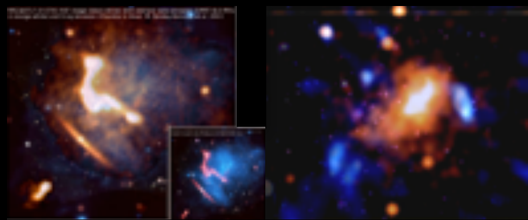
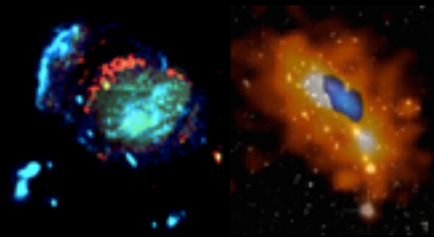


Galaxy Clusters and SKA

- World's largest radio telescope !



Mamta Pommier

CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

Bruno Guiderdoni, Francoise Combes, Johan Richard, J. Bagchi

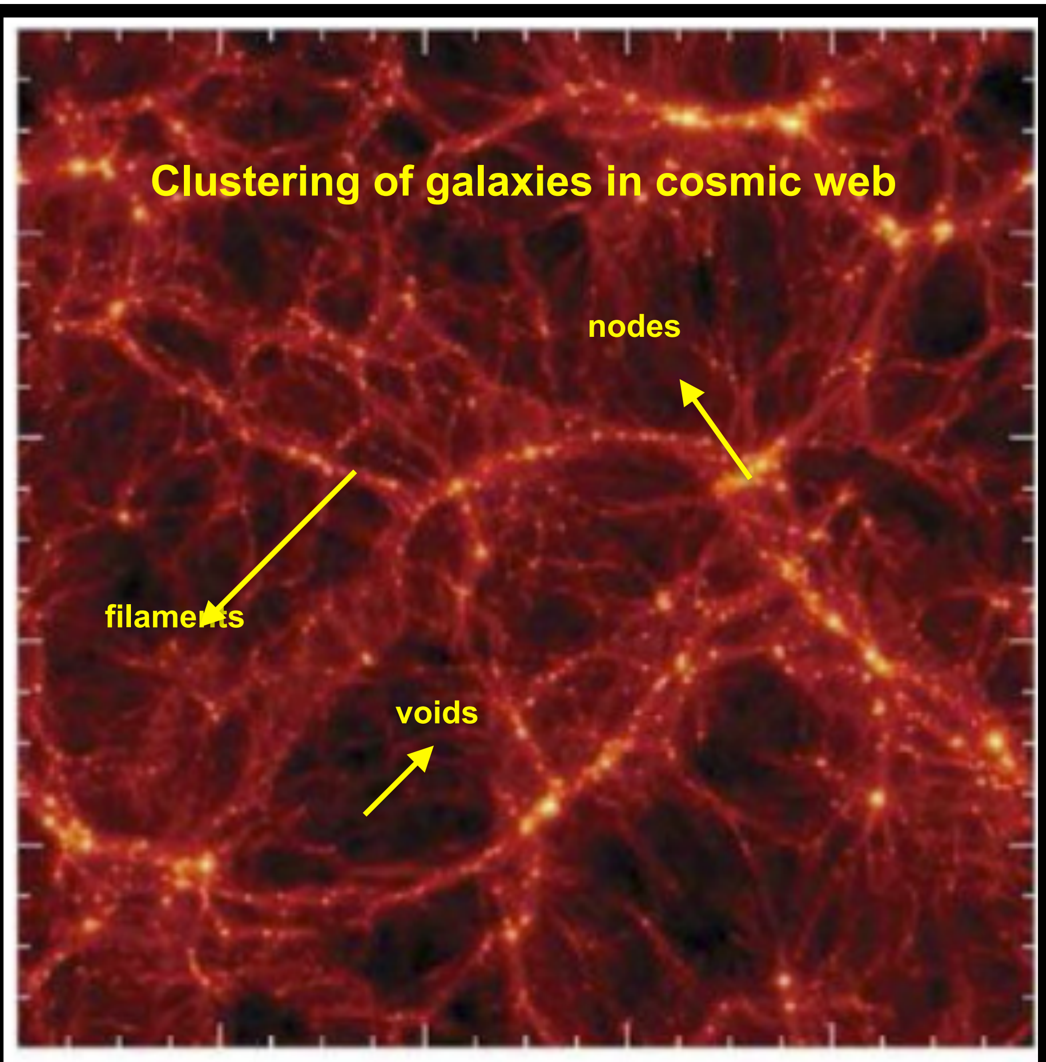
Galaxy clusters

Largest gravitationally bounded structures in the cosmic web with evolution driven by gravitational collapse of dense regions in the Universe followed by subsequent growth via accretion and mergers

Composition- dark matter (~80%), diffuse hot gas (~15%), and (~5%) luminous baryonic matter

Statistical study as a function of redshift provides insight on formation and evolution of large scale structures in the universe

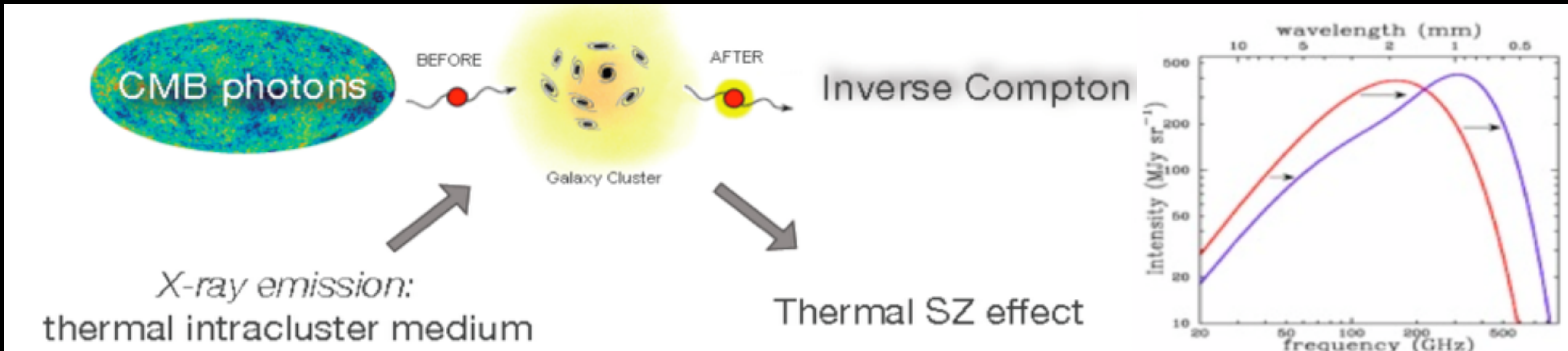
Multiwavelength (radio/X-ray/optical) studies are performed to investigate the association of Dark matter (DM) with the baryonic (visible) matter and dynamical state of the cluster

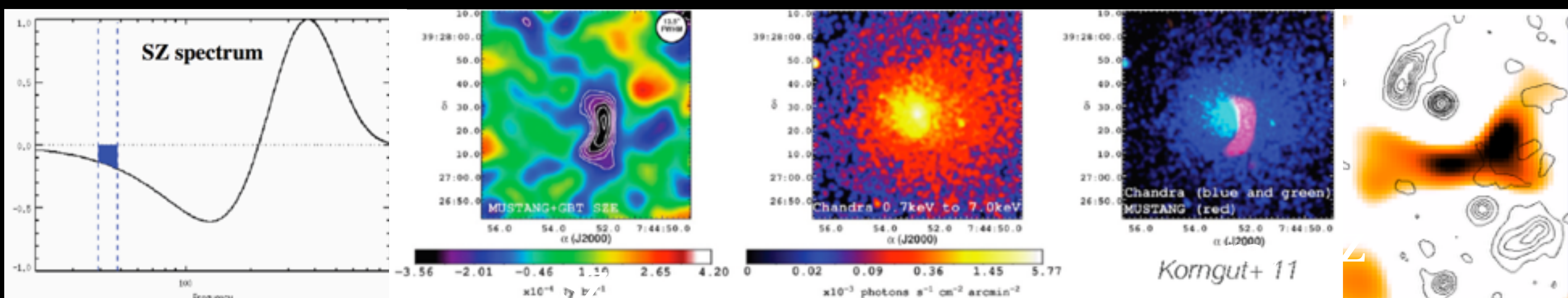


Multi wavelength properties - X-ray

MACSJ0717.5+3745 HST image with overlaid Chandra color map showing hot gas in blue and cool gas in red

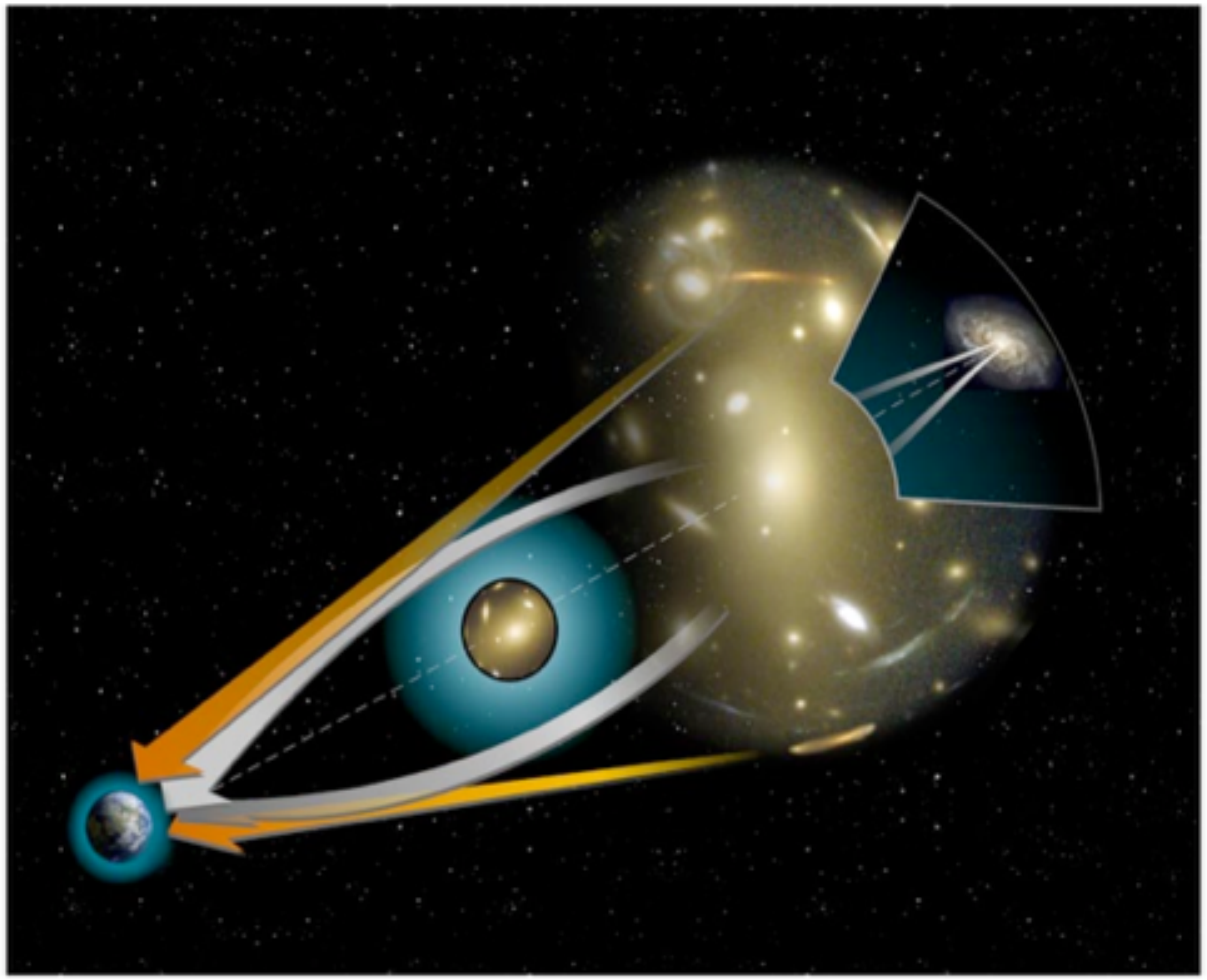
Multi wavelength properties - SZ effect





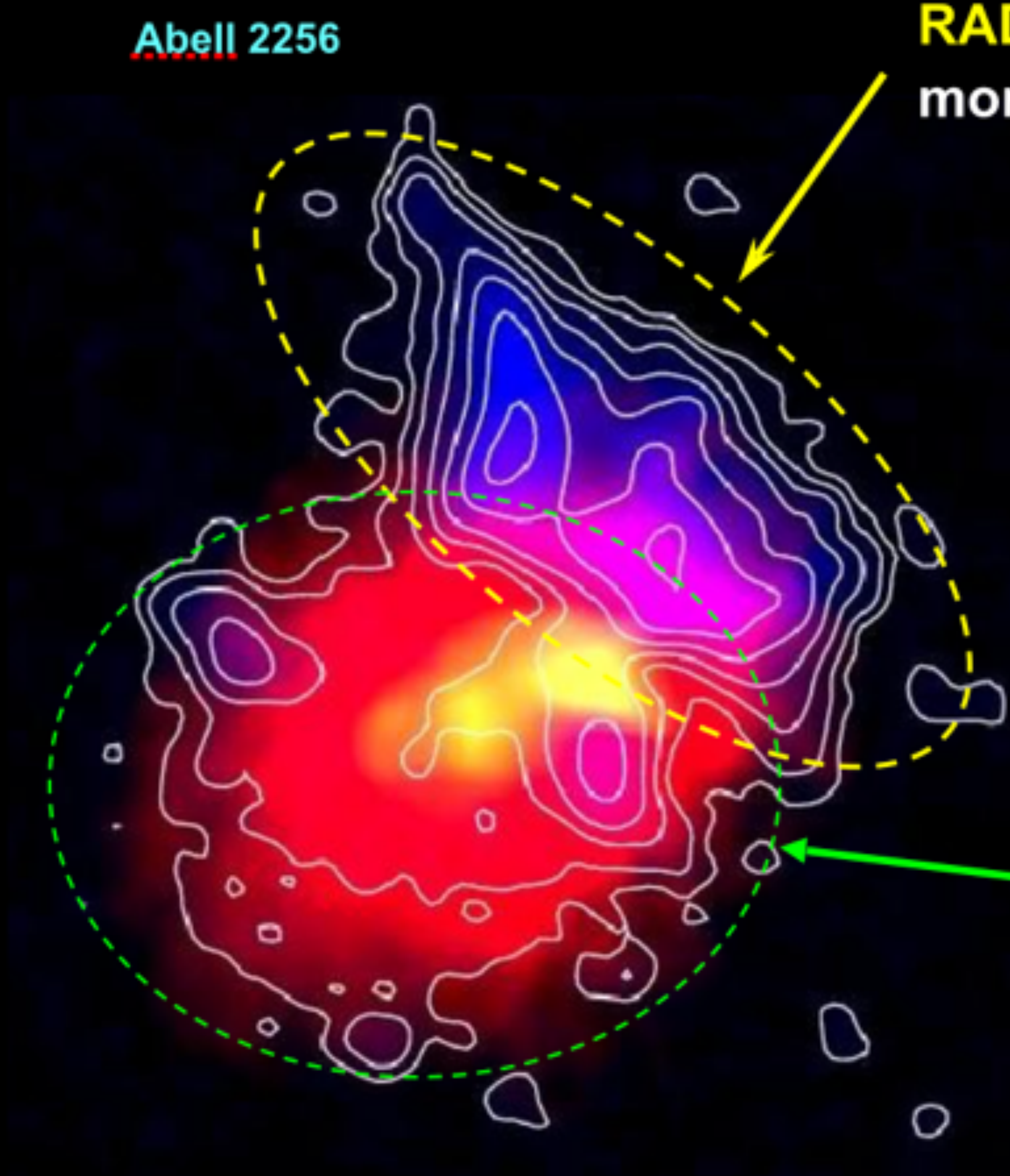
Multi wavelength properties - Optical

MACSJ0717.5+3745 HST image



Gravitational lens

Multi wavelength properties - Radio classification



VLA 1.4 GHz on Chandra
(discrete radio galaxies subtracted)
Clarke & Ensslin 2006

RADIO RELICS: cluster outskirts, elongated morphology, polarized up to 30%

Origin: shock (re)-acceleration of relativistic electrons or shock adiabatic compression of fossil radio plasma ?

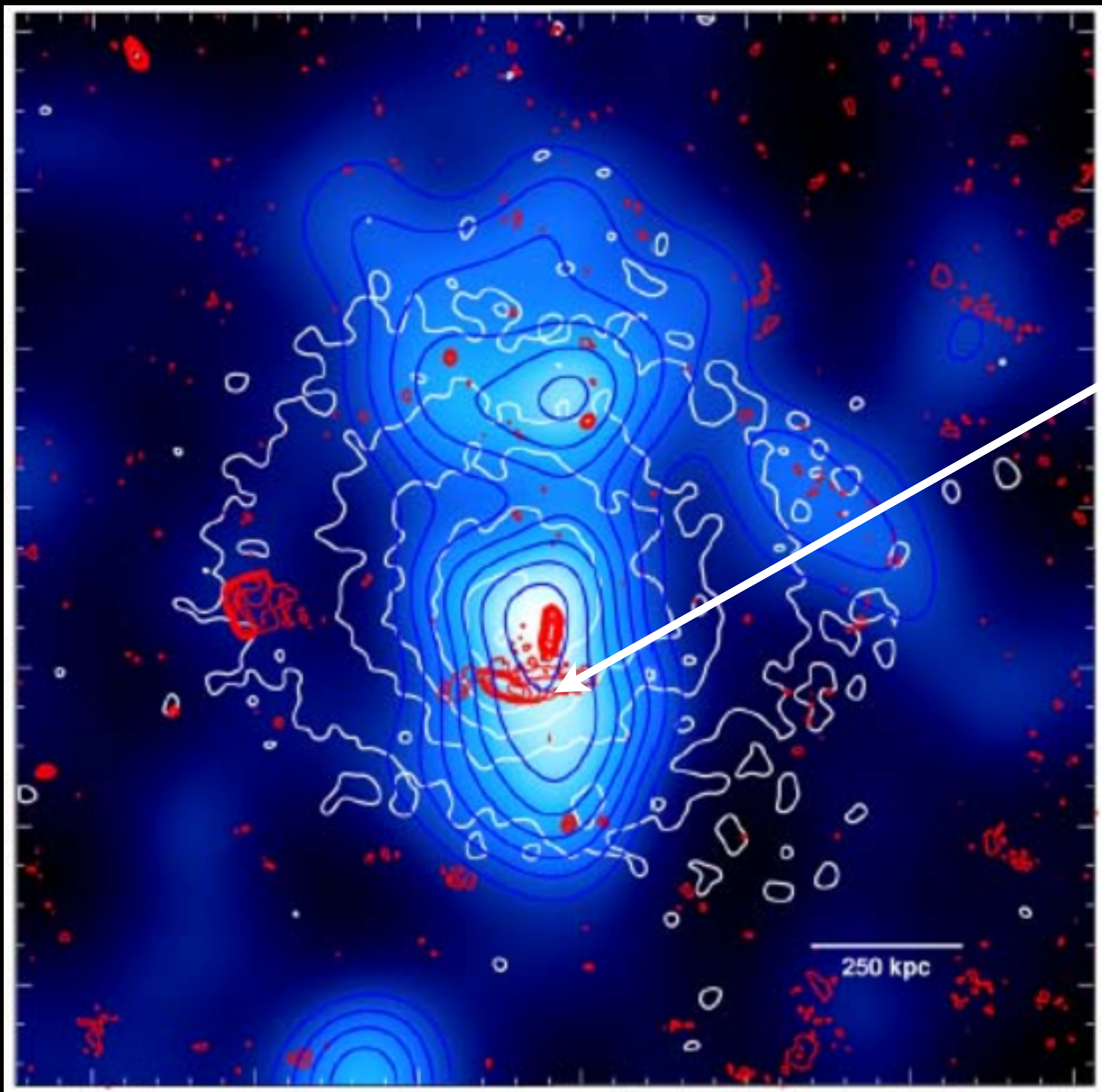
e.g., Ensslin et al. 1998; Rottgering et al. 1997; Ensslin & Gopal-Krishna 2001; Markevitch et al. 2005; Hoeft and Bruggen 2007…

RADIO HALOS: centrally located, regular structure similar to the X-ray morphology, unpolarized

Origin: a promising possibility is the (re)-acceleration of relativistic electrons by merger driven turbulence (Brunetti et al. 2001, Petrosian 2001, Fujita et al. 2003,…)

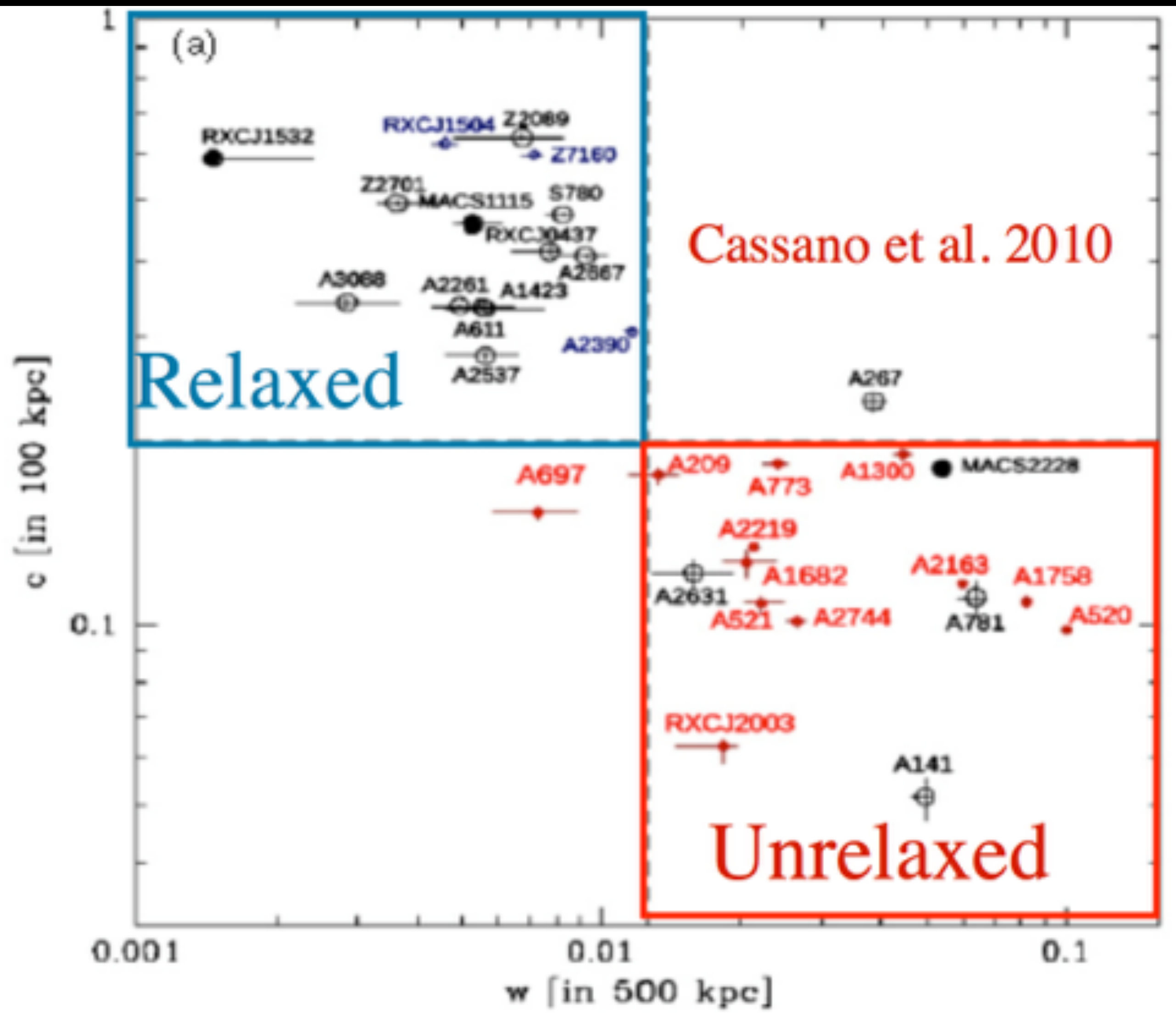
Galaxy clusters: Radio classification

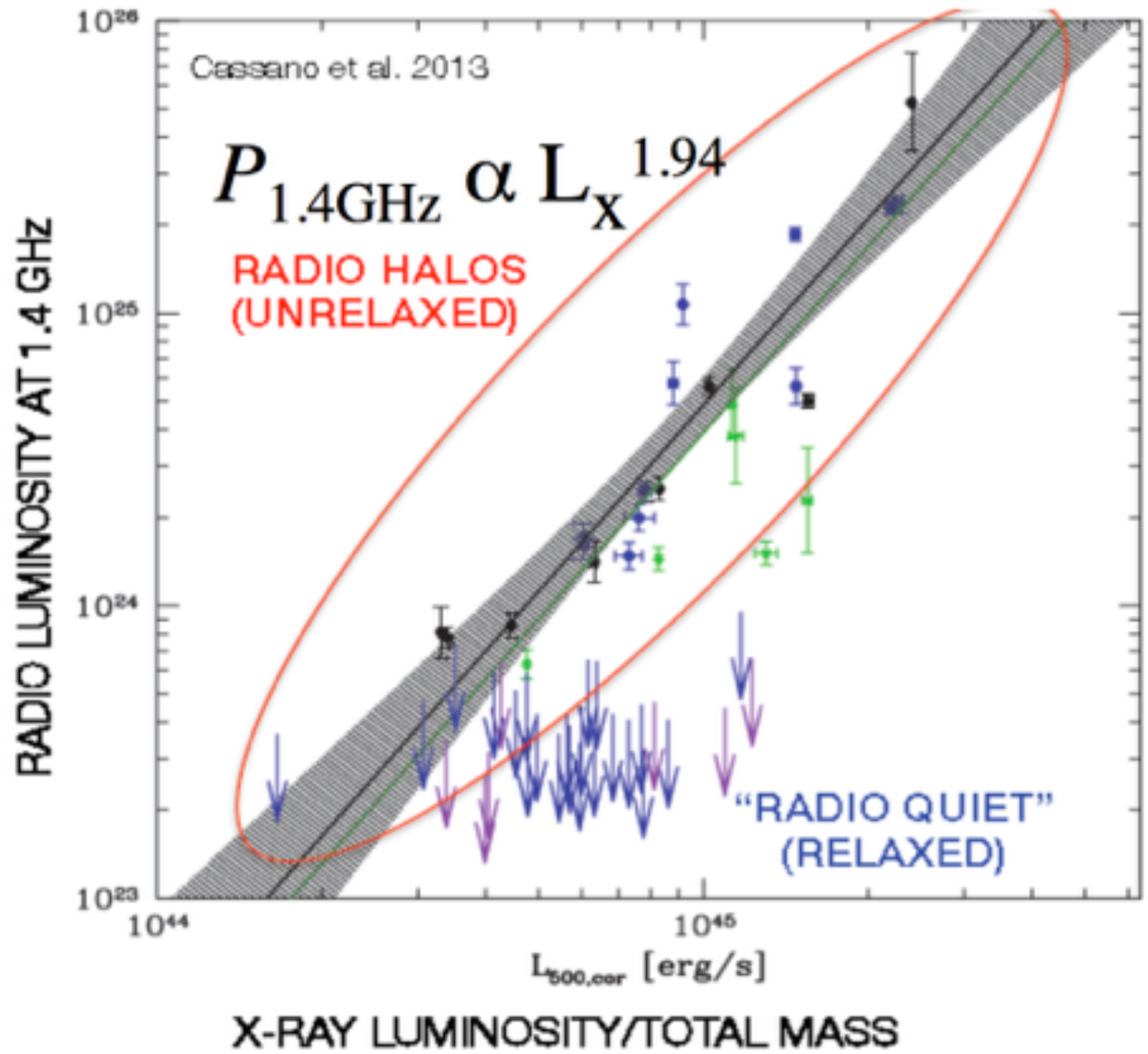
'*Phoenix*'- in which the aged synchrotron plasma is adiabatically compressed by a (cluster merger) shock wave within the central region of the cluster (van Weeren et al. 2015)



Abell 1033: The white contours help identify the X-ray flux levels, and the red contours trace the radio emission. The elongated red structure in the lower center is a radio phoenix: fossil gas that has been reheated by shocks from a nearby galaxy merger

Galaxy clusters: statistical radio properties





GMRT radio halo survey , dynamical properties from Chandra X-ray observations (Venturi et al. 2008)

1. RHs are hosted by unrelaxed clusters

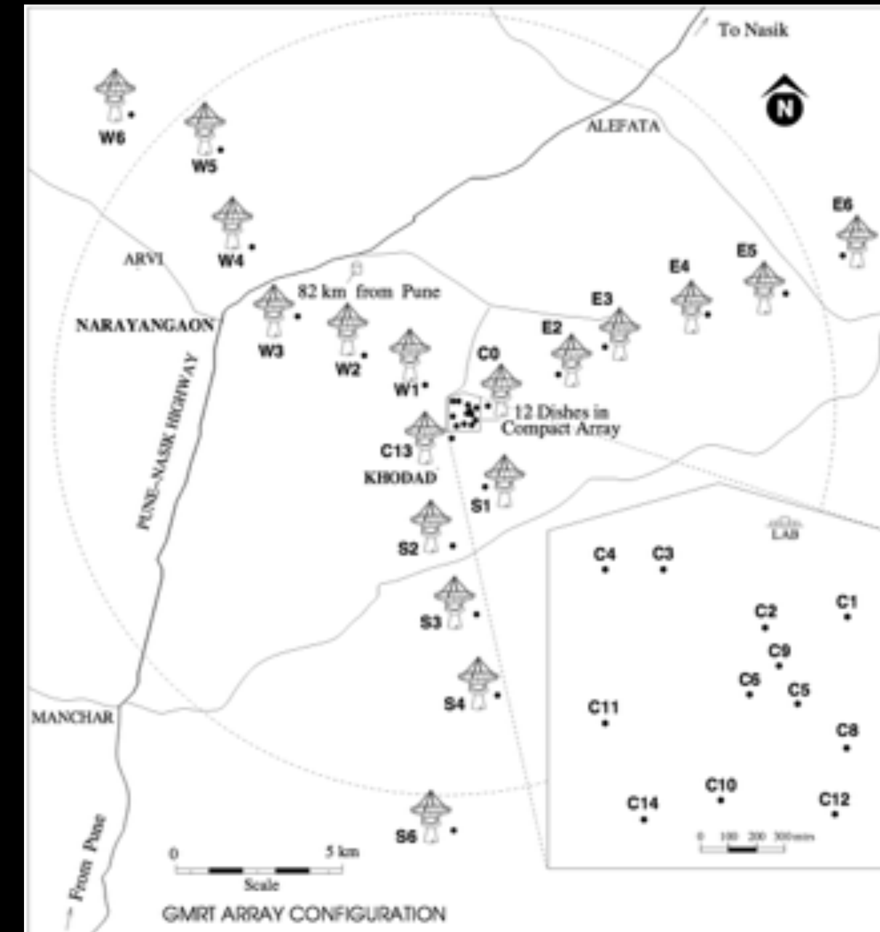
Giant Metrewave Radio telescope (GMRT), India
SKA Pathfinder & SKA Data center

The GMRT, consists of 30 fully steerable parabolic dishes, each of 45m in diameter spread over 25km *(Yashwant's talk)*.

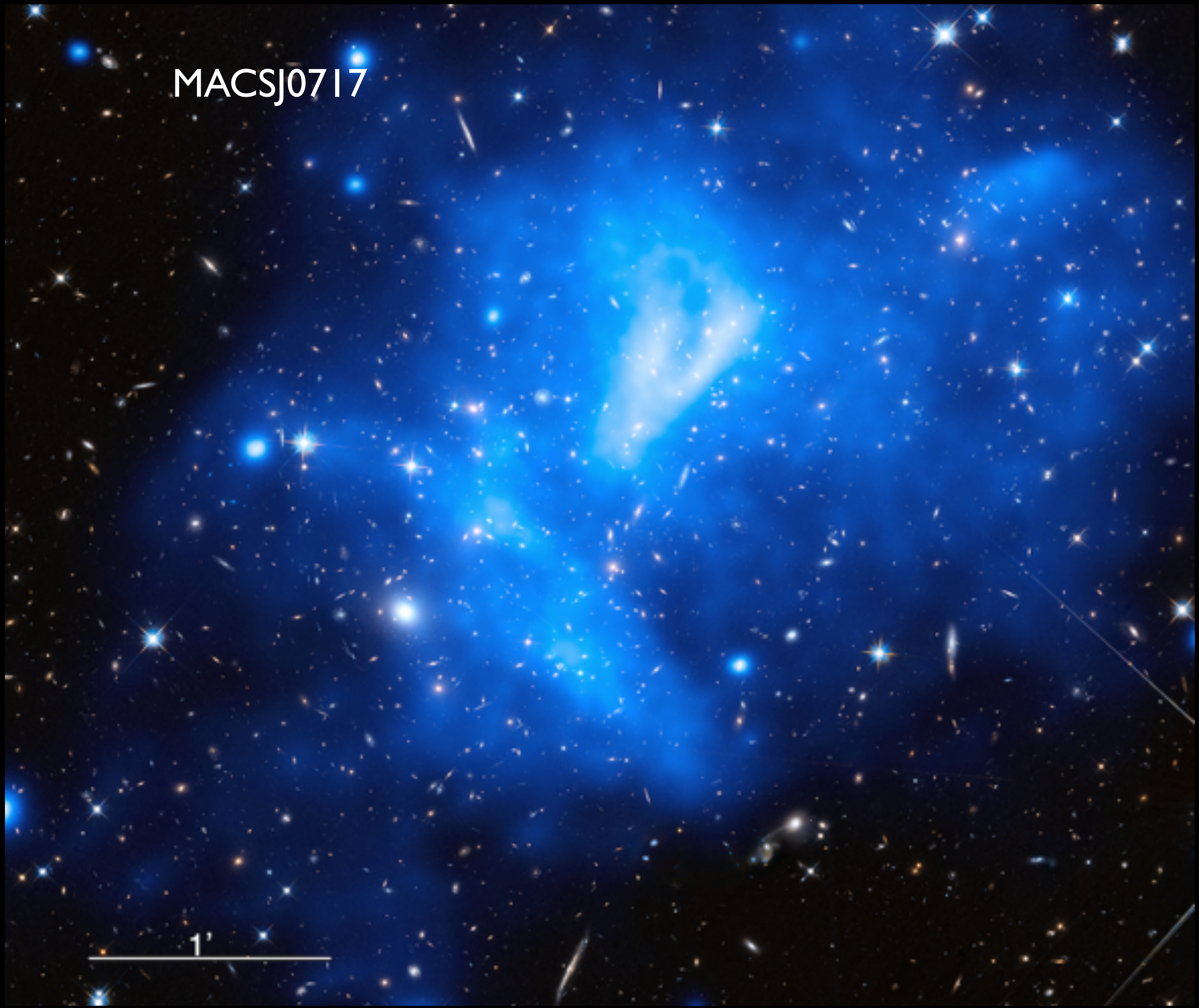
Twelve of the 30 antennas are in a central compact random array of 1km x 1km in size and the remaining 18 antennas are stretched out into 3 arms of each 14 km long.

Frequency bands- 151, 235, 325, 610 and 1000-1400 MHz.

We are carrying out radio survey on massive galaxy clusters with the GMRT



Radio survey on clusters



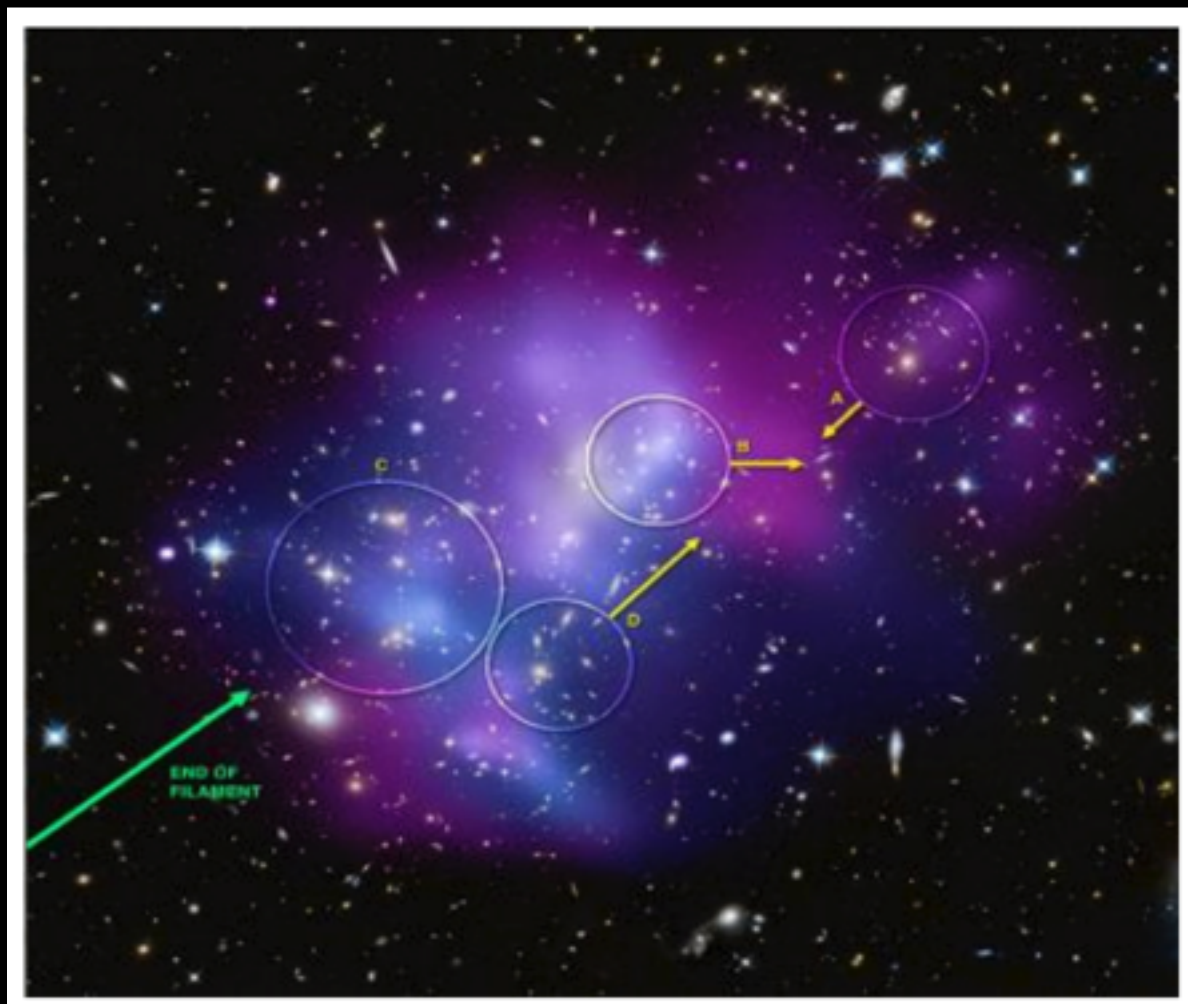
- $z = 0.1 - 0.5$
- $L_X > 10^{44}$ erg s^{-1}
- T >10 keV
- Dual or Quadruple merger event
- Hints of shock heated regions: 20+ keV
- $M_{vir} > 10^{15}$ $M_\odot$

-GMRT/VLA/LOFAR observations to study diffuse cluster emission

Results on MACS clusters : Giant Radio Halo and Phoenix in distant merging cluster MACS J0717.5+3745 (z=0.5548) at low frequencies- Pandey-Pommier et al. 2013a, 2013b

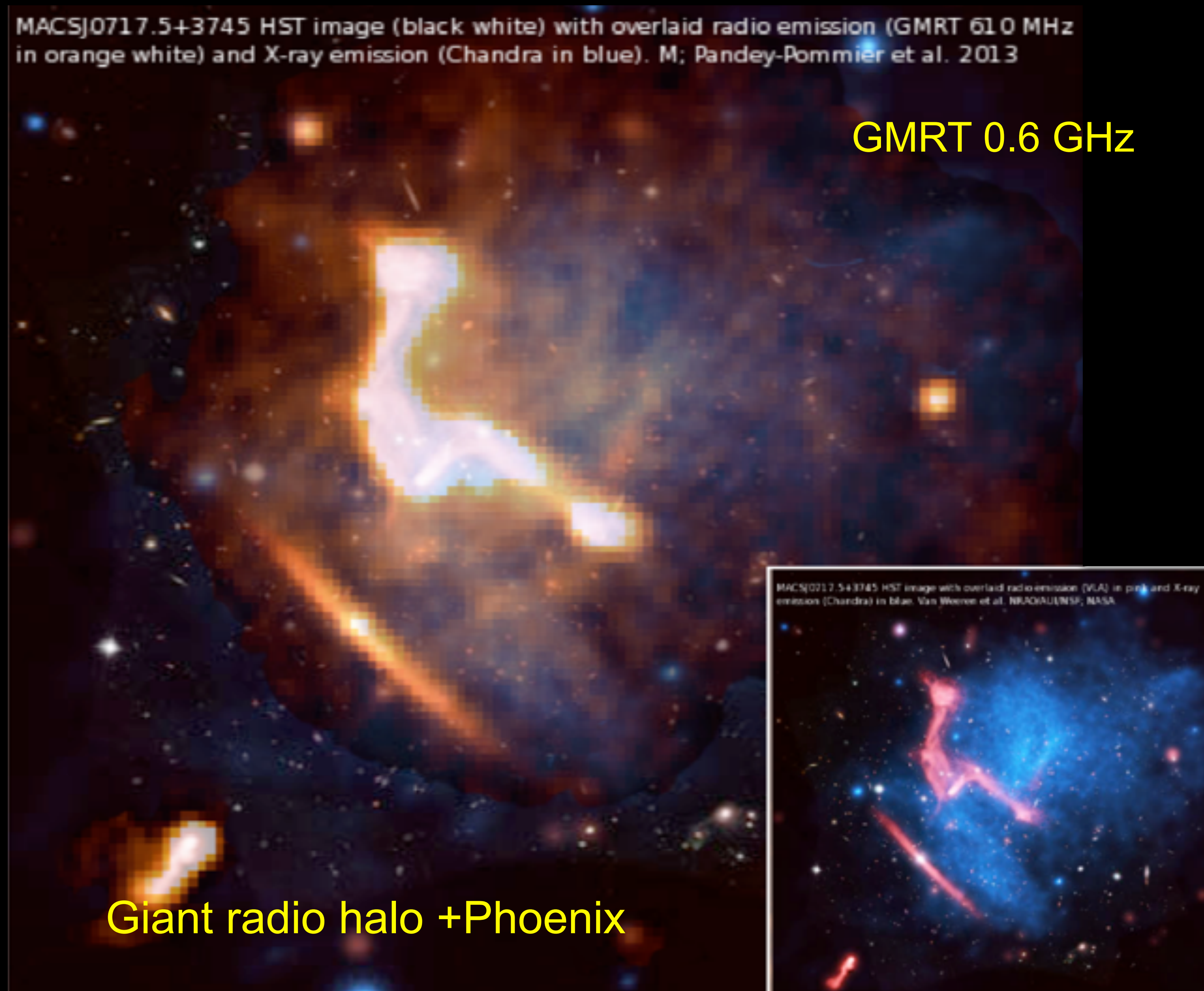
MACS J04717.5+3745 consists of 4 sub groups involved in collision.

-HST data clearly shows 100s of galaxies in the cluster environment with arcs of lensed galaxies



- High frequency VLA observations detected only bright regions (van Weeren et. al. 2009)

Results on MACS clusters : Giant Radio Halo and Phoenix in distant merging cluster MACS J0717.5+3745 (z=0.5548) at low frequencies- Pandey-Pommier et al. 2013a, 2013b

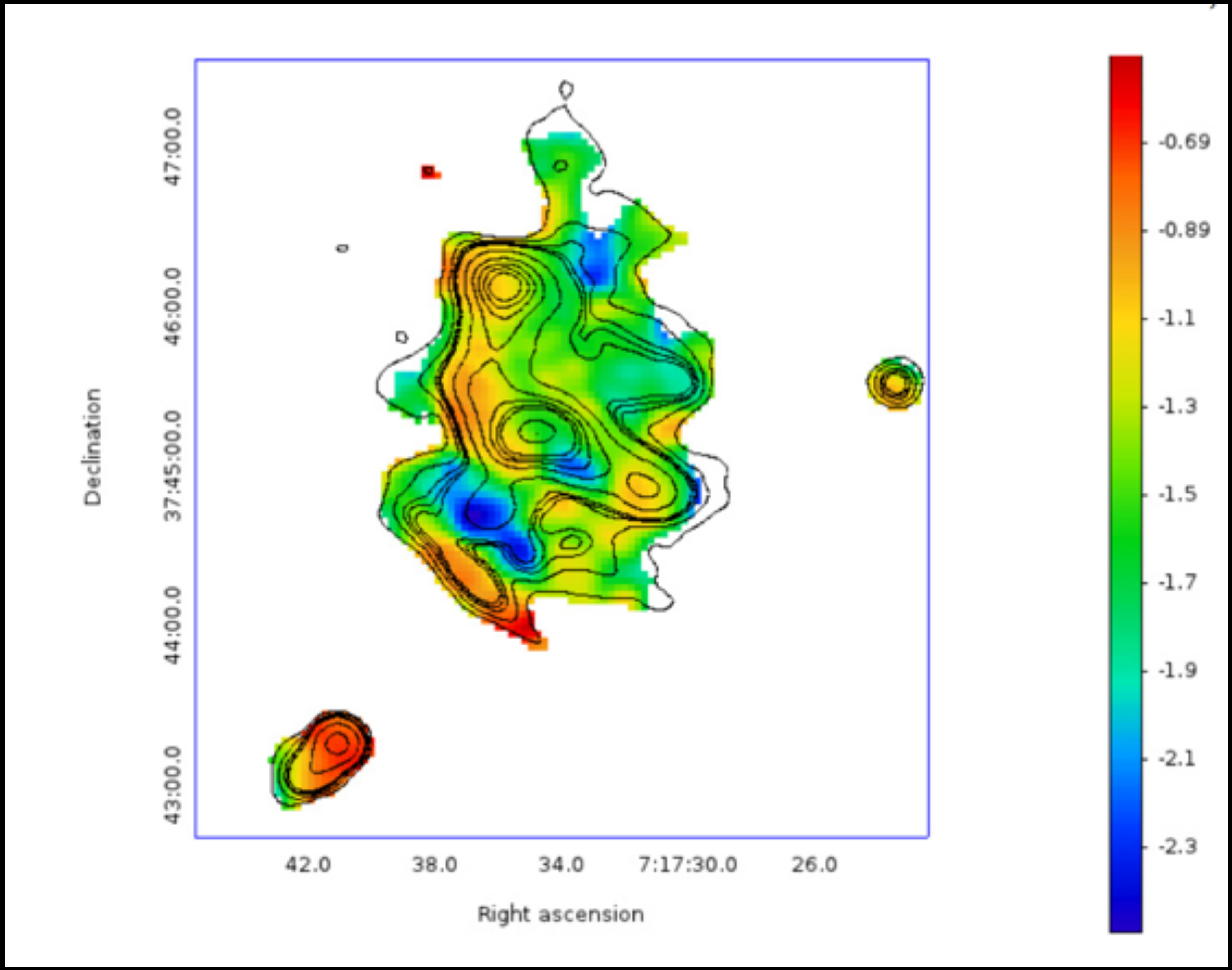


- Giant radio halo of 1.58 Mpc along with compressed fossil plasma traced by Phoenix of 0.85 Mpc, at the center of the merger region is detected at MHz range

- Most powerful Giant radio halo with P(1.4GHz)= 9.9 x 10^25 W/Hz and magnetic field of 6.5 microG.

Results on MACS clusters : Giant Radio Halo and Phoenix in distant merging cluster MACS J0717.5+3745 (z=0.5548) at low frequencies- Pandey-Pommier et al. 2013a, 2013b

- Less steep radio spectra (alpha = -1.1) along with new multiwavelength (Optical, X-ray) data suggest that the cluster is **ongoing-merger**



***Spectral index map** at low frequencies for merging cluster MACSJ0717.5+3745*

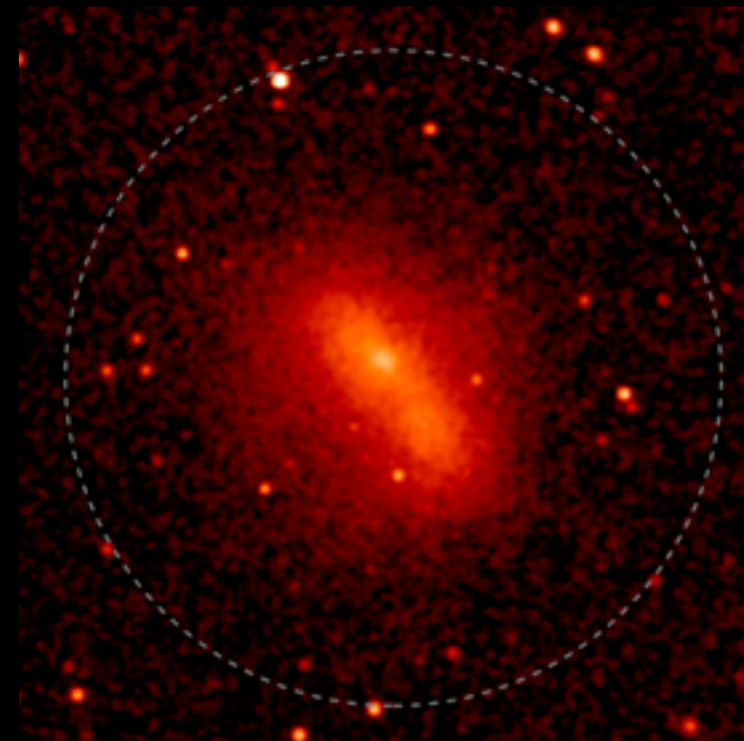
Results on MACS clusters : Ultra steep spectrum radio Halo (USSRH) in distant merging cluster MACS J0416.1+2403 (z=0.396) at low frequencies Pandey-Pommier et al. 2015, Ogrean et al. 2015

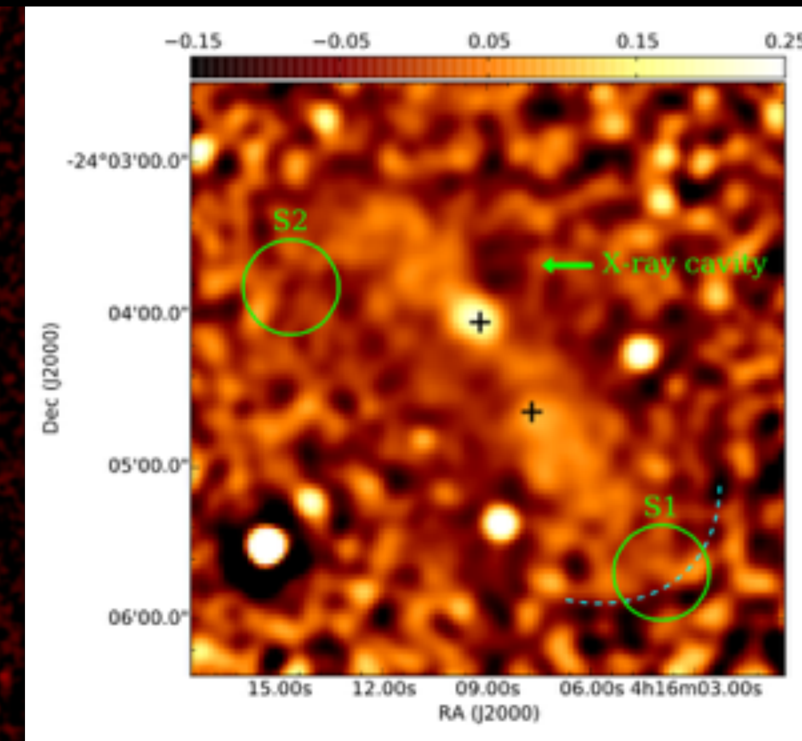
-MACS J0416.1-2403 (z = 0.396) consists of a NE (with X-ray cavity) and a SW subclusters (Ebeling et al. 2001)

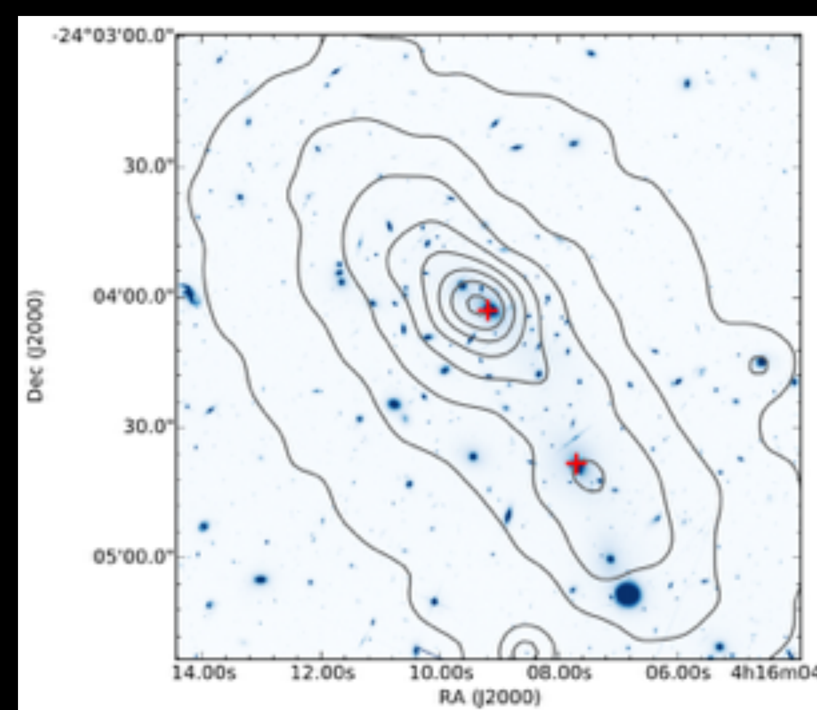
-HST data shows 100s of galaxies in the cluster

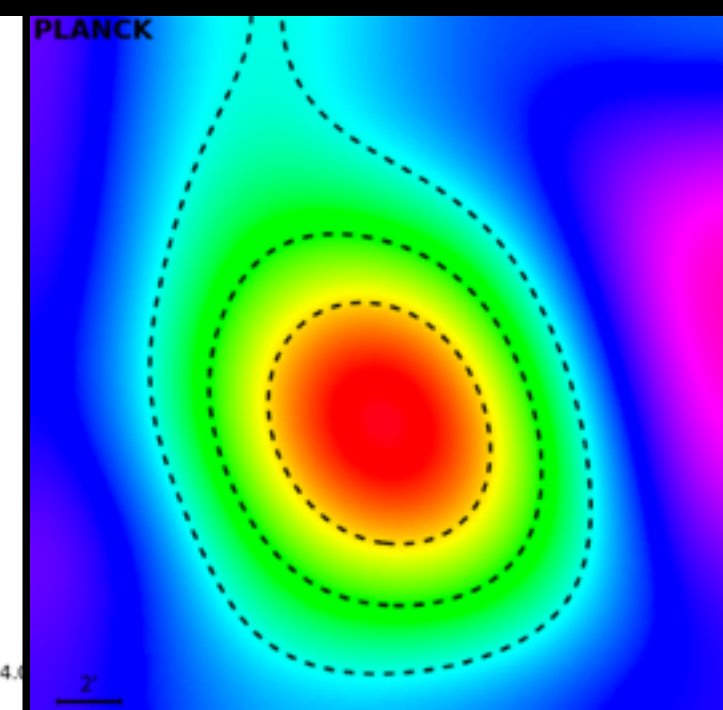
-Jauzac et al. 2014, combined HST lensing data with Chandra archival and found good DM-gas alignment for the NE subcluster, and significant offset for the SW one . They proposed two possible scenarios for the merger event in MACS J0416.1-2403 – one pre-merging and one post-merging – but were unable to distinguish between the two.

-Planck data detects the SZ signal

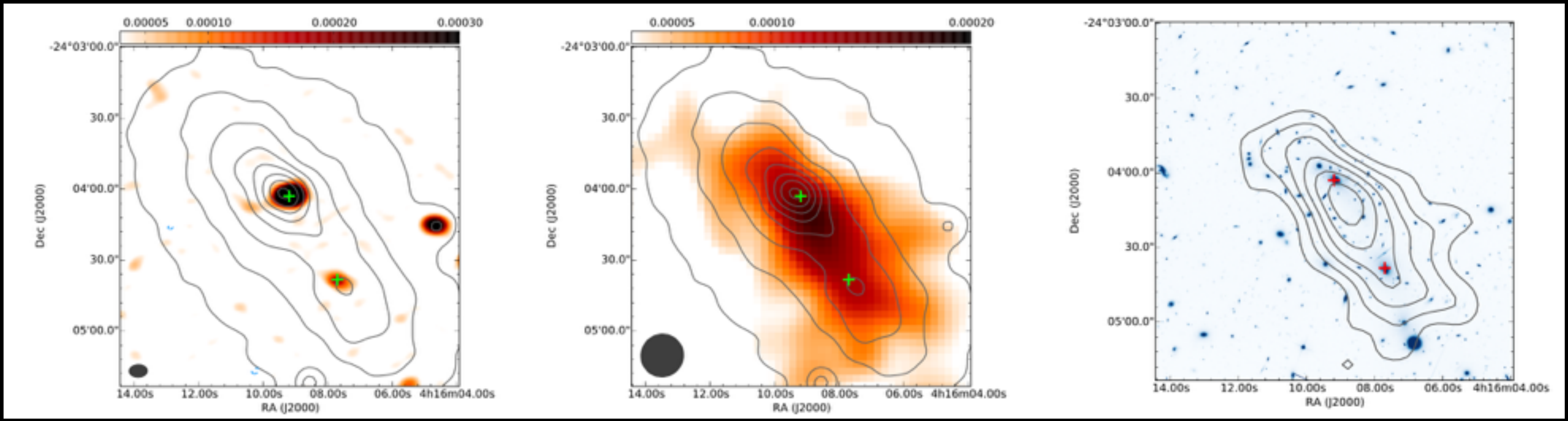








Results on MACS clusters : Ultra steep spectrum radio Halo (USSRH) in distant merging cluster MACS J0416.1+2403 (z=0.396) at low frequencies Pandey-Pommier et al. 2015, Ogrean et al. 2015



1st panel - high (7.8 x 5.5 arcsec, 14 micro Jy/ beam), 2nd panel- low (18 arcsec, 20 micro Jy/ beam) resolution colour images with overlaid X-ray contours and 3rd panel- JVLA contours on HST colour image

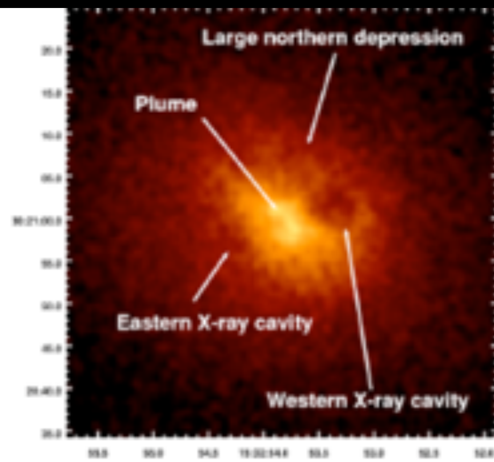
Results on MACS clusters : largest size mini-Halo in cool-core cluster MACS J1532.9+3021 (z=0.362) at low frequencies Pandey-Pommier et al. 2014, 2016a

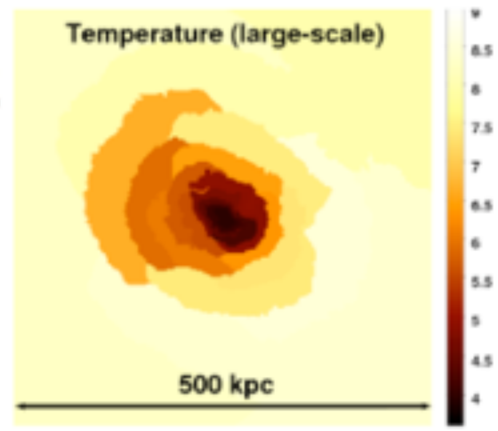
-z=0.362

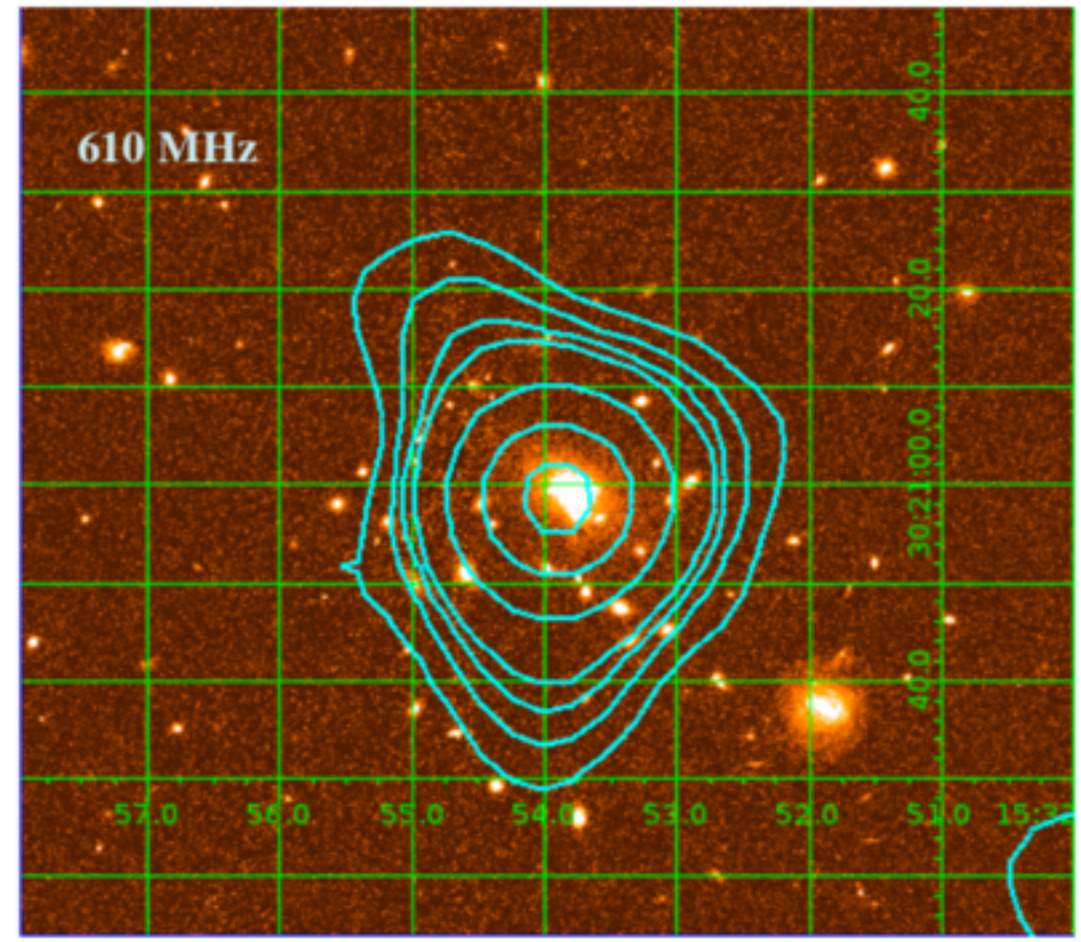
-slightly extended system

-Massive ~ 10^{14} M_{sun}
-X-ray luminous (L_x=2.1 x10^{45} er,
-X-ray Temp 6 keV
-Cool core- central morphology with cavities (X-ray)

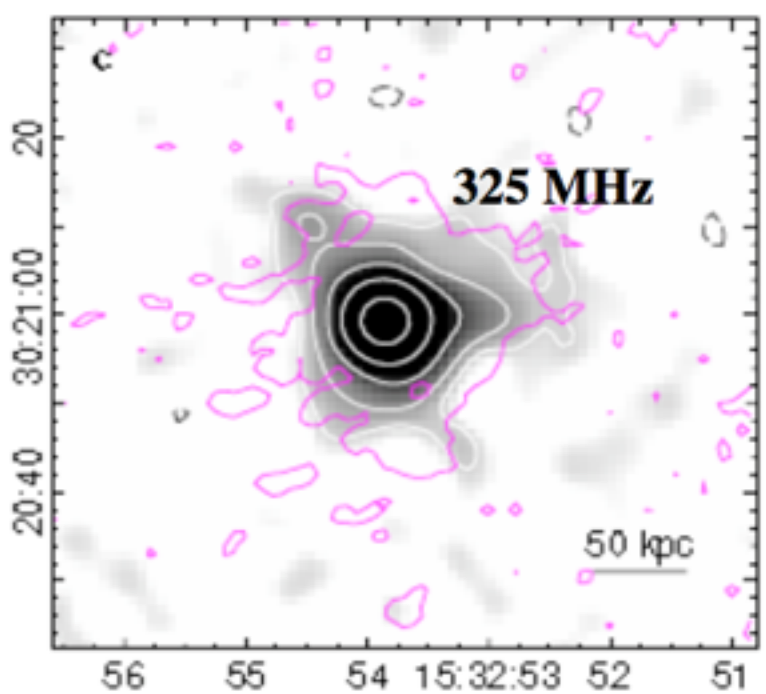
-Radio emission:
•central extended
•central bright AGN







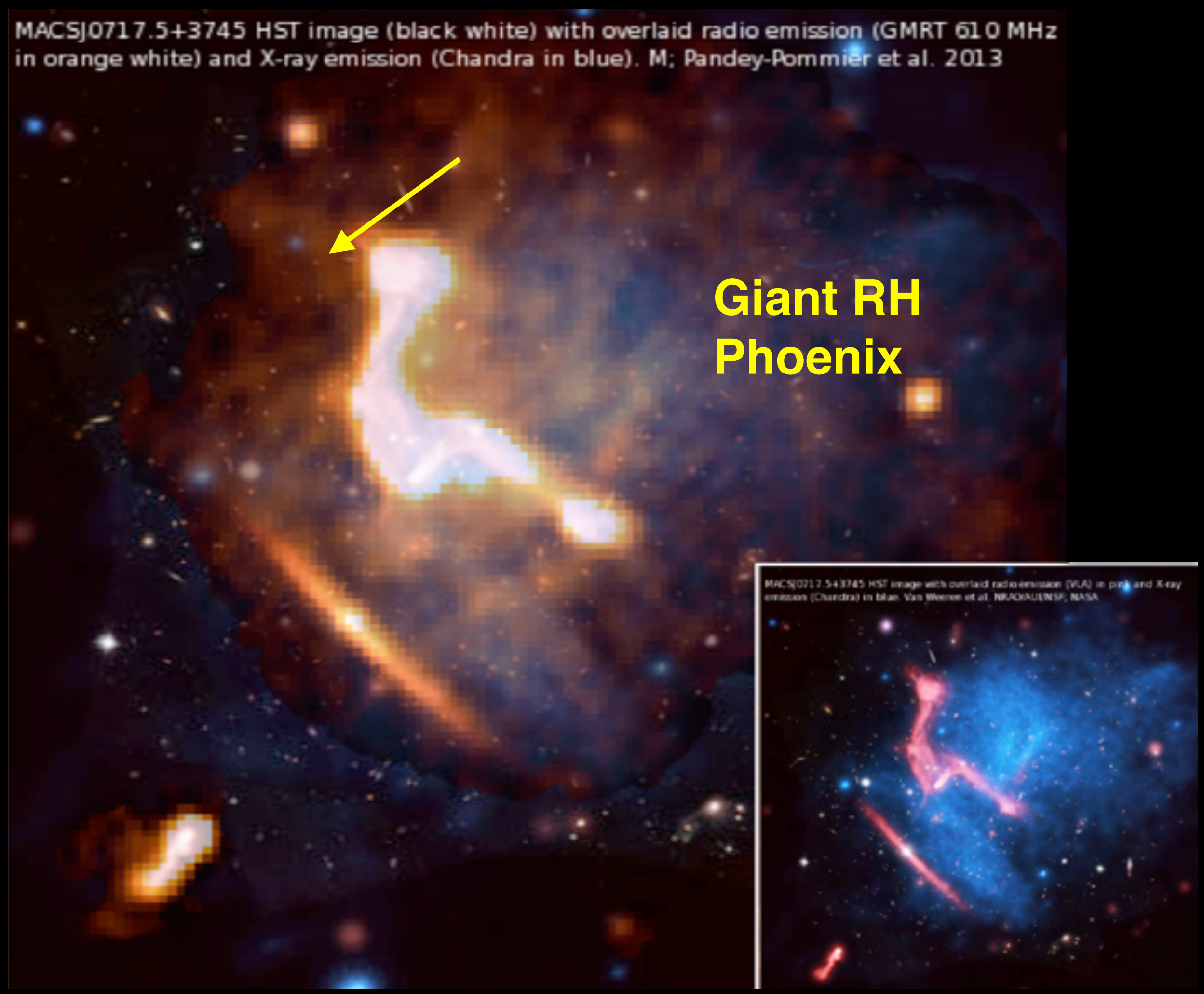
HST

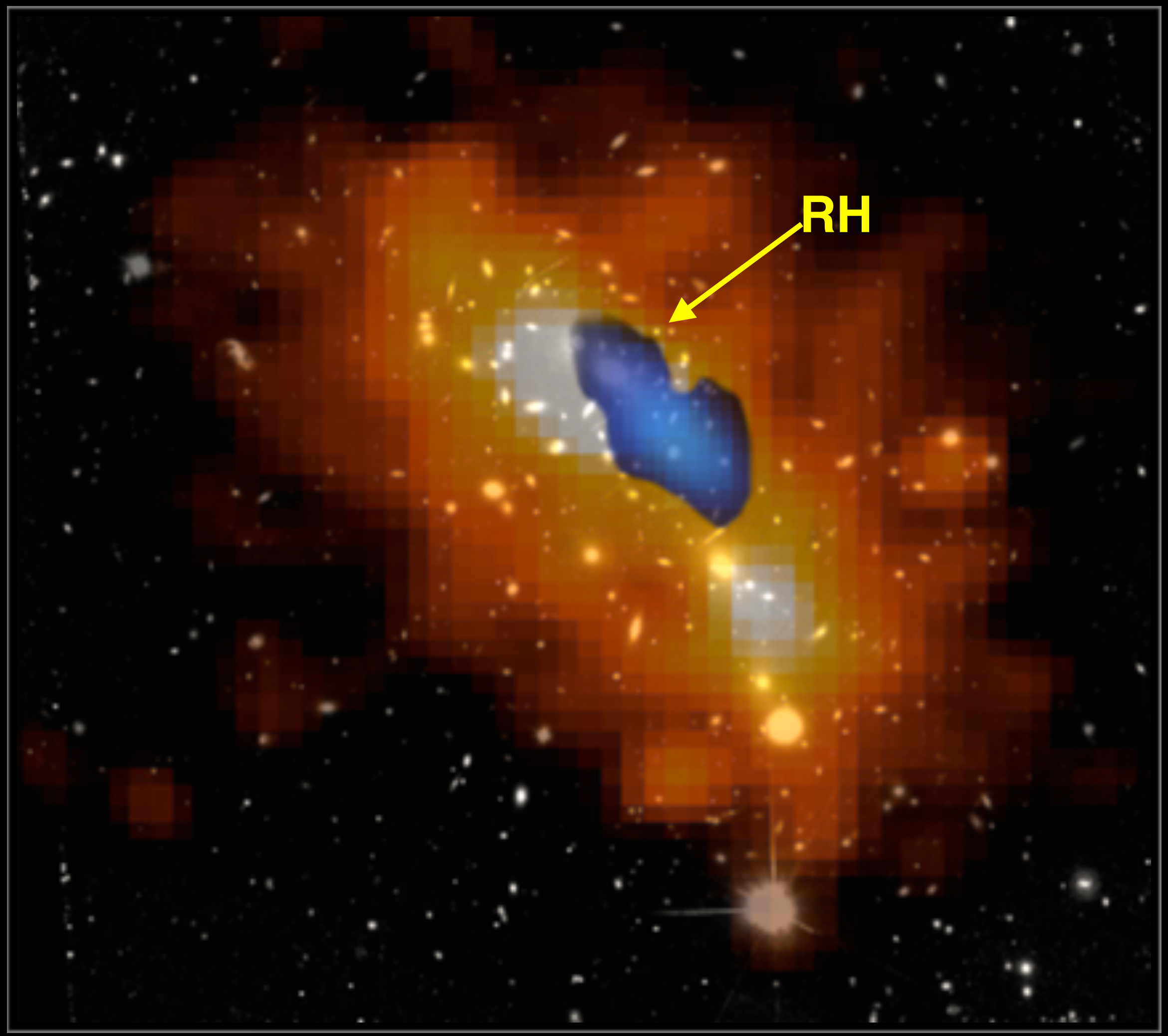


VLA contours
3 x 0.6 mJy/beam @ 325 MHz (5.2" x4.8")
Chandra X-ray - grey scale
Giacintucci et al. 2013, Hlavacek-Larrondo et al. 2013

New Results: Low Frequency Radio survey on clusters

Pandey-Pommier et al. 2013, 2015, 2016a



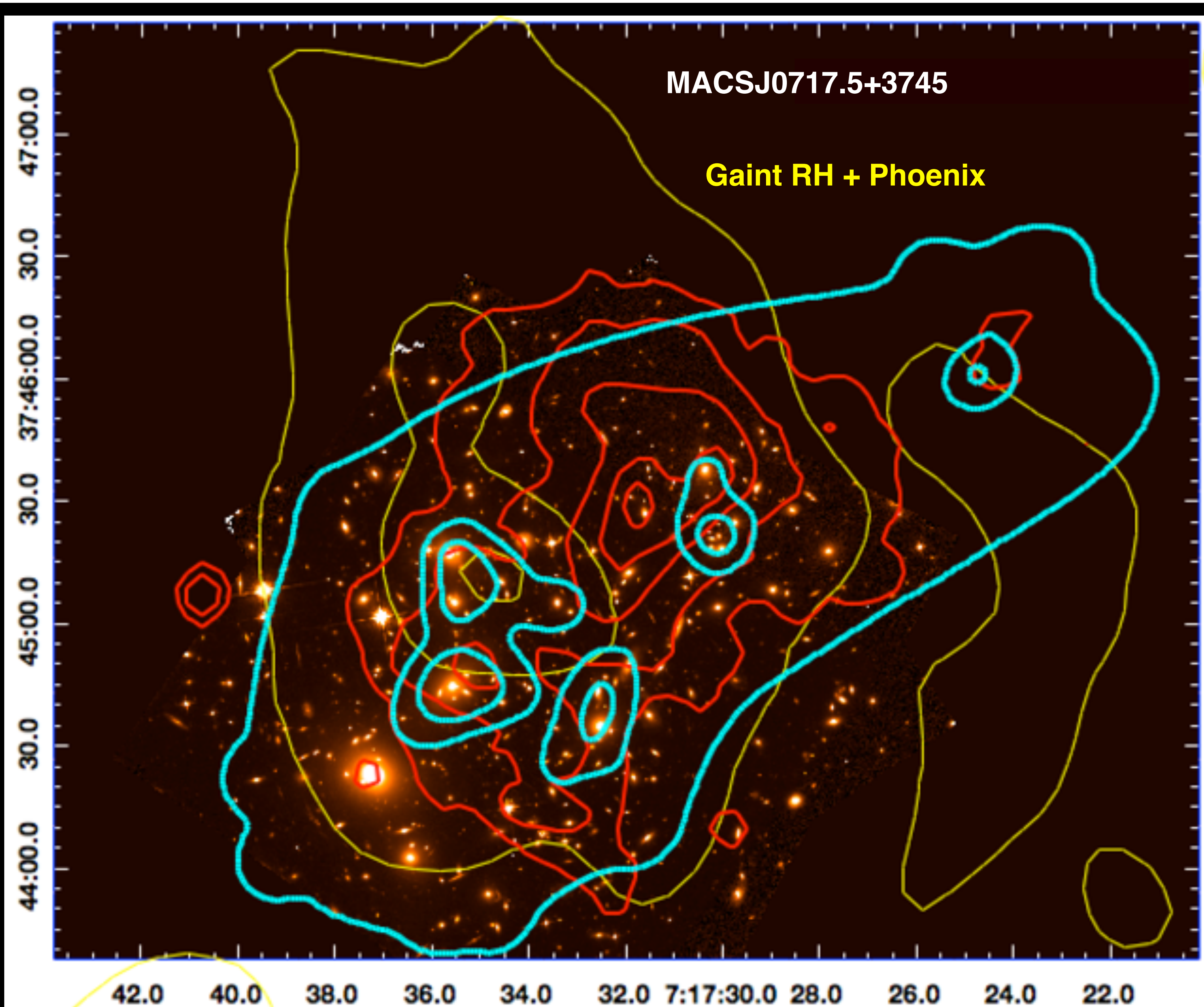


-GMRT survey confirms 5 different types of radio emission (RM, mH, GRH, Phoenix, relics)

-Spectral index (1.4 GHz-250 MHz) for RH = -1.2, RR and Phoenix = -0.8 to -2.2 and **USSRH < -1.5 (rare !)**

Multiwavelength properties and Cluster dynamics - Merging clusters in CLASH catalog

Pandey-Pommier et al. 2016b



No well defined peak in the Total mass map coincident with the X-ray peak- ongoing-merger

MUSE data shows better Total mass distribution map, thanks to high sensitivity

Observed configuration of the 3 components in merging clusters- The background shows HST image, with contours showing the distribution of galaxies (orange-white), gas (thermal in red and non-thermal in yellow) and total mass dominated by DM (cyan)

Cluster dynamics and DM association in massive galaxy clusters

Pandey-Pommier et al. 2016

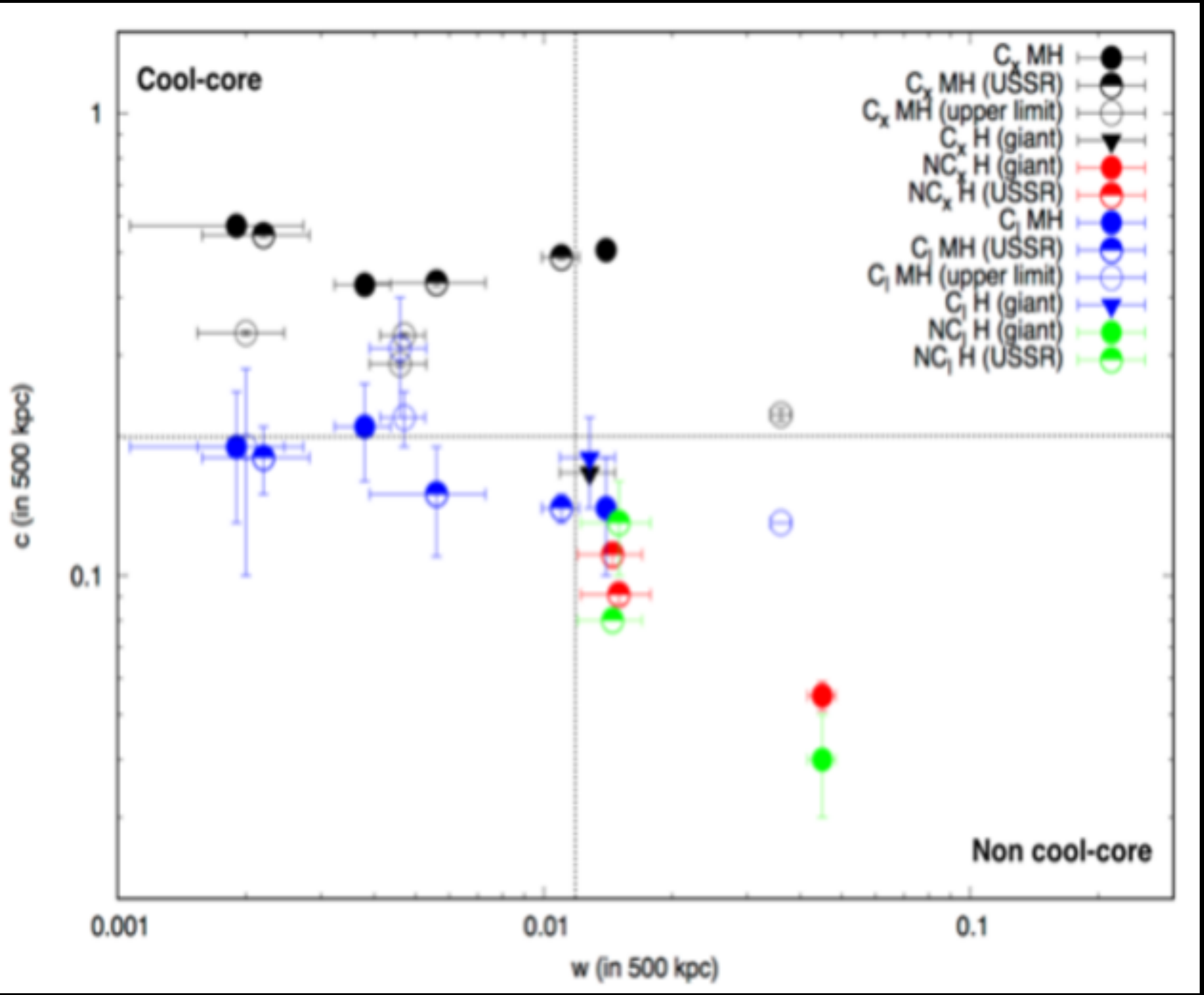
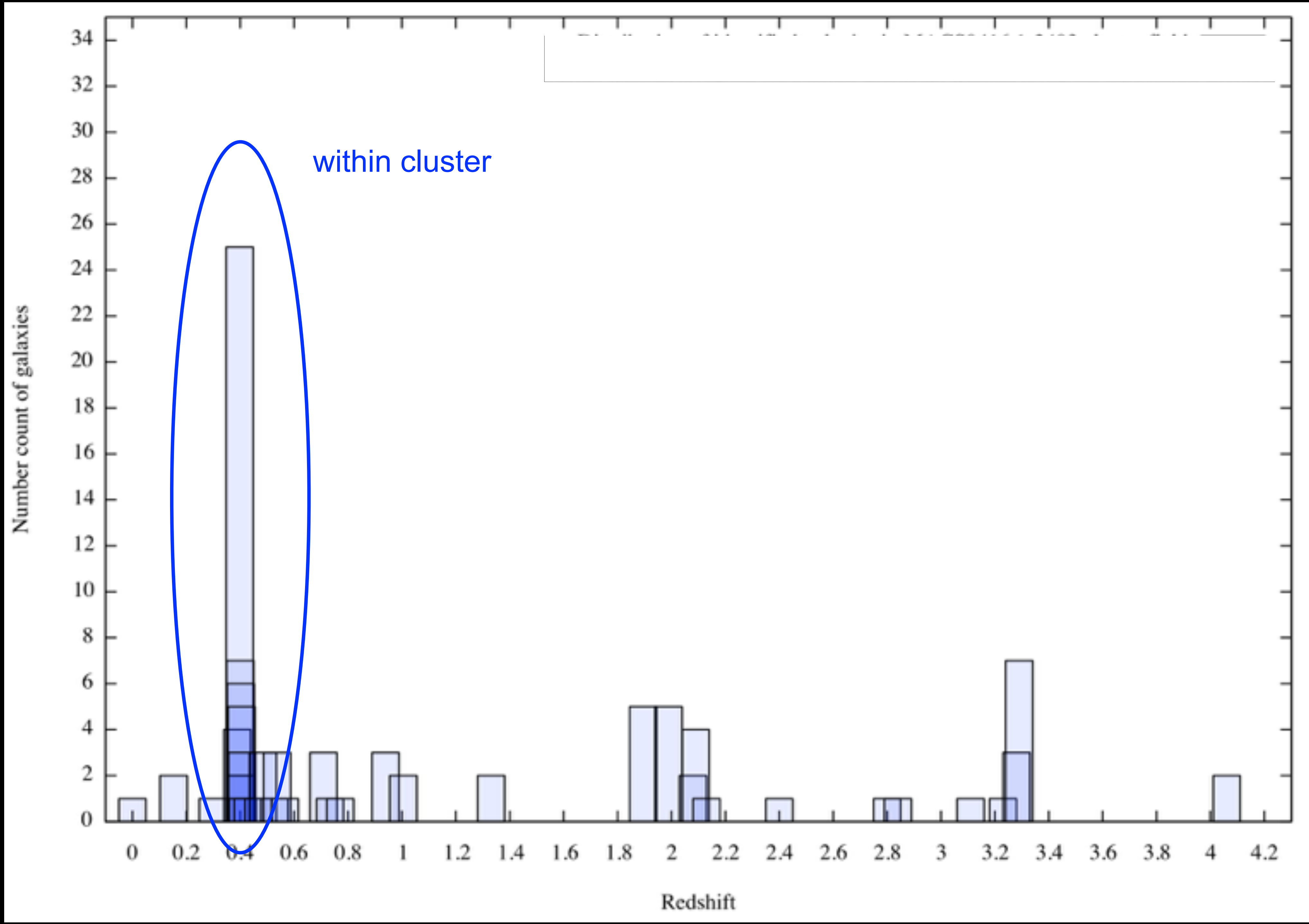


Fig. X-ray concentration in cool-core as 'C_x', X-ray concentration in non cool-core as 'NC_x', Concentration in total mass map via lensing analysis as 'C_l' in cool-cores and 'NC_l' in non cool-core clusters.

Galaxy population in the cluster environment with MUSE

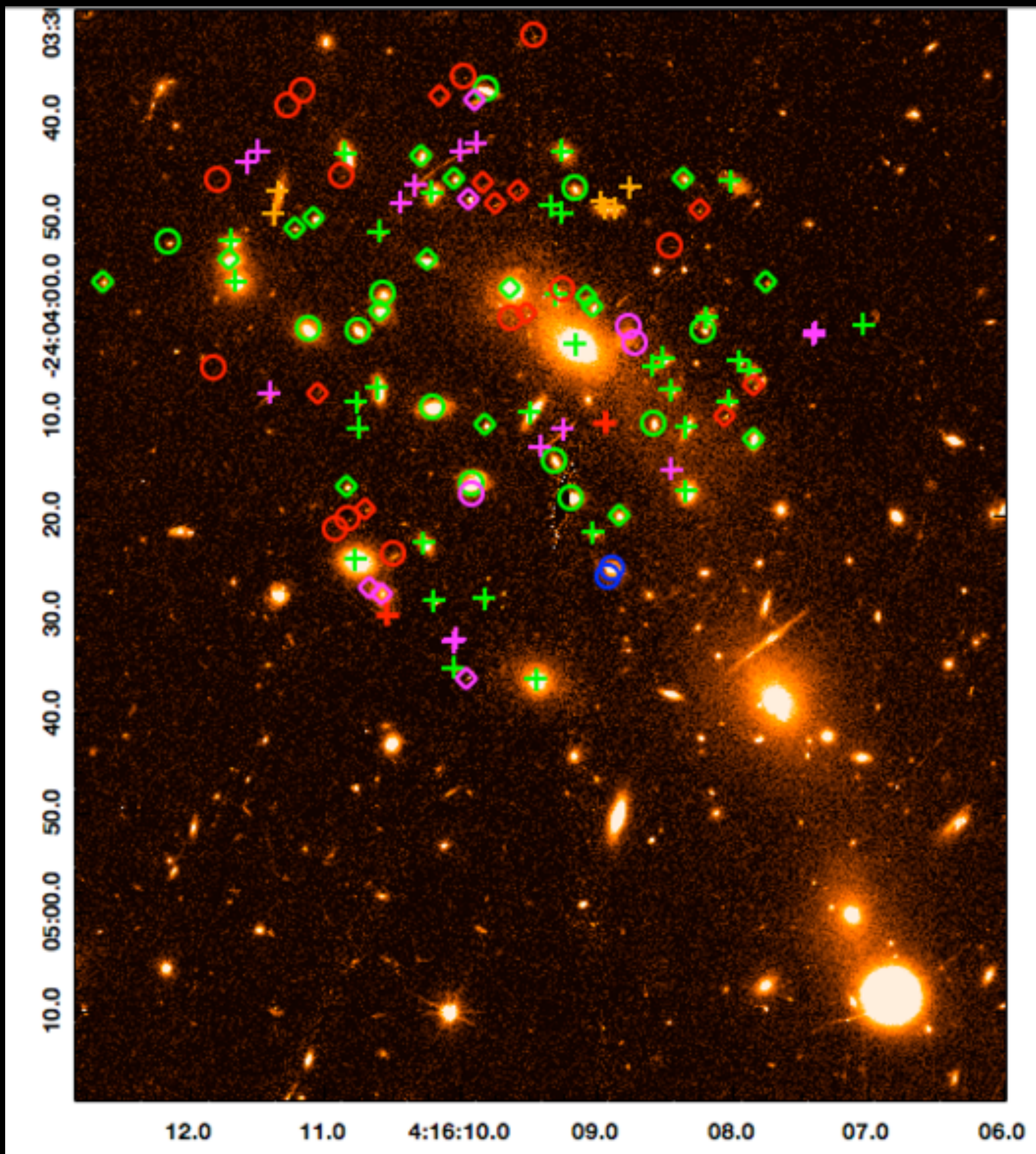
Pandey-Pommier et al.



Study of galaxy population within the cluster field, Star formation Rate (SFR) w.r.t redshift and cluster environment

Galaxy population in the cluster environment with MUSE

Pandey-Pommier et al.



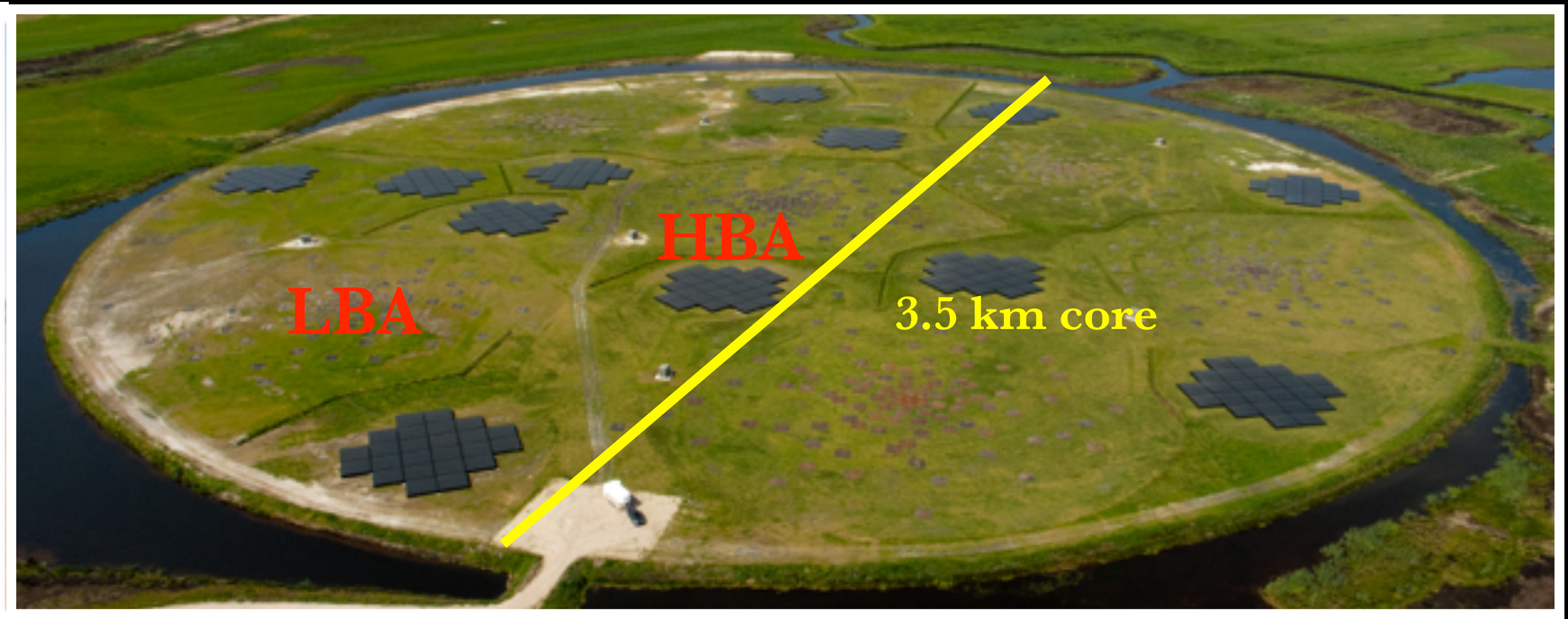
Redshift identification and study of passive and active galaxy population within the cluster environment

More passive galaxies within the cluster

More active SF galaxies outside the cluster

LOFAR - SKA-pathfinders capabilities

largest meterwelength radio telescope ! **Nijbore....Pandey-Pommier et al. 2009**



-40 stations (48 antennas/tiles) over 120 km in diameter within the Netherlands and 8 stations over 1500 km throughout Europe (Netherlands, France, Germany, UK, Sweden)-

-Low Band Antenna (LBA) operates between 10 and 90 MHz and the High Band Antenna (HBA) between 110 and 250 MHz

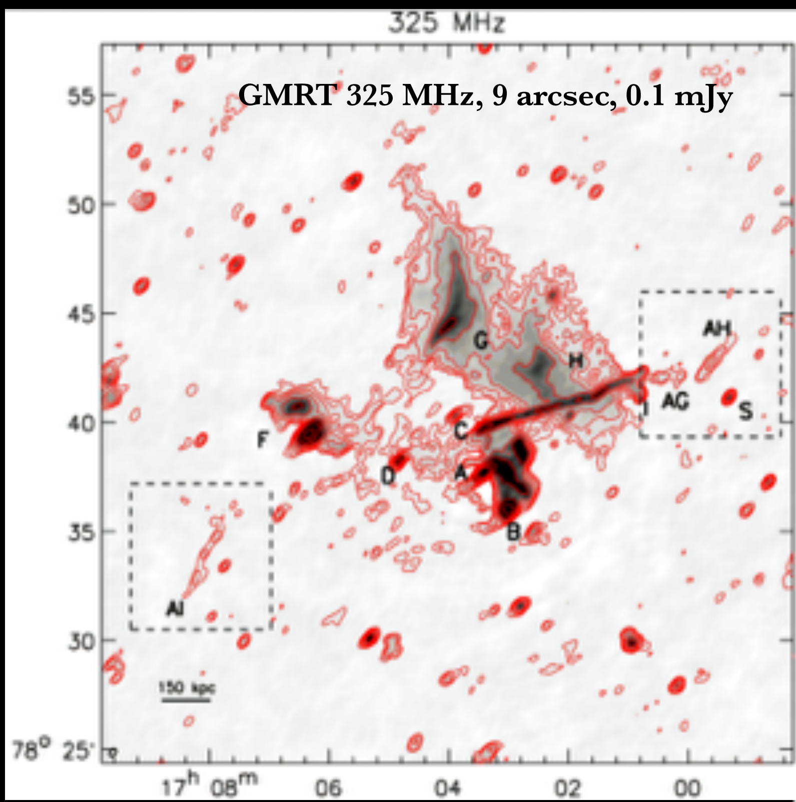
-48 MH bandwidth- 20 sub bands

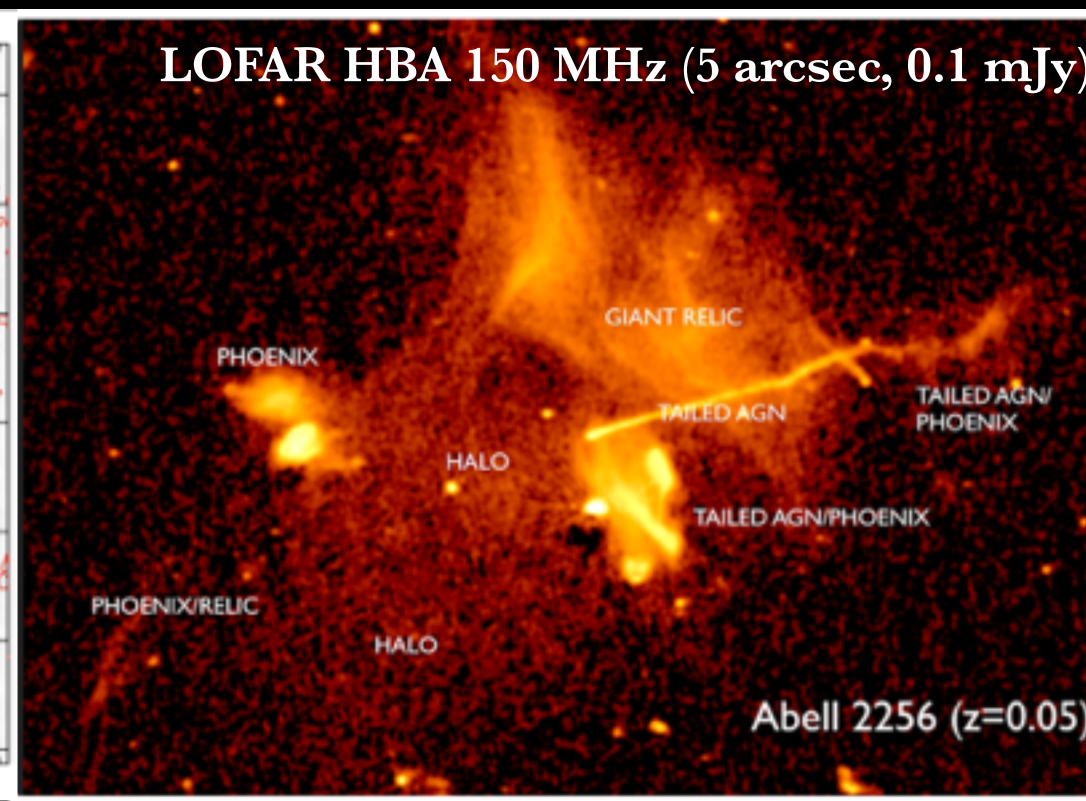
New population of galaxy clusters to discover !

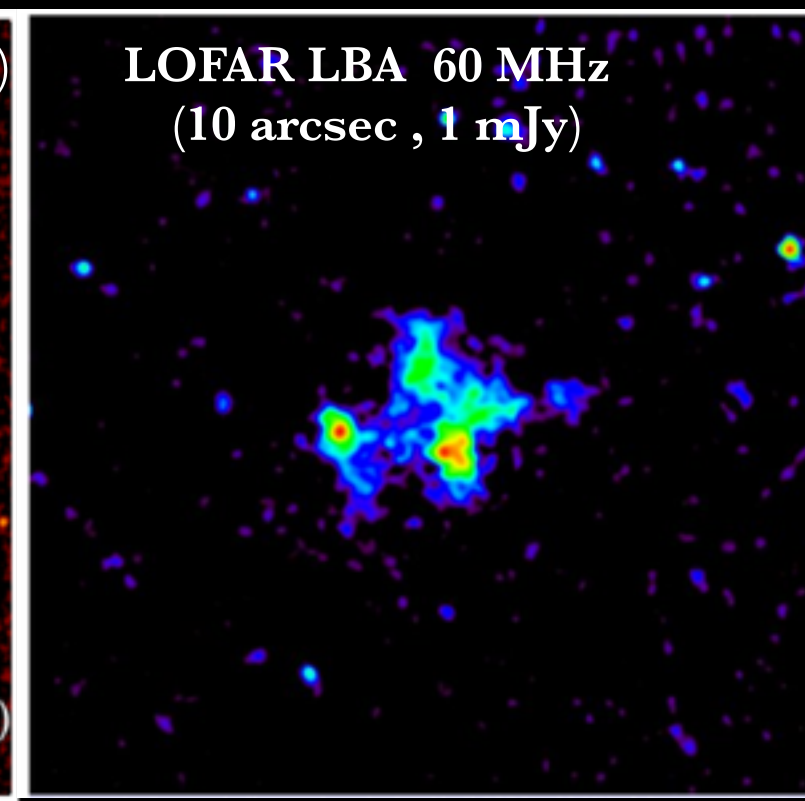
LOFAR - results on cluster of galaxies

largest meterwelength radio telescope !

van Weeren et al. 2015







more morphological details at lower frequencies

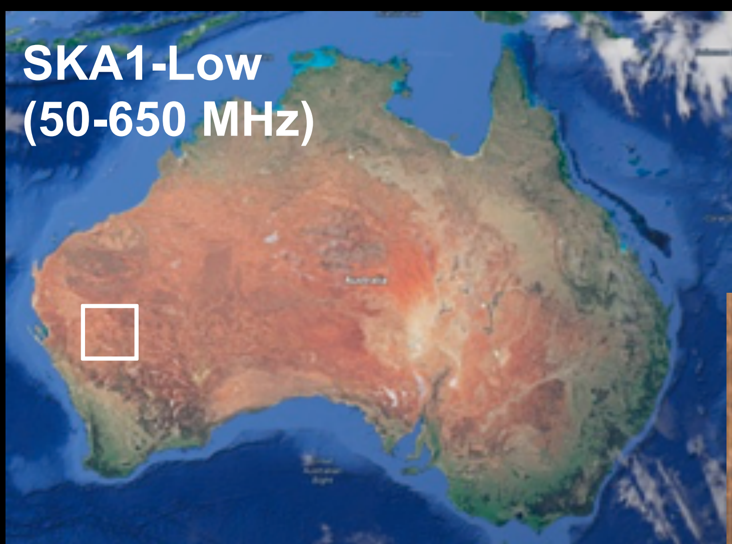
continuous spectral coverage from 20-240 MHz

SKA capabilities Operational since 2024

Cassano et al. 2014, Pandey-Pommier et al. 2015 (SKA Users case), 2016c (JoAA submitted)

The total collecting area of the SKA will be well over one square kilometre, or 1,000,000 square metres.

Desert near Boolardy station in the west of Australia



SKA-Low- 25x better resolution, 8x better sensitivity, 135x better survey speed compared to LOFAR

Square Kilometre Array (SKA)- *World's largest radio interferometer !*

For imaging capabilities refer SKA memo 113 by Pandey-Pommier et al. 2008

Desert near Karoo in the south-west of South Africa

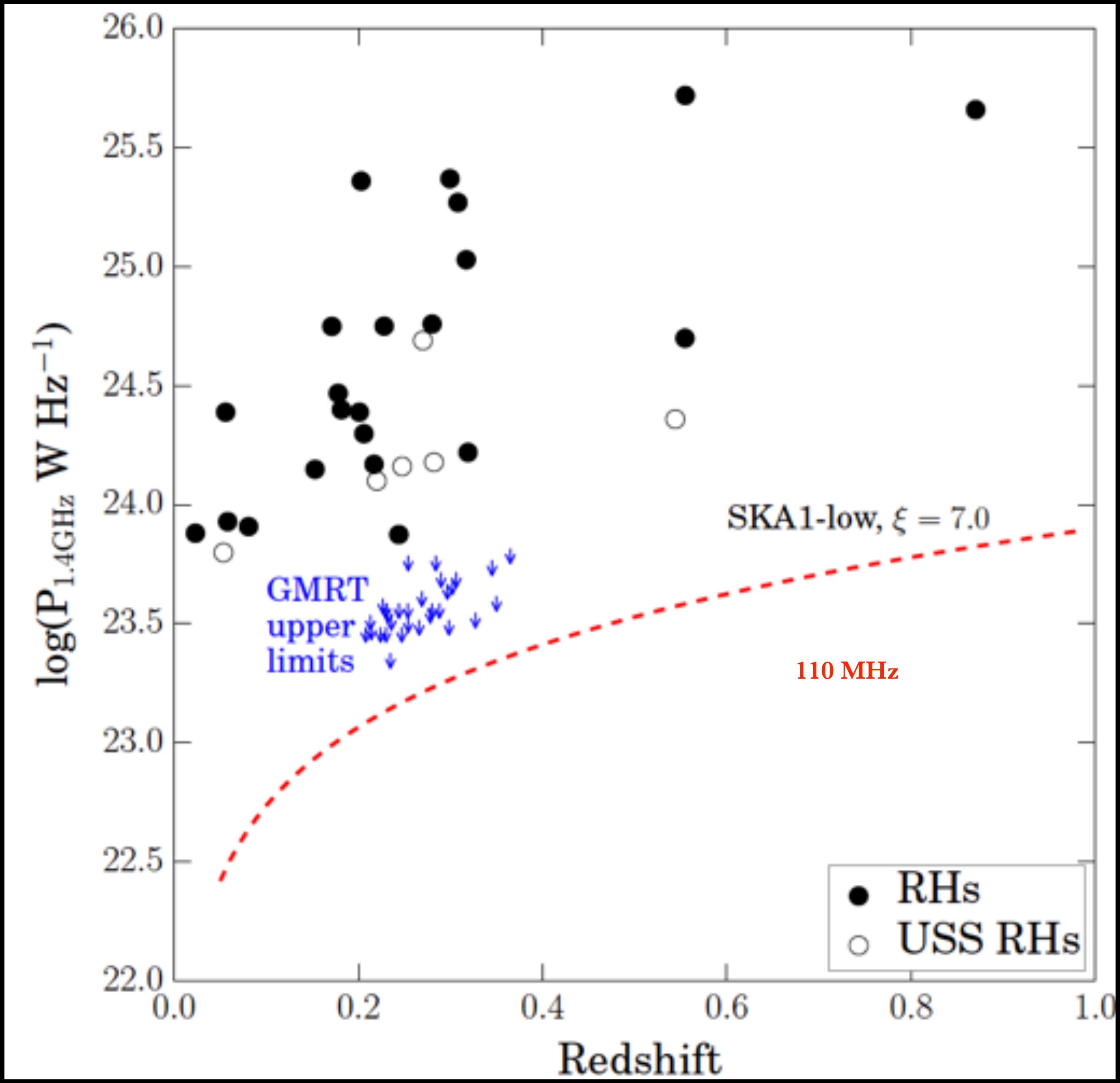
SKA1-Mid
(300-1400MHz)

MeerKAT dishes
+ tiles

SKA-Mid- 4x better resolution, 5x better sensitivity,
60 x better survey speed compared to JVLA

SKO - Head Quarters in UK

Square Kilometre Array (SKA) - *World's largest radio interferometer !*



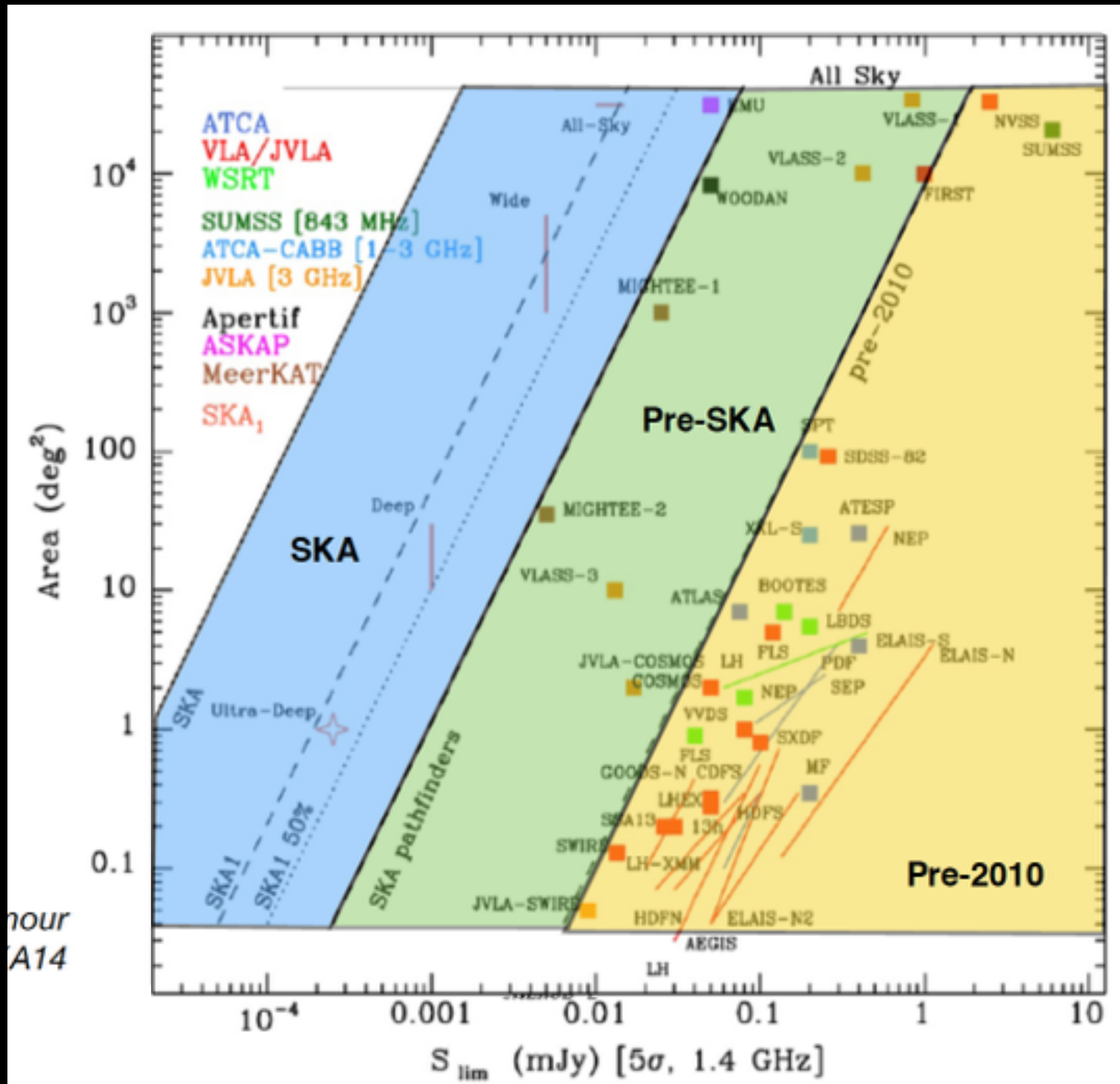
-Continuum surveys will detect 1000s of new mH, relics, Haloes and GH etc emission from galaxy clusters

-Provide the possibility to conduct statistical study on clusters that were previously not detected by the GMRT due to sensitivity limitation

-Help to understand the the formation and evolution of Large scale structures in the Universe

Galaxies in the distant Universe via lensing

Pandey-Pommier et al. 2015 (SKA Users case)
Pandey-Pommier et al. 2017 SKA-France White Book



Cassano R.;…Pandey-Pommier et al. 2014,
Prandoni & Seymour AASKA 14

High sensivity SKA data-study the evolution of galaxies w.r.t redshift

NenuFAR - French SKA-Low Pathfinder (10-85 MHz)— 102 (96+6) MiniArray of 19 dual polaz. antennas over 400m upto 3 Km

Site: Nancay, -100% funded via ANR and INSU *(Zarka's talk)*

NenuFAR imager (10-85 MHz) usable in standalone mode as well as with LOFAR super station (higher resolution and better sensitivity for longer baselines at low frequencies)

Large compact array-beamformer mode: transients, exoplanets, pulsars, AGNs etc.

Summary

Non-thermal synchrotron radio emission is a crucial component of galaxy clusters, which gives us insight of :

-the dynamical state of the cluster on-going merger or relaxed

-Radio halos and relics are rare and transient features in galaxy cluster- connected to cluster formation history

-'Classic'- GHz emitting radio halos and relics are rare

-USSRH expected to be the dominant halo population at lower frequencies **(LOFAR, GMRT, MWA, precursor of SKA)**

-Mini-halos are found in massive systems with cool core and confined to sloshing regions, bounded by cold fronts

-Synergies between **SKA, LOFAR**, PLANCK, **LSST, EUCLID, JWST, ATHENA etc.**

French NenuFAR (SKA-LOW) and Indian u-GMRT (SKA1-MID) are both SKA pathfinders.

Low frequency view of Massive galaxy clusters and their dynamics

Thank you for your attention

धन्यवाद

Merci pour votre attention