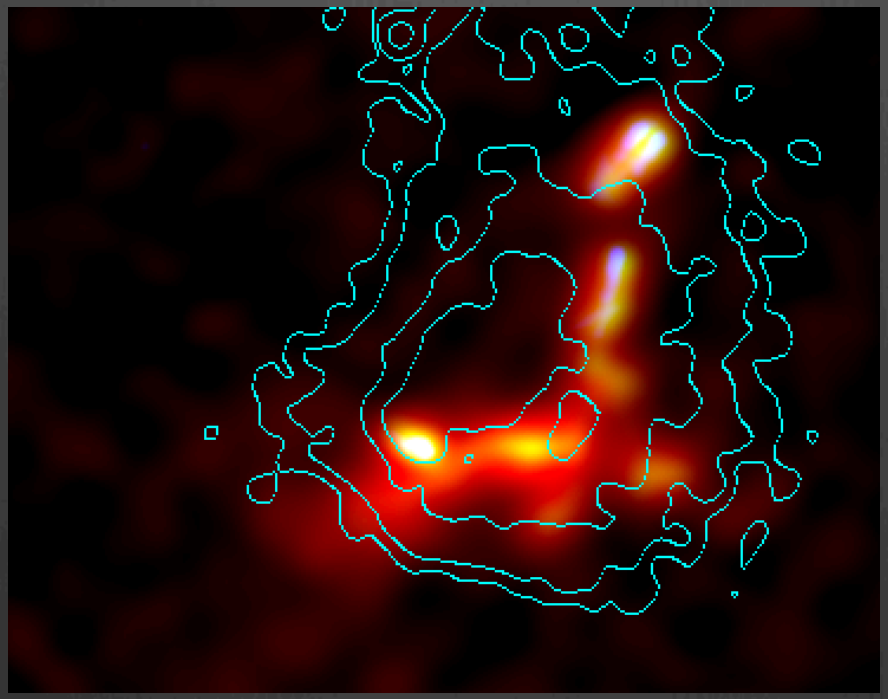
A Wild Ride for Abell 2443:



100 ksec *Chandra* contours
with GMRT + VLA radio

A High Impact Velocity Merger with a Shock, Cold Front, & Relic

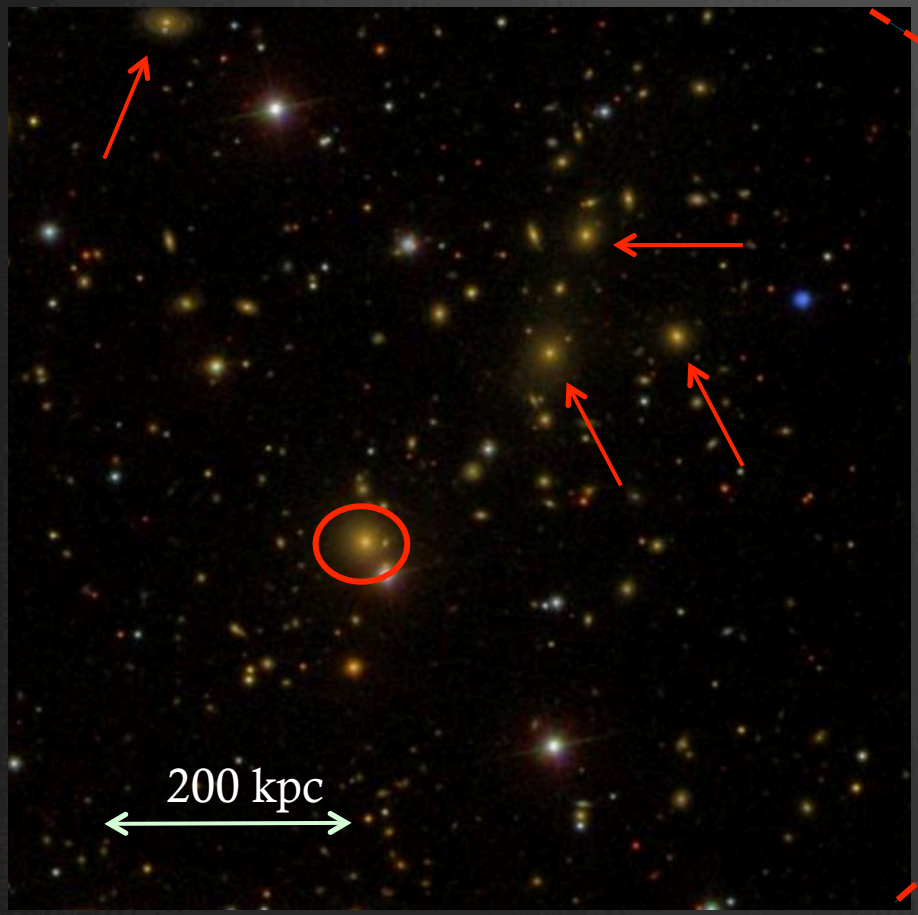
Tracy Clarke (NRL)

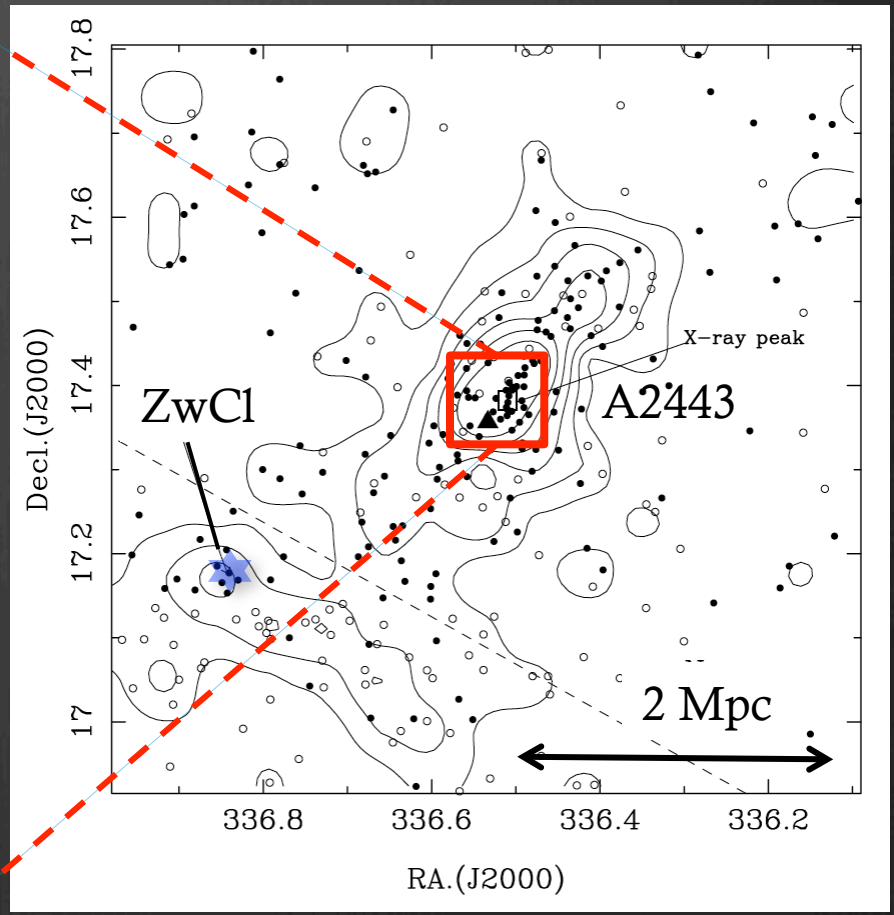
Tony Mroczkowski (NRC at NRL), Scott Randall (CXC), Craig Sarazin (UVA), Elizabeth Blanton (BU), Simona Giacintucci (UMCP), Will Dawson (LLNL), Nathan Golovich (UC Davis), Huib Intema (NRAO), John ZuHone (GSFC)

ABELL 2443

Abell 2443 is a z=0.108 cluster with two dominant galaxies near the core (4 photo-z member ellipticals within 1-mag of the cD)

Photometric galaxy density (Wen et al. 2007) is elongated NW-SE and connects to ZwCl 2224.2+1651 at 2 Mpc (unknown redshift)





CHANDRA VIEW OF A2443

16 ks Chandra exposure showed elongation & edges (Clarke et al. 2013)

New 100 ks Chandra exposure on ACIS-I:

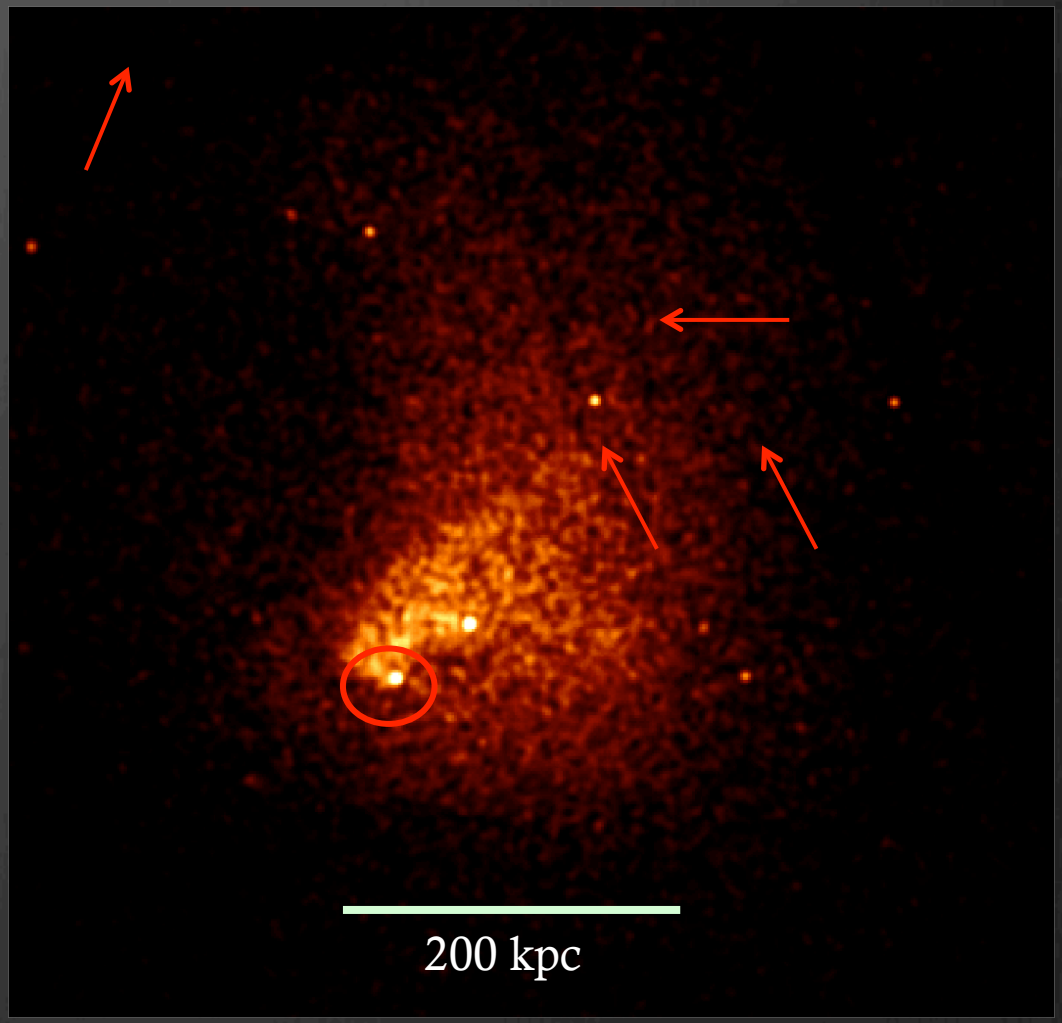
Elongated morphology with clear substructure in core & tail to NE

X-ray counterpart to cD + background source NW of cD

Edge near cD (cold front)

Edge to SE (shock)

Clear merger signatures



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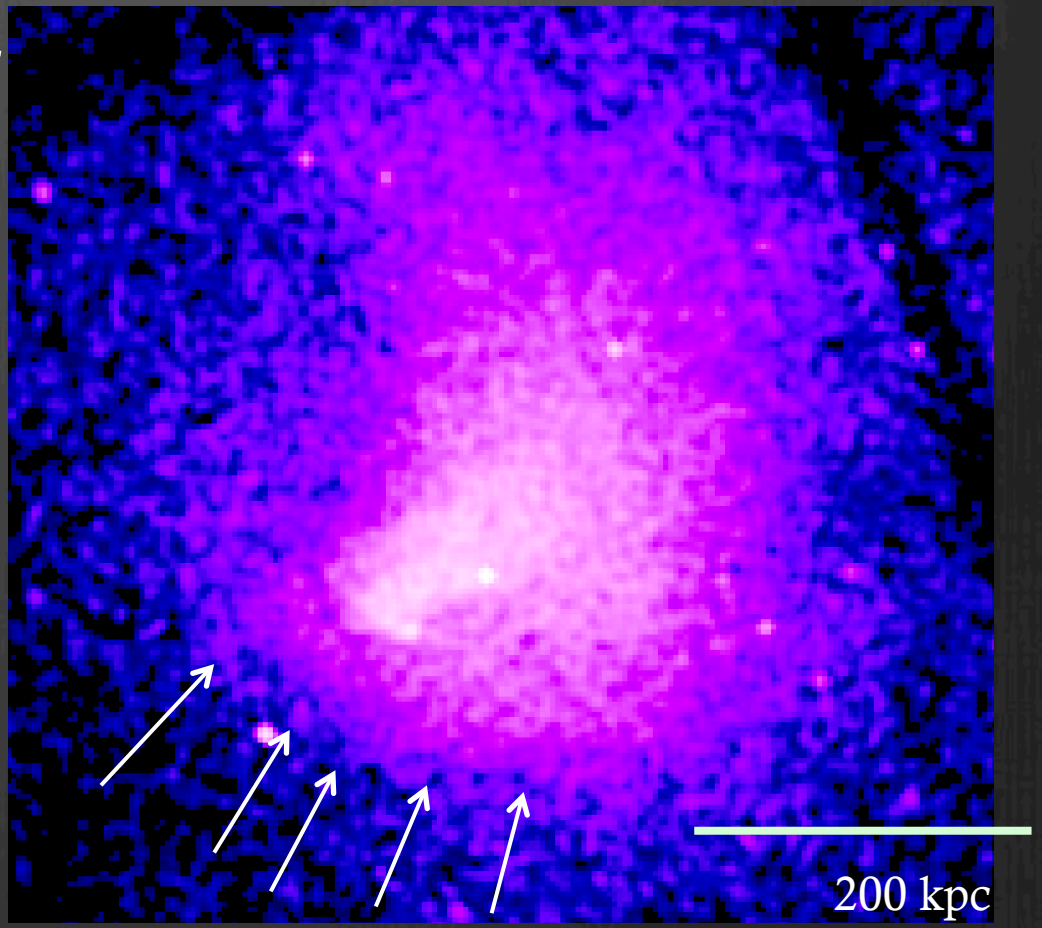


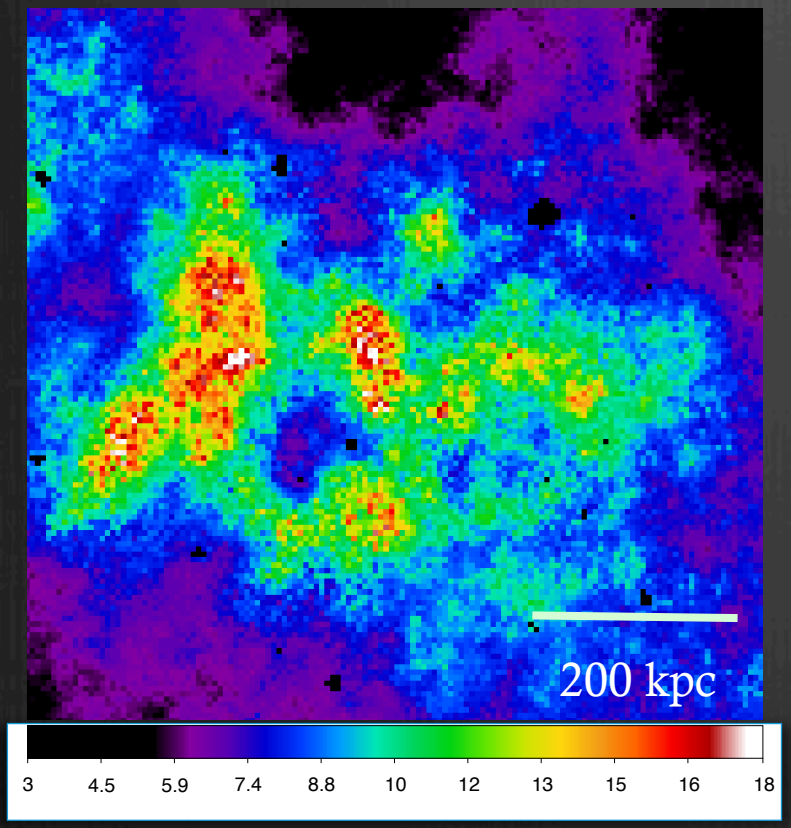
Chandra Temperature Maps

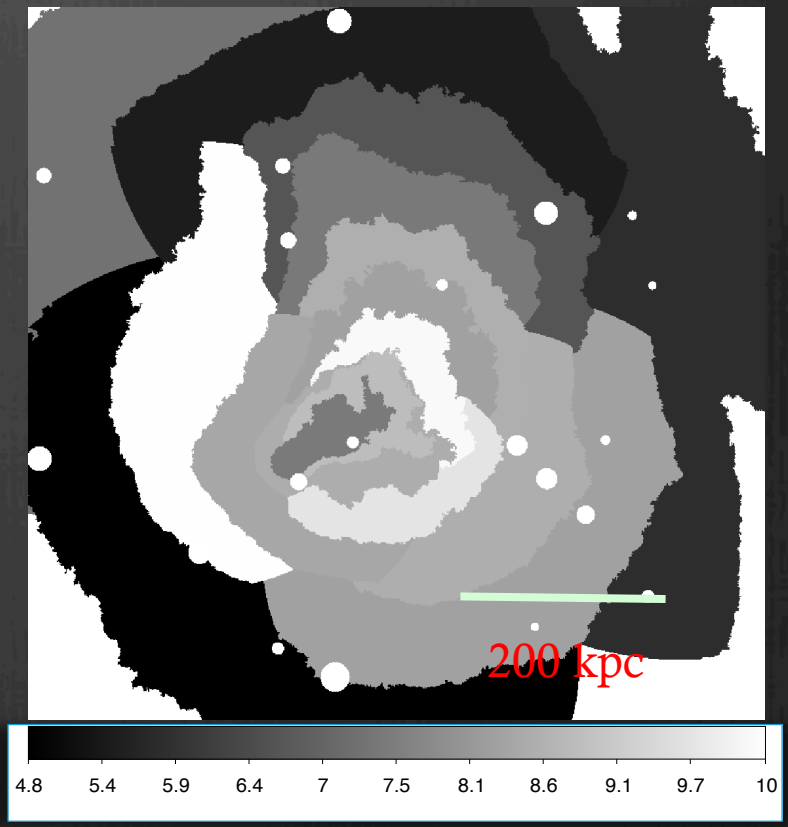
T binning map (O'Sullivan et al. 2005) for > 1000 net counts

Cold core with sharp edges stands out surrounded by hot 'ring' of gas

contbin (Sanders 2006) on surface brightness (S/N > 80, > 3000 net counts)

Cold core and hot surroundings agrees well with binning map





Chandra Temperature Maps

Sanders 2006) on surface
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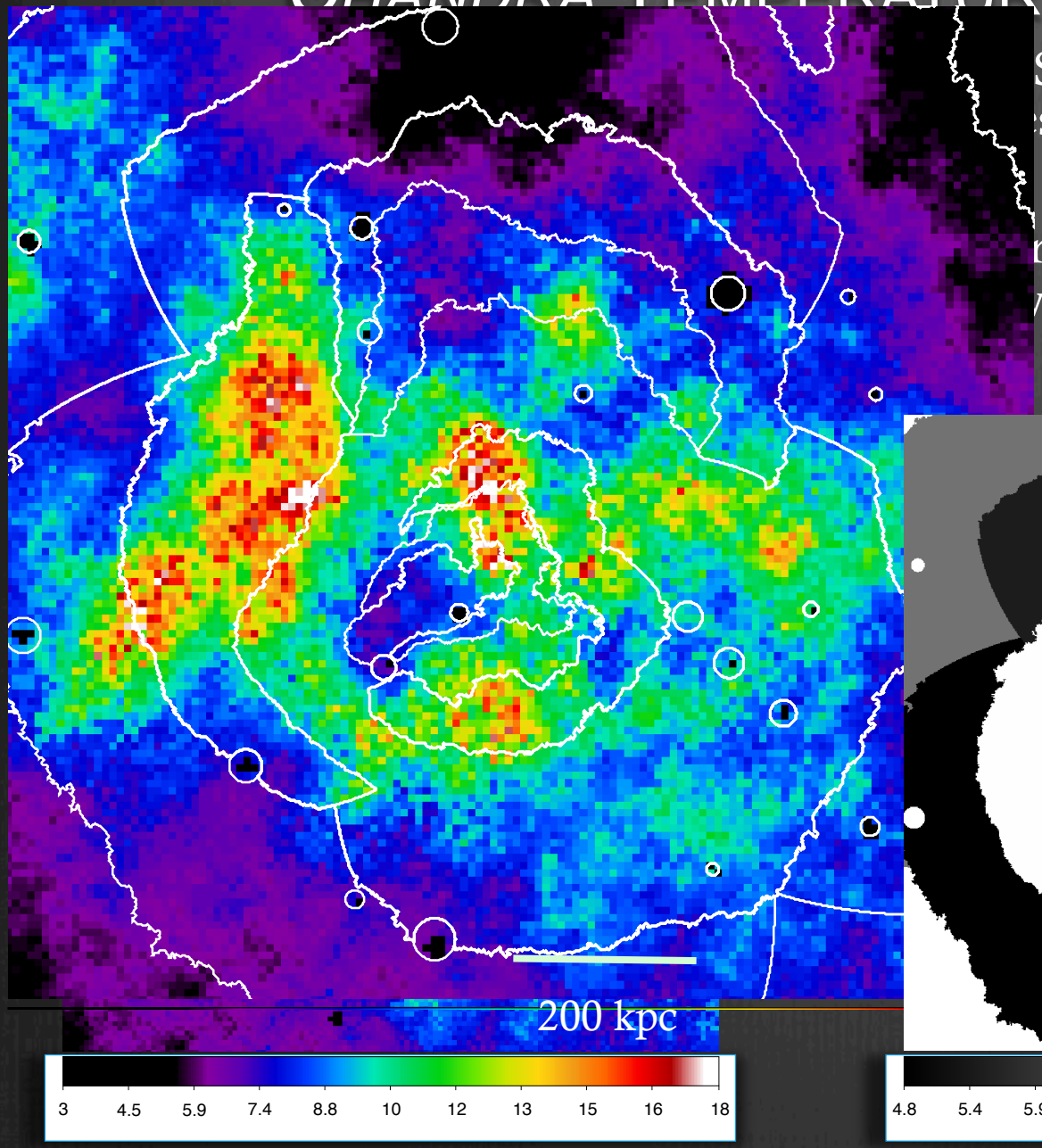
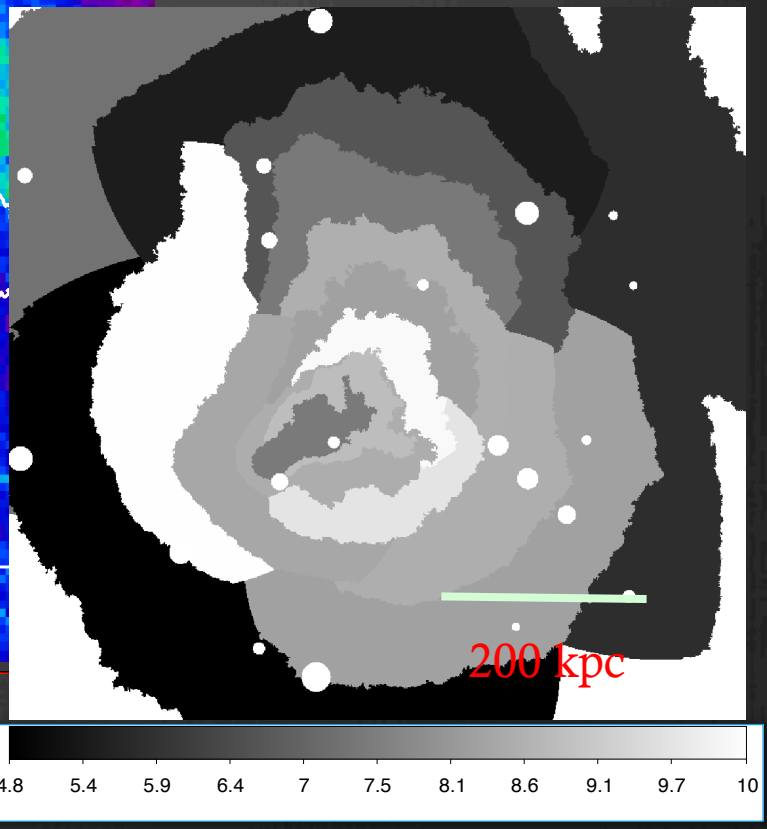
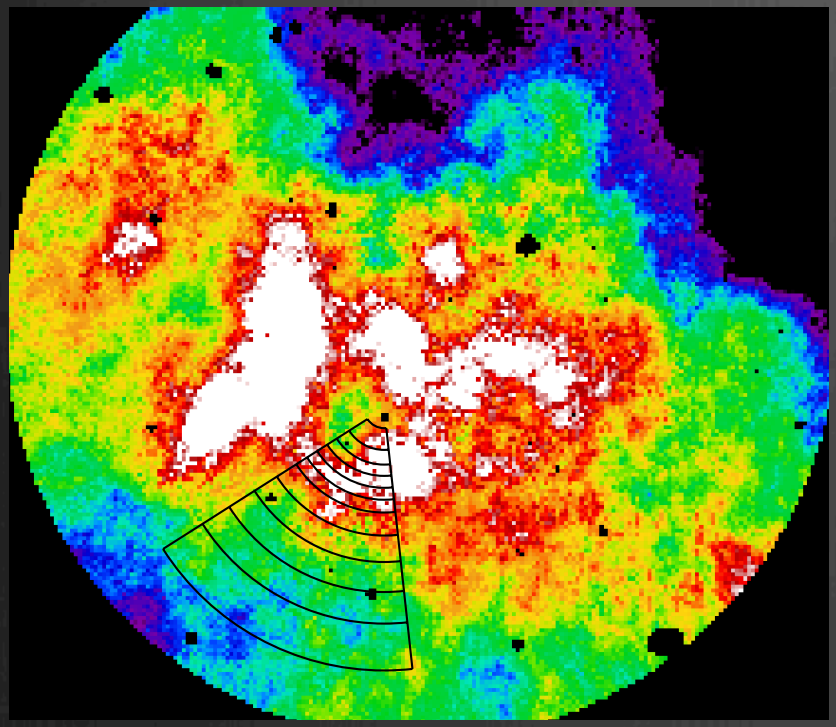




CHANDRA EDGE ANALYSIS

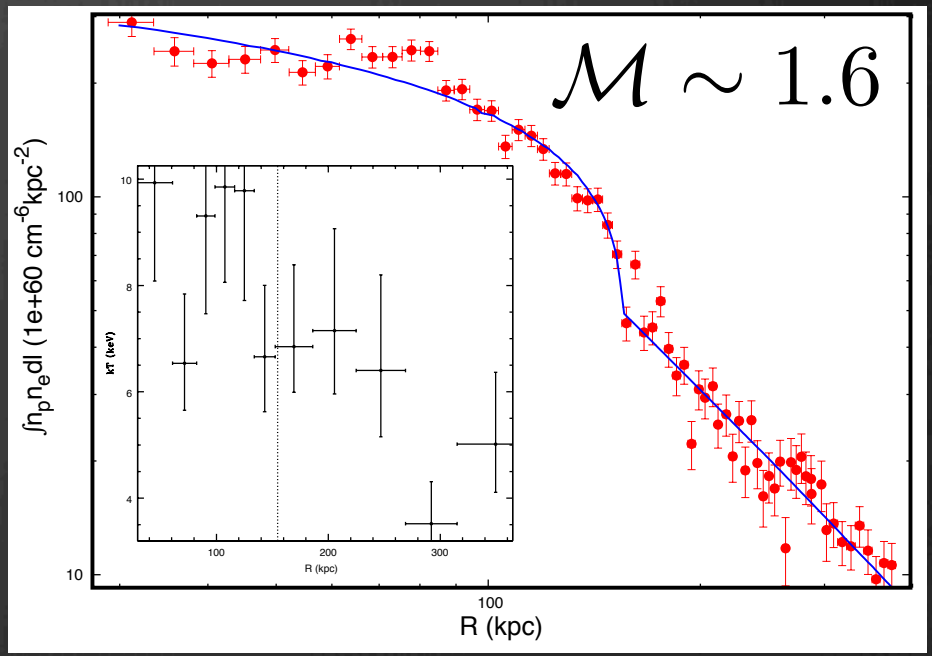


$$\frac{n_e, 2}{n_e, 1} = 1.6 - 1.9$$

Outer SE Edge ('Shock'):

Fit SE outer edge with 3D density models of two power-laws with a discontinuous jump (Randall et al. 2009)

Surface brightness edge not sharp & T drop slightly inside edge suggest complex geometry



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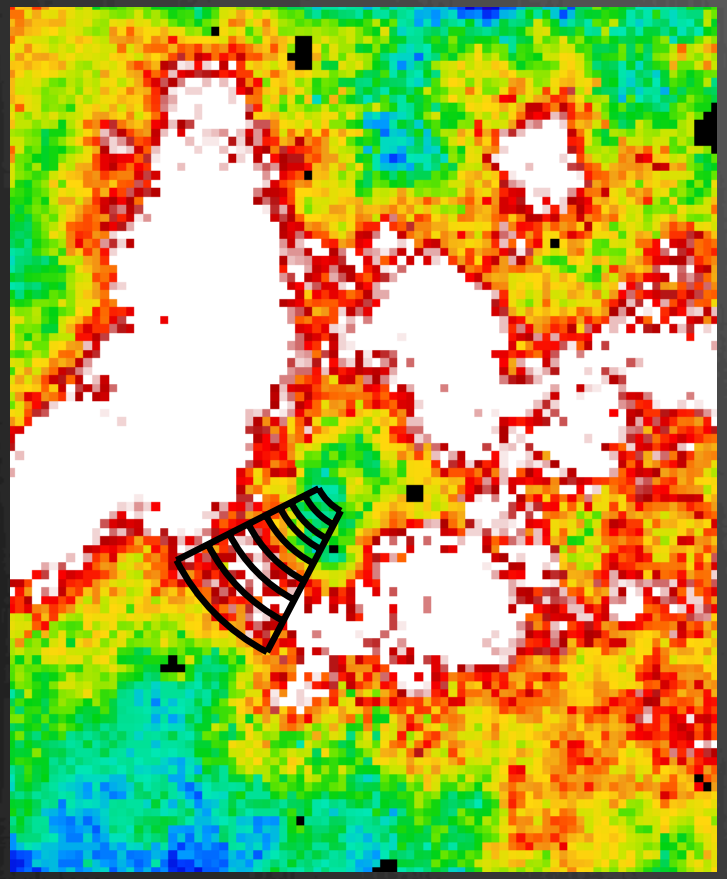
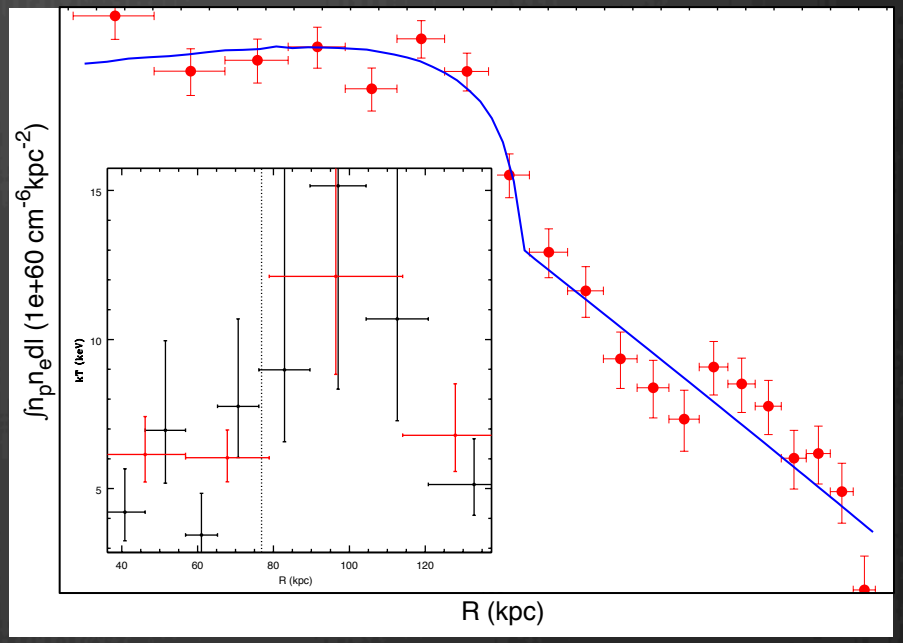


Inner SE Edge ('Cold Front'):

Inner edge is very sharp but narrow with complex emission outside.

Cometary shape consistent with a remnant merging core.



$$\frac{n_e, 2}{n_e, 1} = 1.6 - 2.1$$

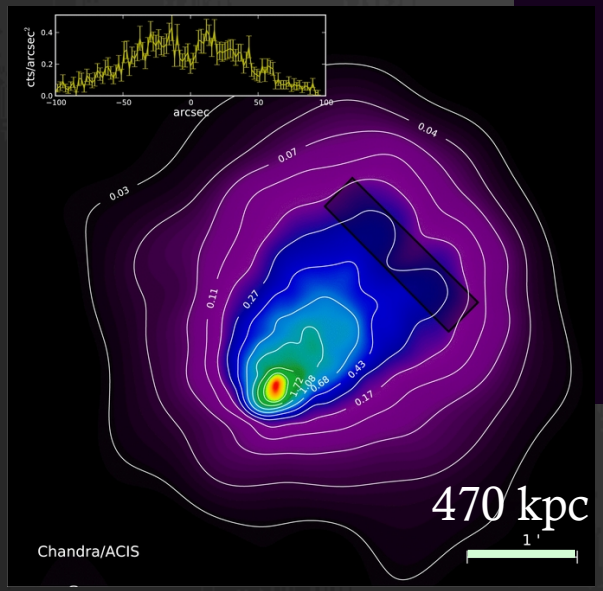
A2443 Merger Geometry

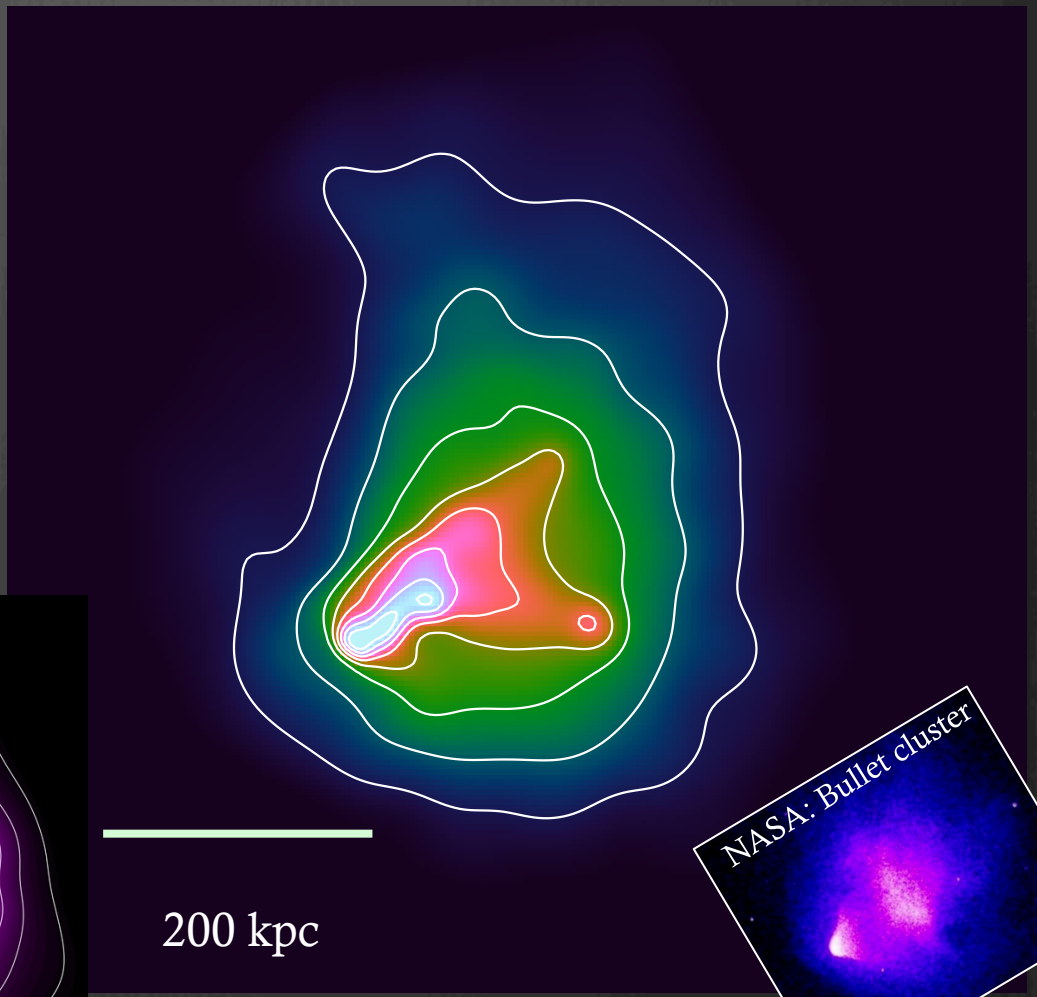
Adaptively soothed (point source free) image:

Bright cometary head & bifurcated tail - similar to ‘el Gordo’ (z=0.87)

Lack of sharp shock edge suggests significant line-of-sight component to merger (i.e. merger axis inclined to los)

Infalling system: NW to SE

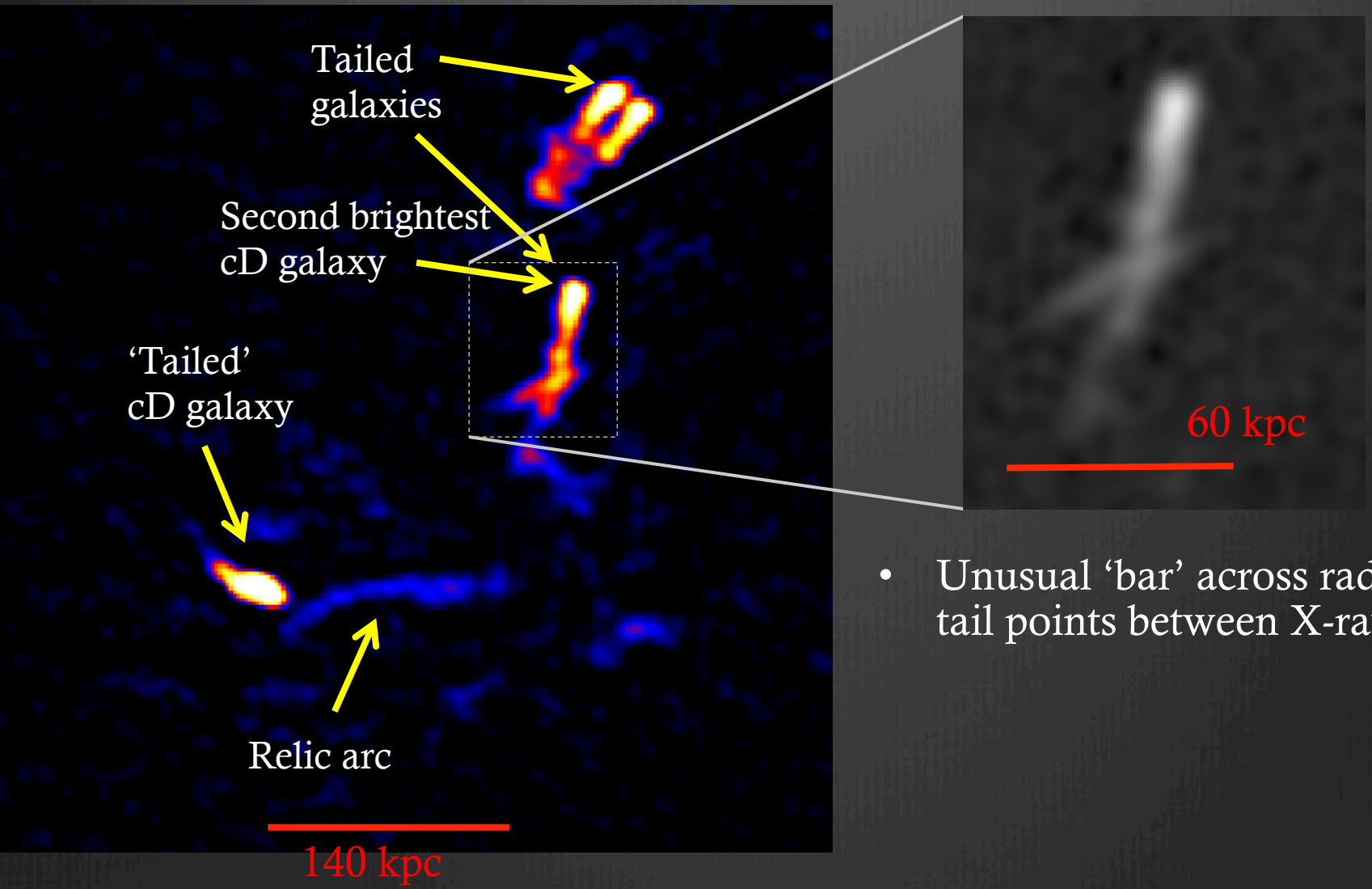




“el Gordo” cluster (Menanteau et al. 2012)

Radio Galaxies in A2443: High Resolution

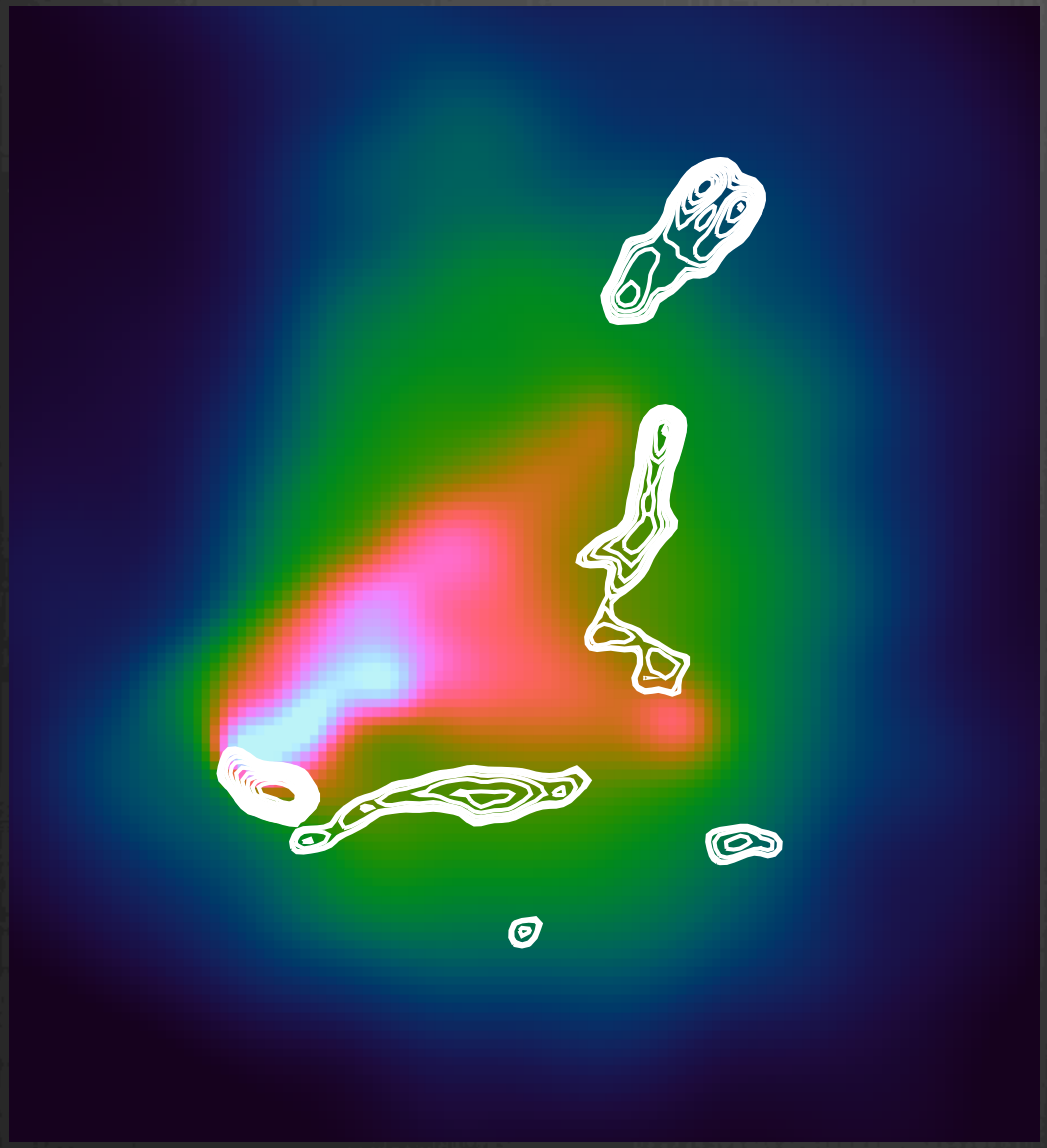
VLA: 330 MHz

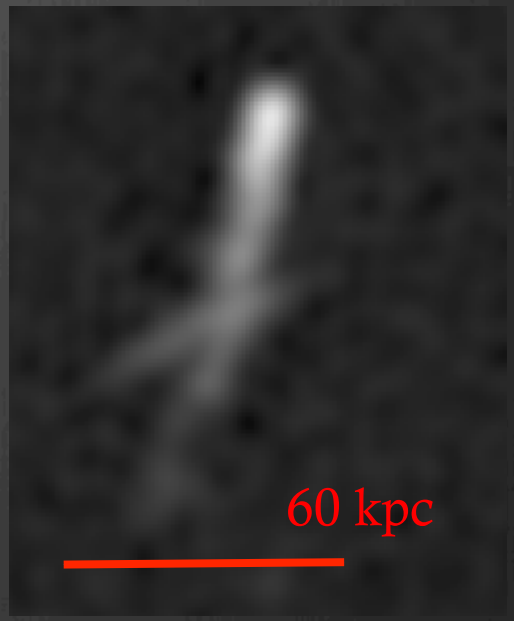


- Unusual 'bar' across radio tail points between X-ray tails

A2443 Radio/X-ray Connection?

Tailed radio source follows X-ray cometary structure





A2443 Component Velocities

contbin to separate merging bullet from main cluster:

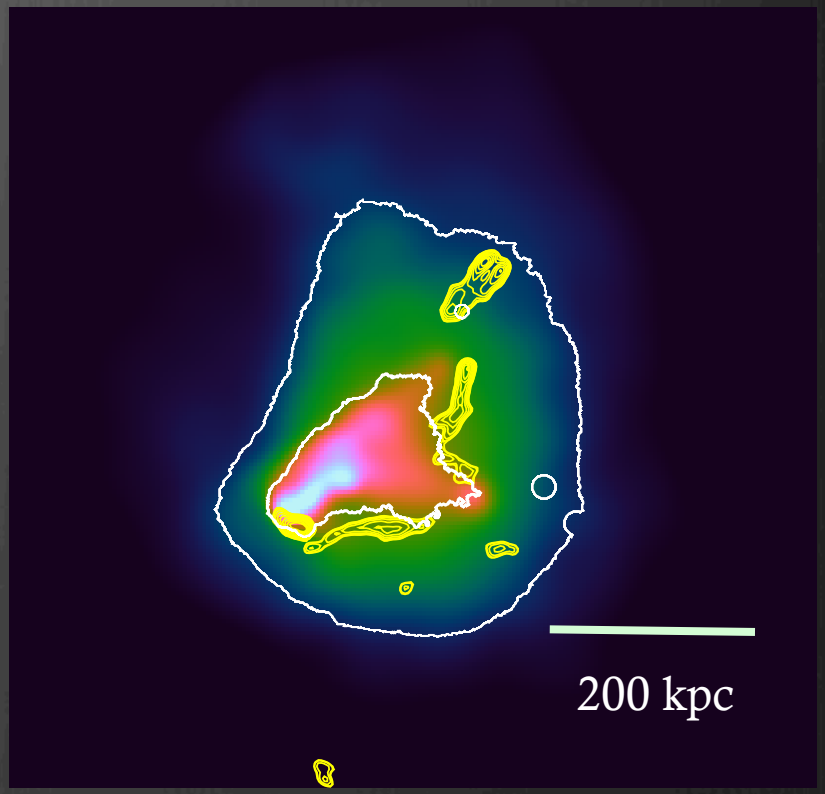
Regions have S/N > 90, combined regions have > 13000 & > 32000 net cts (inner/outer)

Fit Fe-line complex separately for the bullet-like component and surrounding gas

Core significantly blueshifted (z_b=0.0989+0.0049-0.0041) compared to surroundings (z_s=0.1155+0.0050-0.0018)

Velocity diff. is δ v= 4500+1700-1400 km/s

- 'Bullet' (z=0.3) δ v= 2600 km/s (Springel & Farrar 2007)
- 'el Gordo'(z=0.87) δ v= 2250 km/s (Molnar & Broadhurst 2014)



Uncertainty on velocity fits are dominated by region choice.

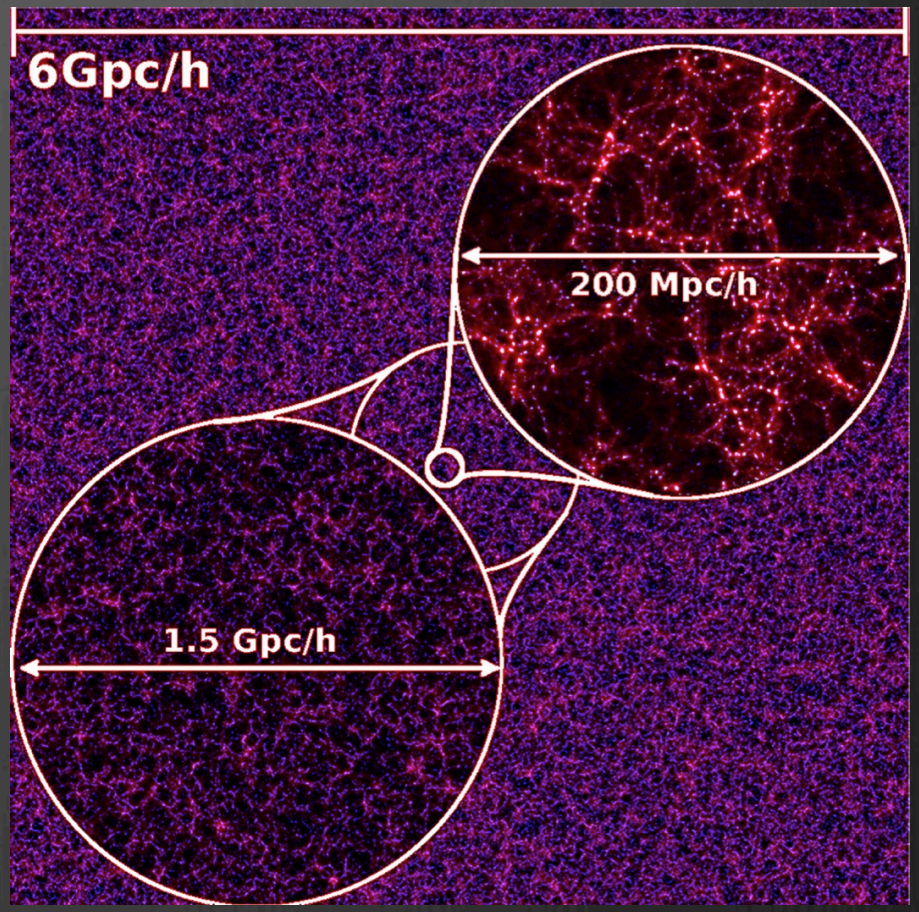
Predictions from Jubilee Simulation

Watson et al. (2014) N-body sims. (DM only) using 6000^3 particles within concordance Λ CDM

Reproduces halo mass function

Volume of 6 Gpc/h is large enough to sample rare systems

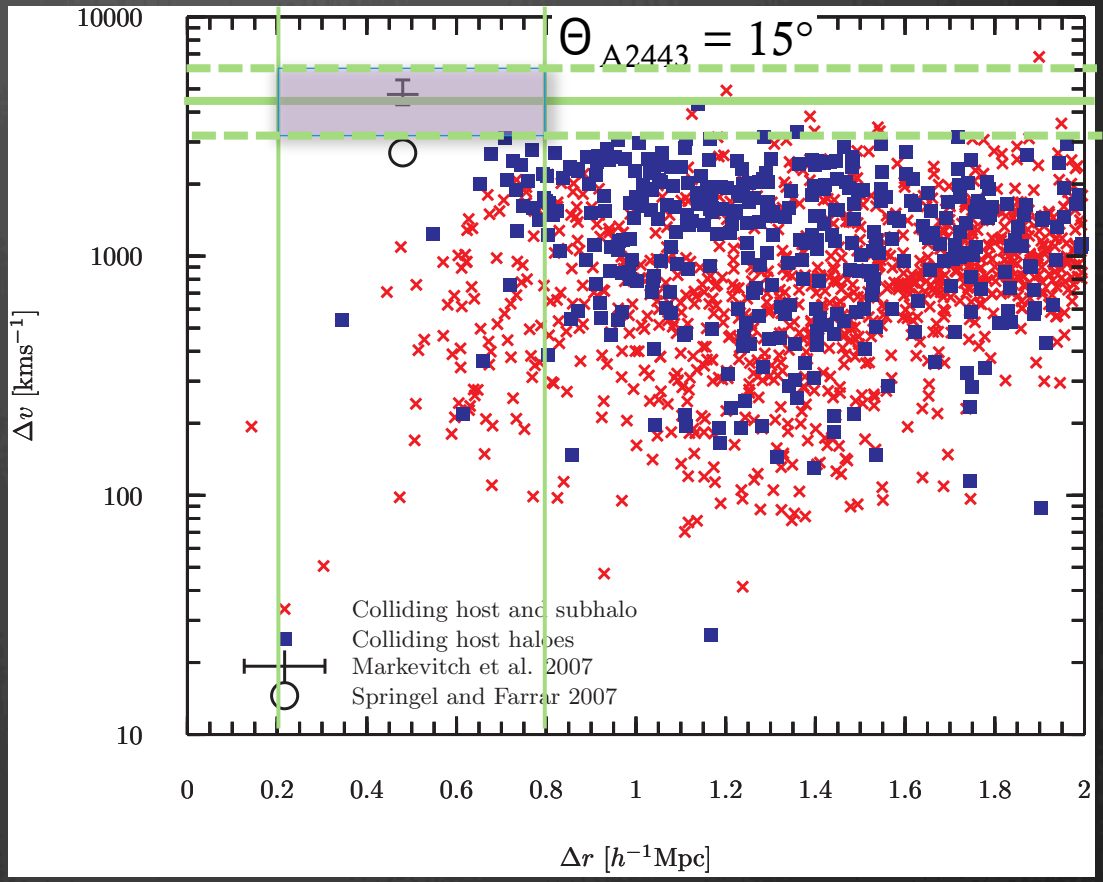
Objects like the Bullet cluster exist in the tail of collisional velocity distribution



Watson et al. (2014)

Predictions from Jubilee Simulation

- Relative pairwise halo velocities vs halo separation
- Halo-halos (blue), subhalo-halo (red)
- Original and corrected Bullet data points are shown
- Bullet cluster velocity is only extreme for separation
- A2443 (1 σ green lines) appears extreme for any separation
- Low statistics of rare mergers at fixed redshift.

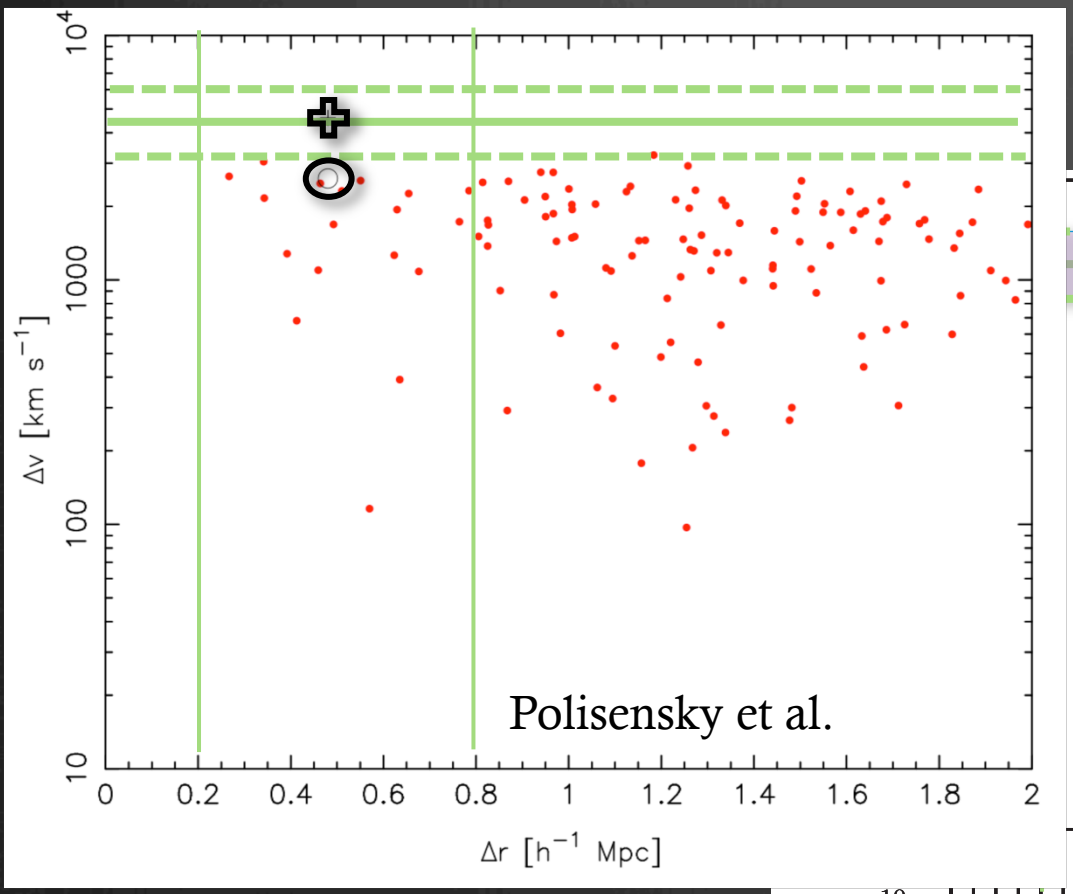


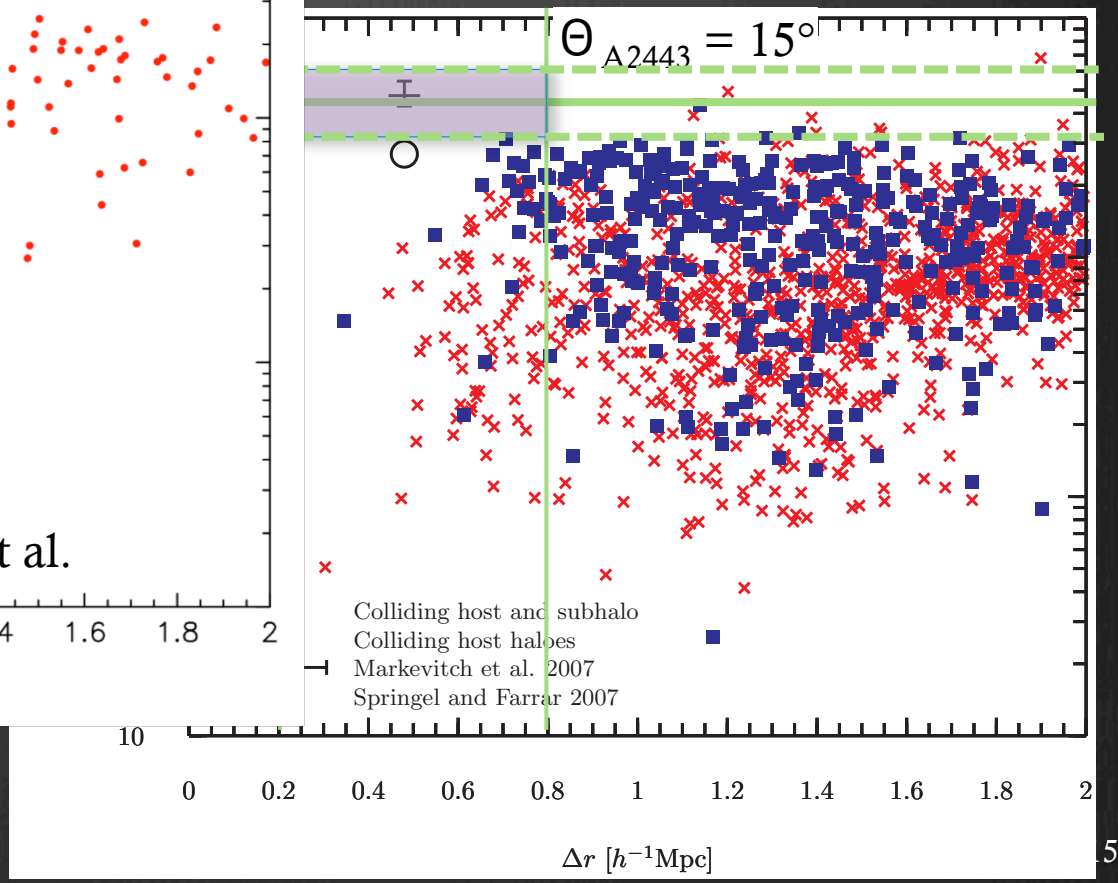
Watson et al. (2014)

On-Going Simulations with Smaller Box

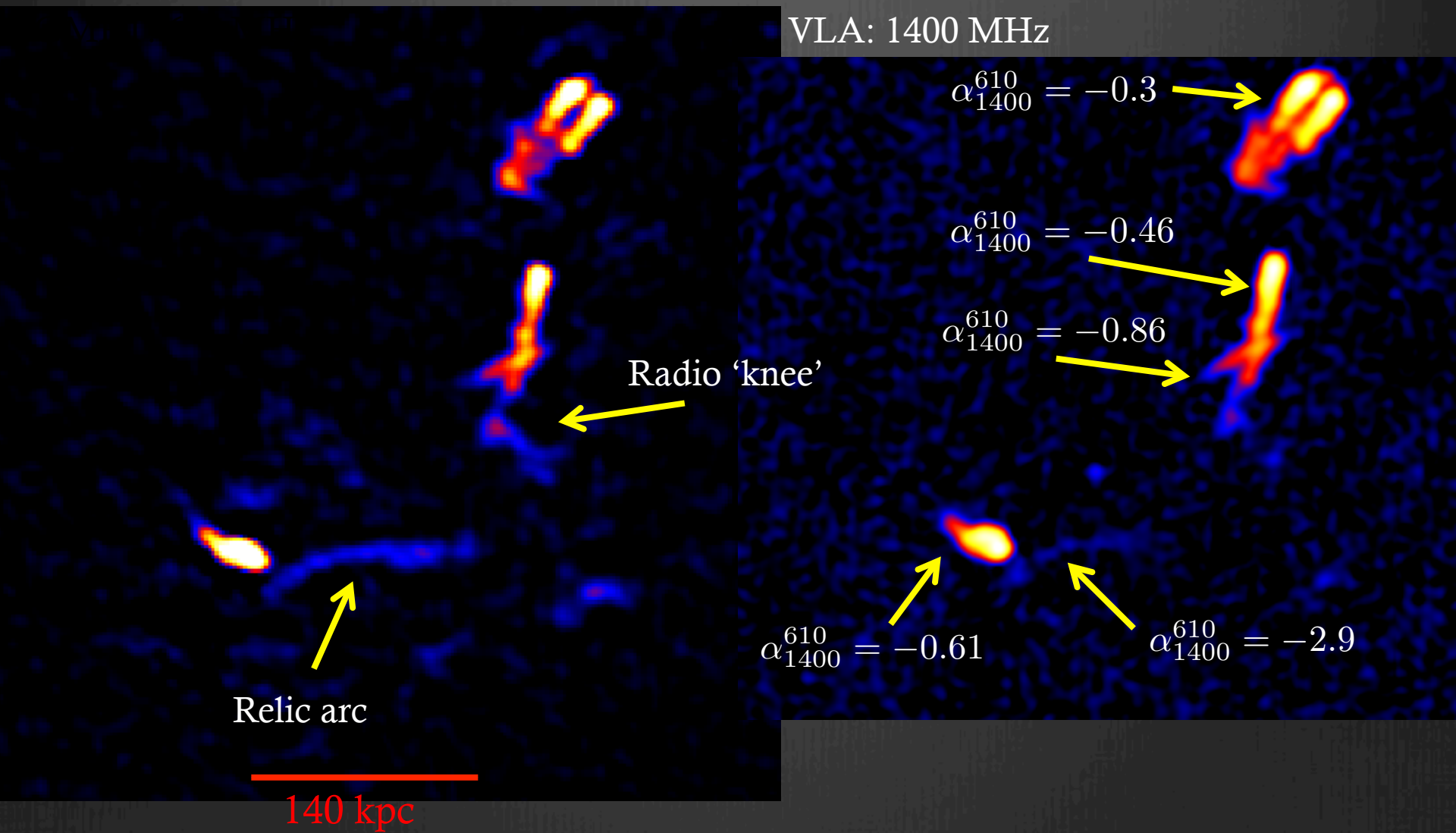
Similar simulation to Watson et al. (box size 1/1000). Gadget2 N-body solver.

Similar velocities but more systems at smaller impact parameter in same z=0.3 slice (work in progress to expand simulations). Adding more slices.

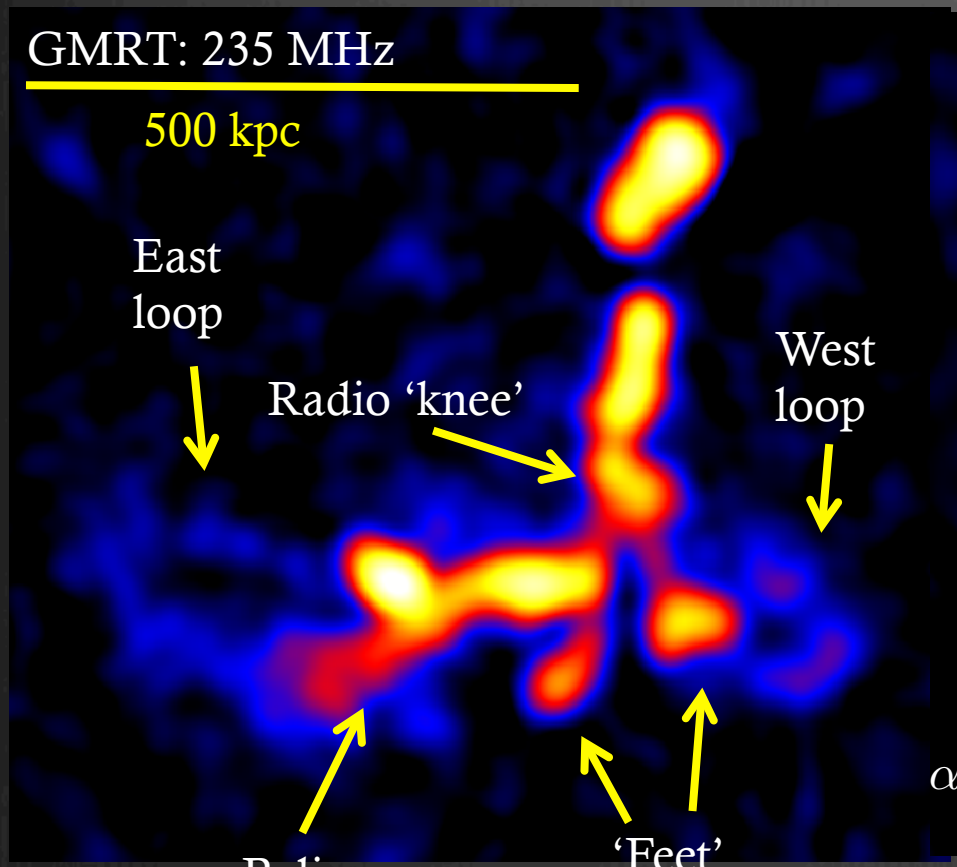


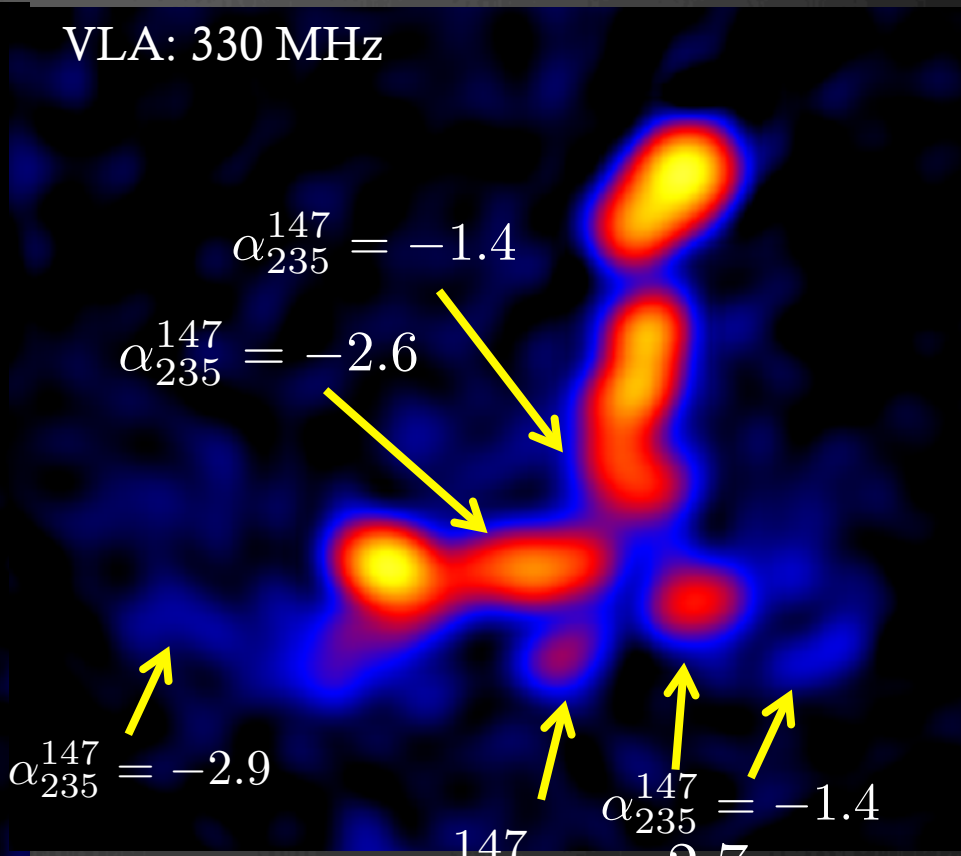


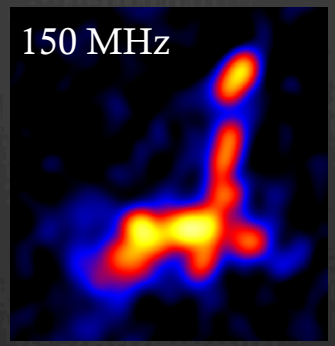
Radio Galaxies in A2443: High Resolution



Low Resolution Radio: Ultra-Steep Spectrum Relic



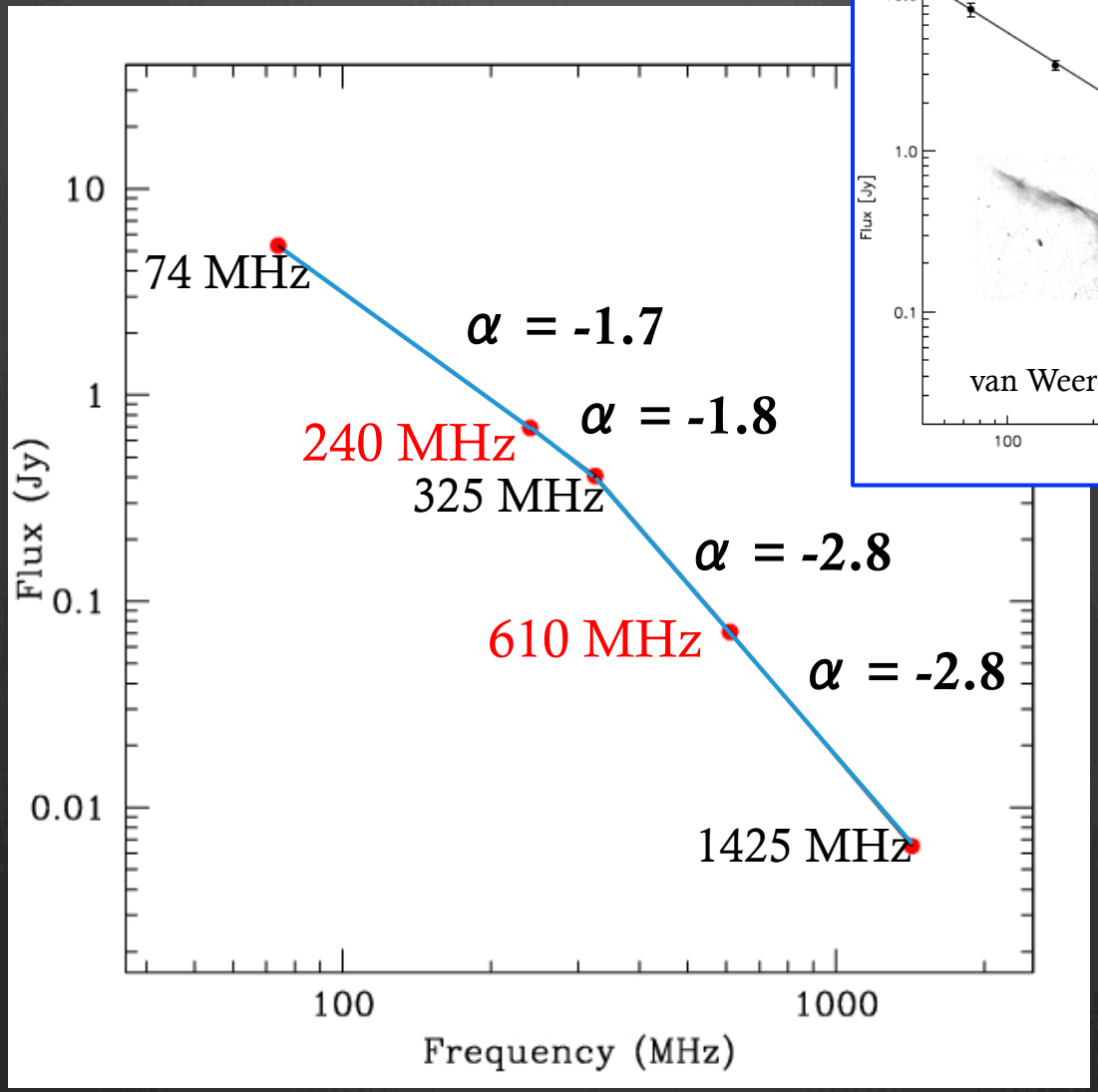




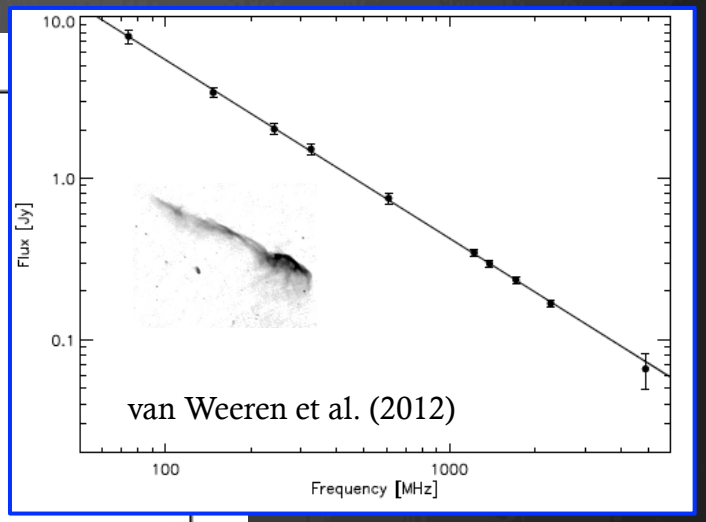
Relic: Integrated Radio Spectrum

Abell 2443

Ultra-steep spectrum relic likely adiabatically compressed plasma (Ensslin & Gopal-Krishna 2001)



Toothbrush Relic



Ogrean plenary talk (Tuesday am) shock-accelerated relic

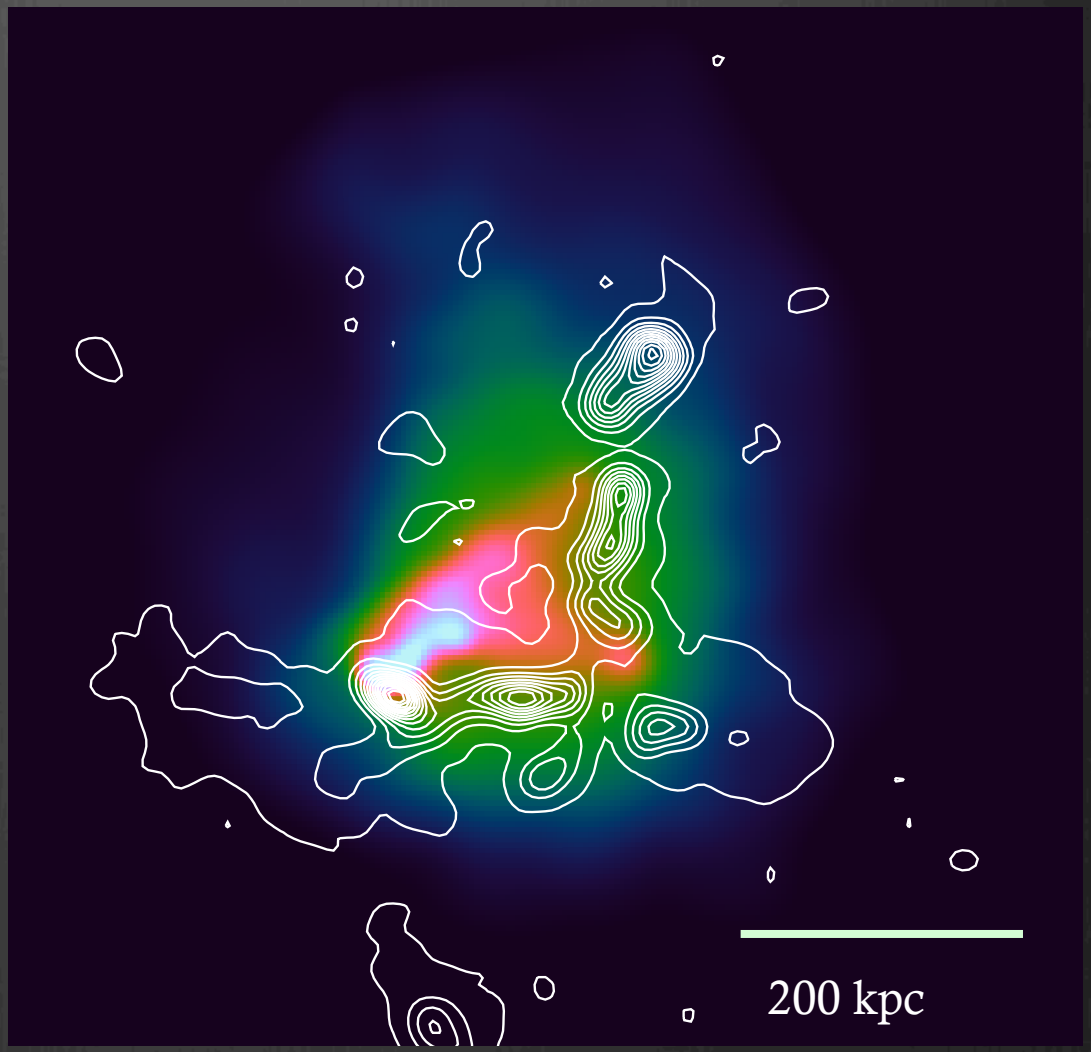
Merger Connection to USS Relic

GMRT 240 MHz contours on *csmooth* map

Low frequency USS relic consists of sharp feature south of southern tail and large surrounding region

Southern tailed galaxy appears to fill in inner region between bifurcated tails

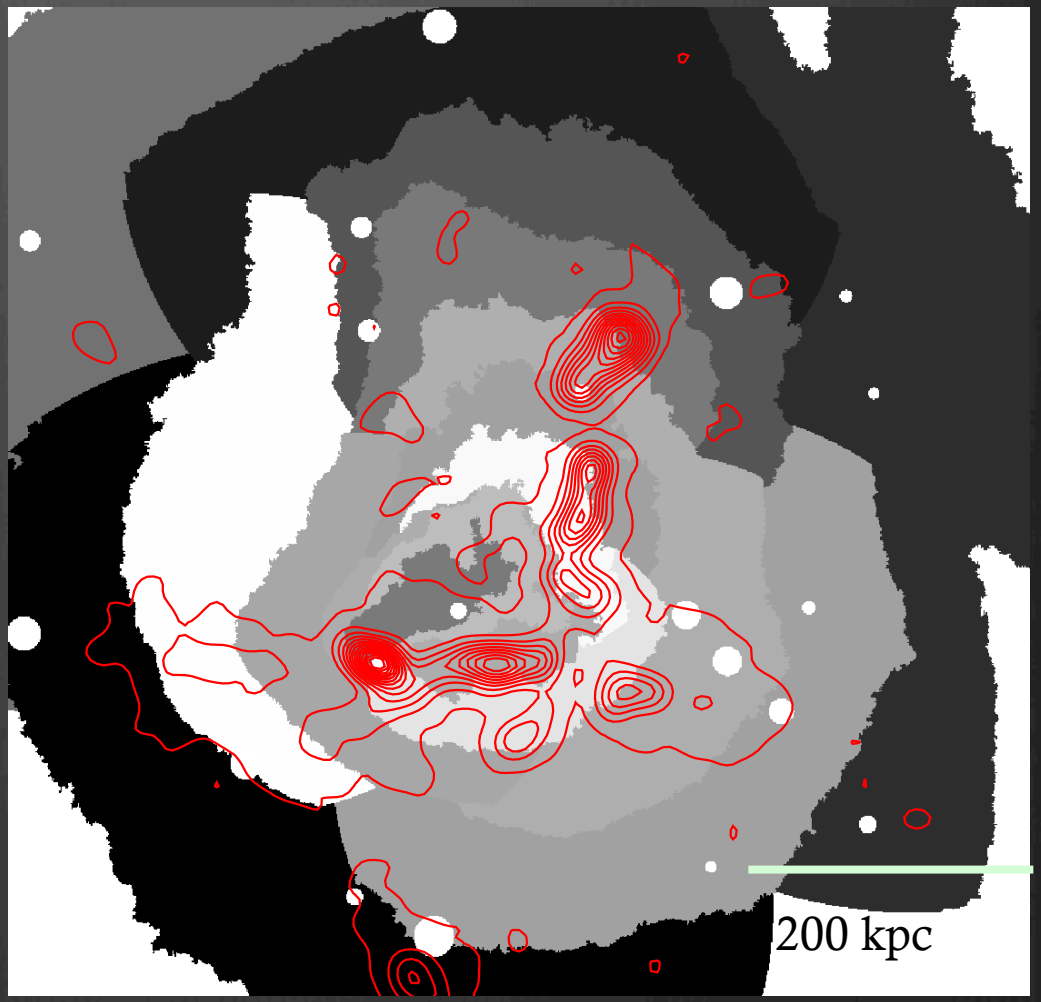
Tailed source may be cD of secondary cluster. Observations sugguest the merger occurred at very small impact parameter.



Merger Connection to USS Relic

GMRT 240 MHz contours on *contbin* temperature map

Relic traces edge of hot gas south of the core and extends to hot eastern region



Summary

A2443 surface brightness shows dynamically complex merger state:

- Central cold front leading a bifurcated tail
- Outer 'shock' edge is hard to define, suggesting significant los component
- Temperature fits show cold core surrounded by a hot ring

Merger scenario: infalling system coming toward us from NW to SE

- Fits with shock edge being less distinct due to projection
- Hot ring is shock heated gas projected on cooler core of infalling system

Spectral fits show velocity difference of $v>3000$ km/s indicating that A2443 is in the extreme range for merger velocities

Next Steps

Keck DEIMOS spectroscopy with up to 200 slits this coming weekend

IRAM NIKA 1.2 and 2 mm priority B program approved for this fall to look for thermal and kinetic Sunyaev-Zel'dovich signals (kinetic expected at the 5σ level)

High time resolution velocity measurements from simulations

Radio spectral mapping along and across the relic

Tests of Velocity Systematics

- Using CIAO 4.6 and CALDB 4.6.1.1 (latest calibration as of March 2014). Also used CALDB 4.6.0 & 4.5.9 and CIAO 4.5.
- Fits to entire region and only the iron line complex give a similar result.
- An independent reduction with CHAV, which includes a temperature dependent charge transfer inefficiency and gain correction depending on Au instrumental lines – results consistent.
- Checked spatial dependence in gain by extracting chip coordinates and fitting deep, recent VFAINT ACIS-I observations of the Coma Cluster and A401. We found no chip-based systematic discrepancies.
- Observation has a significant focal plane temperature change so we tested the most susceptible region of the chip for effects that would change the line energies – we found none. We also tested temperature dependence by fitting first and second half of data looking at the energies of three instrument lines (Au lines 11.41 keV, Au 8.66 keV, and Ni 7.46 keV). No systematic shifts found in CIAO or in CHAV.
- Partial list of other things: *cstat* vs *chisq*, binning in 3 different bin sizes, unbinned counts with *cstat*, mekal vs apec, switching RMF and ARF of each region with that from the other, many *contbin* realizations, …