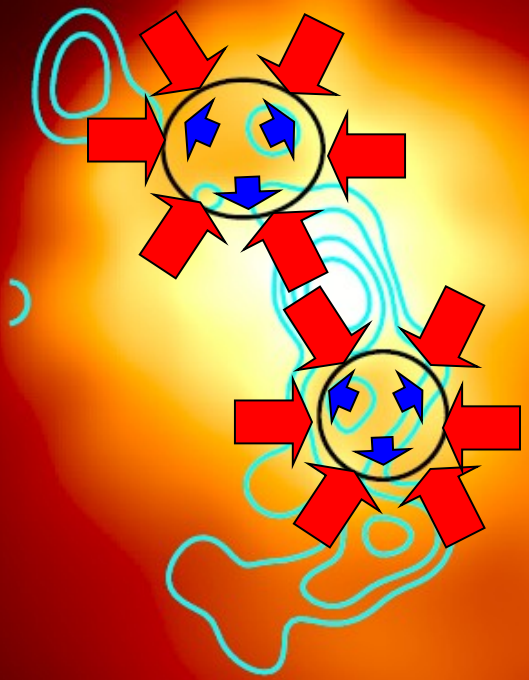
The cavities are close to pressure balance

Vice versa:

$E_{pr} = k\, E_{el}$

k = [6-27] required for pressure equilibrium

⇒ "light" hadronic jets



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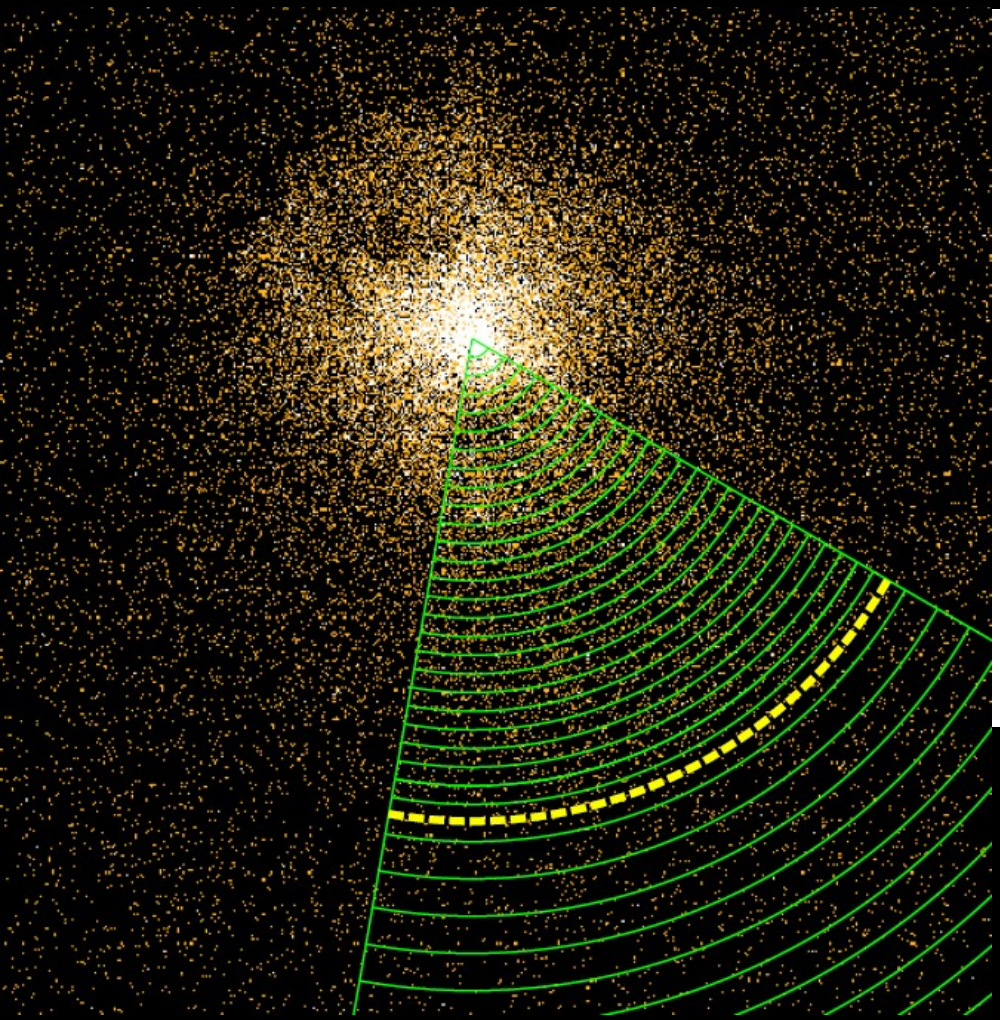
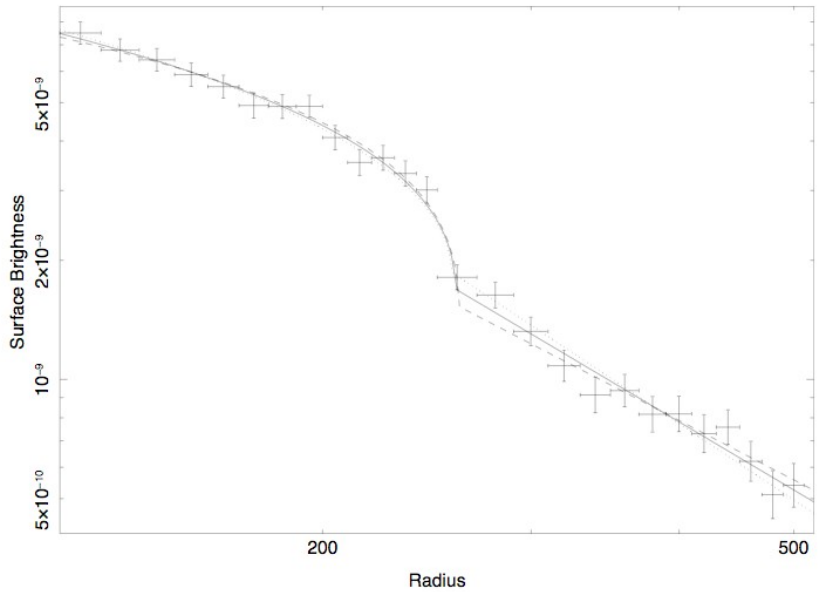
SHOCK FRONT – *Chandra* SB profile



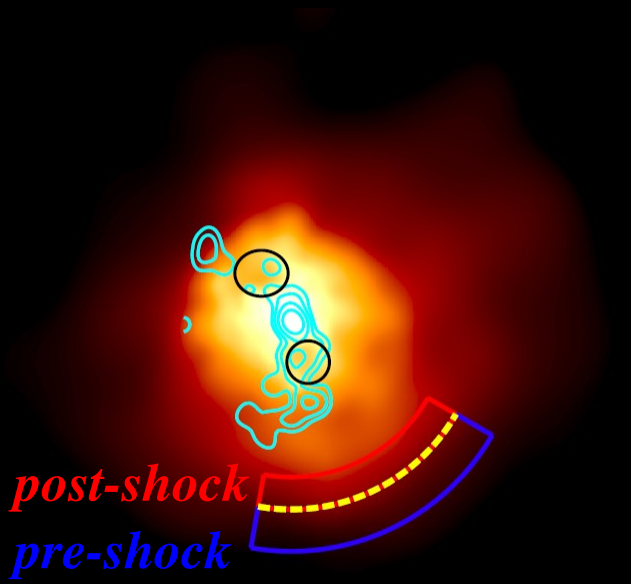
Shock model - fit to SB

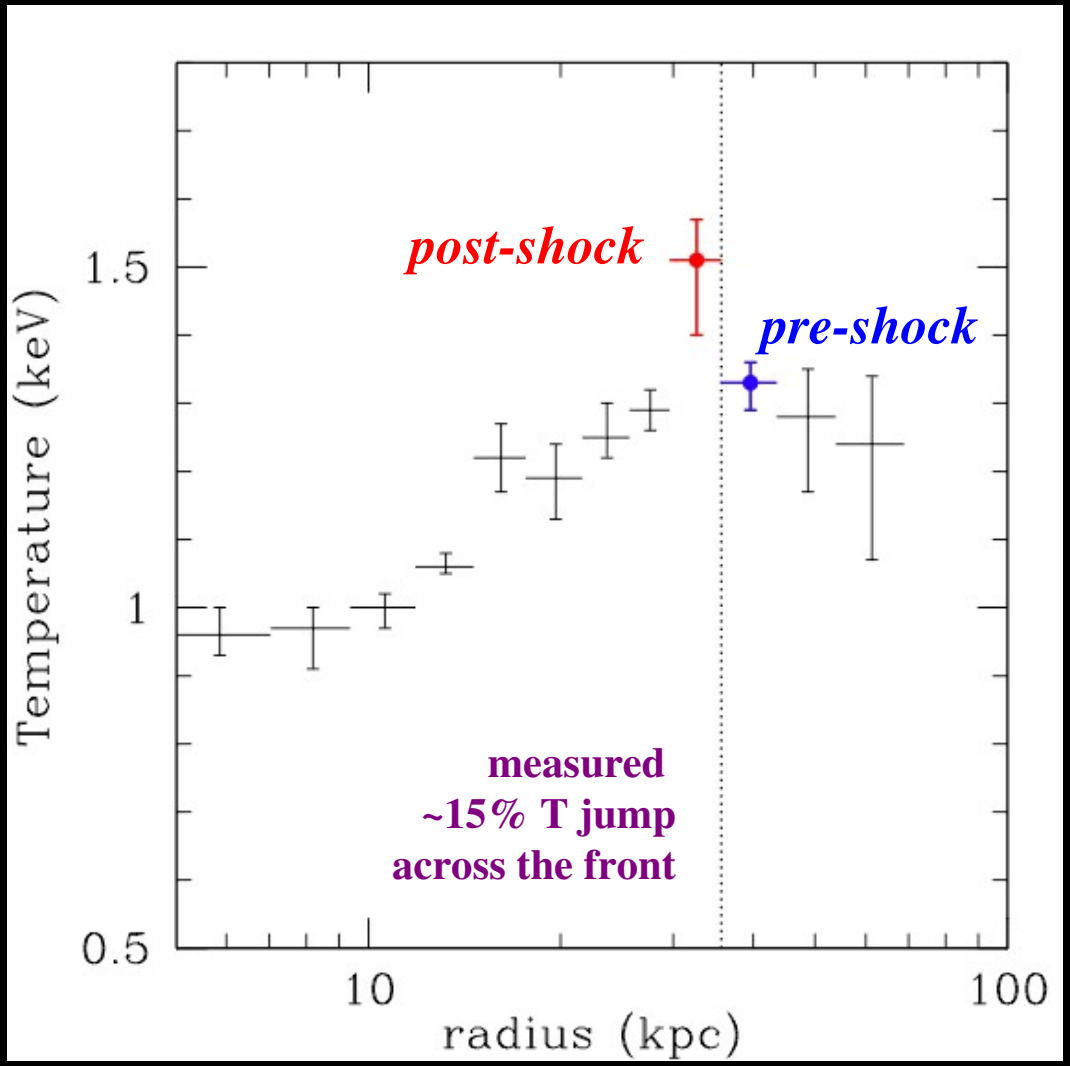


R_{shock}=35.7 kpc

(Gitti, O'Sullivan, Giacintucci et al., in prep.)

SHOCK FRONT – *Chandra* T profile



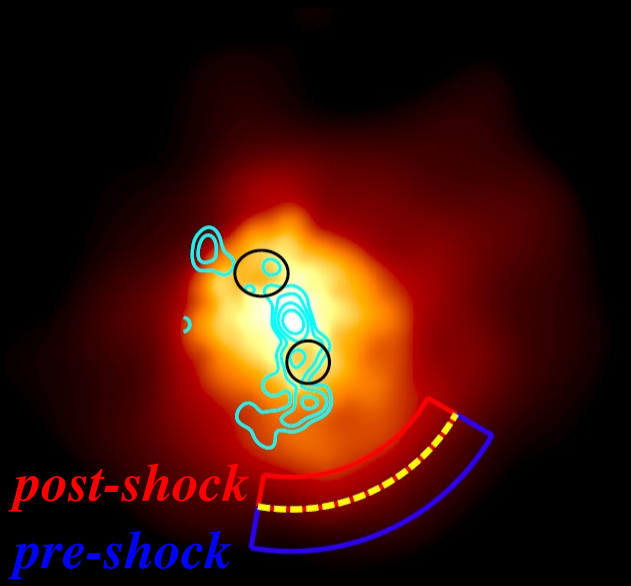


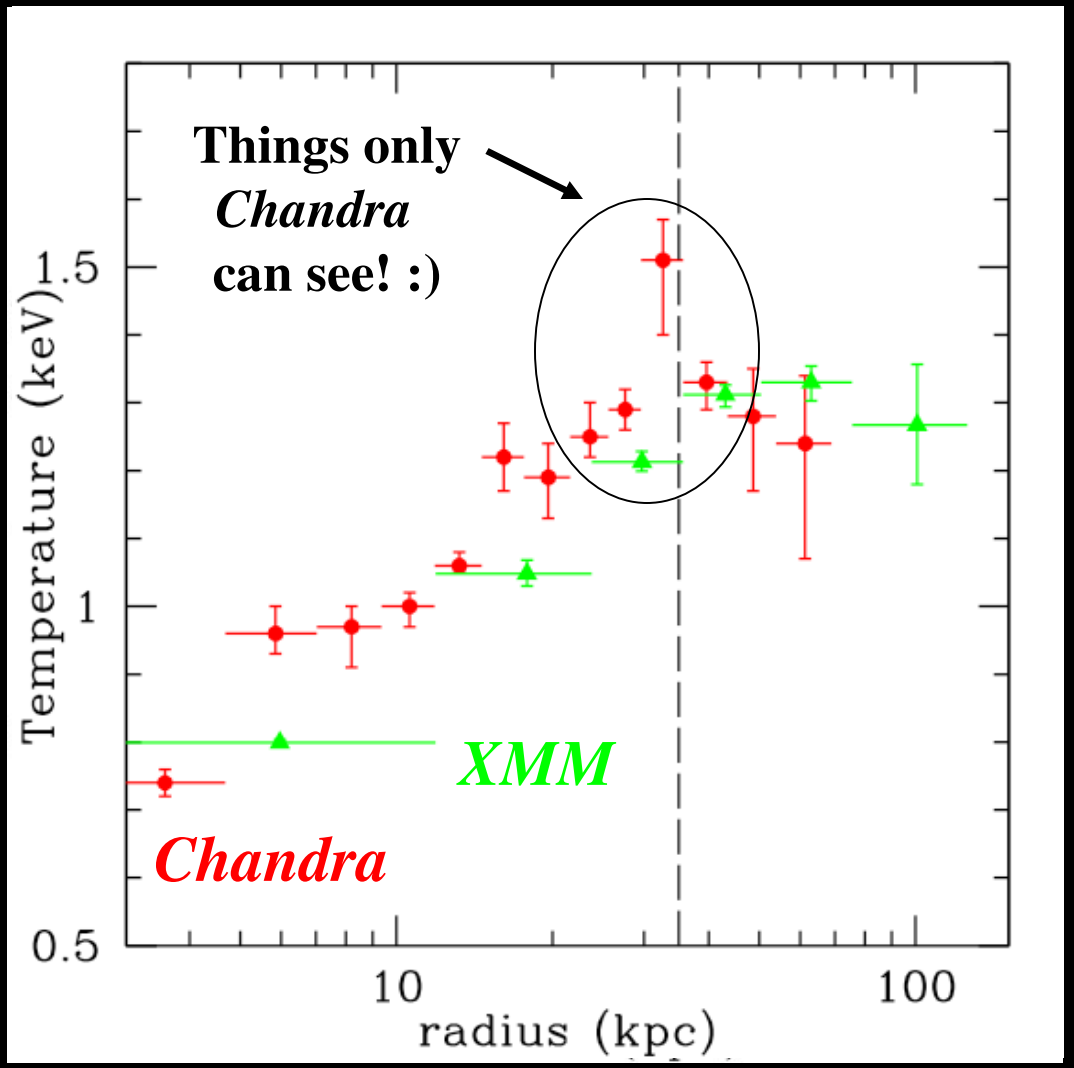
(Gitti, O'Sullivan, Giacintucci et al., in prep.)

Shock model properties:

- Mach = 1.45
- Energy = 6.2×10^{57} erg
- Age = 2.7×10^{7} yr
- Power = 7.3×10^{42} erg s^{-1} ~$2\times P_{cav}$

SHOCK FRONT – *Chandra* vs. *XMM* T profile





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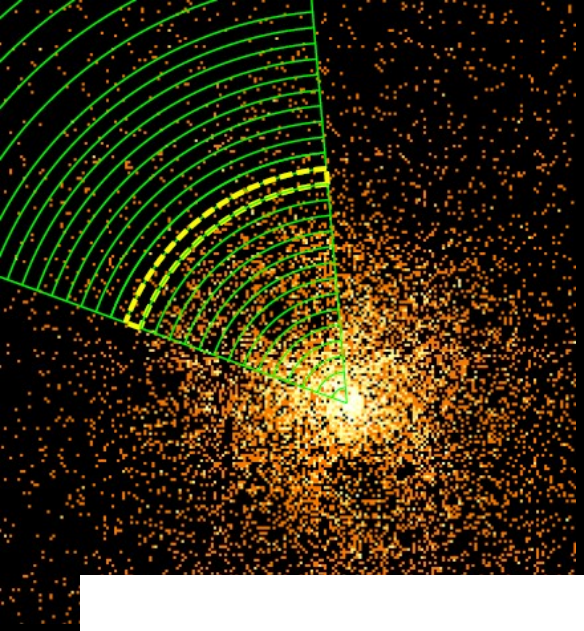
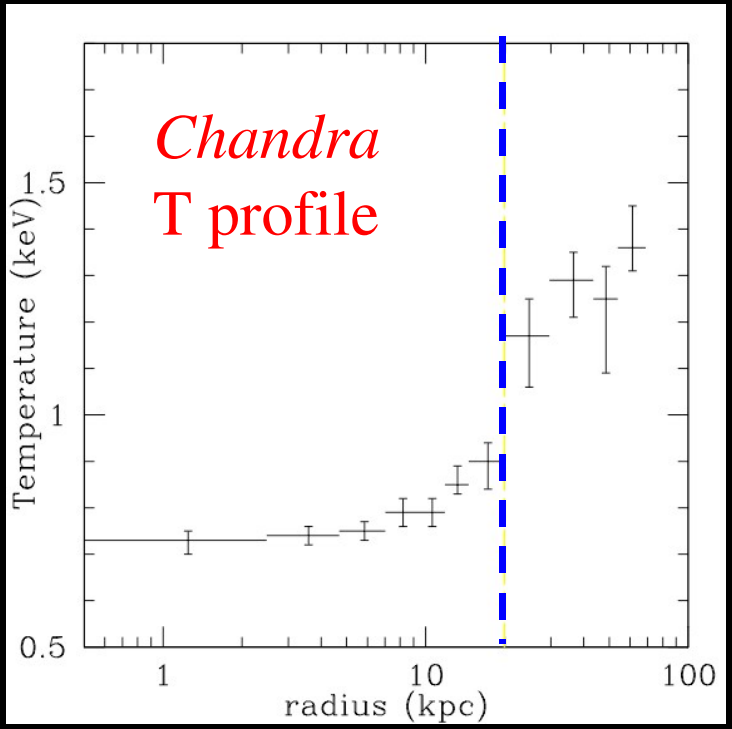
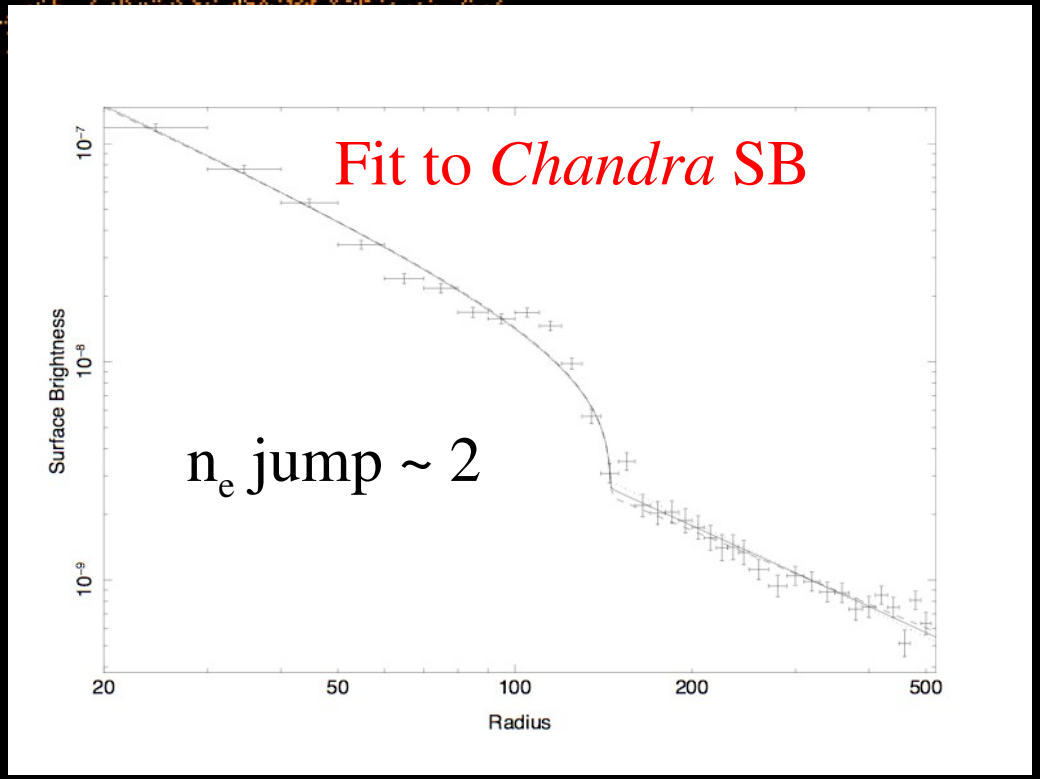
(Gitti, O'Sullivan, Giacintucci et al., in prep.)

A cold front?



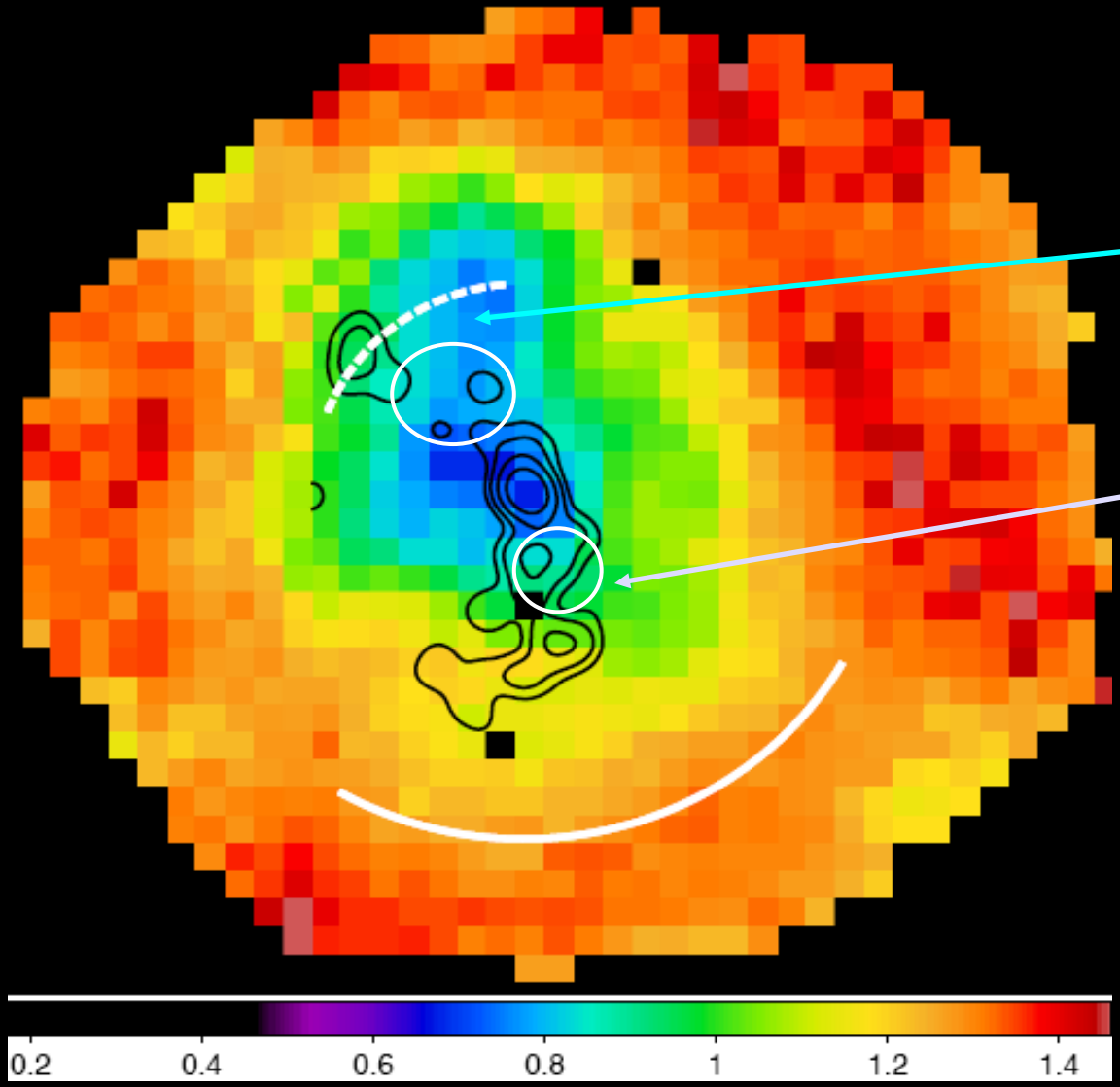
R_{front} = 20 kpc





Work in progress…

TEMPERATURE MAP



Cool region along the N cavity limbs

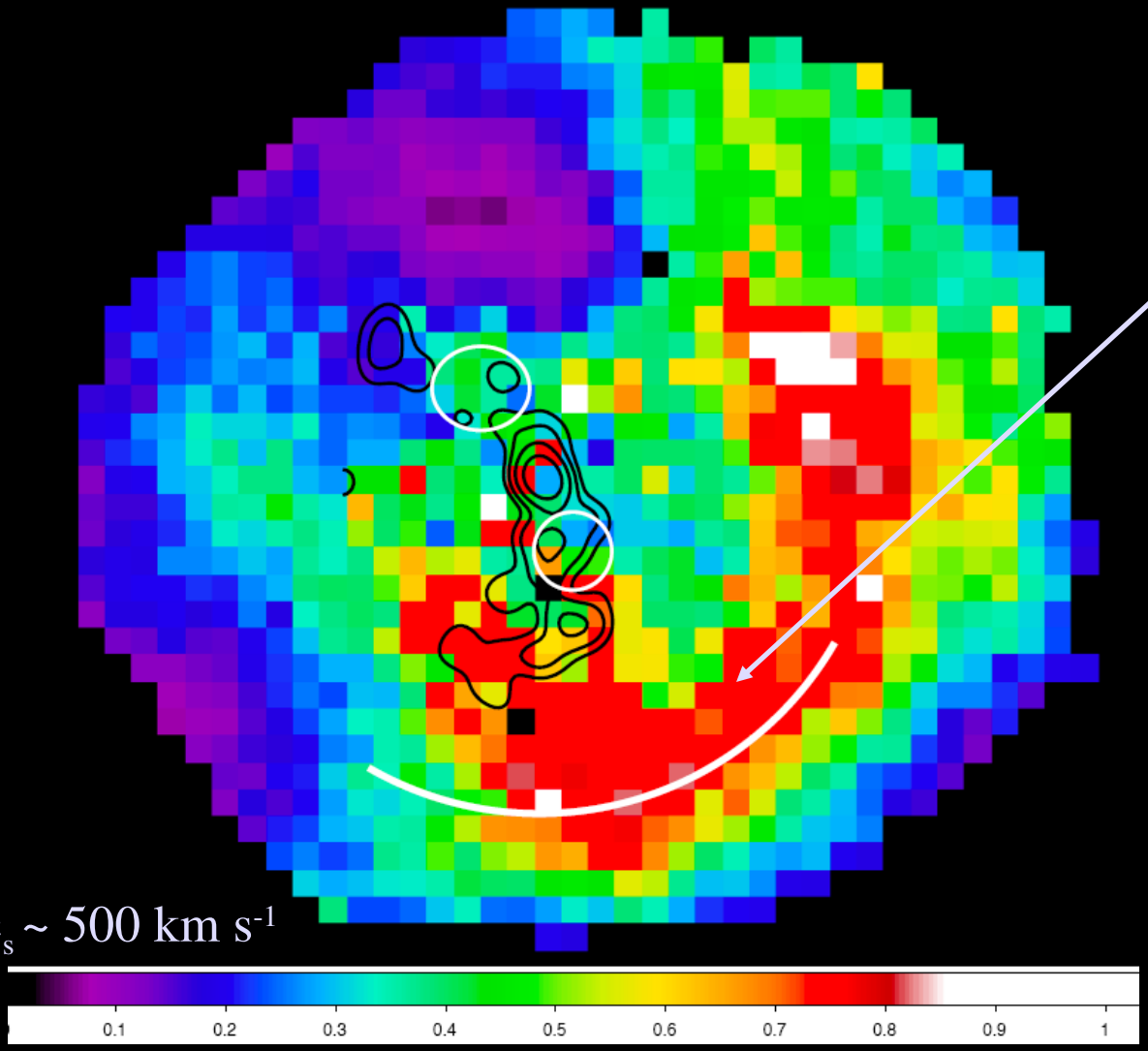
why not in the S one? maybe heated by the passage of the shock

→ asymmetric shock?

Chandra spectral map

(*XMM* consistent)

Fe-ABUNDANCE MAP



Arc-like region of enriched material at ~2′ from the center

– stripping from central galaxies?

– tidal interaction?

(see *Gu et al 2007*)

but also..

possible Fe abundance overestimate due to non-Maxwellian electron distributions near the shock

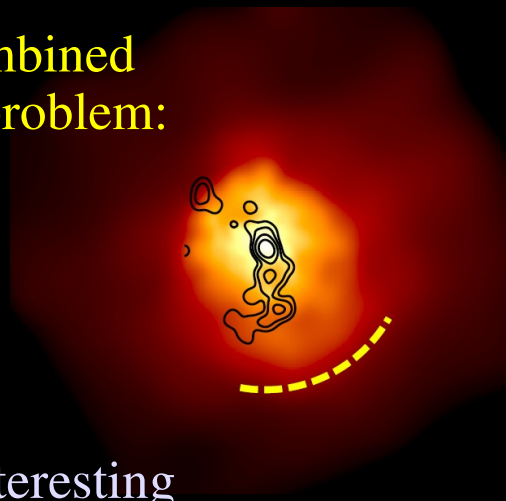
(Kaastra et al. 2009)

Chandra spectral map (*XMM* consistent)

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 that are the direct result of AGN activity
  - Groups are an important/dominant locus for evolution of baryonic material

- Our analysis of HCG 62 demonstrates the power of a combined X-ray / (low-frequency) radio approach to the feedback problem:
  - Low-frequency radio emission detected in the cavities
  - "Light" hadronic jets (k~10-30)
  - Detection of shock front with $M \sim 1.45$, $E_{shock} \sim 3 \times E_{cav}$



- 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 study of X-ray/radio properties of the whole group sample (in progress..)