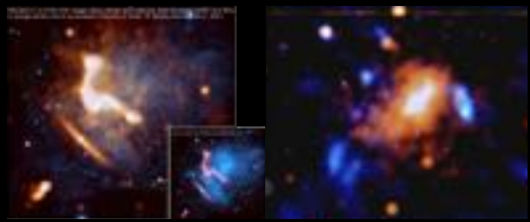
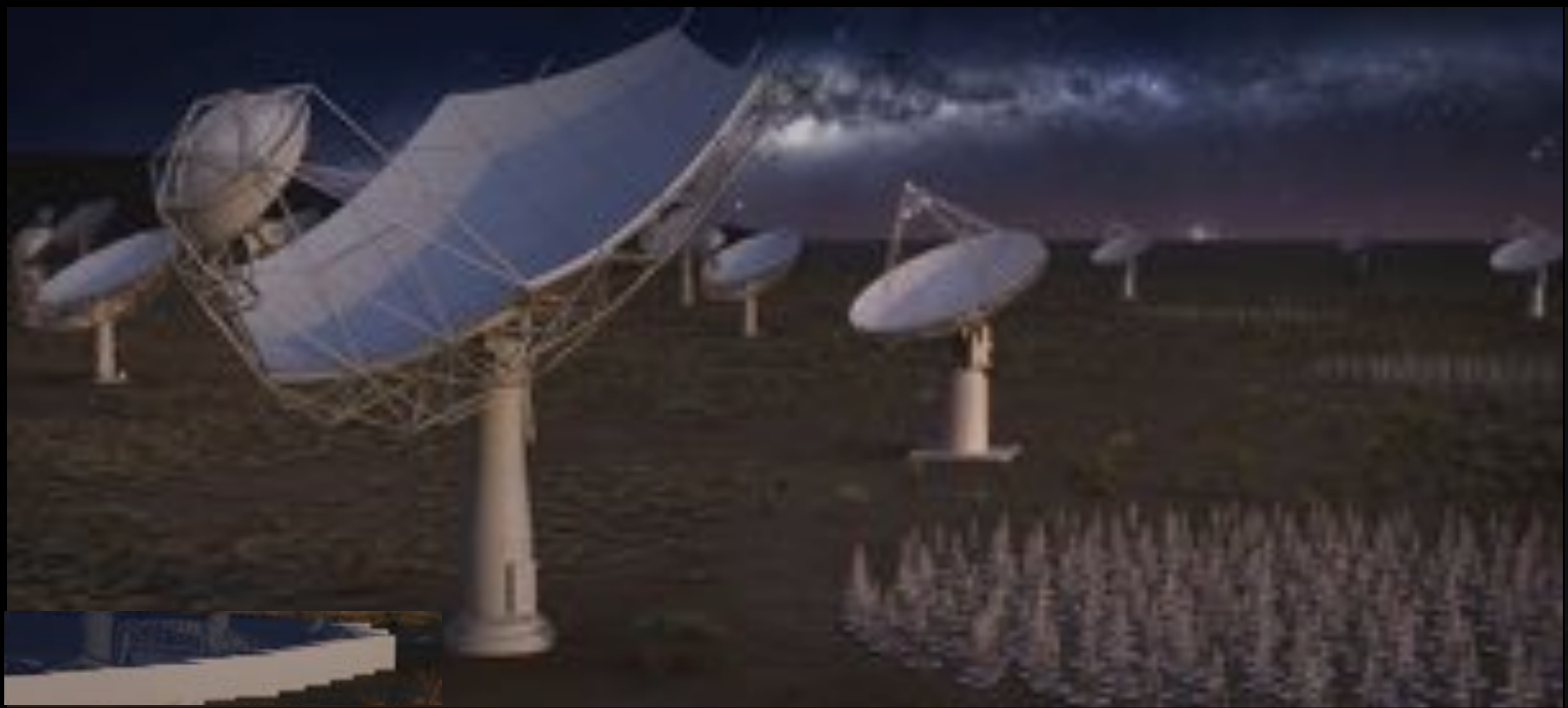


Non-thermal emission in Galaxy clusters with the SKA and pathfinders



Mamta Pommier

USN- l'Observatoire de Paris & CRAL

in collaboration with **- T. Shimwell, D. Lagattuta, H. Intema, M. Akhlaghi, C. Tasse, J. Richard, F. Combes et al.**

Plan of the talk

- Cluster of Galaxies
- Multi wavelength properties (X-ray, Optical, Radio)
- Radio classification, statistics and global properties of cluster of galaxies
- Why low frequency radio studies
- Results
- Synergies with on-going MUSE survey on cluster of galaxies
- LOFAR/SKA/NenuFAR capabilities
- Summary

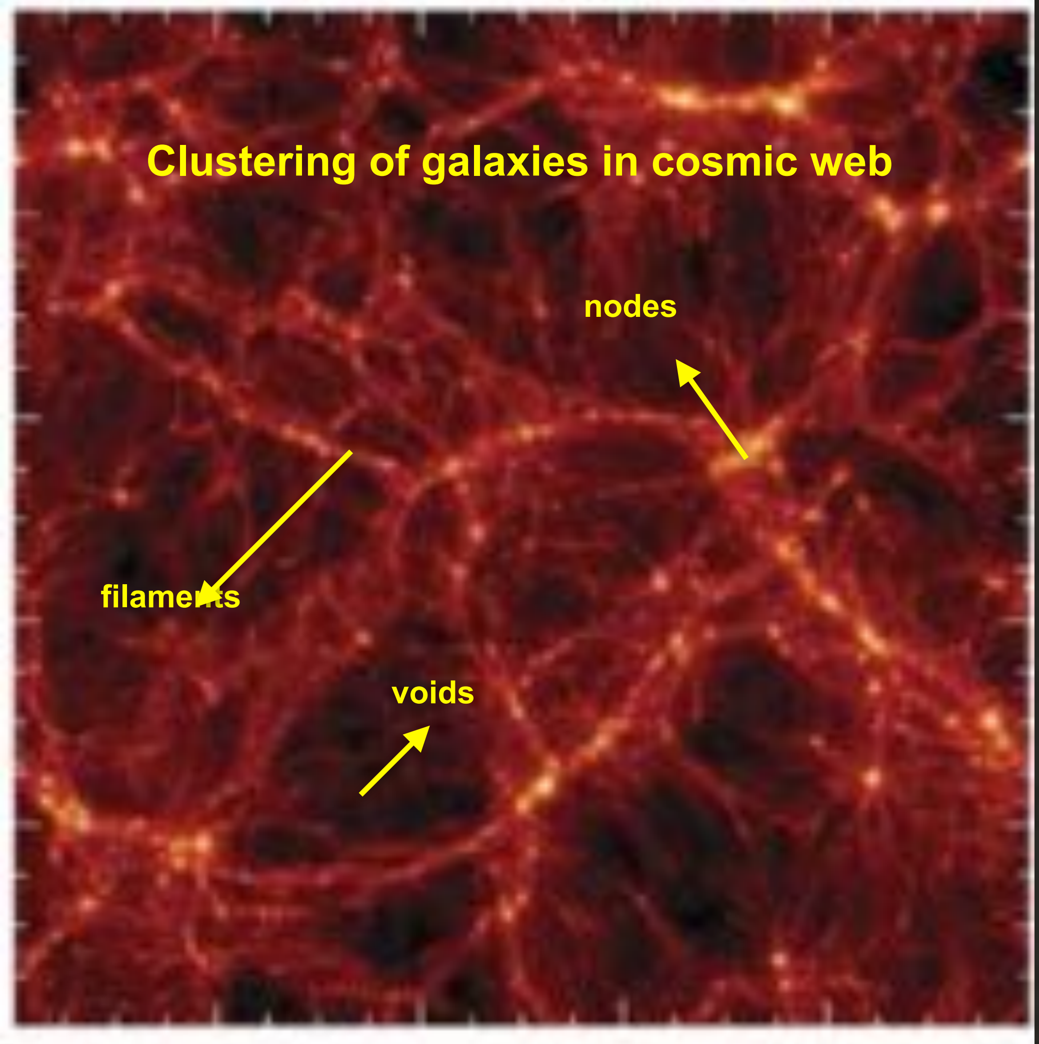
Galaxy clusters

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) study to investigate the association of Dark matter (DM) with the baryonic (visible) matter and dynamical state



Multi wavelength properties - X-ray

X-ray emission gives information about the hot intra cluster gas

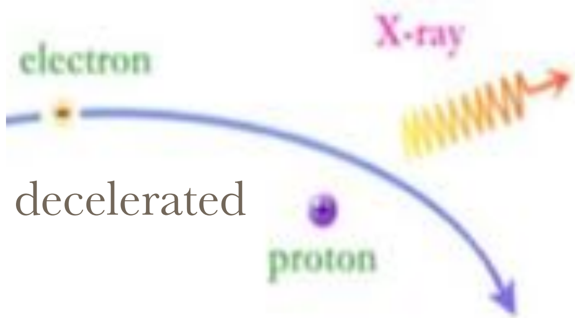
-Cluster of galaxies are the most bright and extended (Mpc-scale) extragalactic X-ray sources.

-Extremely luminous in their X-ray emission with luminosities $10^{43\text{-}45}$ ergs/sec.

-Thermal bremsstrahlung emission by diffuse hot intracluster gas provides the main X-ray emission from clusters.

-Observations provide information about X-ray luminosity, Temperature, morphology (gas distribution)

unrelaxed and cool core



$$\boxed{\text{X-ray} \sim n_e^2\ \Lambda(T_e)}$$

n_e = *gas density*

T_e = *gas temperature*

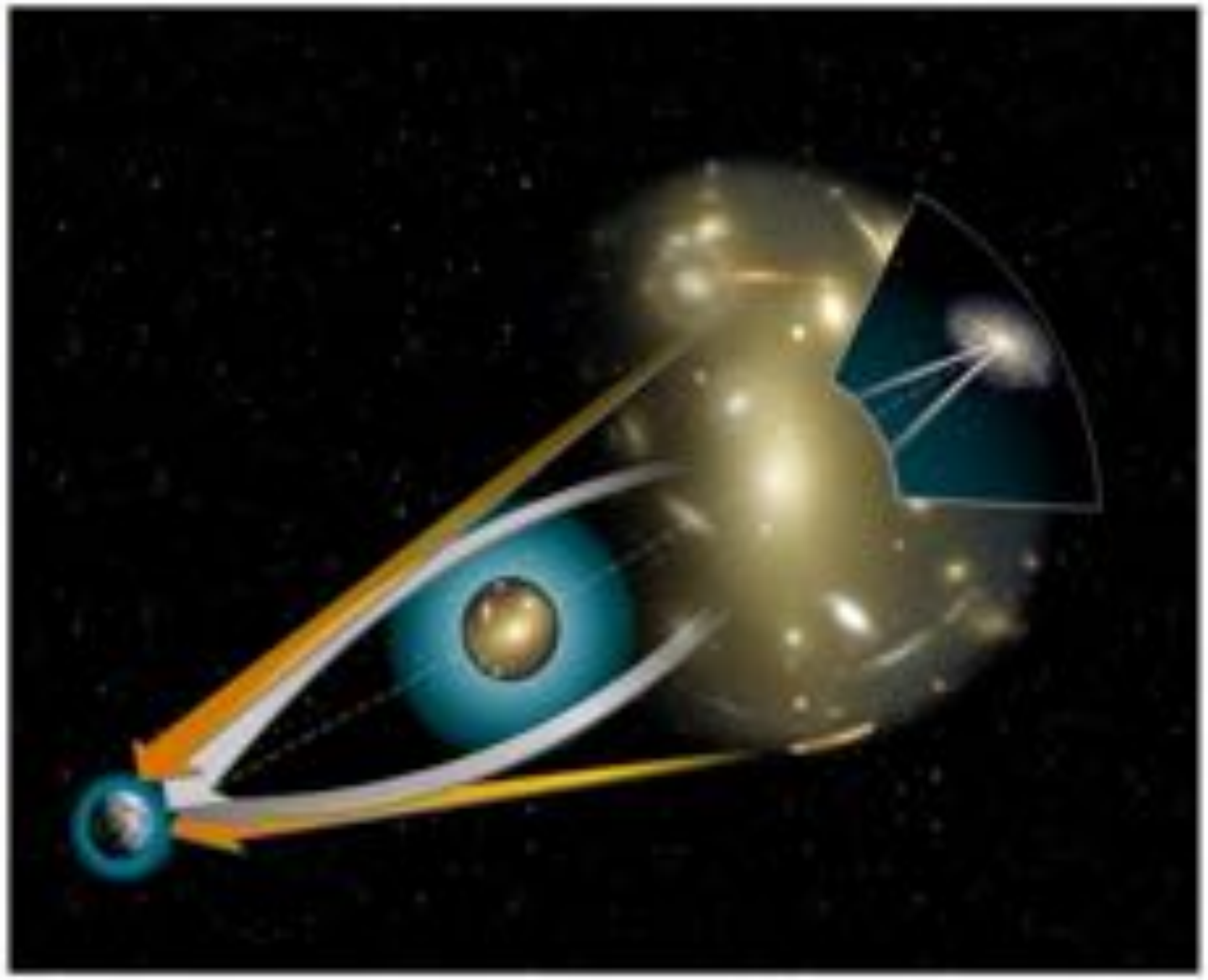
MACSJ0717.5+3745 HST image with overlaid Chandra color map showing hot gas in blue and cool gas in red

Multi wavelength properties - Optical

Optical observations gives information about the member galaxies within the cluster

The spatial and kinematical analysis of member galaxies used to identify substructure and analyse possible pre-merging clumps or merger remnants (redshift distribution and velocity dispersion)- complementary to X-ray data

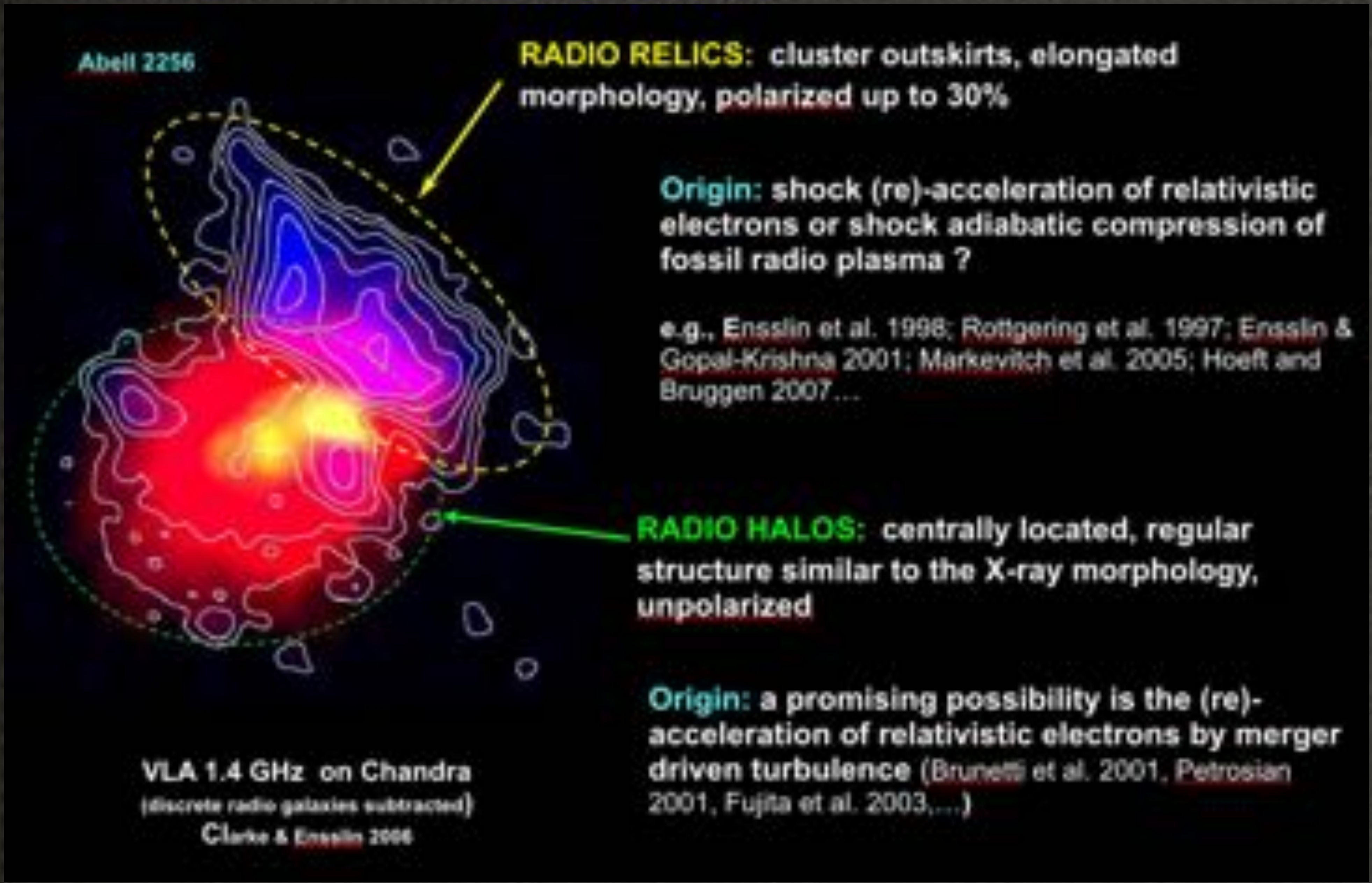
MACSJ0717.5+3745 HST image

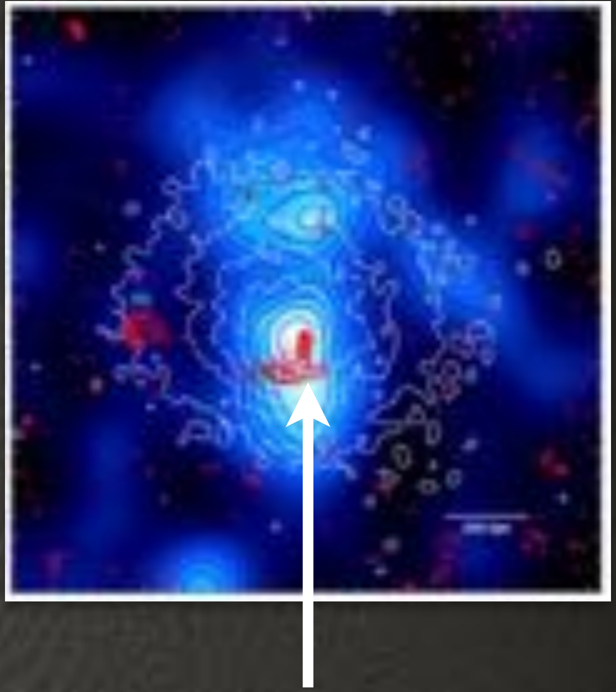


Gravitational lens

Multi wavelength properties - Radio classification

Radio observations gives information about both, the intra cluster gas, independent radio emitting member galaxies

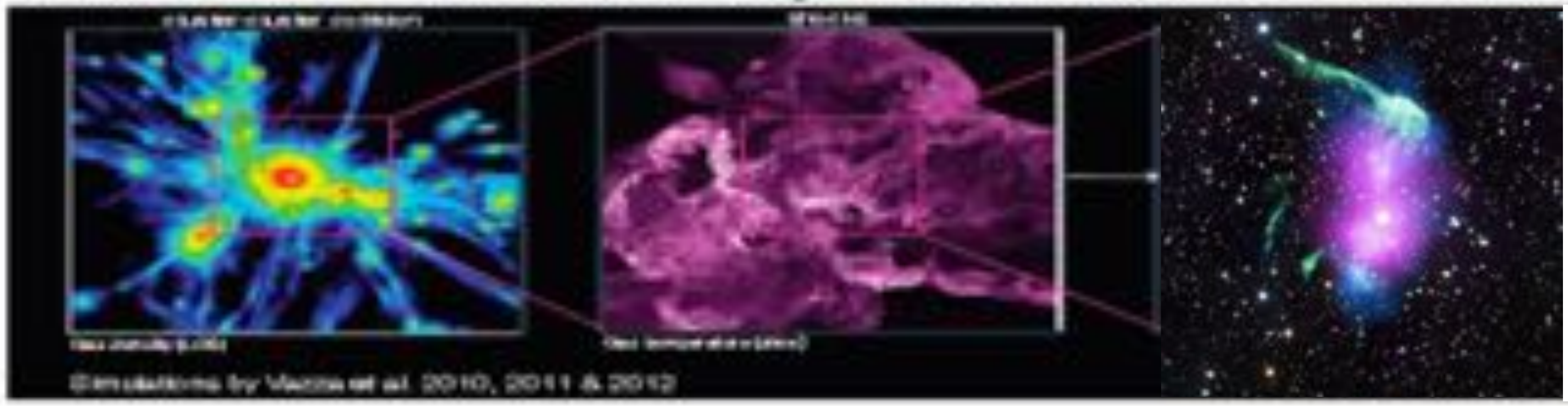




Abell 1033: The white contours help identify the X-ray flux levels, and the red contours trace the radio emission. The elongated red structure in the lower center is a radio phoenix: fossil gas that has been reheated by shocks from a nearby galaxy merger

Galaxy clusters: Radio emission

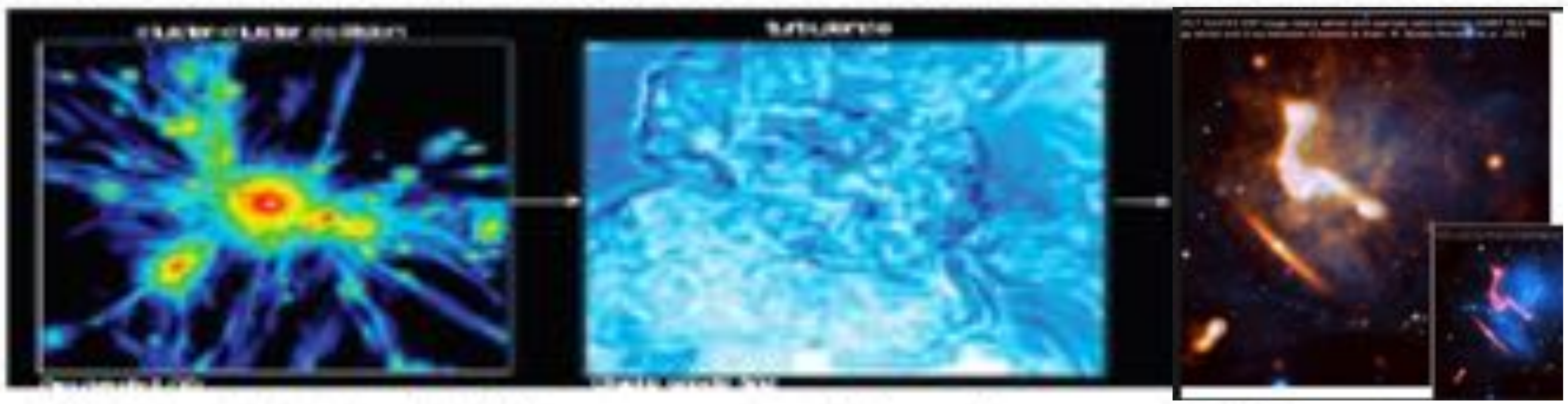
➢Radio emission in relics- tracers of merger shocks-Diffuse shock (re)acceleration of electrons in the ICM



van Weeren et al. 2012

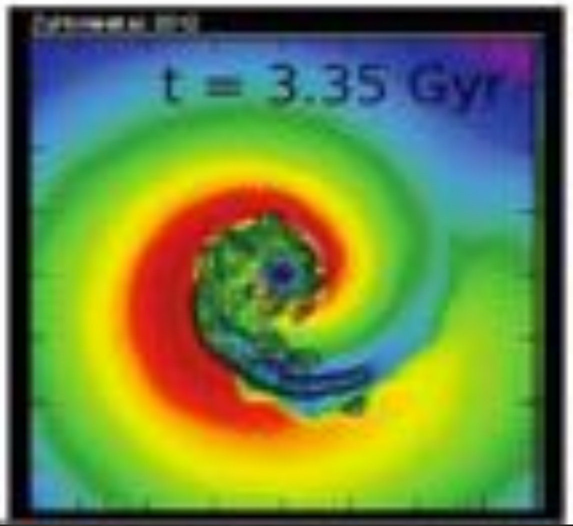
Vazza et al. 2012

➢Radio emission in halos-tracers of turbulence- Turbulence in mergers can accelerate low energy electrons in the ICM



Vazza et al 2012

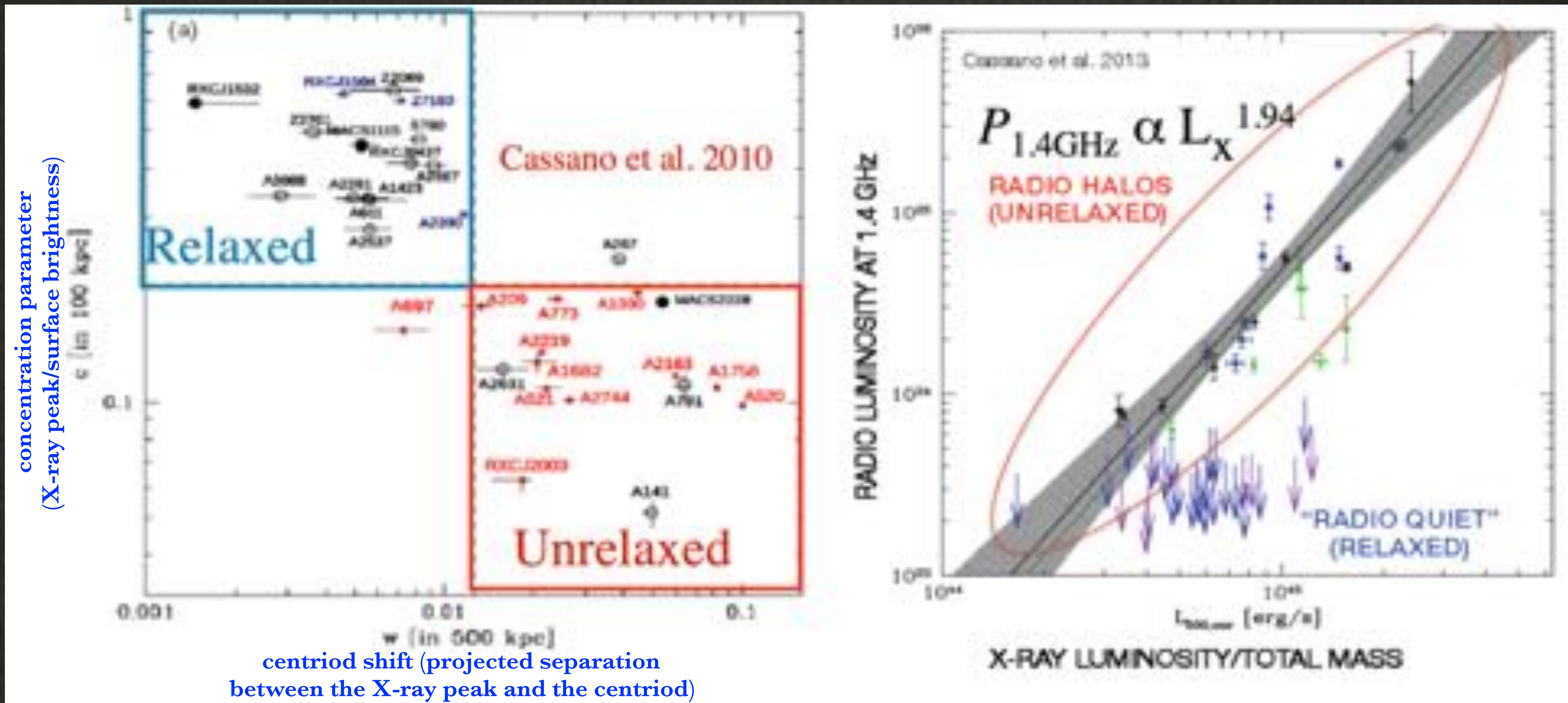
Pandey-Pommier et al. 2013



➢Radio emission in mini-halos- tracers of turbulence due to gas sloshing- of cool core gas in DM Turbulence re-accelerates electrons in ICM- host X-ray cavities - spiral or arc–shaped non-thermal emission around central BCG

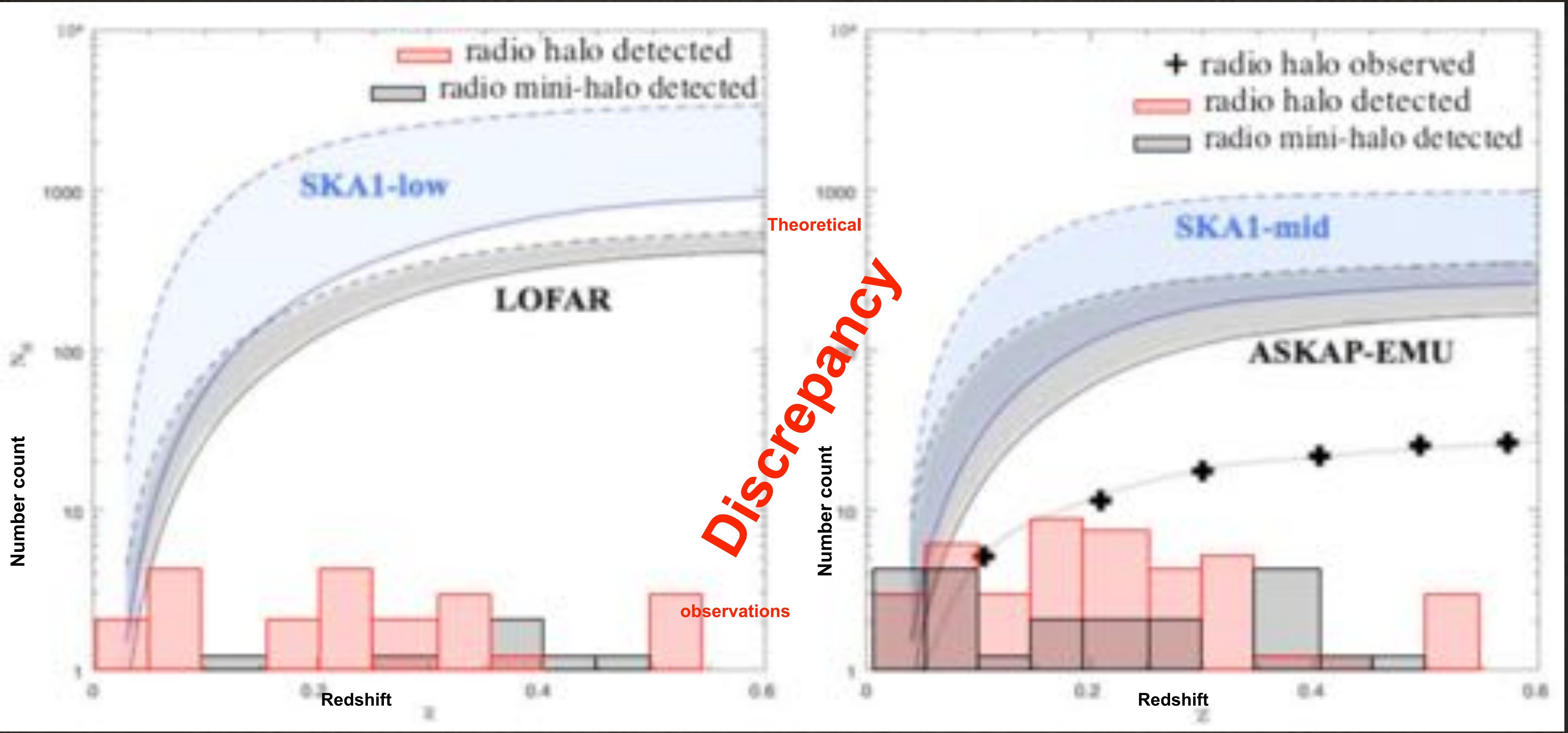
Giacintucci et al. 2014, ZuHone et al 2012

Galaxy clusters: statistical radio properties



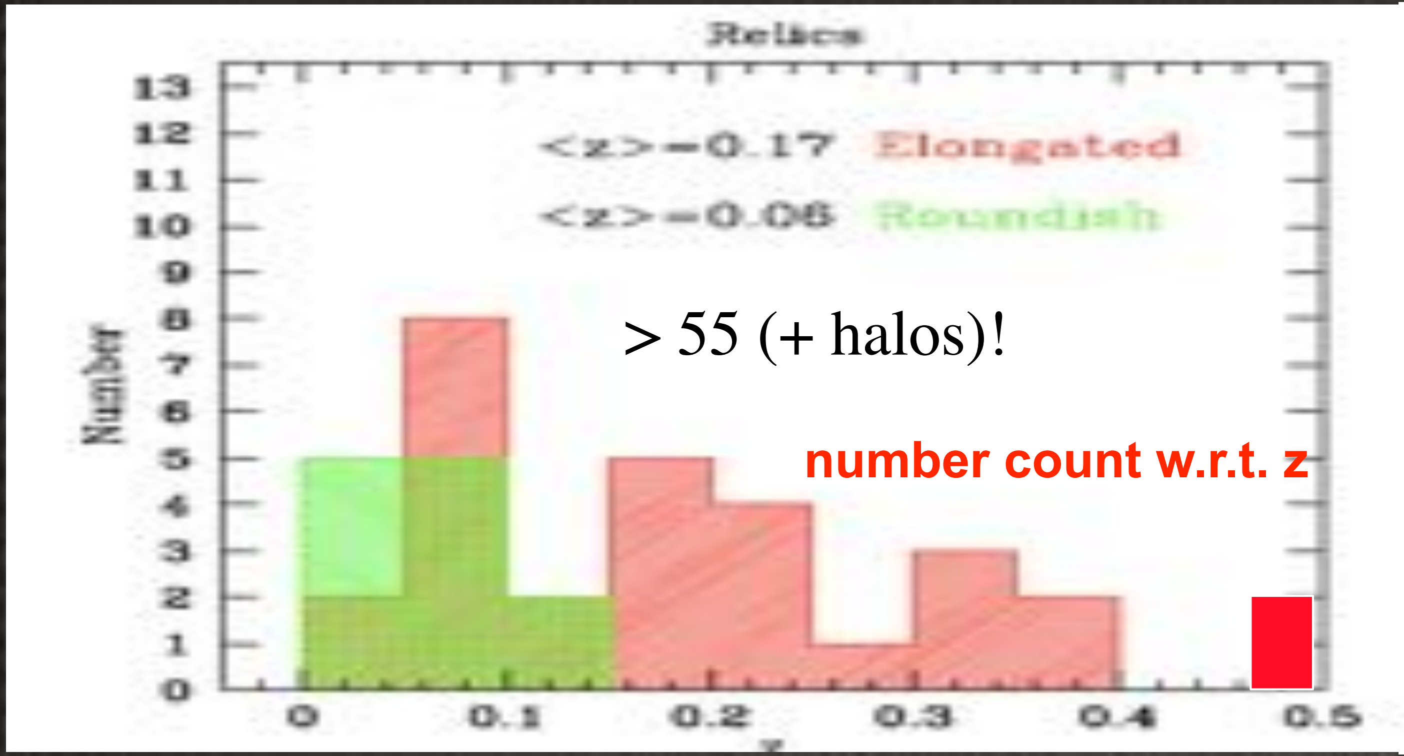
Galaxy clusters: Why low frequency radio studies ?

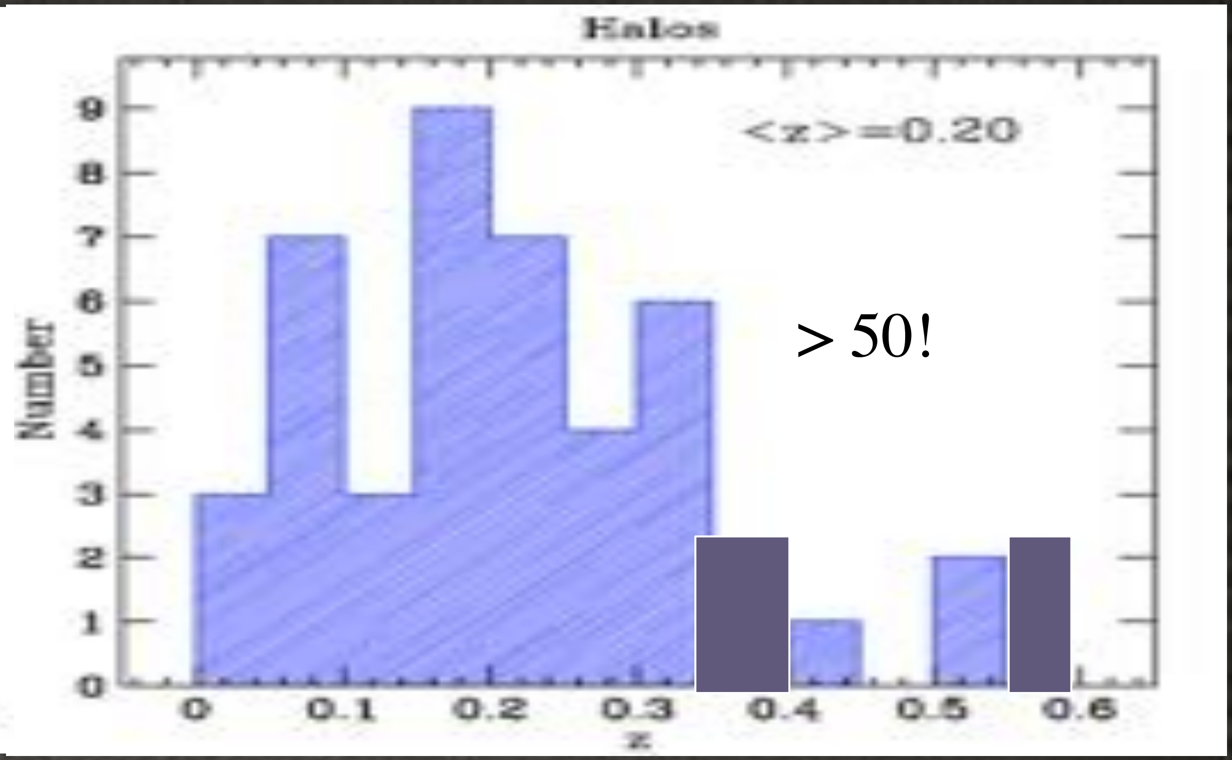
Cassano et al. 2012
Pandey-Pommier et al. 2015



Galaxy clusters: statistical radio results

Pandey-Pommier et al. 2013, 2014, 2016





1- Many new radio halos, mini-halos and relics discovered at low frequencies beyond z=0.3, in agreement with Power(radio) vs L(x-ray), thanks to LOFAR and GMRT

2- Steep spectrum RHs and USSRHs (rare!) associated with on-going or post-mergers and expected tobe the dominant halo population at lower frequencies (LOFAR, GMRT, SKA and pathfinders). GMRT/LOFAR survey confirms 5 different types of radio emission (RH, mH, GRH, Phoenix, relics)

Synergies with on-going MUSE survey

Pandey-Pommier et al. 2018

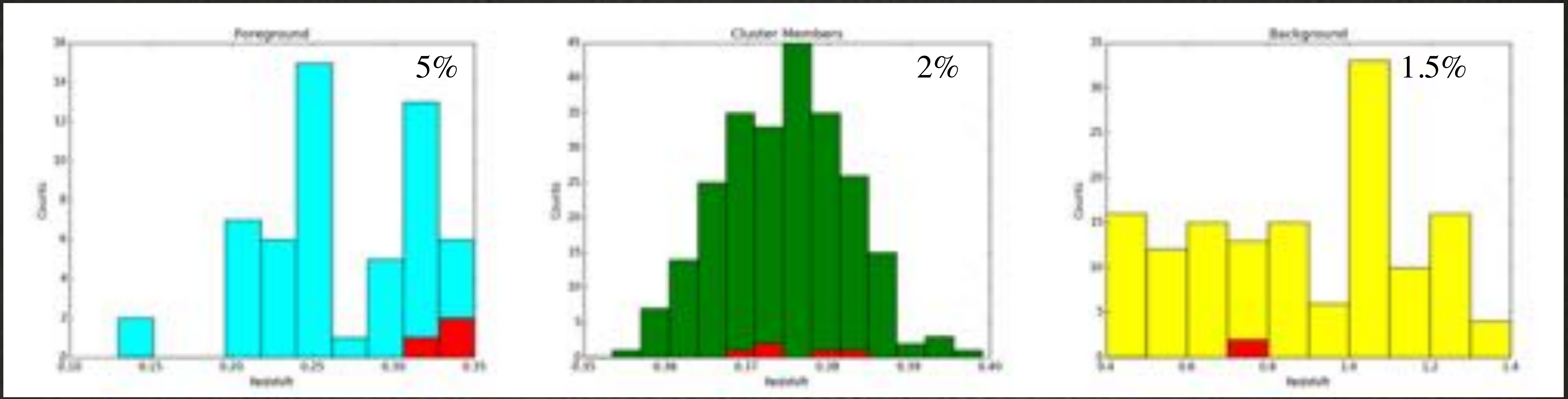


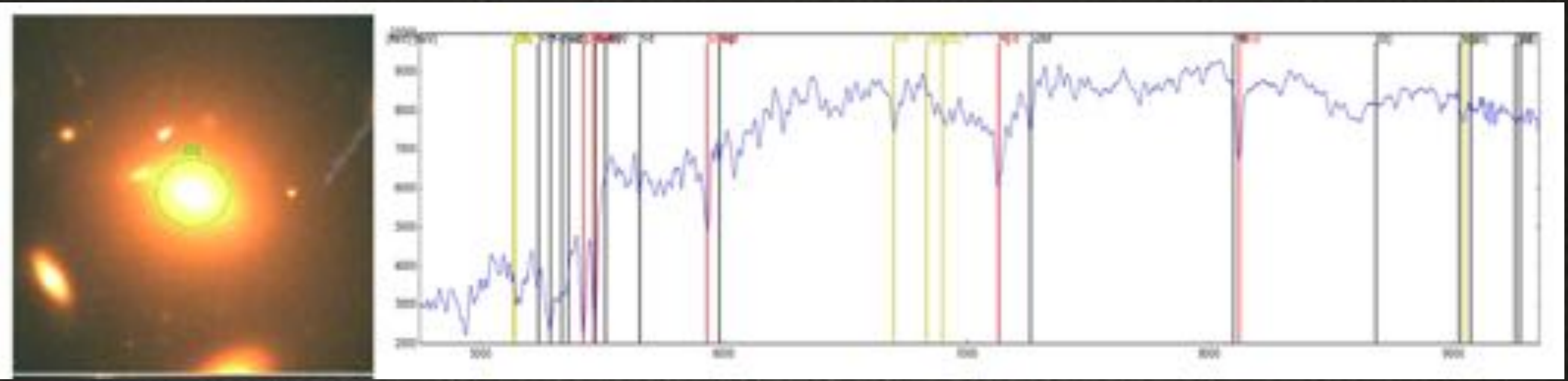
Fig. Galaxies discovered with HST and MUSE in the cluster field. Radio emitting galaxies are marked in red

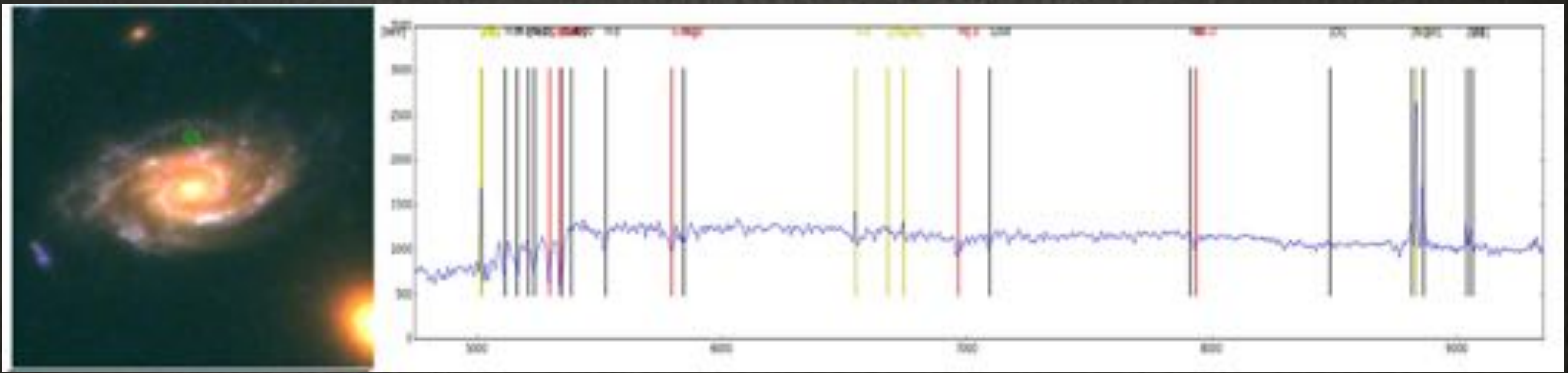
-Most of the galaxy population in the cluster are passive and elliptical type

-Only 2% galaxies are radio emitting in the cluster field of view

Synergies with on-going MUSE survey

Pandey-Pommier et al. 2018



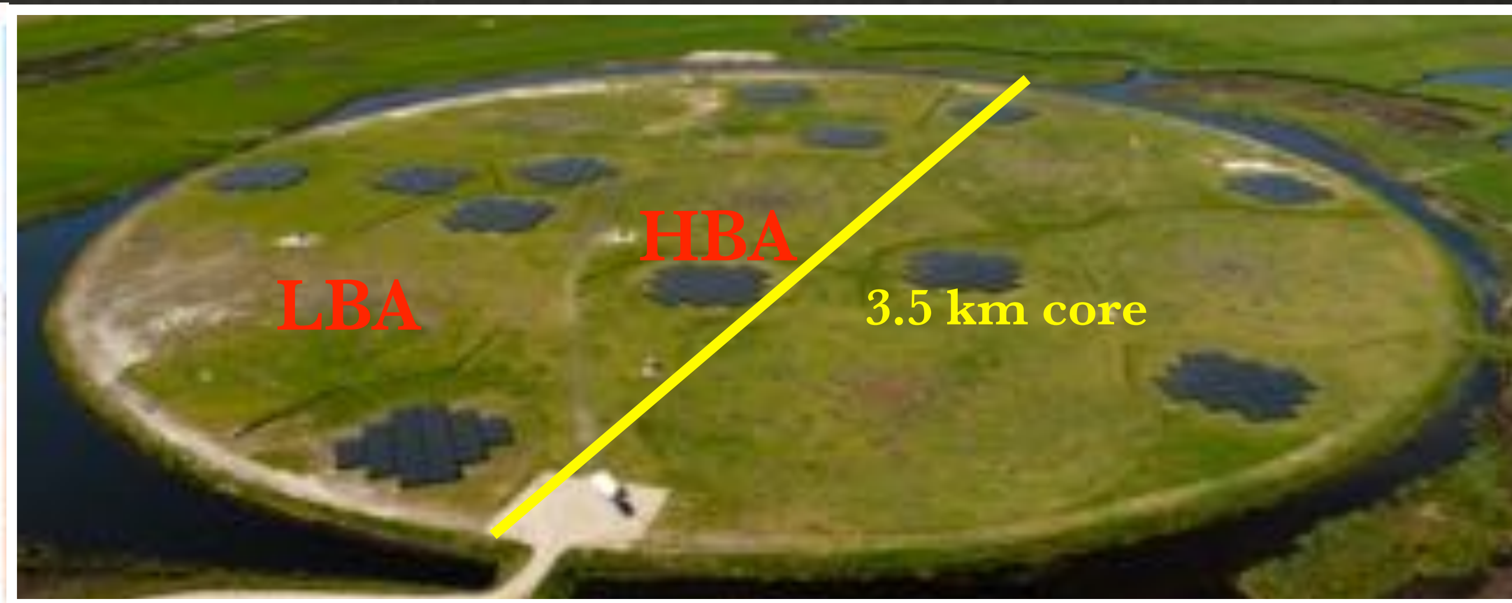


-Elliptical galaxy in the center of the cluster is a bright radio emitter and shows-red-type spectra

-Spiral galaxies are occassionaly radio emitters and show intermediate or blue-type spectra

LOFAR - SKA-pathfinders capabilities

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 subbands

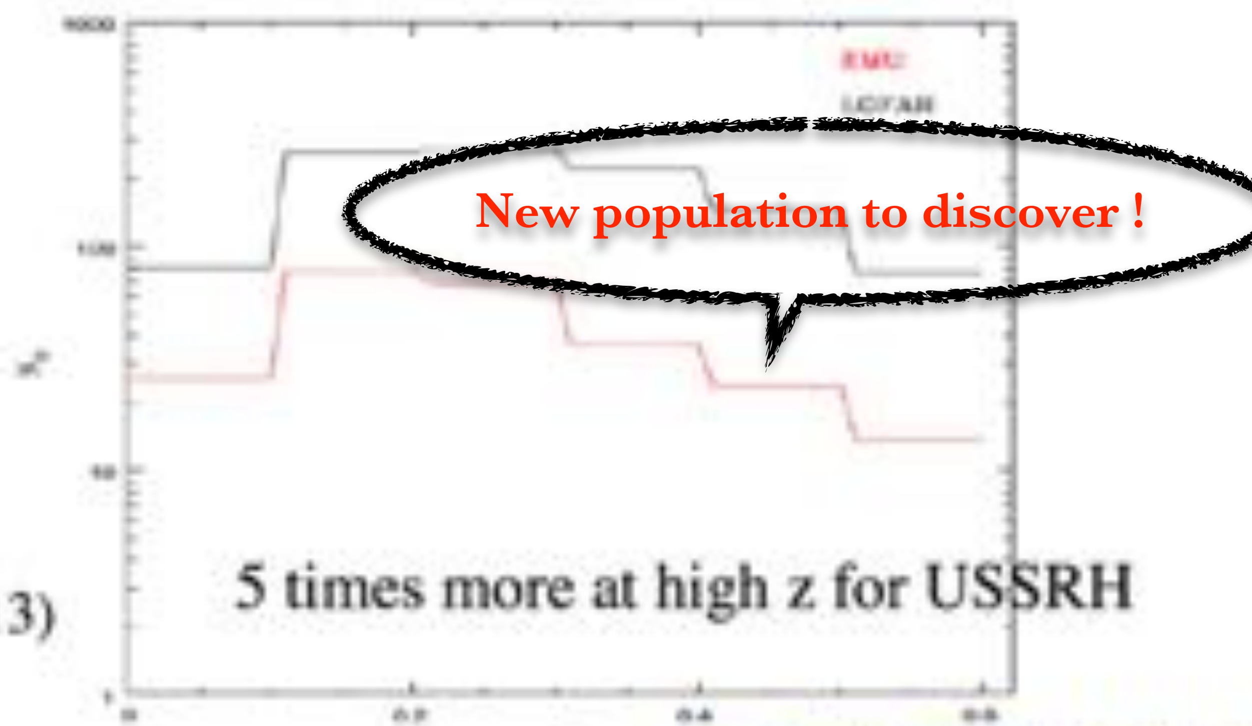
-LOFAR @ 20-240 MHz, 6", 0.2 mJy

-GMRT @ 150-1420 MHz, 2", 20 microJy

-ASKAP-Evolutionary Map of Universe southern continuum survey @ 1.4 GHz, 10", 10microJy

-MWA @ 80-300 MHz, 2.7', 8-9 mJy (Tingay et al. 2013)
(collaboration- Australia, NZ, US and India)

-ASKAP/ EMU, MWA-SKA Precursor



Cassano et al. (2012)

SKA capabilities Operational since 2021

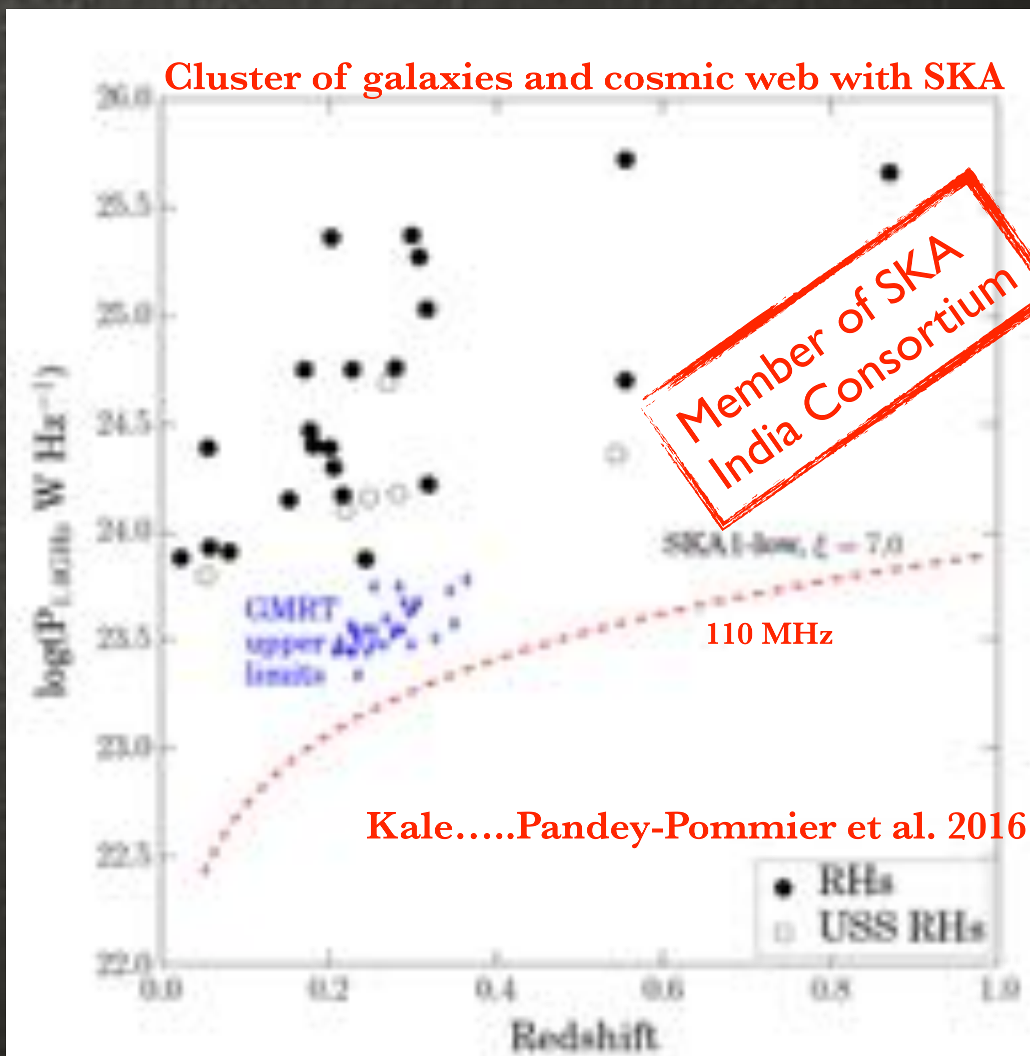
Cassano et al. 2014, Pandey-Pommier et al. 2015 (SKA Users case), Kale…Pandey-Pommier et al.2016

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

SKA1-Low (50-650 MHz)- 25x resolution, 8x sensitivity, 135x survey speed compared to LOFAR

SKA1-Mid (300-1400MHz)- 4x resolution, 5x sensitivity, 60 x survey speed compared to JVLA

- Complete overview of ICM and radio emitting sources within the cluster (haloes, relics, phoenix, filaments, etc.)- morphology details
- Discover new Ultra steep spectrum radio haloes (not detected easily at high frequencies), filaments and super clusters
- statistical studies, constraint turbulence model, formation and evolution of LSS in the universe with redshift



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

Table 1: System parameters

Pandey-Pommier et al. 2016 NenuFAR White Book

Instrument	Frequency	Resolution	Sensitivity (mJy/beam) (8hrs observation)
NenuFAR-1	15-80MHz	3''	120-240
NenuFAR	15-80MHz	[illegible]	50-100 & 8 arcmin (@ 3 km)
LOFAR+NenuFAR	30-80MHz	2''	35-70
MSSS LBA	30-80MHz	1.7''	15
MSSS HBA	120-160MHz	2''	5
LOFAR LBA	30-80MHz	30''	18
GMRT	1400MHz	2''	0.03
GMRT	150MHz	20''	0.7
SKA Low	120MHz	10''	0.02
SKA Mid	1400MHz	15''	0.005
MWA	80-300MHz	3'	9

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

-NenuFAR offers improved sensitivity (10-80 MHz range, 40-5 arcmin standalone synthesis mode and 0.1arcsec with LSS) at low frequencies at a sensitivity level of <10 mJy. It will detect diffuse emission from galaxy clusters with linear size of a few 100 kpc scale.

-Low surface brightness diffuse emission in large scale structures (clusters, Giant galaxies etc.). **SKA precursor** for French Low frequency radio community and training for SKA Low

Construction and commissioning on-going with the available LOFAR imager tool developed via Leiden and Meudon team (Shimwell &Tasse et al.)

Summary

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

-the dynamical state of the cluster (pre- or post-) on-going merger or relaxed

-Radio halos and relics are rare and transient features in galaxy cluster- connected to cluster formation history. The lifetime of a RH depends strongly on the level of turbulence in the cluster.

-RHs number count should increase with redshift (increasing merger fraction), decreasing frequency and increasing sensitivity. **Good news for upcoming radio surveys like LOFAR and SKA 1 !**

-'Classic'- GHz emitting radio halos and relics are rare- involve major merger events

-Steep and USSRH associated with more common, minor mergers- expected to be the dominant halo population at lower frequencies **(LOFAR, GMRT, MWA, precursor of SKA and path-finders)**

-the interplay between dark and baryonic matter in galaxy clusters- Merging clusters show decoupling of Dark Matter (DM) and baryonic matter gas components and pre- or post- merger state in radio. In cool-core clusters, the DM and baryonic matter is usually coupled and relaxed state in radio.

-French NenuFAR (SKA-LOW) - SKA pathfinders.

Non-thermal emission and dynamical state of massive galaxy clusters

Thank you