

Radio Survey on CLASH clusters & the SKA - World's largest radio telescope !



Mamta Pommier

CRAL- l'Observatoire de Lyon

Francoise Combes, Johan Richard, Philippe Zarka, Huub Rottgering, Neal Jackson, Huib Intema, Bruno

Outline

- 
- Cluster of Galaxies
 - Ongoing surveys with SKA precursors (GMRT, VLA) & pathfinders (LOFAR)
 - SKA Telescope and Cluster science
 - NenuFAR- French SKA pathfinder
 - Synergy with other up-coming instruments (EUCLID, LSST, etc.)

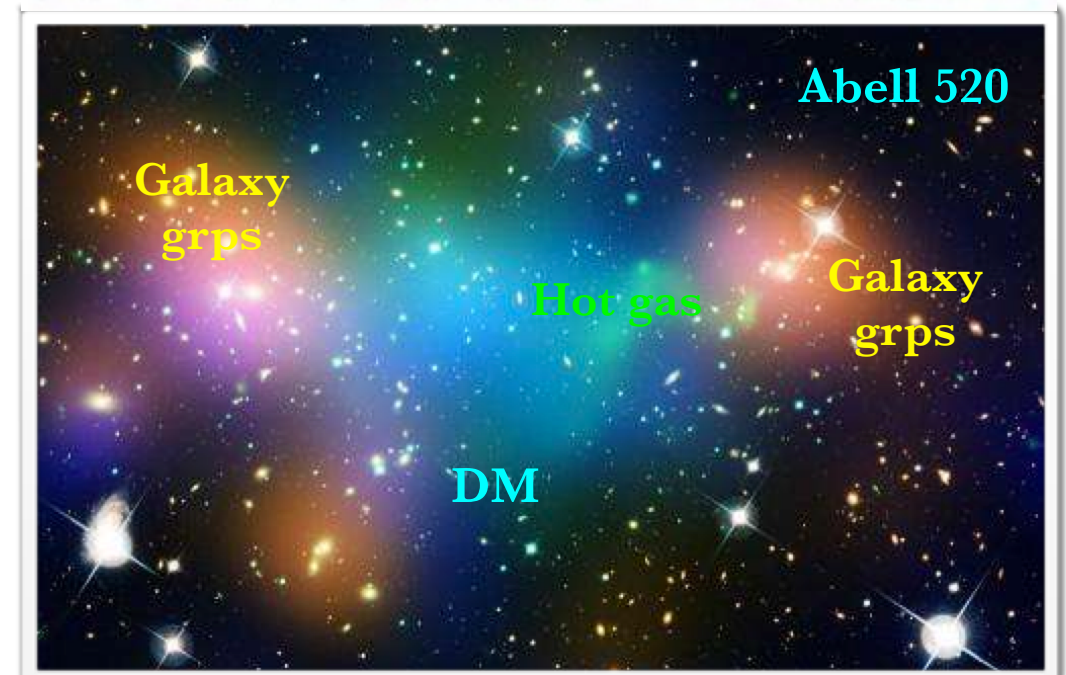
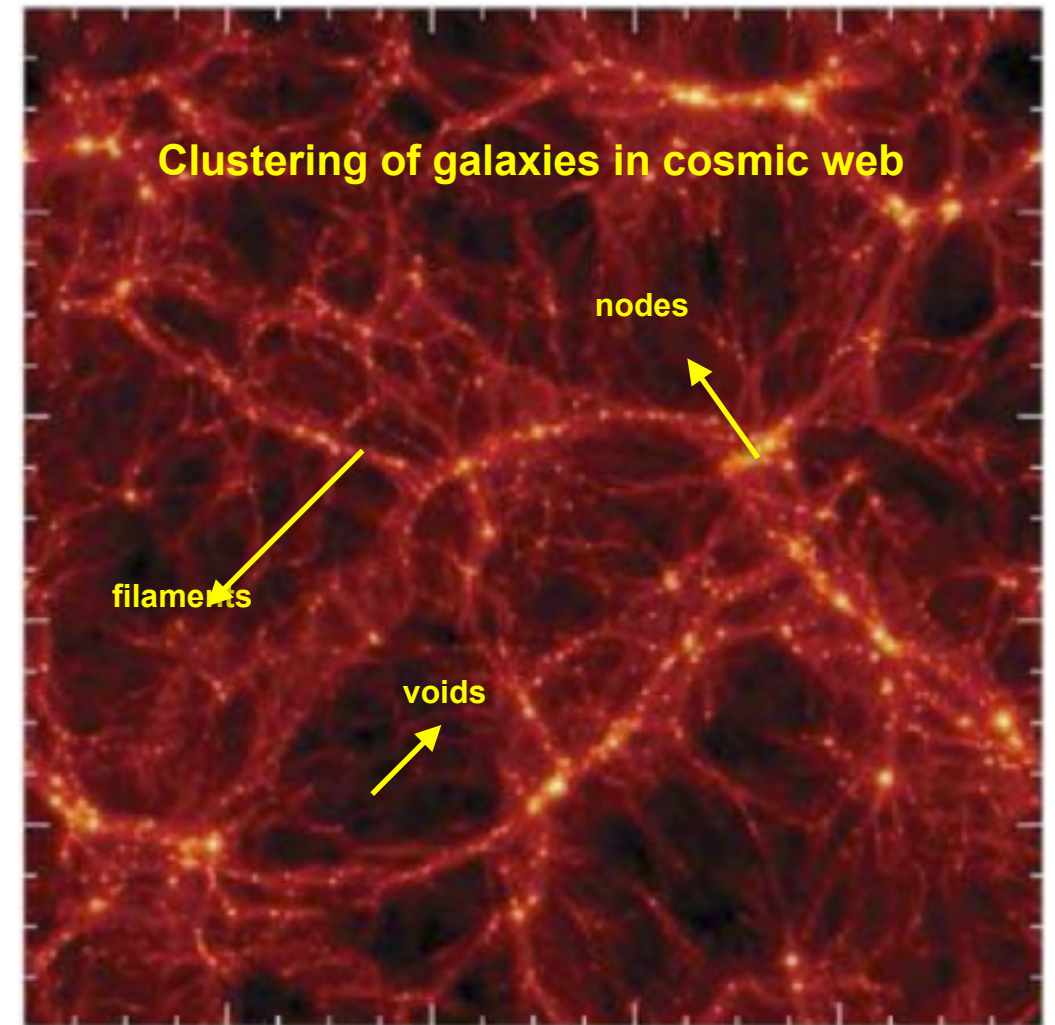
Cosmology with SKA- Galaxy clusters

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

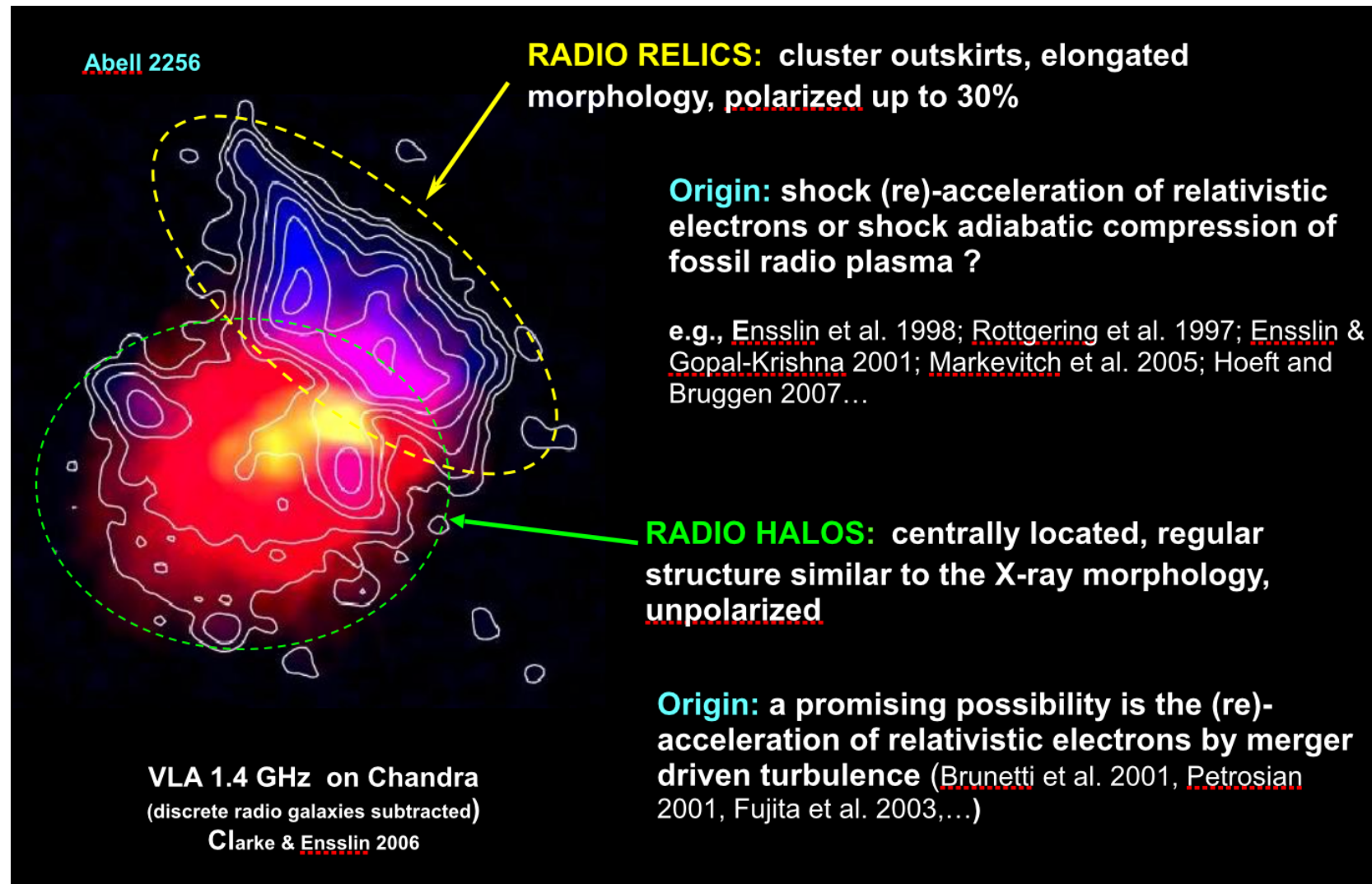
Statistical study as a function of redshift provides insight on formation and evolution of large scale structures in the universe

Multi-wavelength (radio/X-ray/optical) study to investigate the association of Dark matter (DM) with the baryonic (visible) matter and dynamical state

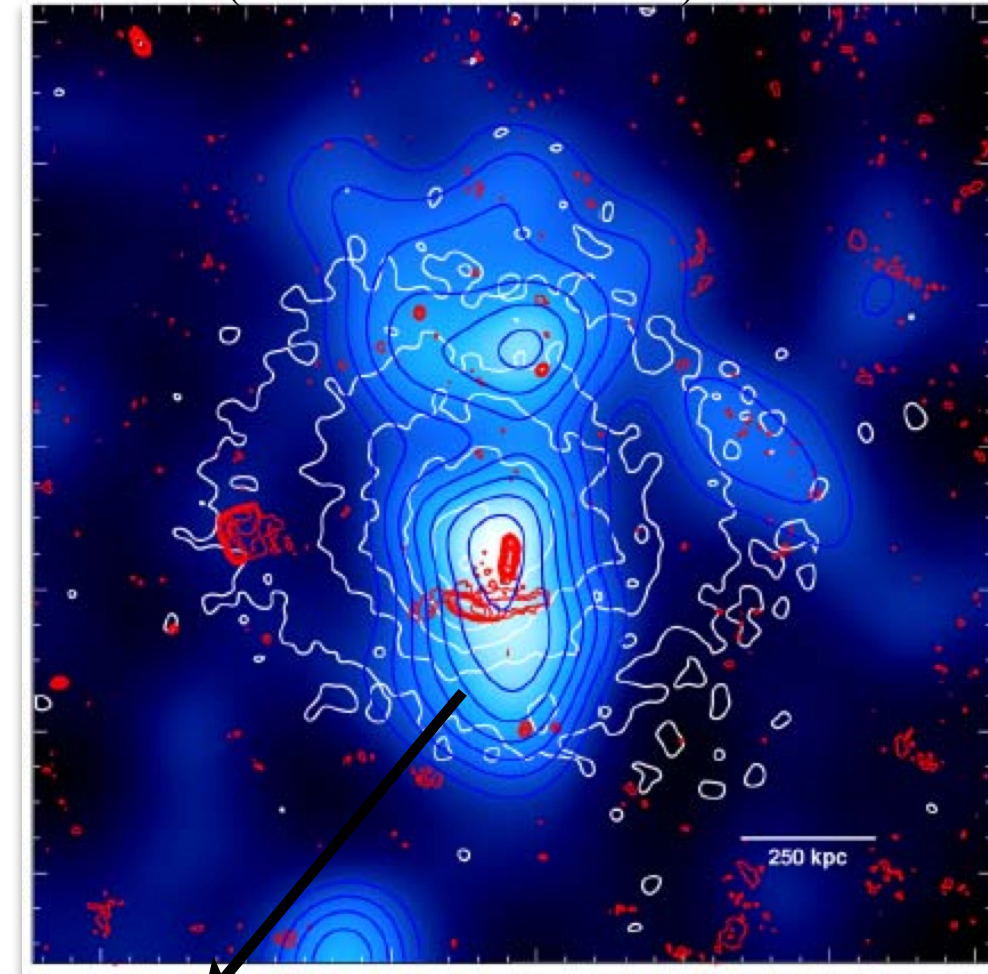


Classification of radio emission from the ICM- Radio Haloes (RH) and Radio Relics (RR)

Dynamically active cluster with Radio emission

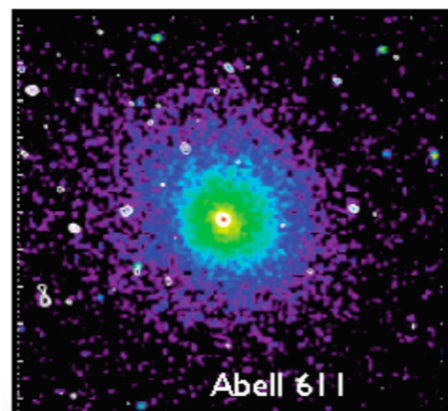


'Phoenix'- in which the aged synchrotron plasma is adiabatically compressed by a (cluster merger) shock wave within the central region of the cluster ([van Weeren et al. 2015](#))



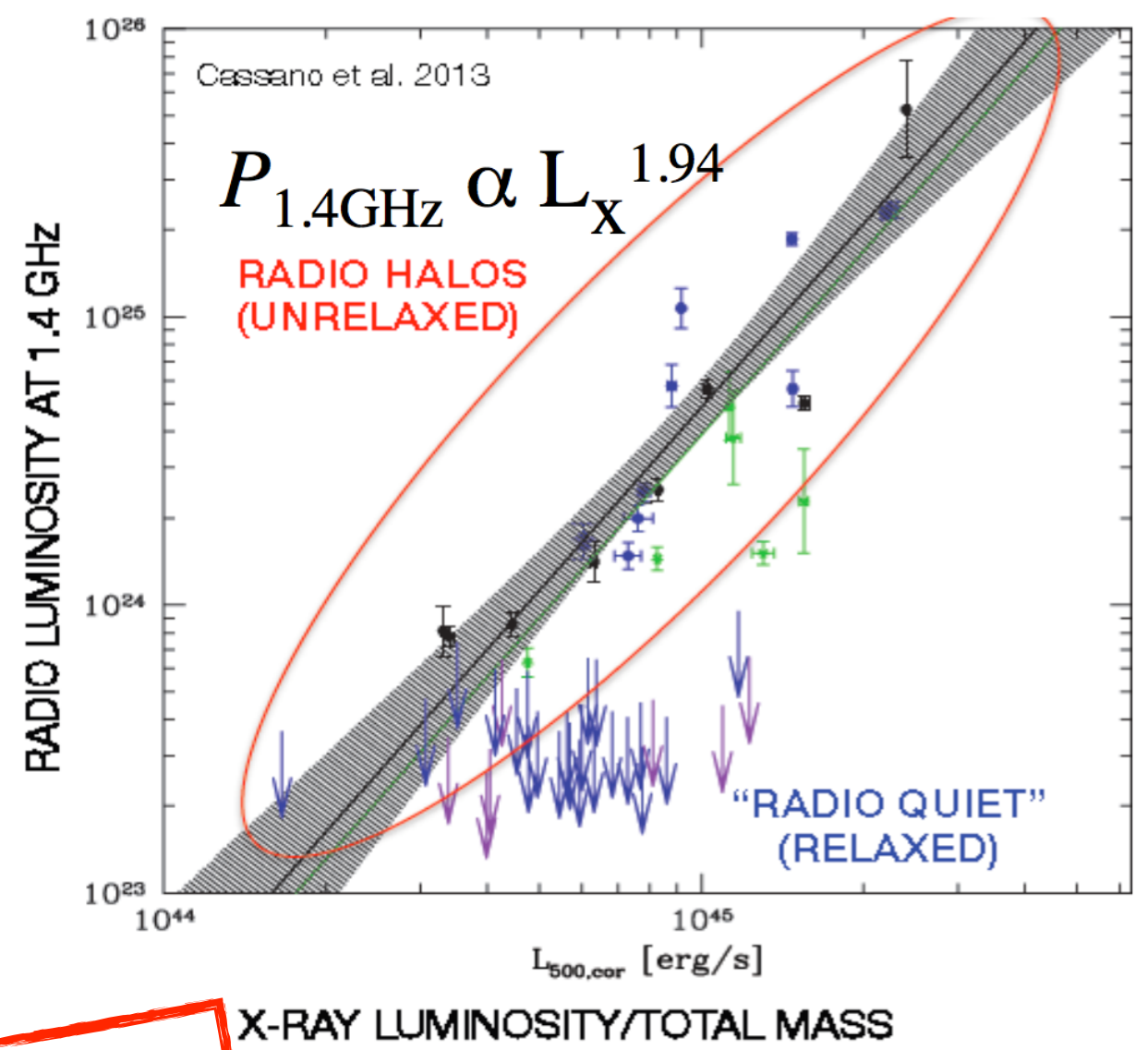
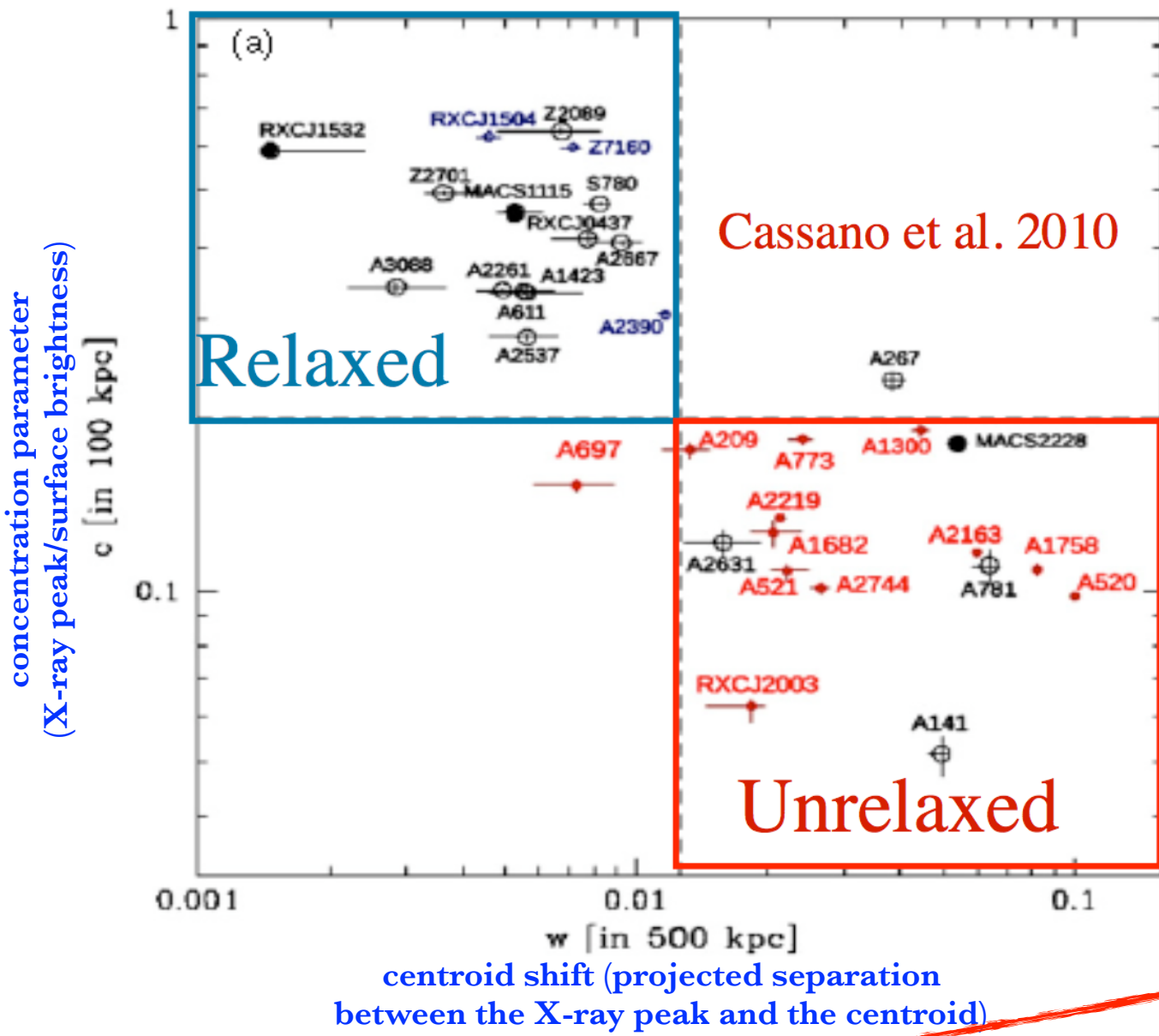
Abell 1033: The white contours help identify the X-ray flux levels, and the red contours trace the radio emission. The elongated red structure in the lower center is a radio phoenix: fossil gas that has been reheated by shocks from a nearby galaxy merger

Relaxed cluster with no radio emission



Radio observations gives information about the dynamical state of the cluster, the intra cluster gas, independent radio emitting member galaxies

SKA precursor survey results- statistical radio properties

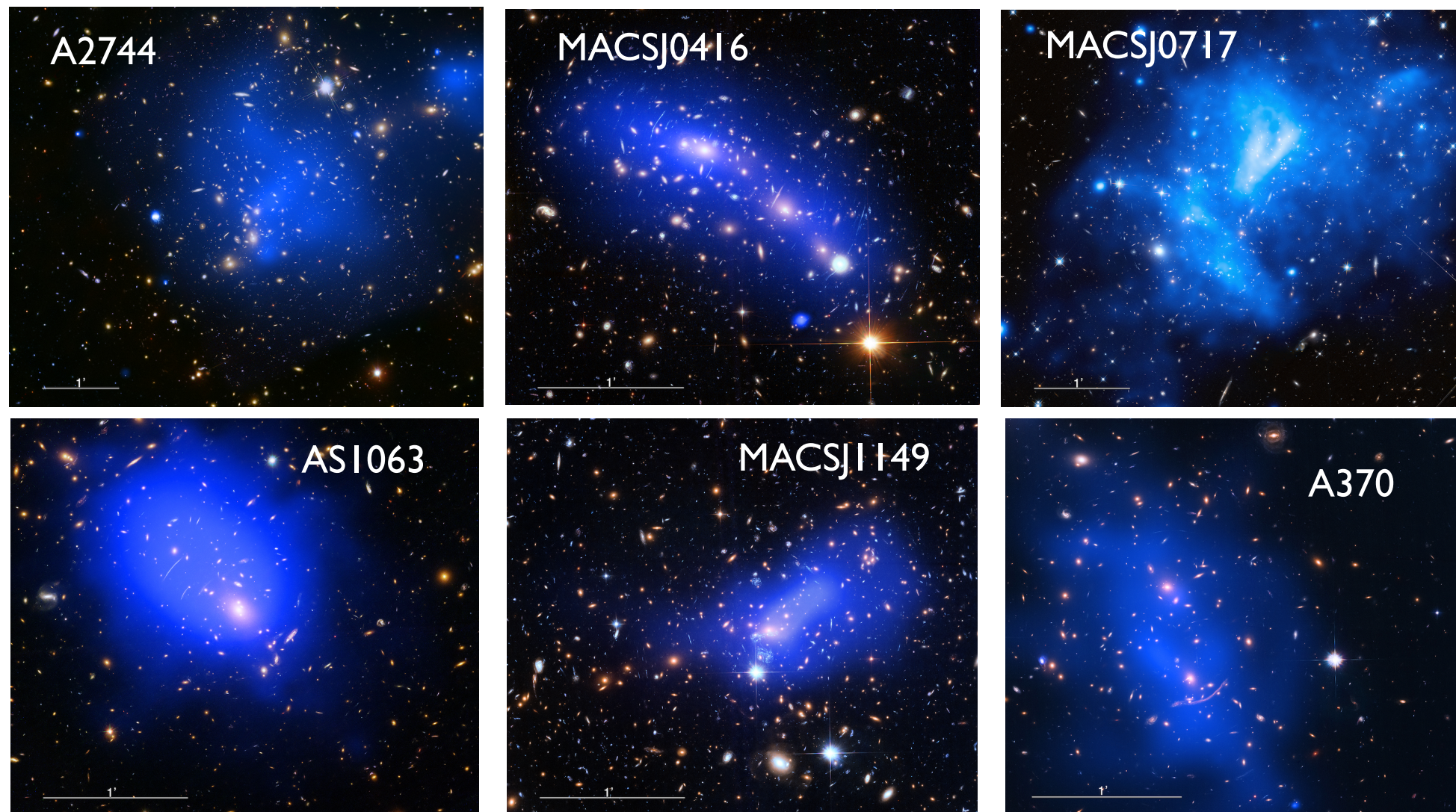


Radio emission in roughly 120 clusters discovered by GMRT/VLA
 Bimodality in L_r vs L_x plot!
 Is it sensitivity limited or a transient phenomenon based on
 dynamical state of the cluster

Radio survey of CLASH and Frontier field clusters

-Study high- z galaxies through gravitational lensing for best lensing clusters (largest areas of high amplification)

HST + Chandra



- Lensing clusters
- $z > 0.3$
- $L_x > 10^{44} \text{ erg s}^{-1}$ (0.5-2.0 keV);
- $T > 10 \text{ keV}$
- Dual or Quadruple merger event
- Hints of shock heated regions: 20+ keV
- $M_{\text{vir}} > 10^{15} M_{\odot}$

-Deep targeted cluster studies with multi-wavelength data available ($z_{\text{spec}}/z_{\text{phot}}$)

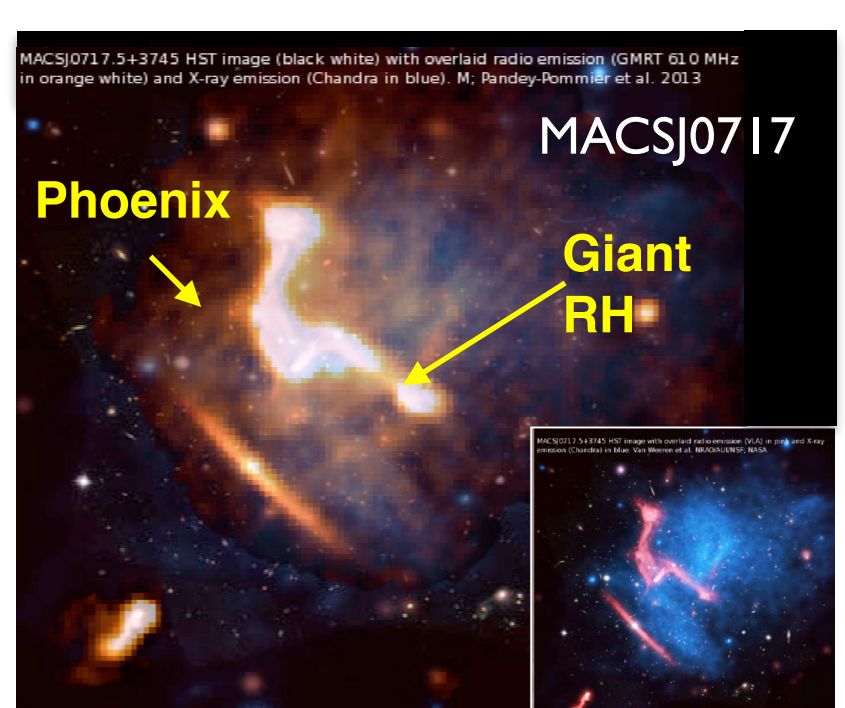
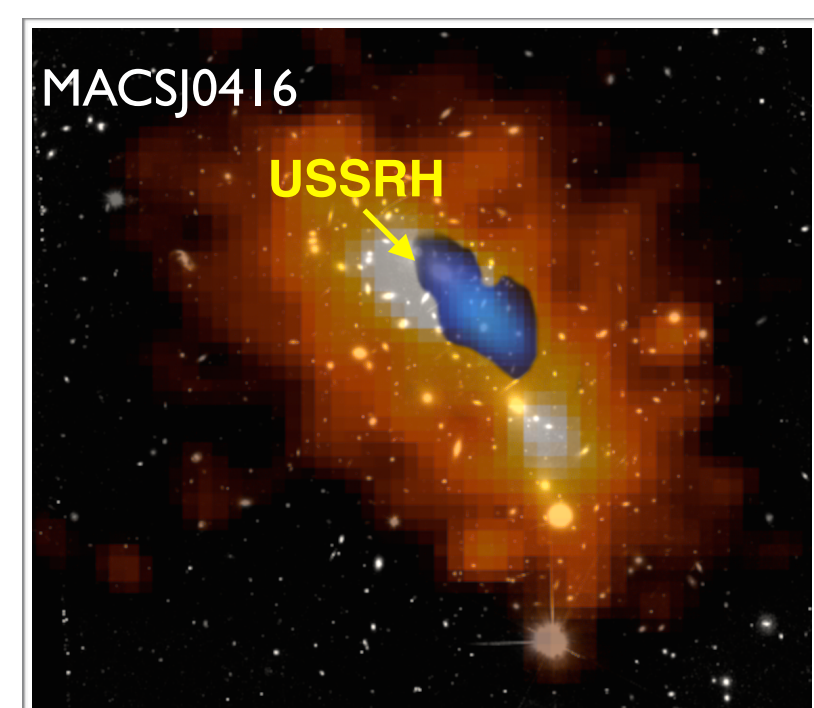
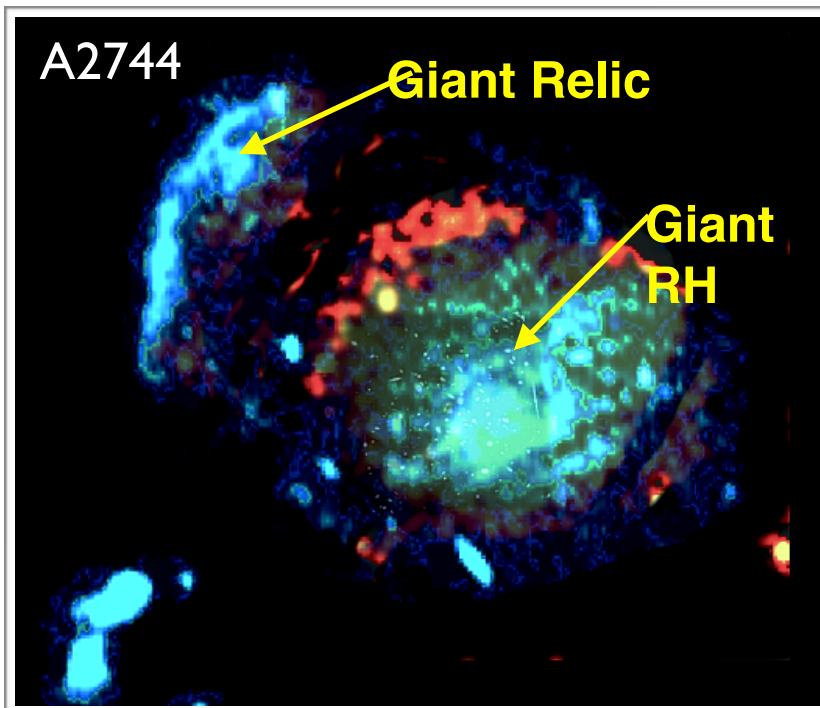
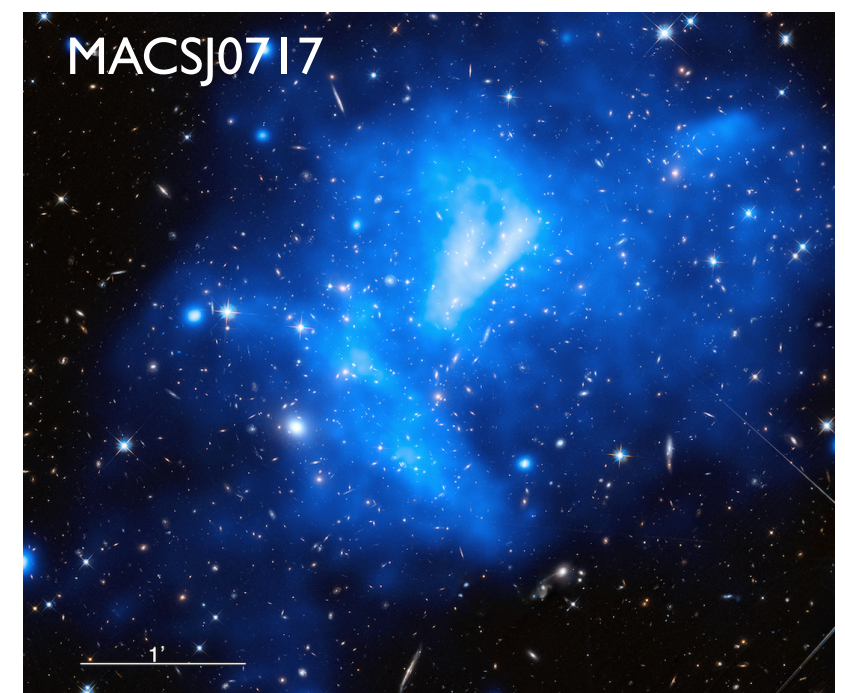
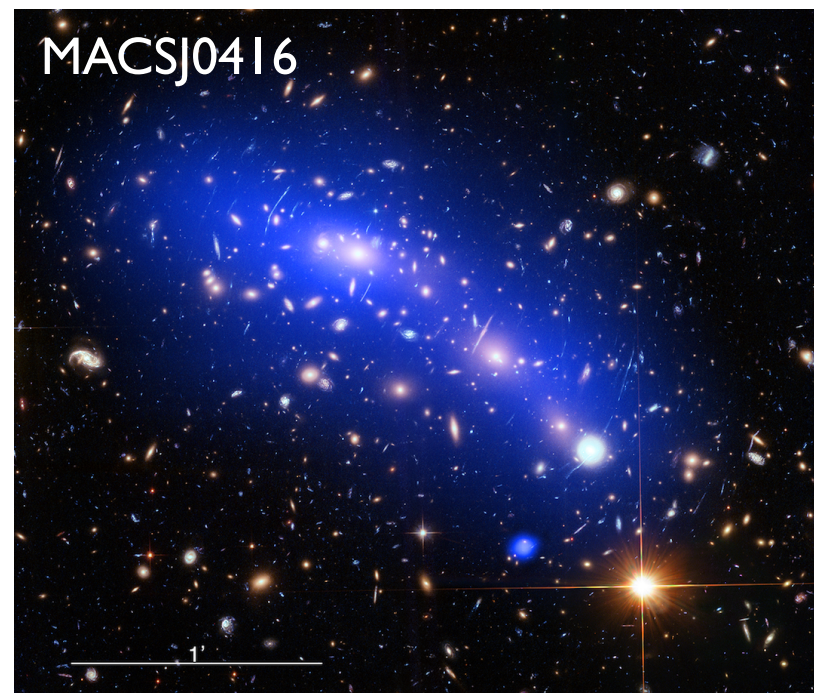
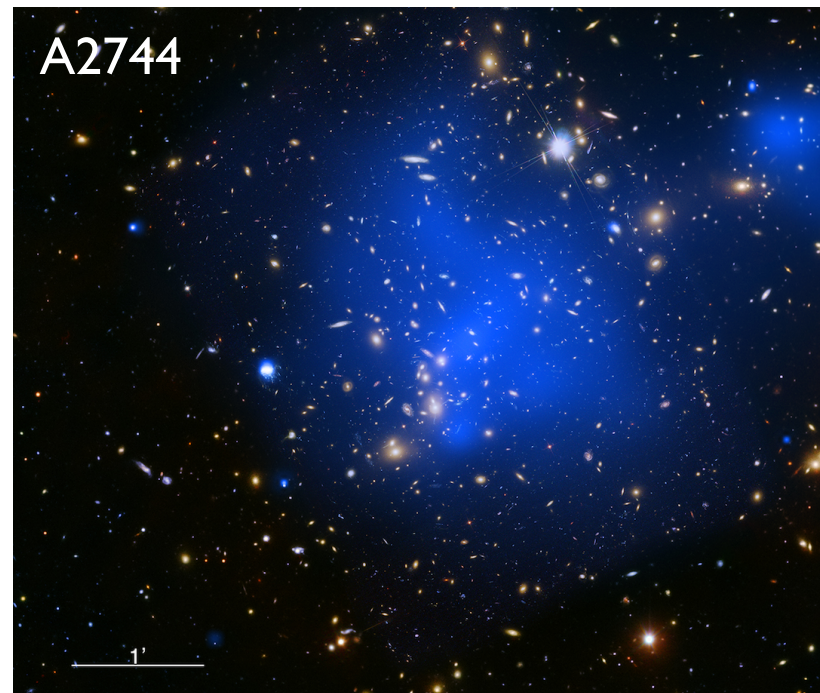
-Lensing models/ X-ray data publicly available too

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

New Results: Low Frequency Radio survey on CLASH & Frontier Field clusters

HST + Chandra+ GMRT/VLA

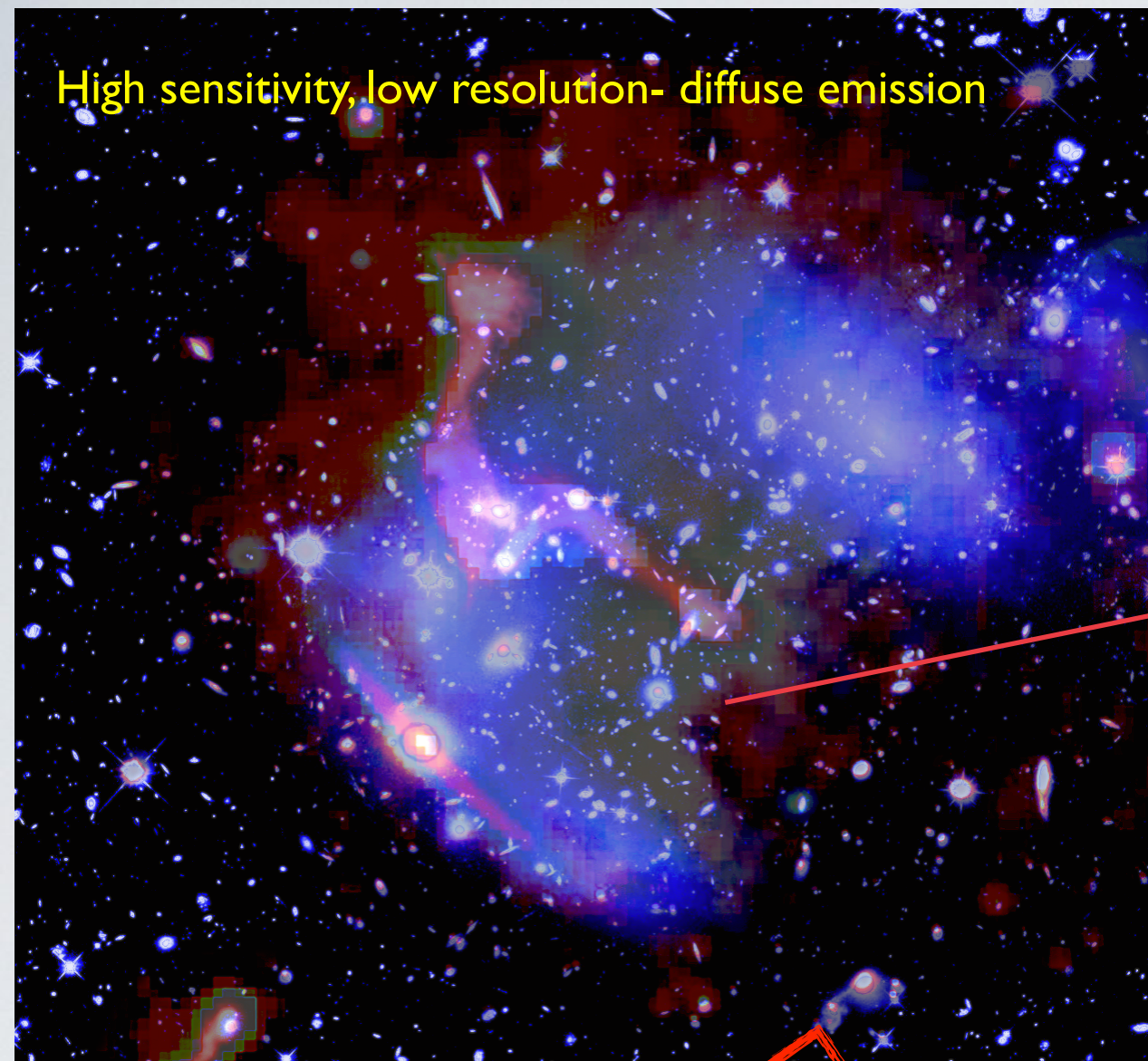
Pommier et al. 2013-2017



- Clusters in on-going and poste-merger state tend to emit in radio.
- Spectral index (1.4 GHz-250 MHz) for RH = -1.2, RR and Phoenix = -0.8 to -2.2 and **USSRH < -1.5 (rare !)**

Do all lensing clusters host radio counterparts ?

High sensitivity, low resolution- diffuse emission

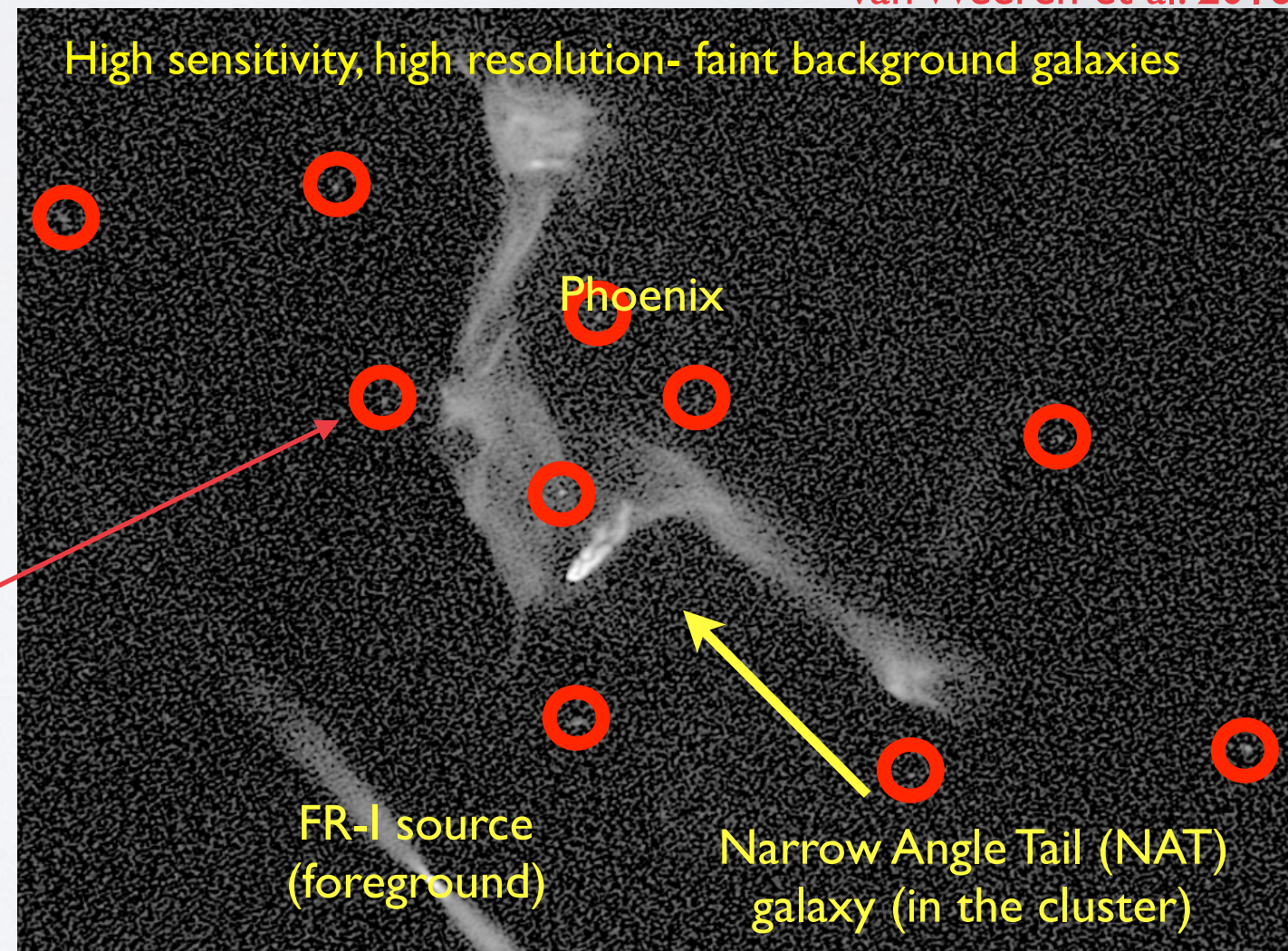


-Most powerful giant (1.6 Mpc) radio halo discovered with the GMRT (235 MHz, 13 arcsec, 0.7 mJy) shown in red & X-ray (Chandra) emission in green overlapping the DM emission (HST) in blue.

-The complex nature of the mass distribution demonstrates that a clear centre is not well-defined in this cluster as already seen in X-rays, and has several bright galaxies associated with the different mass clumps, indicating different sub-groups under collision in the central region of this cluster.

van Weeren et al. 2016

High sensitivity, high resolution- faint background galaxies



Pandey-Pommier et al. 2013

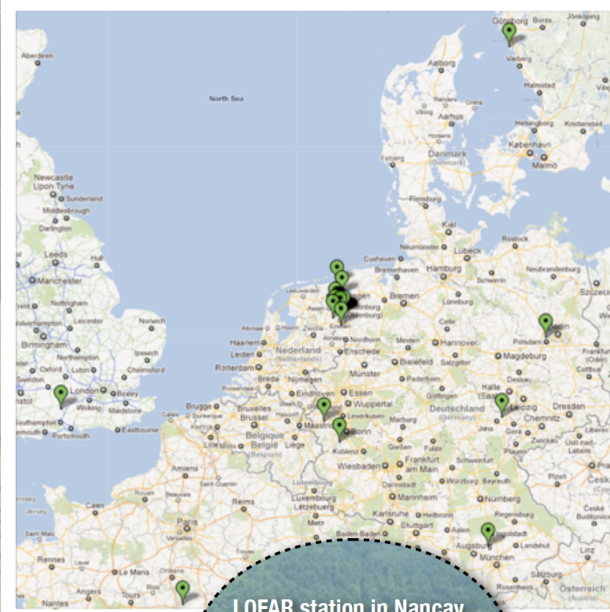
Need microjy-level sensitivity & arcsec-scale resolution at MHz range!

Lensed galaxies emitting in radio discovered with the JVLA (1.4 GHz, 0.6 arcsec, 1.8 microJy/beam)

LOFAR - SKA Pathfinder 50 (38NL+12) MA of 96 LBA & 48 HBA elements over 100km

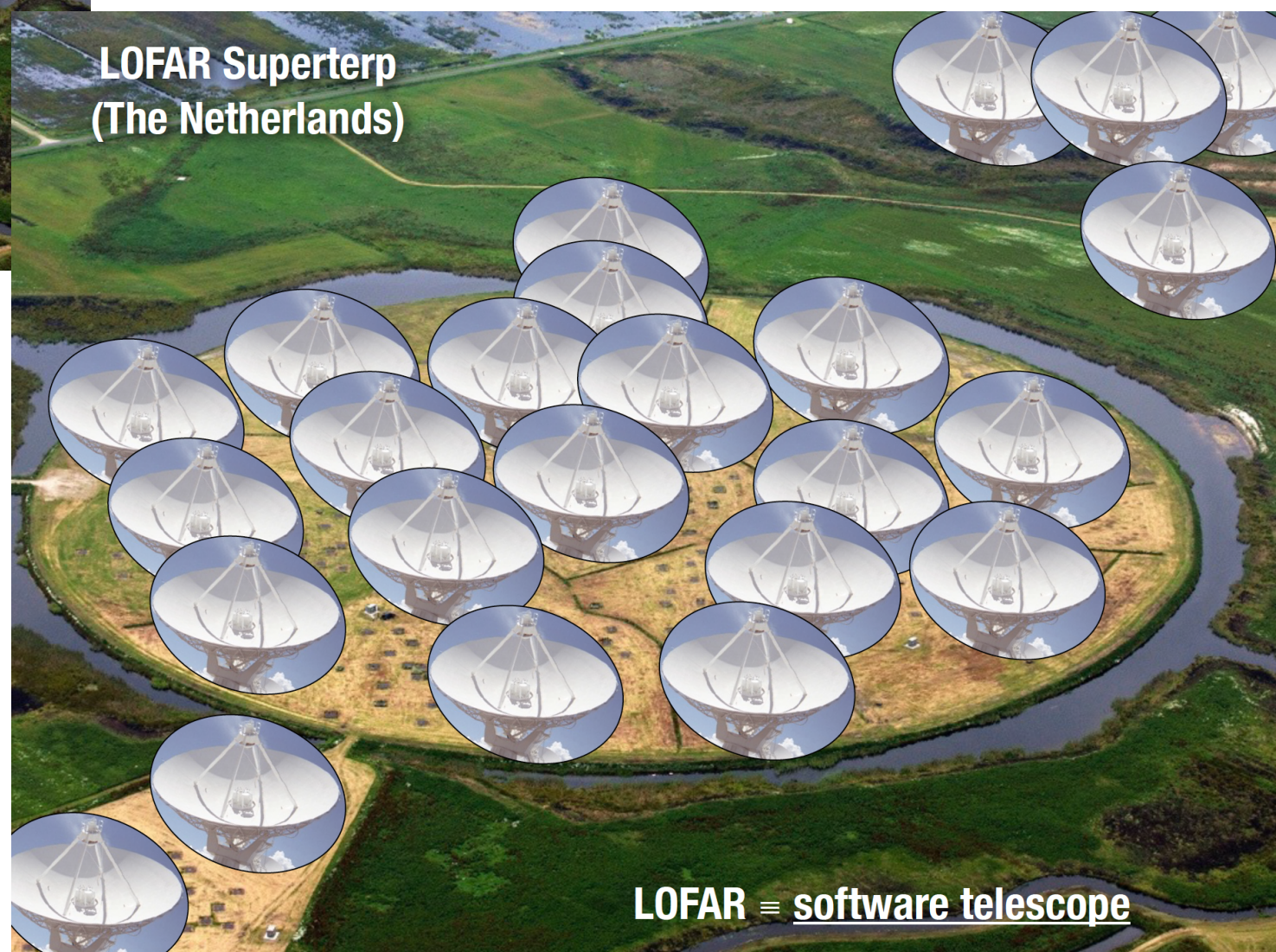
LOFAR Superterp
(The Netherlands)

LOFAR station



LOFAR station in Nançay

LOFAR Superterp
(The Netherlands)

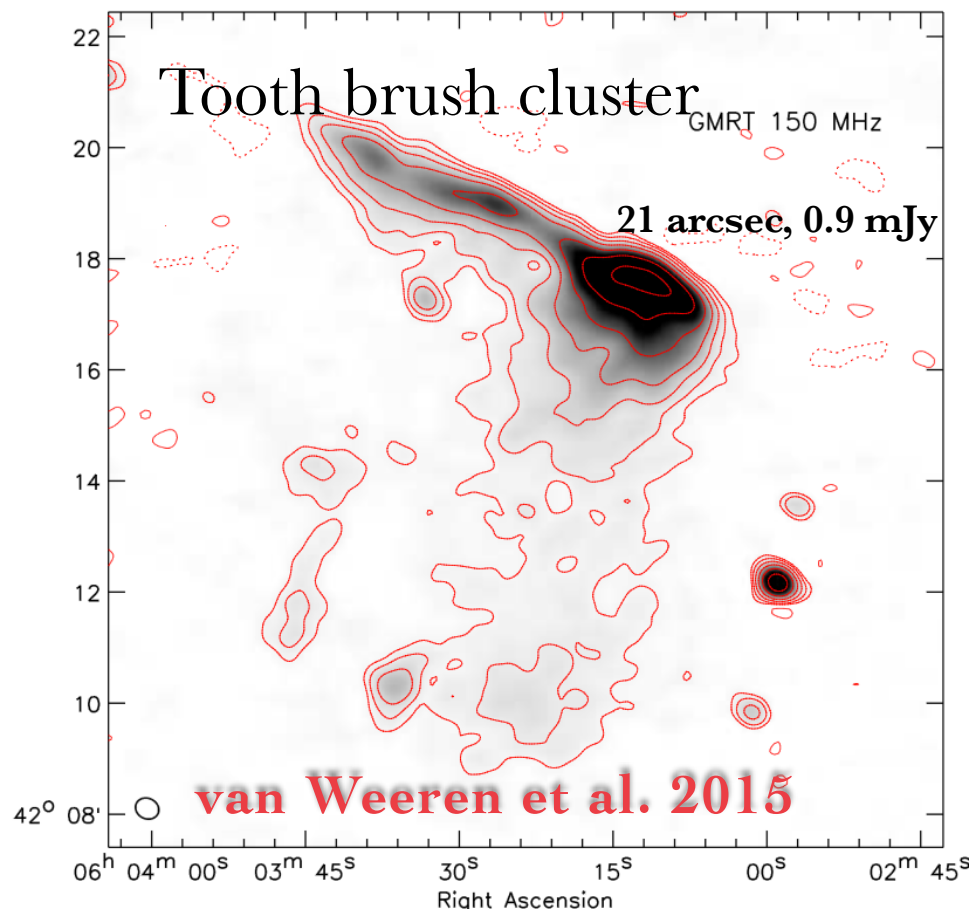
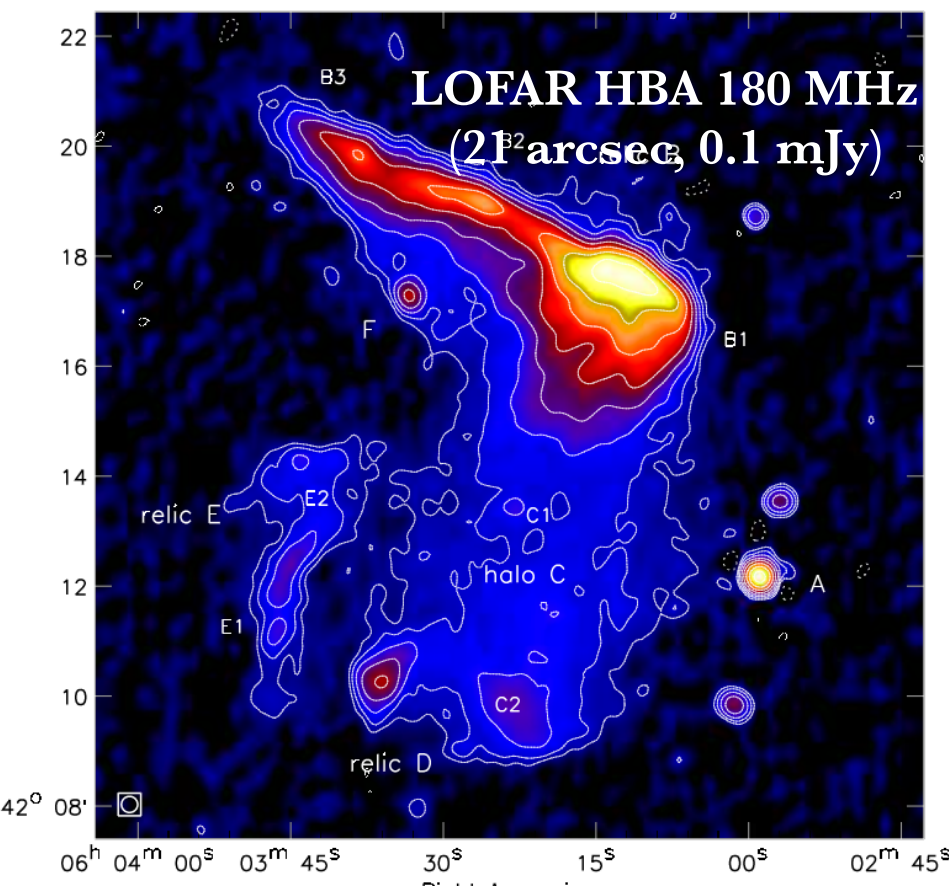
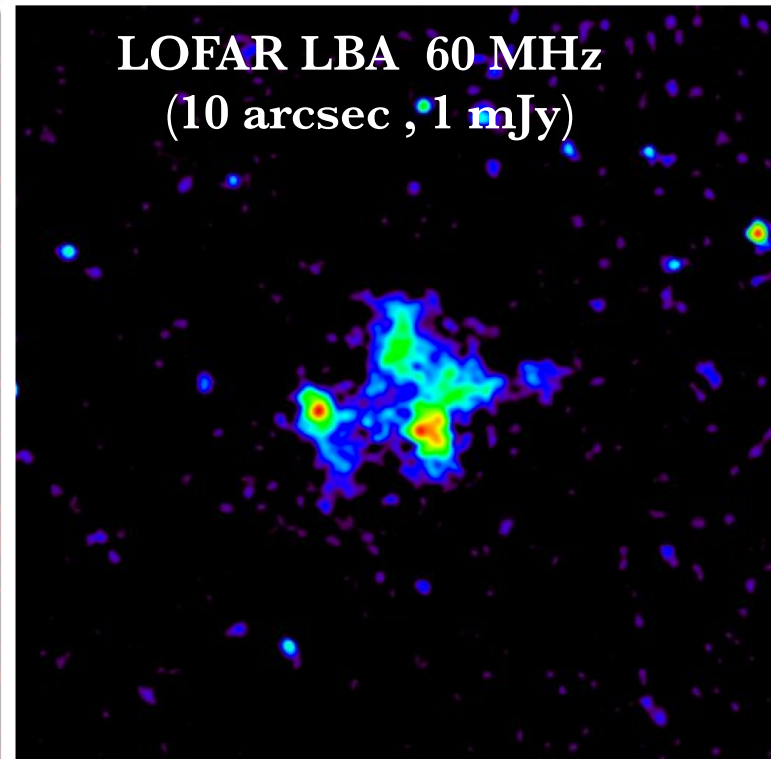
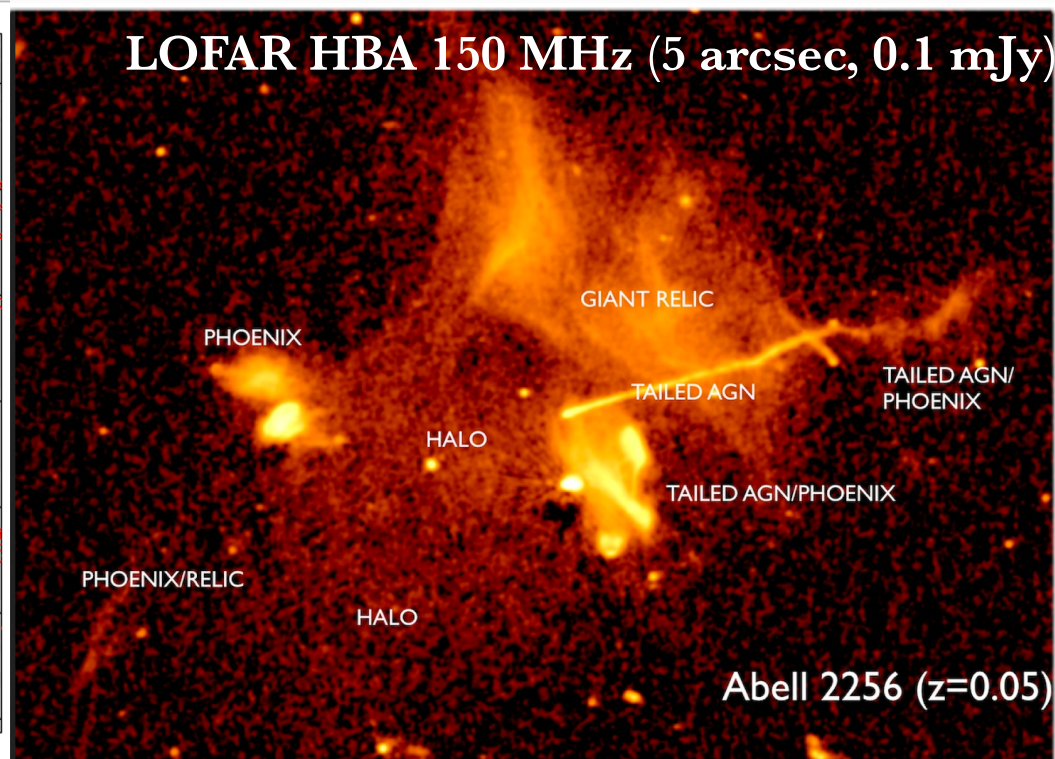
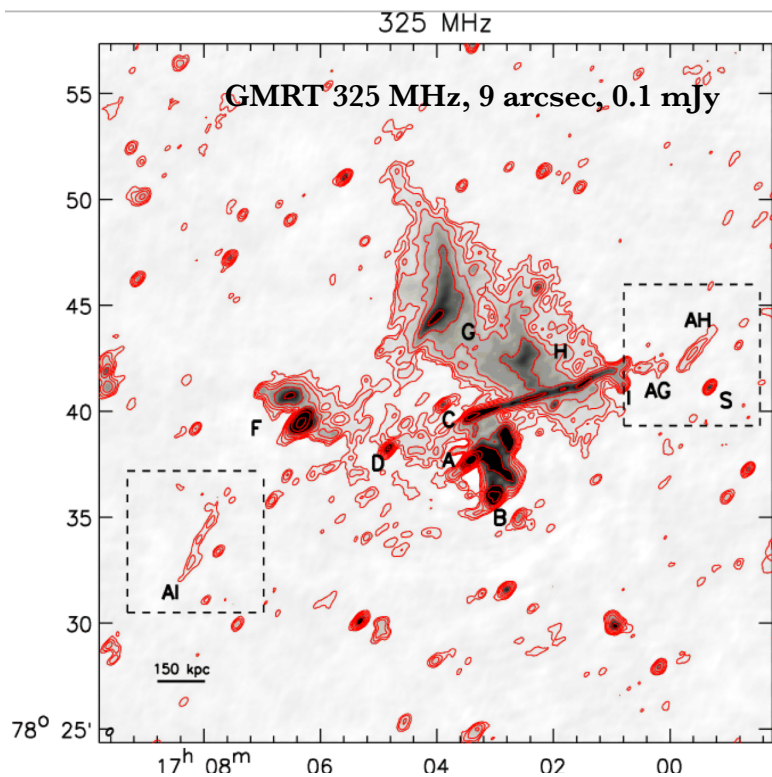


LOFAR = software telescope

-large FOV needs direction dependent calibration
hence multiple beams are used

Needs All sky model to apply correct calibration
scheme & control ionospheric fluctuations
(equivalent to seeing !)

LOFAR/GMRT - more results on cluster of galaxies



more morphological details
at lower frequencies

LOFAR continuous
spectral coverage from
20-240 MHz

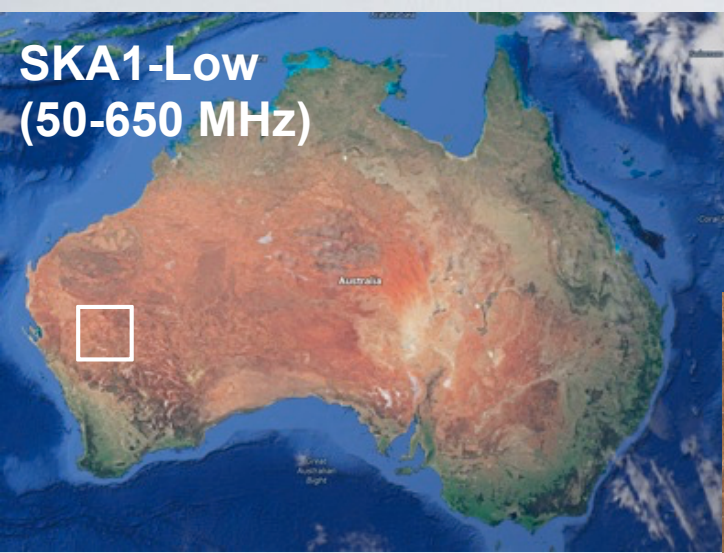
high sensitivity to detect
faint Star forming galaxies
in the cluster environment

Northern sky!

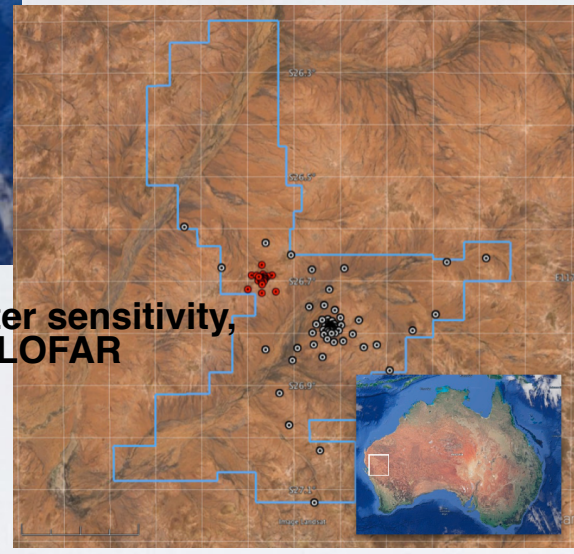
Square Kilometre Array (SKA)- World's largest radio interferometer in the southern sky !

Head Quarters in UK

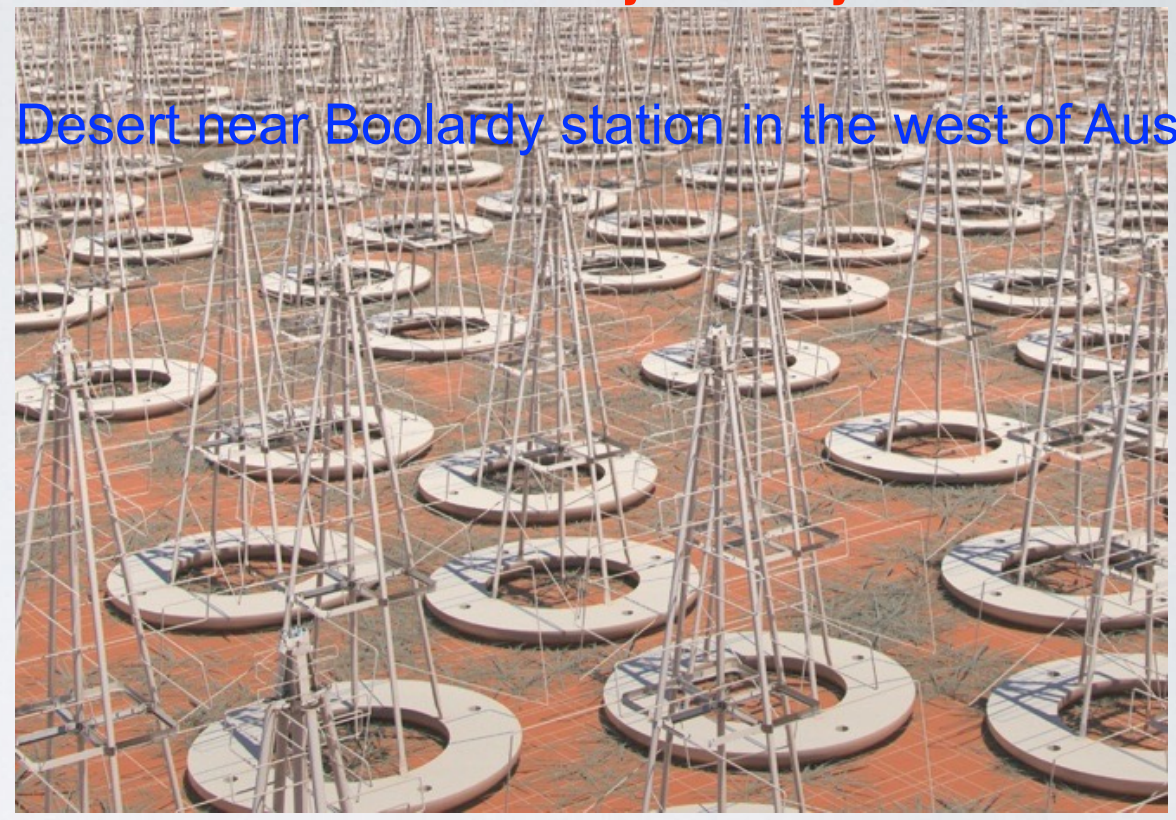
For imaging capabilities refer SKA memo 113 by Pandey-Pommier et al. 2008



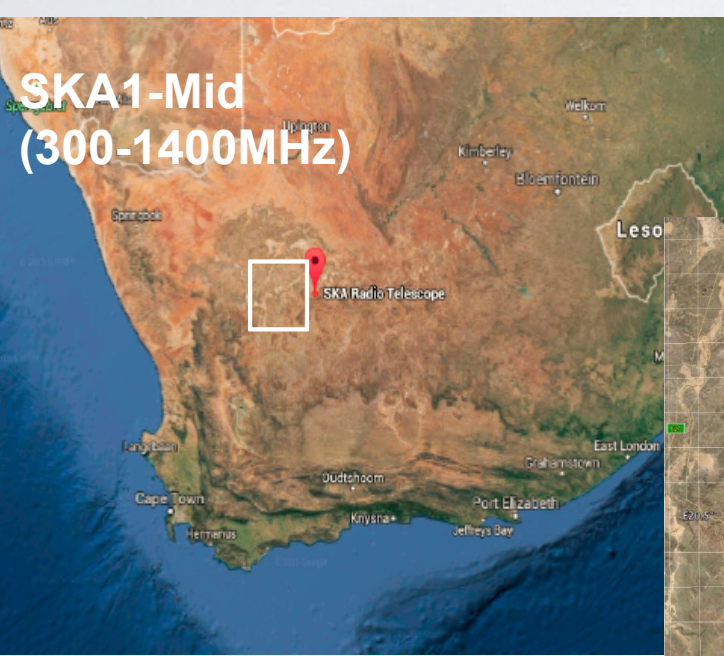
SKA1-Low
(50-650 MHz)



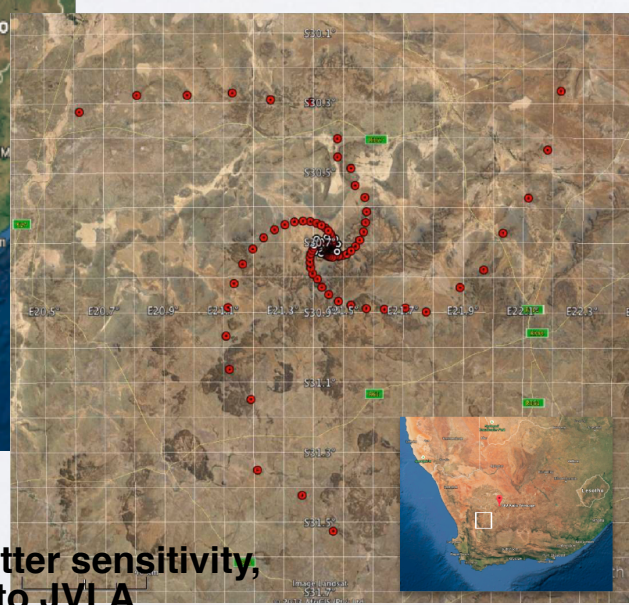
SKA-Low- 25x better resolution, 8x better sensitivity, 135x better survey speed compared to LOFAR



Desert near Boolardy station in the west of Australia



SKA1-Mid
(300-1400MHz)



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

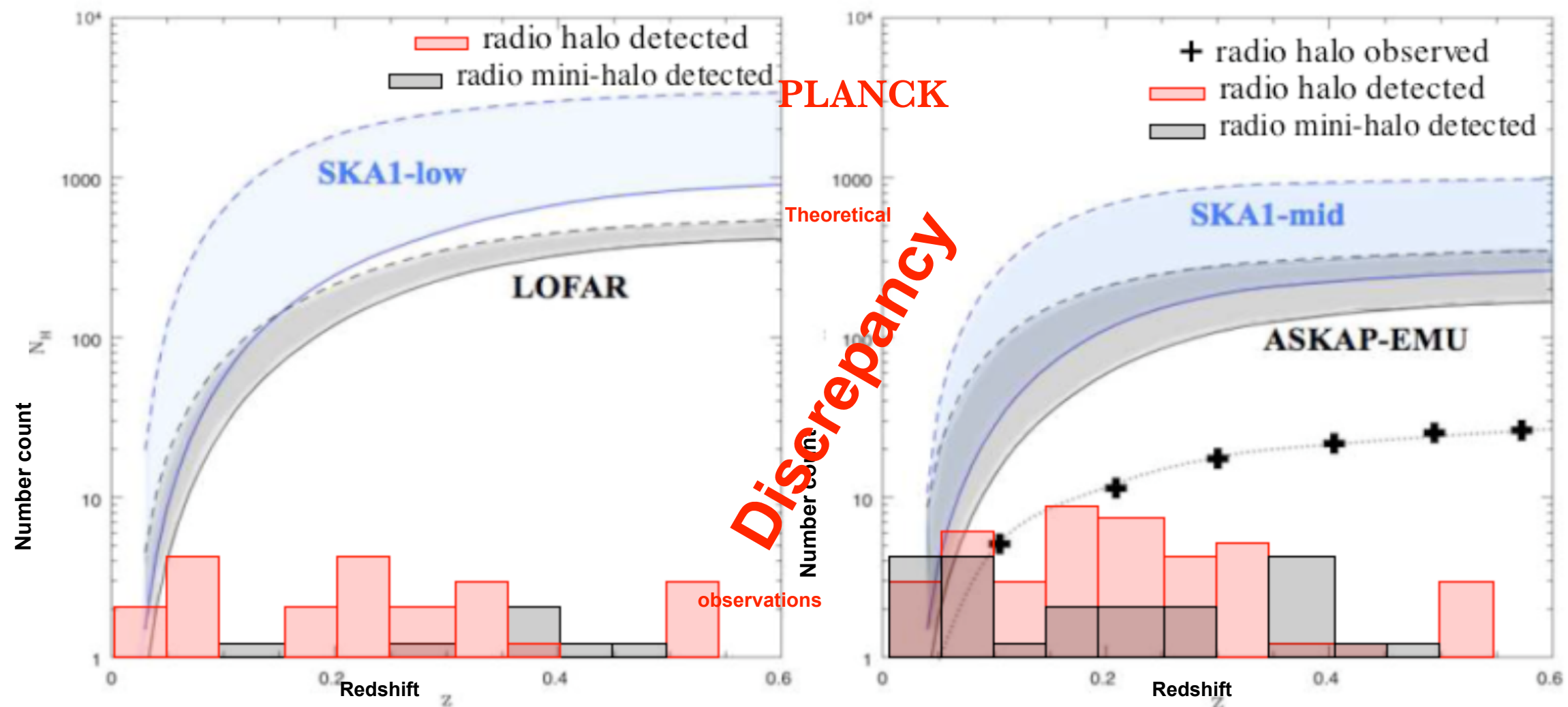


Desert near Karoo in the south-west of South Africa

MeerKAT dishes + tiles

Southern sky !

Cluster of galaxies with the SKA

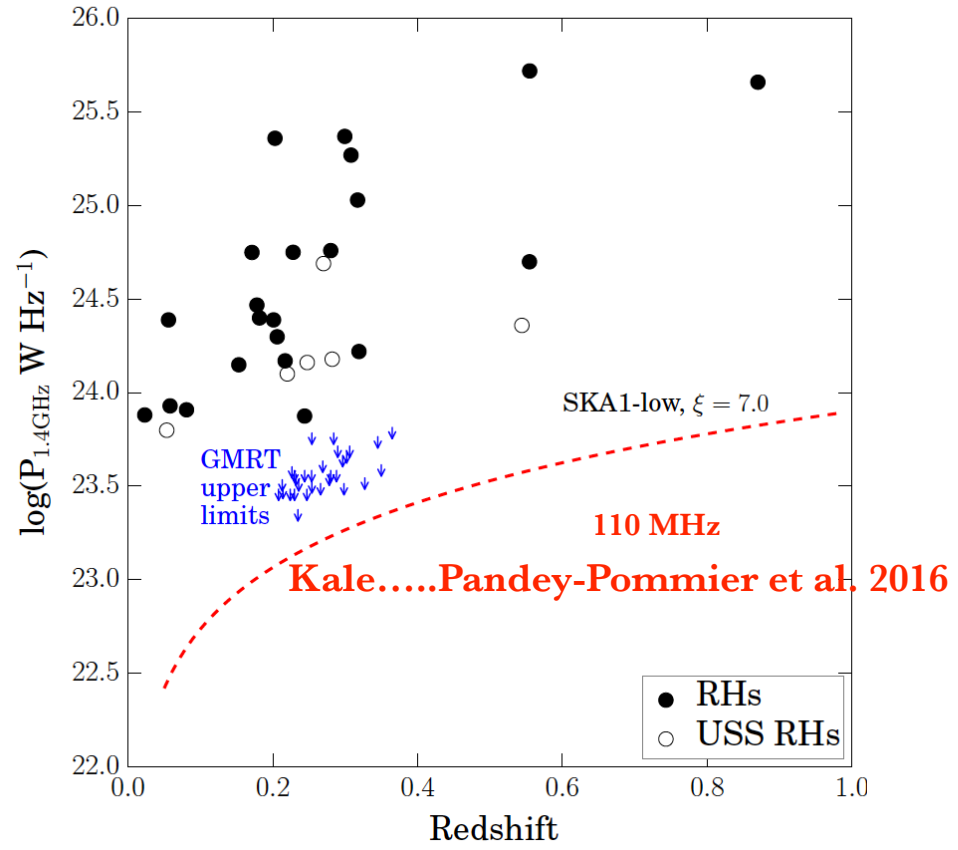


- Complete overview of ICM and radio emitting sources within the cluster (haloes, relics, phoenix, filaments, BCGs)- morphology details
- Discover new Ultra steep spectrum radio haloes (not detected easily at high frequencies)
- Constraint turbulence model
- **LOFAR, GMRT, JVLA and ASKAP observations on clusters !**

Pandey-Pommier et al. 2015 (SKA White Book)

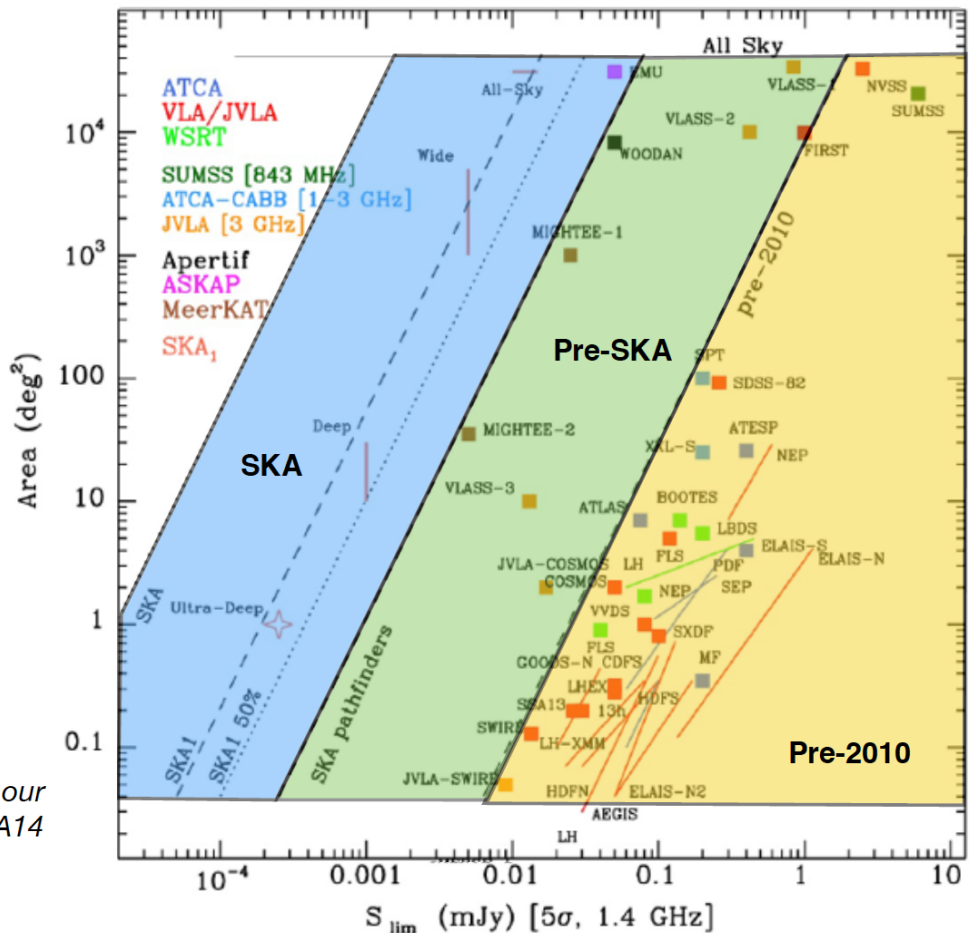
Square Kilometre Array (SKA)- Sensitivity and Capabilities

Member of :
International SKA Continuum Survey group
French SKA consortium
SKA-INDIA consortium



SKA lensing cluster studies:

- order(s) of magnitude more SF galaxies per cluster, detect $z \gtrsim 3$ objects
- study the evolution of galaxies w.r.t redshift
- Bulk of AGN population down to $L=10^{22}$ W/Hz @ $z=0.5$ (Wide), $z=2$ (Deep) and $z = 4$ (Ultra Deep)
- Complementary morphology of HI up to $z = 0.8-1$ & study correlation between HI mass function and SFR, as well as their evolution with respect to the cluster center
- 0.5 arcsec resolution at 1 GHz (Euclid=0.2 arcsec and LSST=0.7 arcsec)



Cassano R.;...Pandey-Pommier et al. 2014,
Pandey-Pommier et al. 2015 (SKA Users case)
Pandey-Pommier et al. 2017 SKA-France White Book

Prandoni & Seymour AASKA 14

Members of International SKA consortium

Les groupes de travail scientifiques de SKA

La participation française aux différents groupes de travail scientifiques est déjà assez fournie, avec au moins un représentant par groupe. À noter que les noms en gras correspondent aux chercheurs membres des « core teams » des groupes de travail:

- **Epoque de la réionisation**: Benoit Semelin (Obs. Paris) ; Dominique Aubert et Pierre Ocvirk (OAS)
- **Cosmologie** : Simon Prunet (IAP) ; Jean-Luc Starck (AIM)
- **Physique fondamentale avec les pulsars** : **Gilles Theureau**, **Ismael Cognard**, **Jean-Mathias Griessmeier** et Lucas Guillemot (Univ. Orléans) ; Antoine Petiteau (APC)
- **L'Univers transitoire** : **Stéphane Corbel** (AIM/USN)
- **Le continuum extra-galactique** : **Chiara Ferrari** (OCA) ; Emanuele Daddi et Gabriel Pratt (AIM) ; **Mamta Pandey-Pommier** (CRAL)
- **Le magnétisme cosmique** : Marta Alves et Katia Ferrière (IRAP) ; Mathieu Langer (IAS)
- **Le berceau de la vie** : **Philippe Zarka** (Obs. Paris) ; Cecilia Ceccarelli (Univ. Grenoble)
- **L'hydrogène neutre dans les galaxies** : **Albert Bosma** (LAM) ; **Wim van Driel** (Obs. Paris) ; Marc-Antoine Miville-Deschenes (IAS)
- **Les raies spectrales extra-galactiques** : **Françoise Combes** (Obs. Paris) ; Emanuele Daddi (AIM)
- **Notre Galaxie** : Francois Levrier (ENS-Paris) ; Marc-Antoine Miville-Deschenes (IAS)
- **La physique solaire et héliosphérique** : Nicole Vilmer (Obs. Paris)

La bonne implication française dans la préparation scientifique à SKA est démontrée par la participation importante au dernier ouvrage concernant la science avec SKA. Cinq chercheurs français ont été auteurs principaux et seize co-auteurs de 31 parmi les 135 chapitres publiés en 2015 suite à la conférence « Advancing Astrophysics with the Square Kilometre Array » de juin 2014.

SKA- France White Book

NenuFAR - French SKA-Low Pathfinder- 102 (96+6) MA of 19 dual polaz. elements over 400m

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	1° (@400 m)	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

Part of NenuFAR commissioning team & 1st scientific results

LOFAR Continuum KSP and International long baseline group



Site: Nancay, -100% funded via ANR and INSU (Zarka et al.)

NenuFAR imager (15-80 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

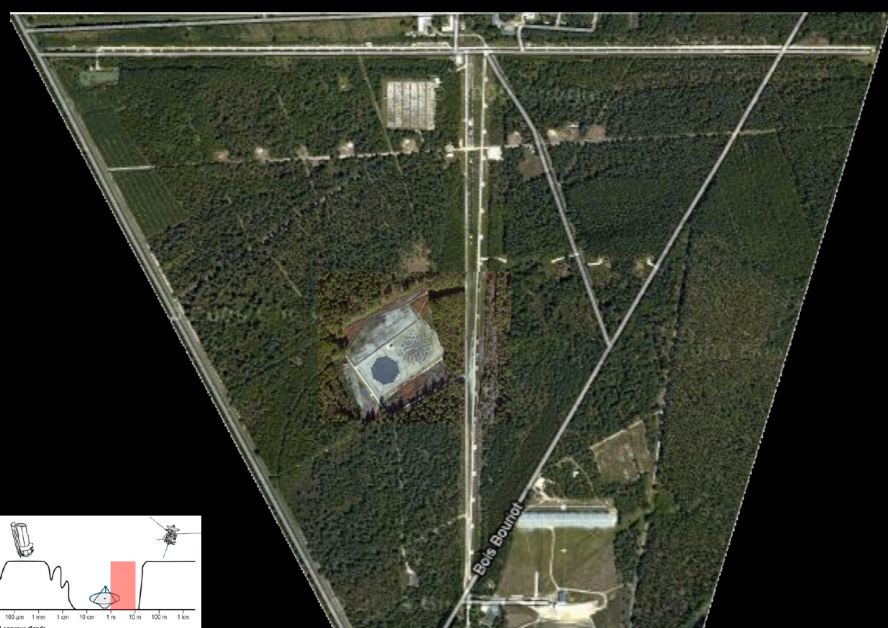
Large compact array-imager mode: diffuse emission in large scale structures (clusters, Giant galaxies, dark ages etc.).

SKA precursor for French Low frequency radio community and training for SKA Low

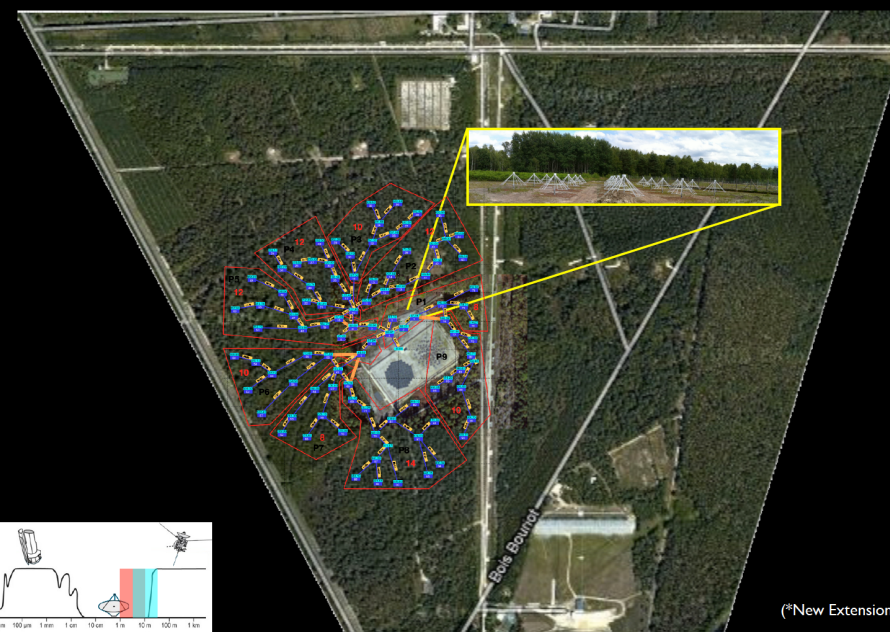
Construction and commissioning on-going with the available LOFAR imager tool developed via Leiden and Meudon team (Shimwell & Tasse et al.)-

NenuFAR - French SKA-Low Pathfinder

In Nançay : From LOFAR FR606

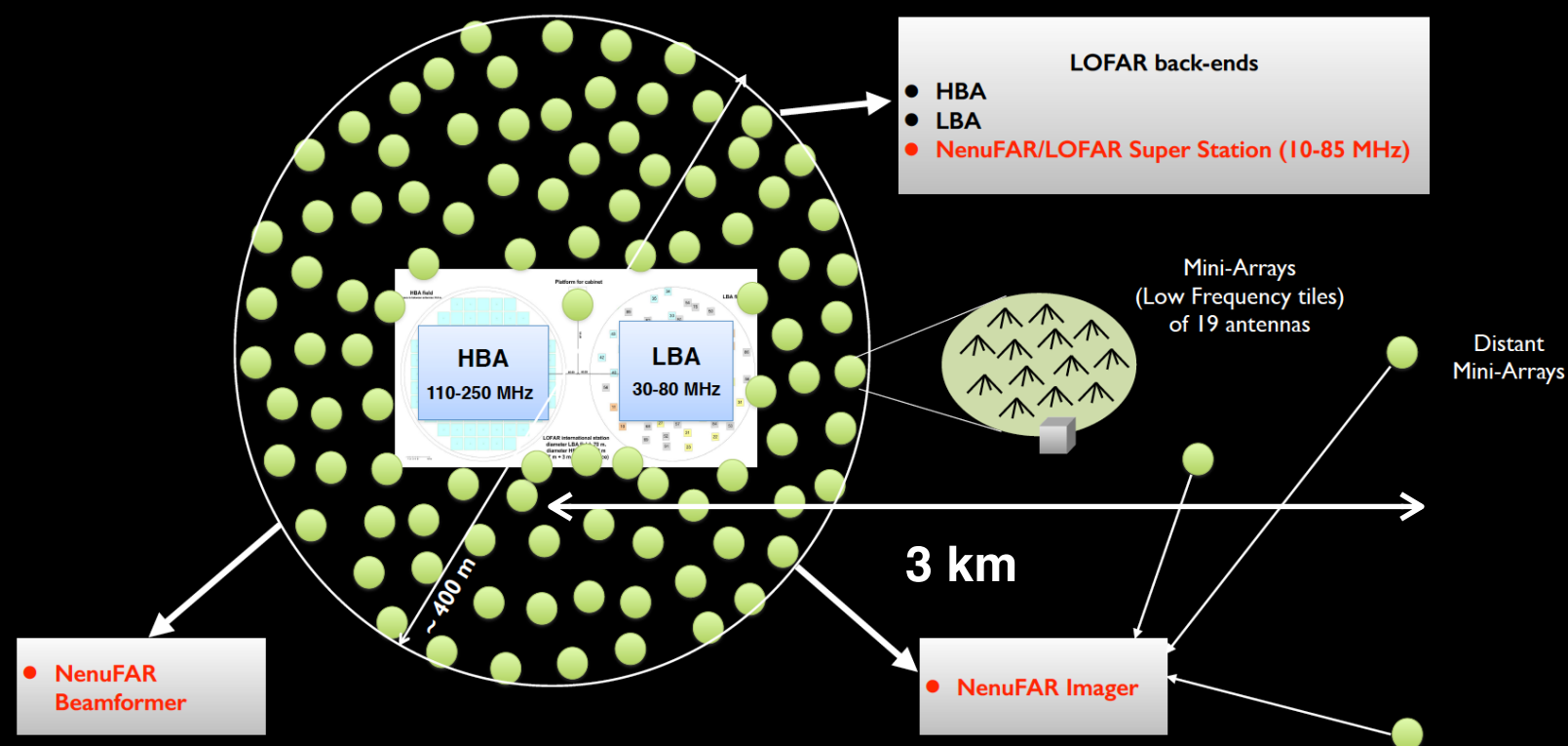


In Nançay : From LOFAR FR606 to NenuFAR*



(*New Extension in Nançay Upgrading LOFAR)

The concept of NenuFAR (2007-2008)



1. Motivation for radio surveys with SKA pathfinders and precursors:

-Low frequency studies of relics (shocks) and halos (fusion and turbulence) in cluster of galaxies.

-Spectral index studies using high frequency data to discover USSRH, identify age of the radio emitting plasma and dynamical state (Pre- or Post- merger) of the cluster

-Evolution of large scale structures in the Universe with respect to the redshift

-SF galaxies in the distant universe via lensing technique

2. Observation with NenuFAR- SKA pathfinder and LOFAR:

-prepares us directly as SKA Low Frequency community

3. Synergy with many new up-coming facilities:

-complementary with imaging facilities Euclid, LSST, ATHENA, JWST for the study of Dark and baryonic matter interaction

-spectroscopic surveys (4MOST, DESI, E-ELT etc.) for SF galaxies and AGN population studies.

4. SKA- Biggest International scientific effort:

-deliver world-leading science for decades, have made a real difference to its local communities and be inspiring future generation world wide.

Thank you!