New frontiers in galaxy clusters with SKA-LOW

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New frontiers in galaxy clusters with SKA-LOW

- Scientific background in a nutshell
- Main features of SKA-LOW
- Some recent advances in our knowledge of radio sources in galaxy clusters
- Prospects and challenges for SKA-LOW
- Prospects for the collaboration between Italy and Australia

Radio sources in galaxy clusters

Three main flavours of radio sources in galaxy clusters

- Mpc-scale steep spectrum radio sources of very low (μJy/arcsec^2) surface brightness originating during cluster mergers and accretion events (**halos** and **relics**)

Steep spectrum sources, with α in the range ~1.1 (*normal*) – 2 (*ultrasteep*) and steeper

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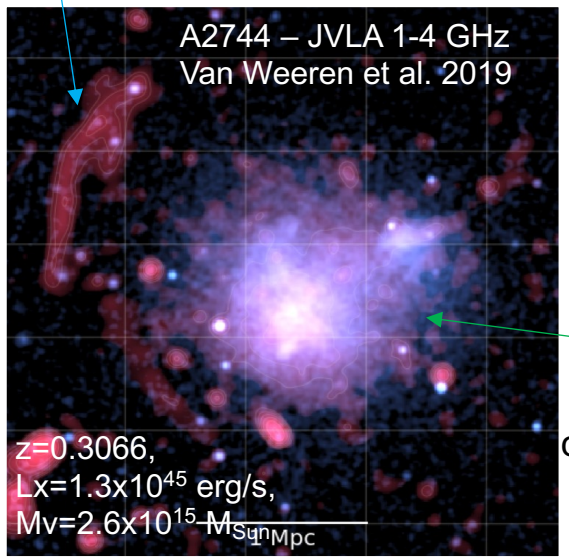
Best observed at few hundred MHz

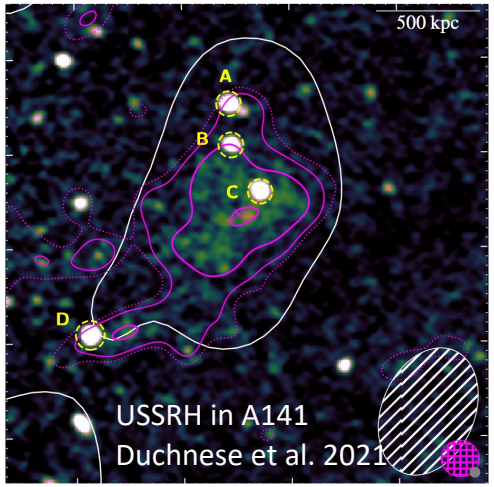
Relic

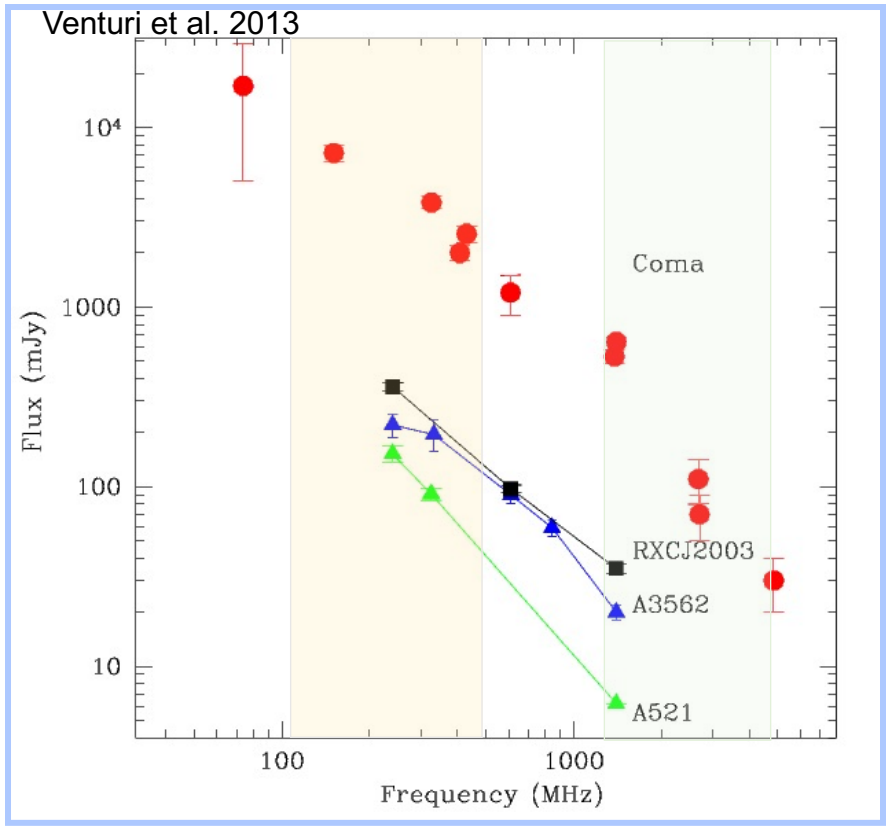
Located in the cluster outskirts, at the edge of the X-ray emission



Halo

Centrally located coincident with the X-ray emission

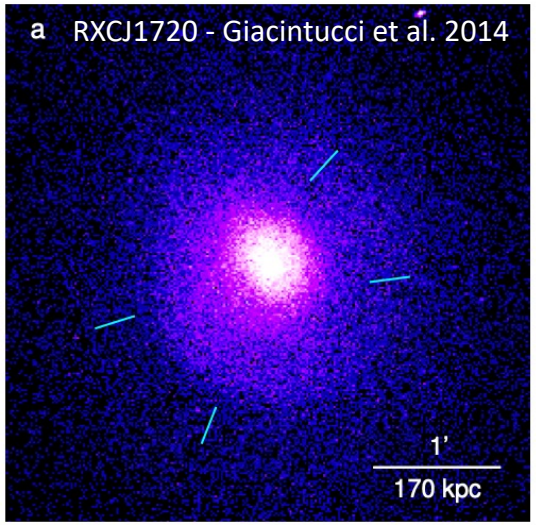


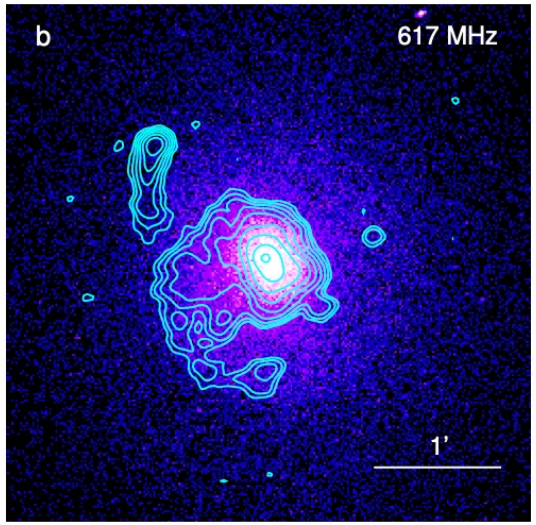


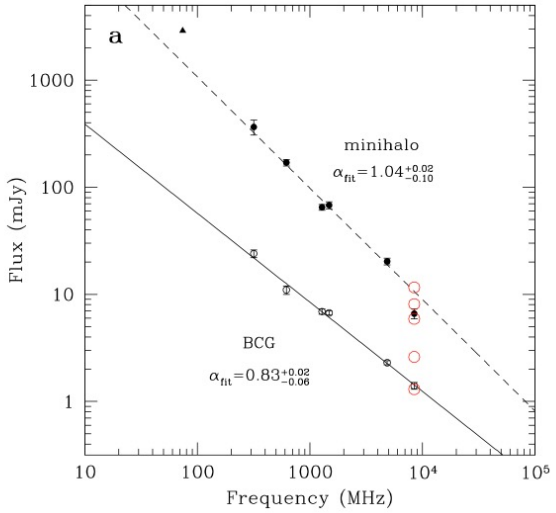
Radio sources in galaxy clusters

Three main flavours of radio sources in galaxy clusters

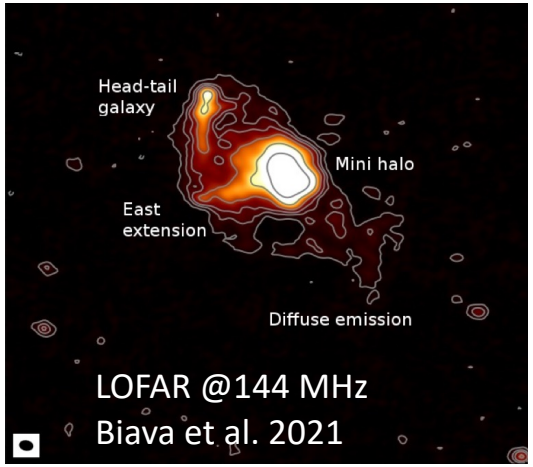
- **Mini-halos,** steep spectrum radio sources smaller in size but still on cluster scale and associated with relaxed clusters







Giacintucci+ 2014



Very steep spectrum diffuse emission detected beyond the cool core.

How common is it?

Need for high sensitivity observations at low frequency

Steep spectrum sources, with α in the range ~1 – 1.5

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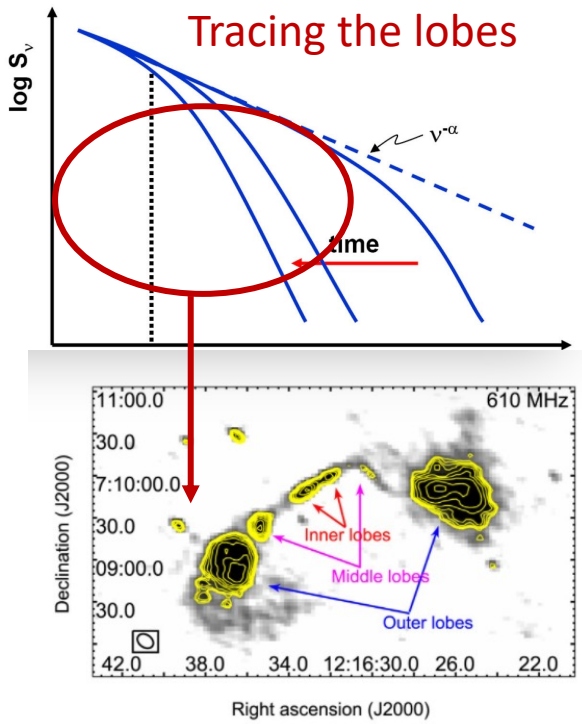
Best observed at few hundred MHz

Radio sources in galaxy clusters

Three main flavours of radio sources in galaxy clusters

- **Radio galaxies** (AGN, starburst), most remarkable when characterized by jets and lobes



Singh et al.2016

$\nu \gtrsim 5$ GHz tell us about the core
$\nu \lesssim 1.4$ GHz tell us about the lobes

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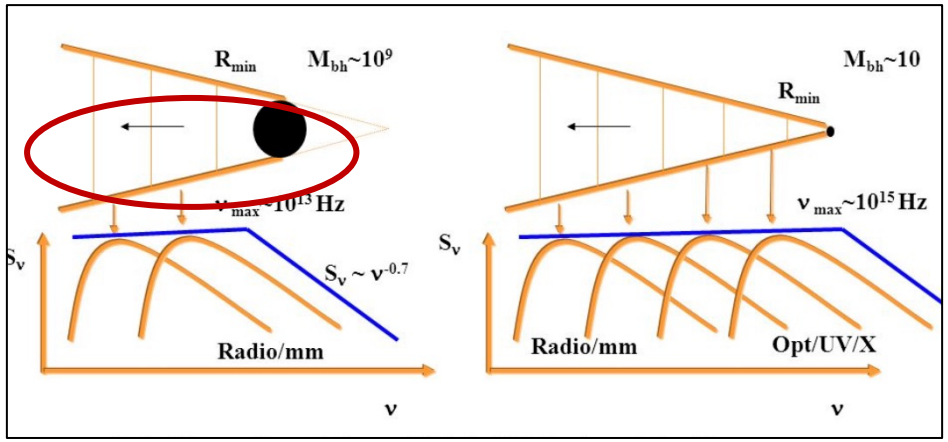
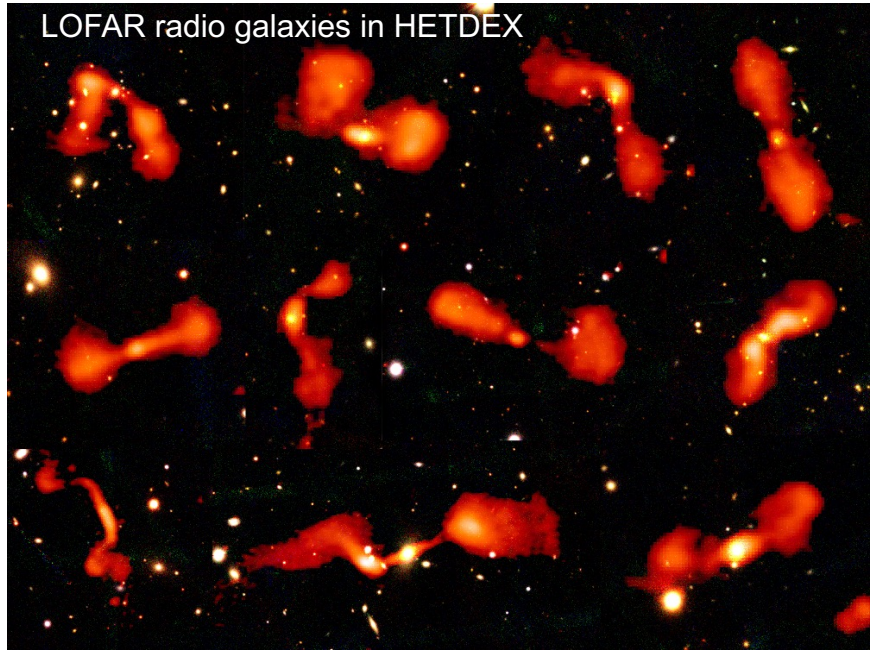
Lobes & emission from old cycles of radio activity **best studied at few hundred MHz**

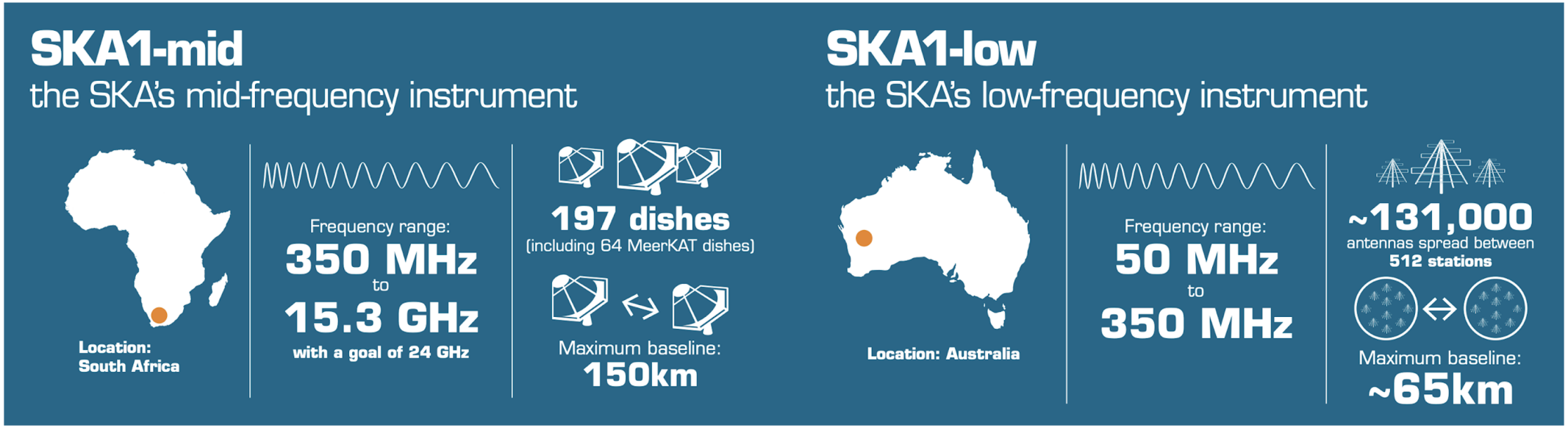


Low luminosity radio galaxies, with **lobes and jets shaped by the** local and large-scale **environment**



SKA - Square Kilometer Array

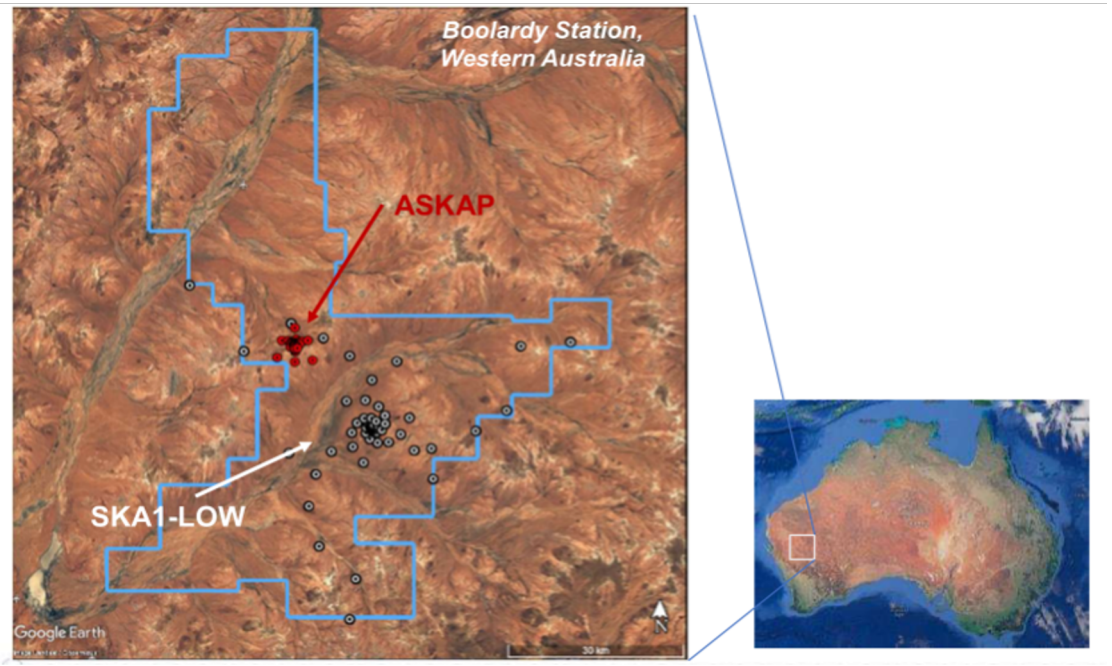
- *Huge* science project: global collaboration of 16 countries
- *Biggest* radio interferometer ever: km-square collecting area, thousands km extension
- Construction phase: 07/2021 – 07/2029
- Sites: Karoo and Murchison *remote* deserts (radio-quiet/good atmospheric conditions)



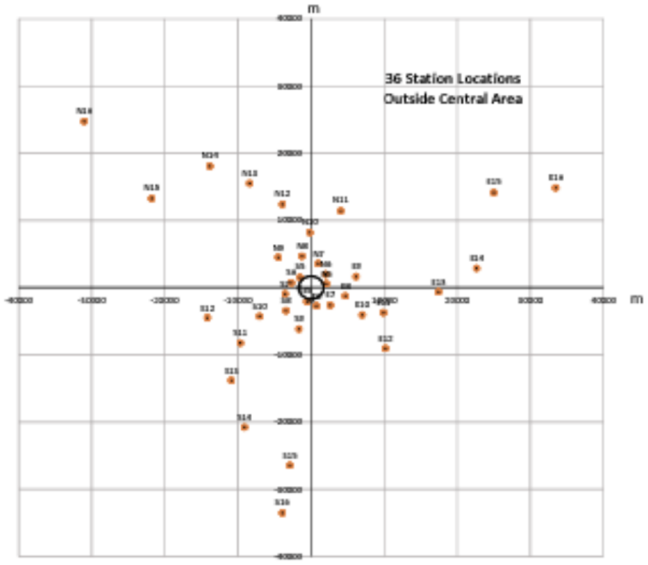
- **Unprecedented** performances:

SKA1-LOW – Configuration and parameters

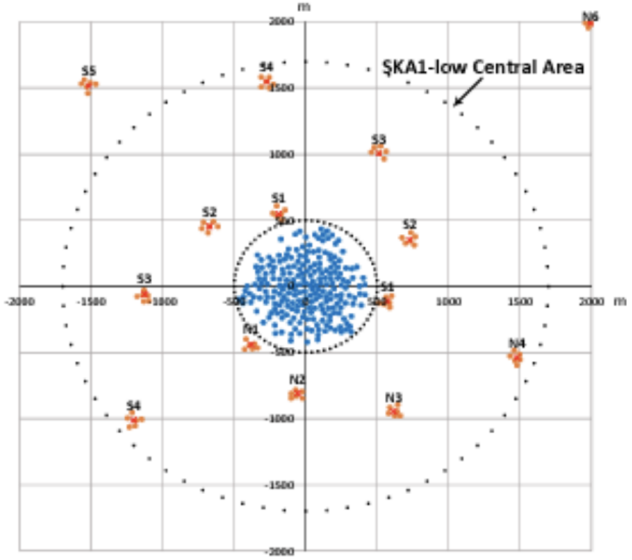
- *Frequency range: 50-350 MHz*
- *Aperture phased array*: no moving parts - digital beamforming
- 256 *elements* x 512 *stations* -> **~131000 wide bandwidth identical antenna**
- total *collecting area* of ~ **0.4 square Km**
- ***close-packed*** pseudo-random configuration



3 spiral arms, out to a radius of ~65 km



core , 75% of the antennas within 2km

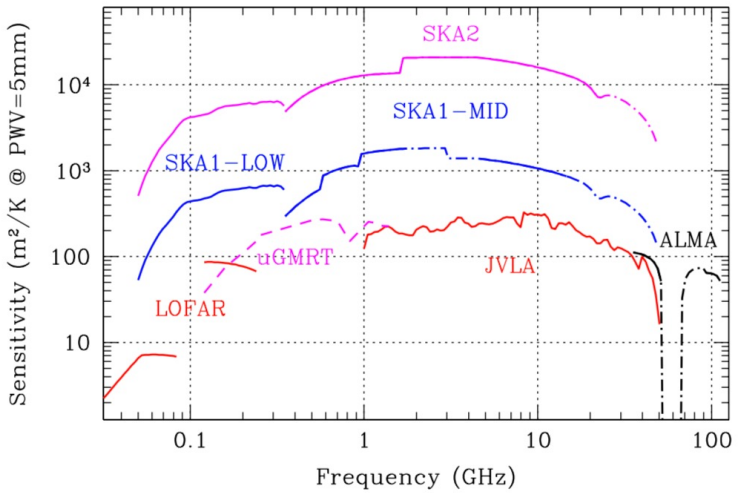


Labate et a. 2017

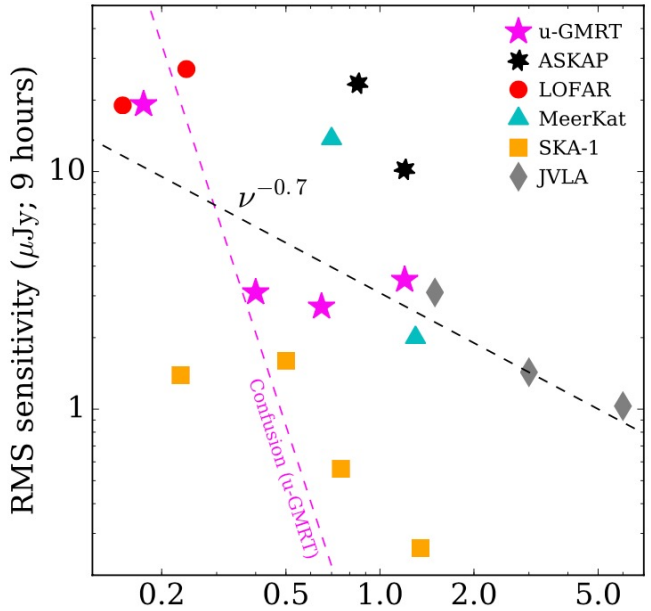
SKA1-LOW - Performances

	Nominal Frequency	110 MHz	300 MHz
Continuum	FoV [arcmin]	327	120
	Max. Resolution (arcsec)	11	4
	Max. Bandwdith [GHz]	0.3	0.3
	Cont. rms, 1 hr (μJy/beam)[a]	26	14
Spectral line	Line rms, 1 hr [μJy/beam][b]	1850	800
	Resolution Range for Cont. and Line rms [arcsec][c]	12–600	6–300
	Channel width (uniform resolution across max. bandwidth) [kHz]	5.4	5.4
	Spectral zoom windows X narrowest bandwidth [MHz]	4 X 4.0	4 X 4.0
	Finest zoom channel width [Hz]	244	244

SKA1-LOW and other instruments



Sensitivity compared to the current radio facilities

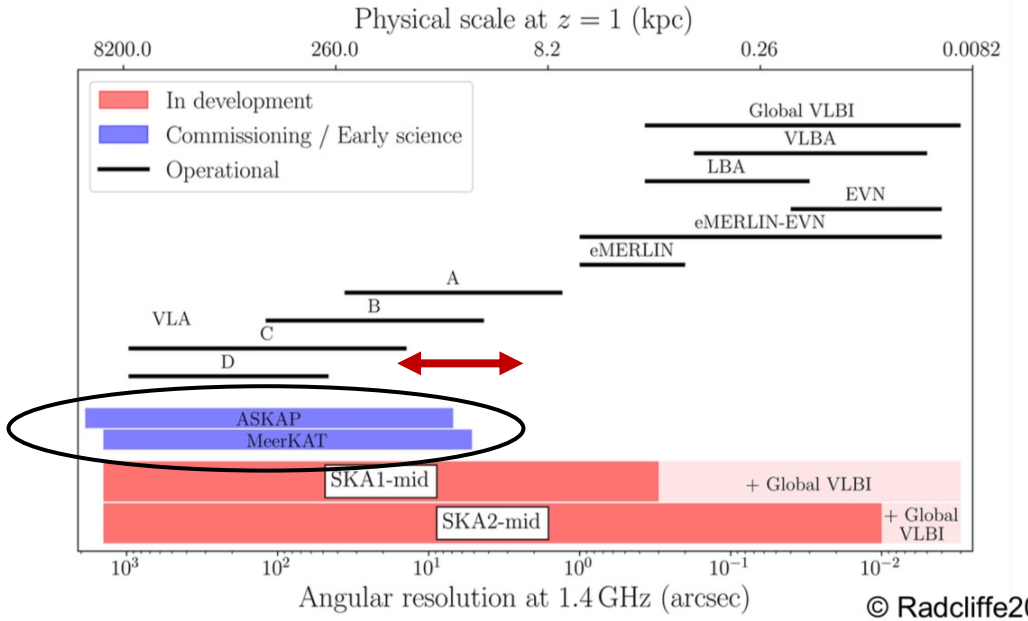


From Patra et al. 2019

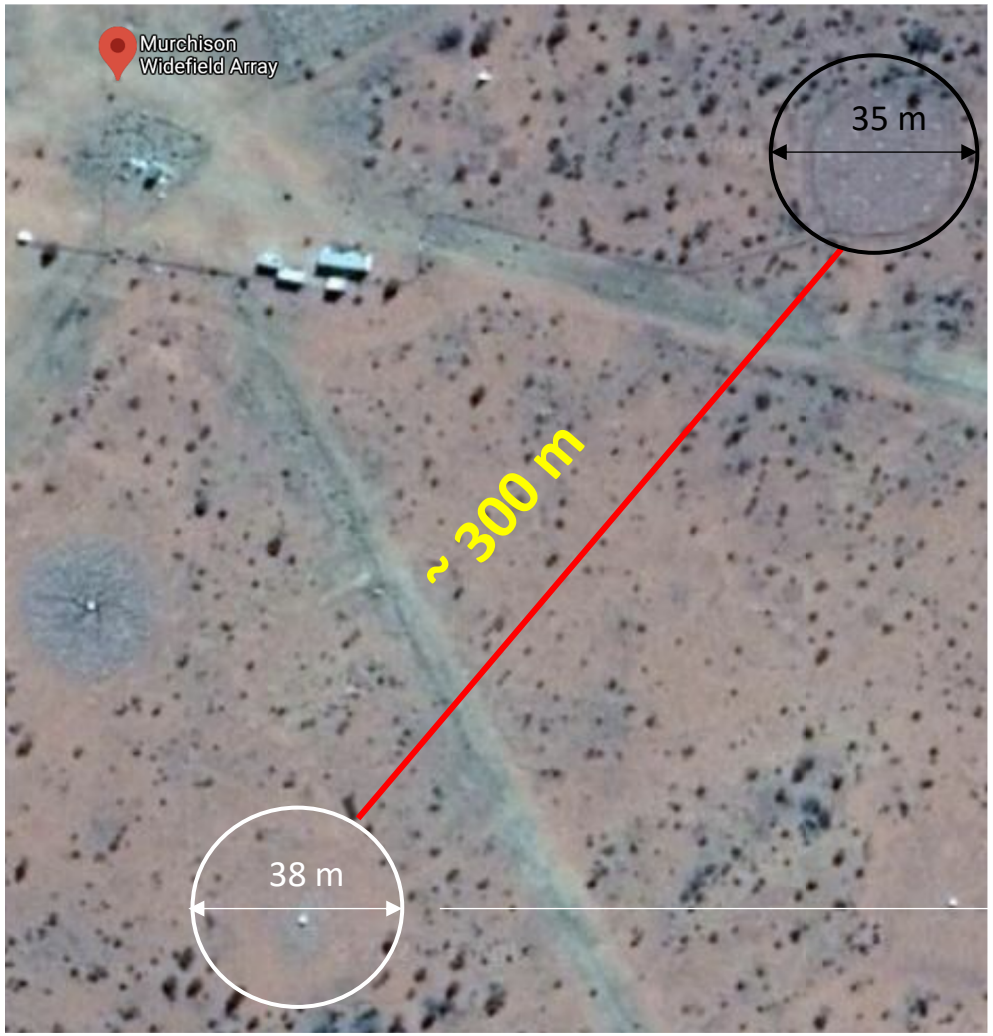
Highest angular resolution comparable to LOFAR and to the current facilities operating at 1.4 GHz

Thanks to its configuration, a very broad range of angular scales are covered simultaenously

Now fully operational

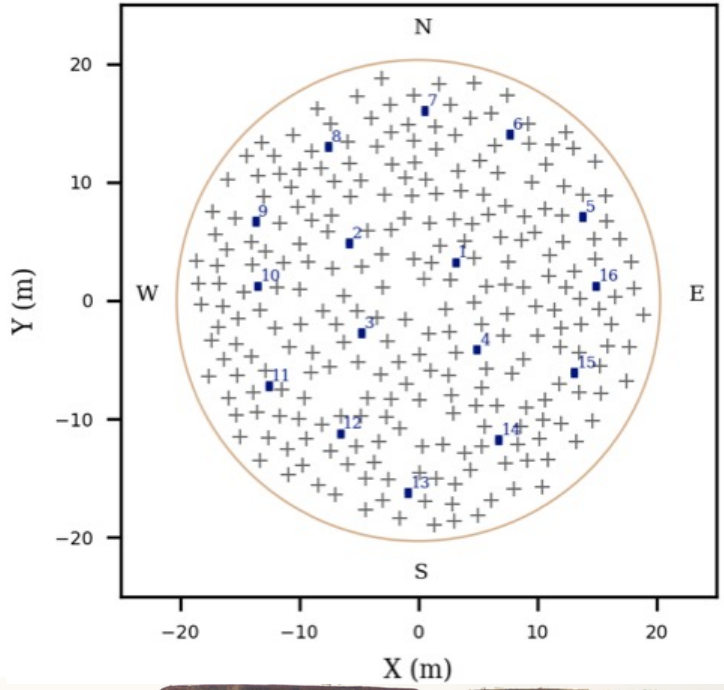


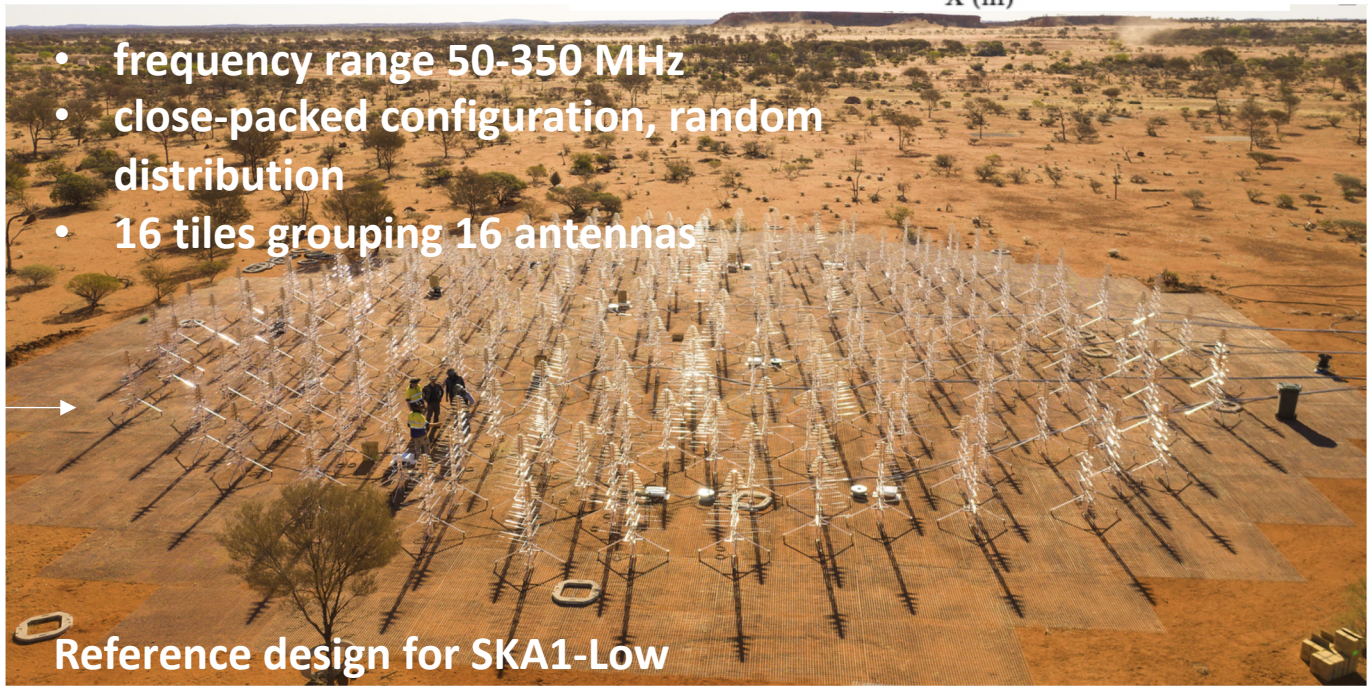
Two demonstrators currently operational at MRO
to test the SKA-low system before full construction



AAVS2 – 256 **SKALA 4.1 log periodic** antennas
SKALA 4.1 passed the critical design review

EDA2 - 256 **MWA dipoles**
with modified LNA for 50-350 MHz





Calibration campaigns

datasets" of parallel AAVS2/EDA2 acquisitions:

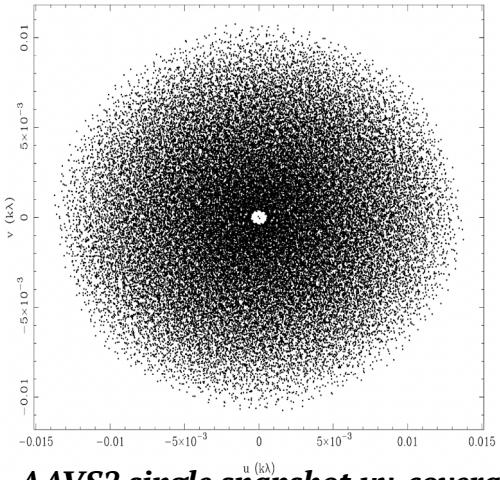
50, 70, 110, (137), 160, 230, 320 MHz (based on UAV)

started in 12/2019, stable since 02/2019

snapshots every 5 minutes, across ~24-48 hours LST

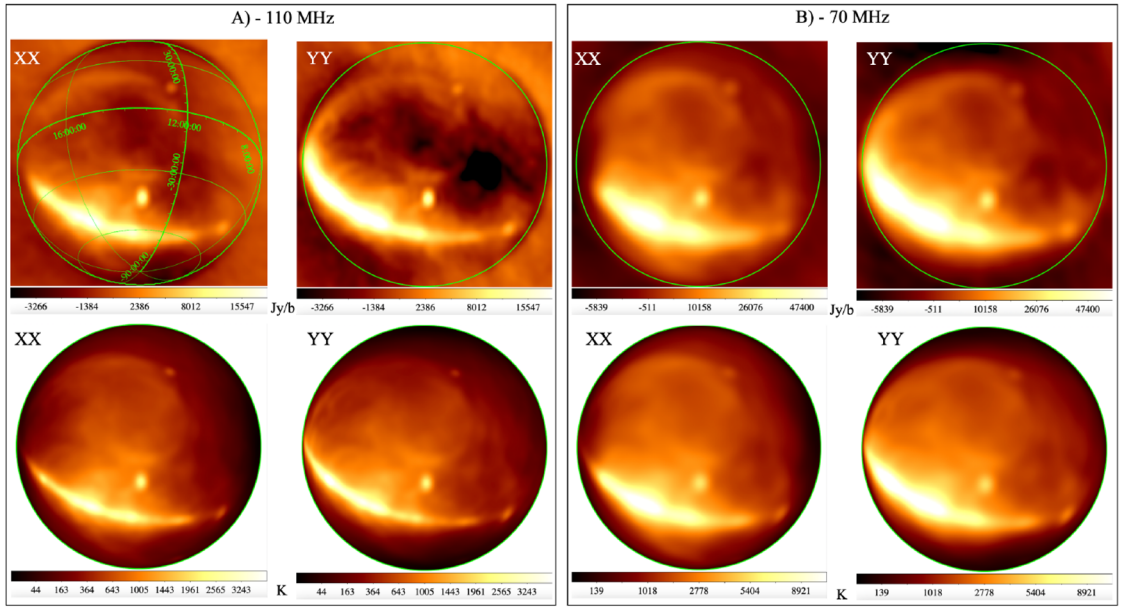
when Sun at transit

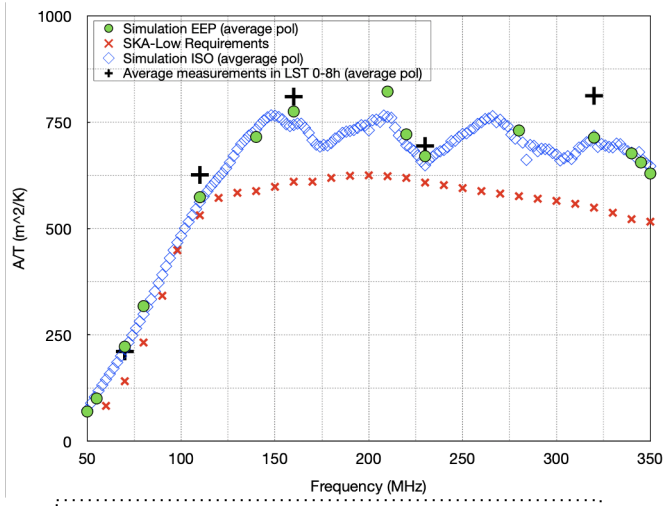
(t_{int}=0.14s, ~1 MHz BW, main purpose: sensitivity)



AAVS2 single snapshot uv-coverage at 110 MHz (Sun transit)

PSF~3.9° **PSF~6.2°**





Macario, Pupillo, Bernardi et al. 2021
Sokolowski et al. 2021a & 2021b
Wayth et al. submitted

- AAVS2 is calibratable
- AAVS2 is fairly stable over at least 24 hours
- measured sensitivities meet the SKA1-Low requirements and are in agreement with simulations

SKA1-LOW timeline

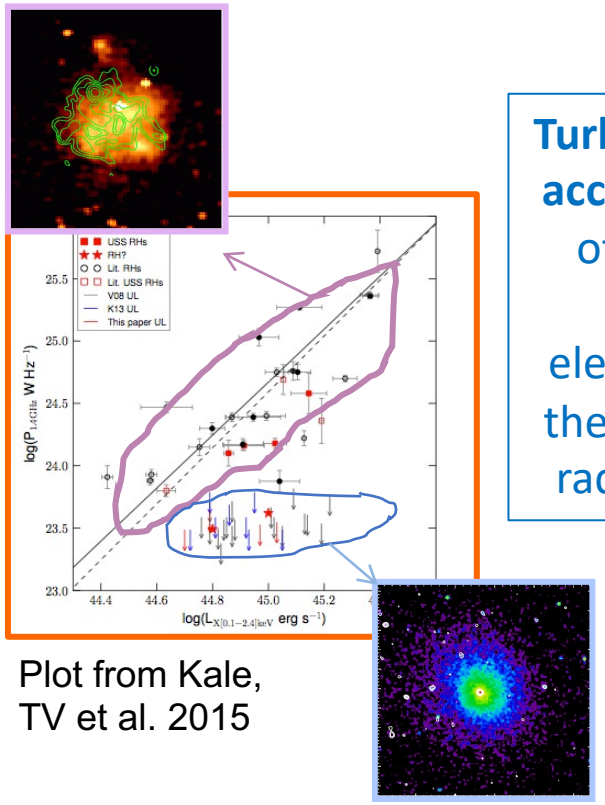
Stage	Date
SKA-low 6 station array (AA0.5)	March 2024
SKA-low 18 station array (AA1)	February 2025
SKA-low 64 station array (AA2)	December 2025
SKA-low 256 station array (AA3)	September 2026
Full Array (AA4)	June 2027
Operation Readiness review	December 2027
End of construction	July 2029

Adapted from Diamond (Third Italian SKA Meeting)

Radio sources in galaxy clusters

Current knowledge for halos and relics

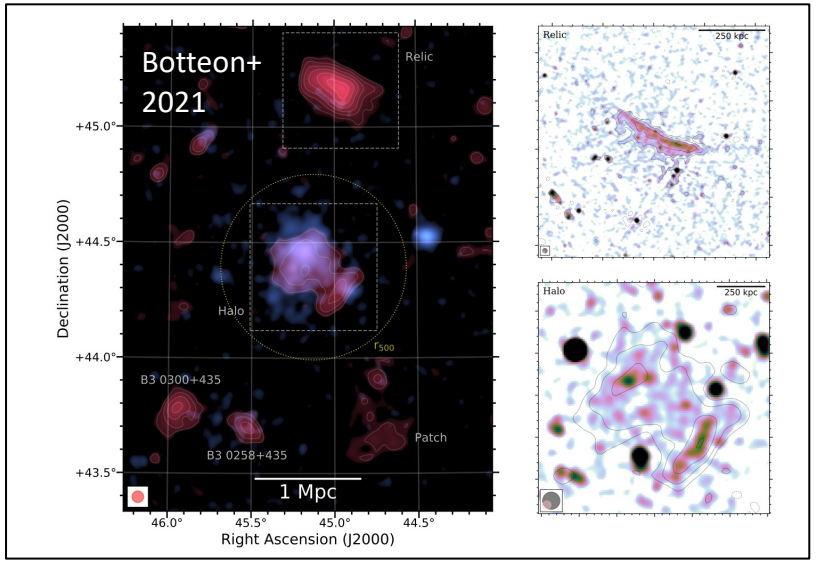
- The parameter space sampled in the M_{500}/logX-logP plane has considerably expanded and we are now detecting **signatures** of structure formation and accretion **in systems with very low mass**
- **Ultra-steep spectrum radio halos** are found

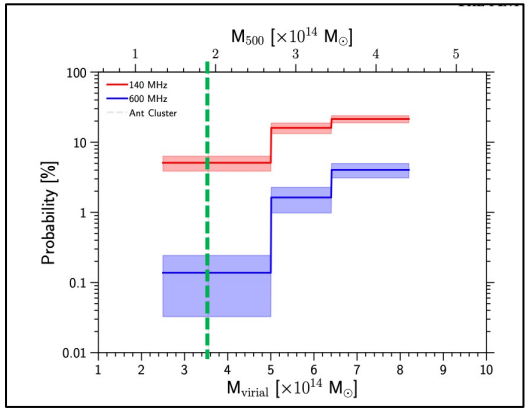


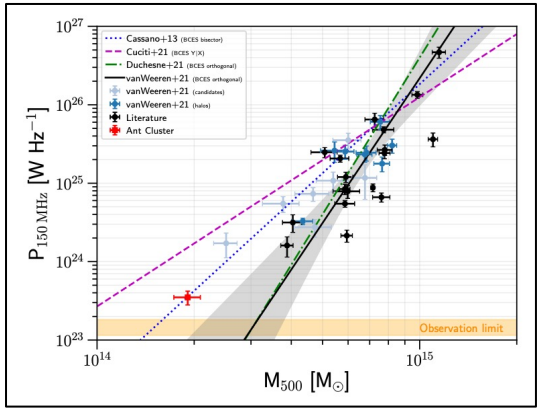
Plot from Kale, TV et al. 2015

Turbulent re-acceleration of in-situ seed electrons at the origin of radio halos

PSZ2G145.92 (z=0.03) is the least massive cluster (M ~2x10^{14} M_{sun}) with the least powerful radio halo (P_{150}=3.9x10^{23} W/Hz)







Predictions on the number of radio halos at low frequencies in the framework of turbulent re-acceleration (Cassano et al. 2015)

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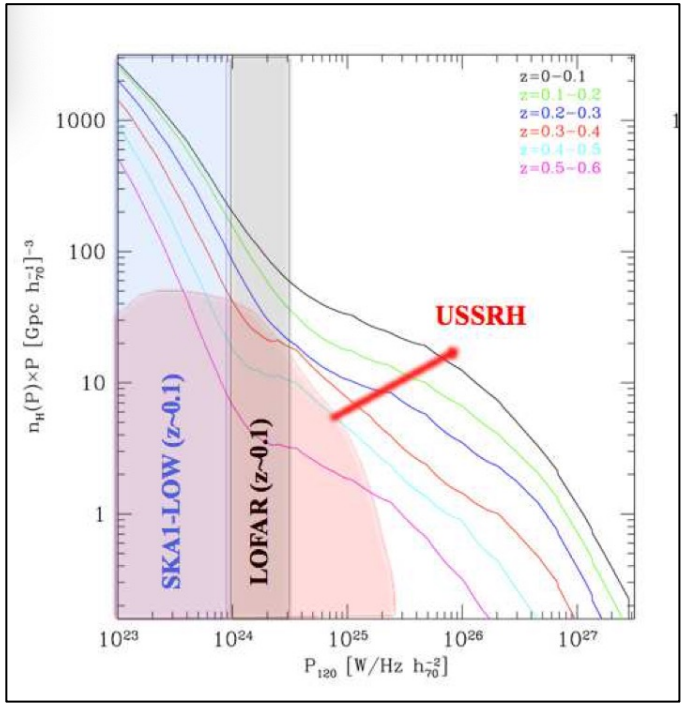
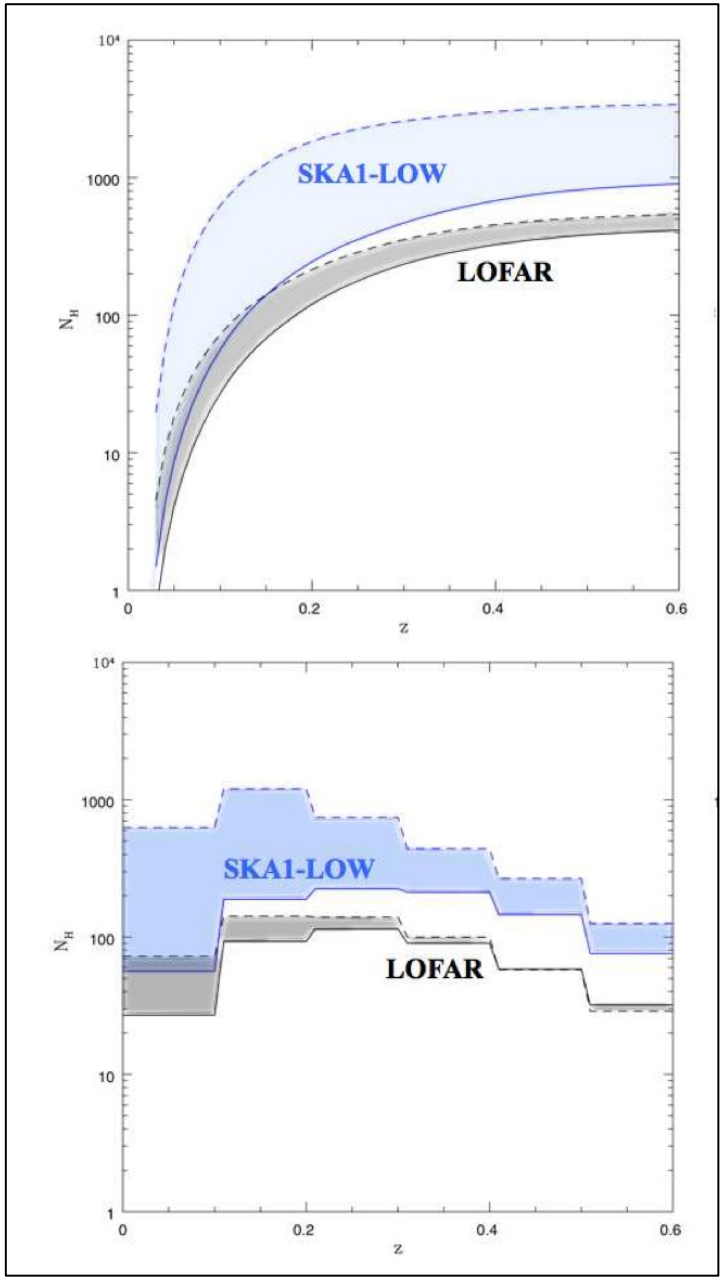
Statistical investigations from LoTSS @140 MHz confirm the expected numbers (Botteon, Cassano, et al. in prep.)

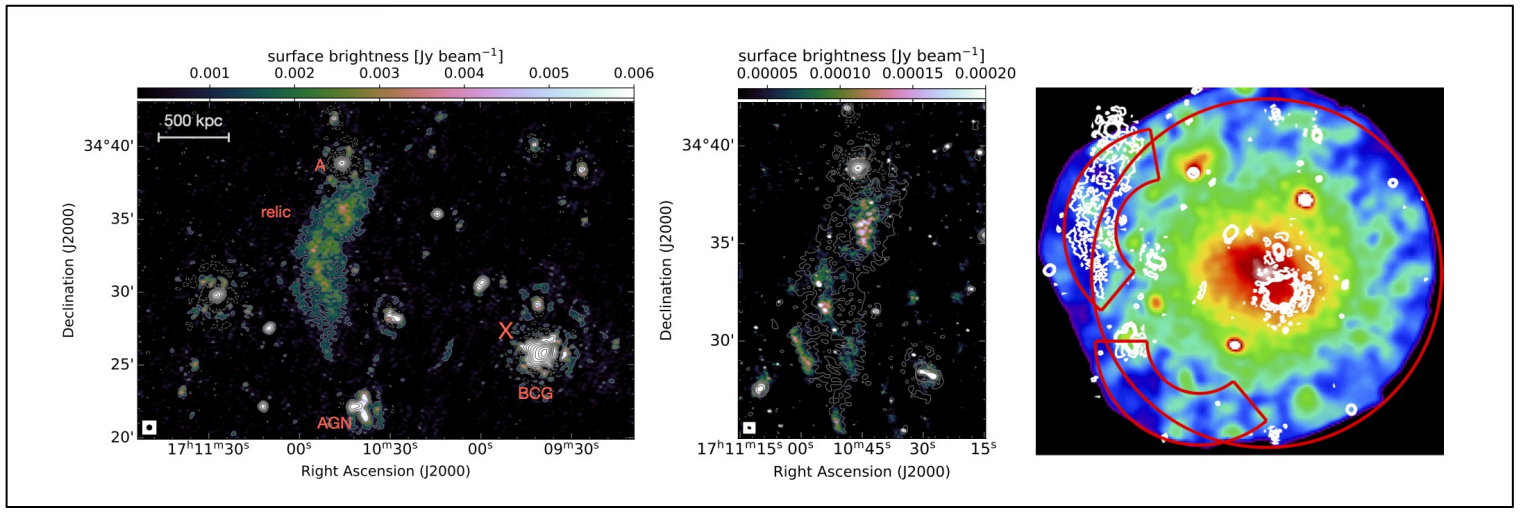
Crucial to constrain the origin of such sources at **high redshift** and for **low masses** and **minor accretion processes** which are really the building blocks of large scale structures and the dominant processes at high z

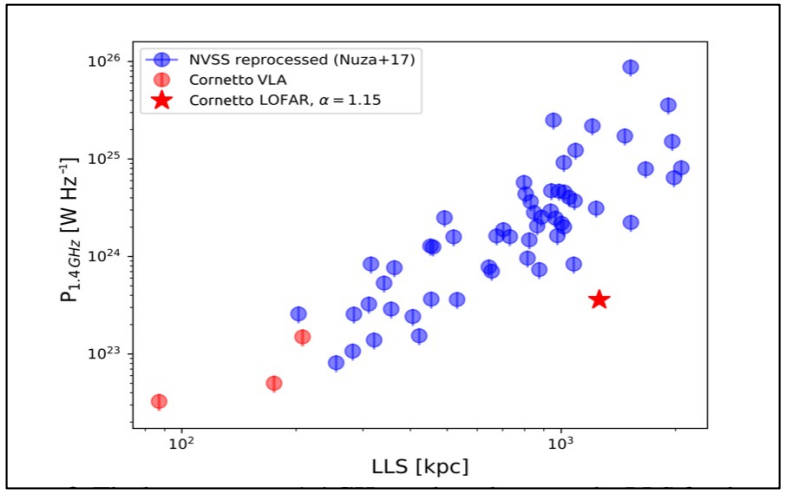




Cassano et al. 2015

New region of the parameter space for relics

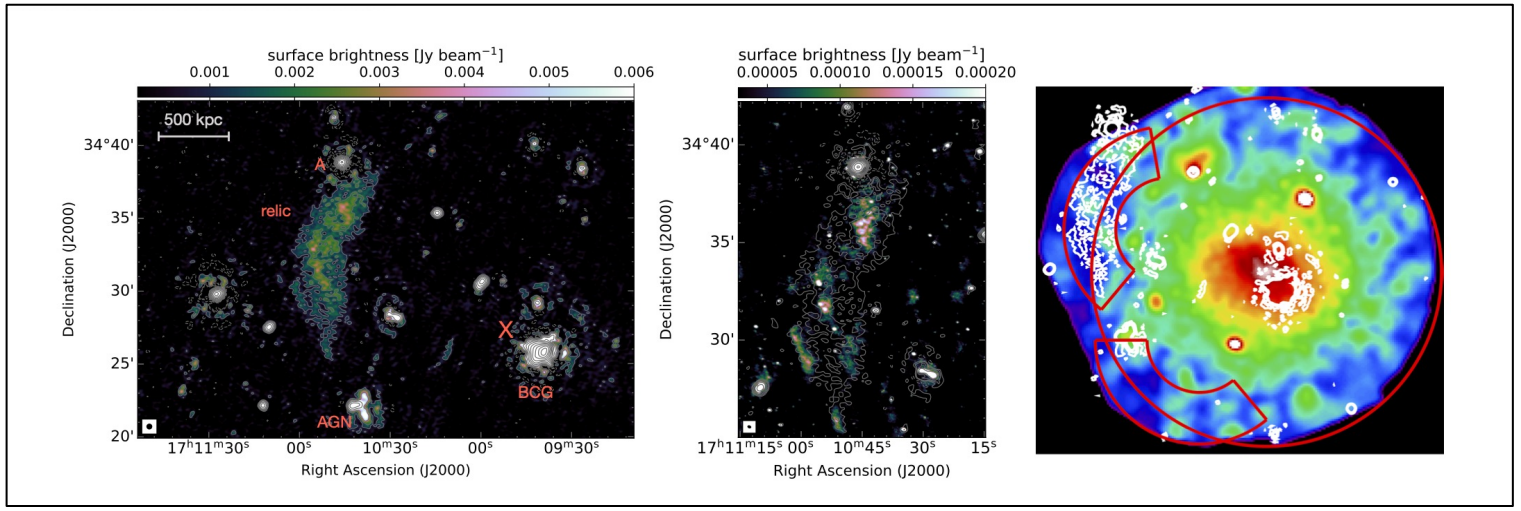


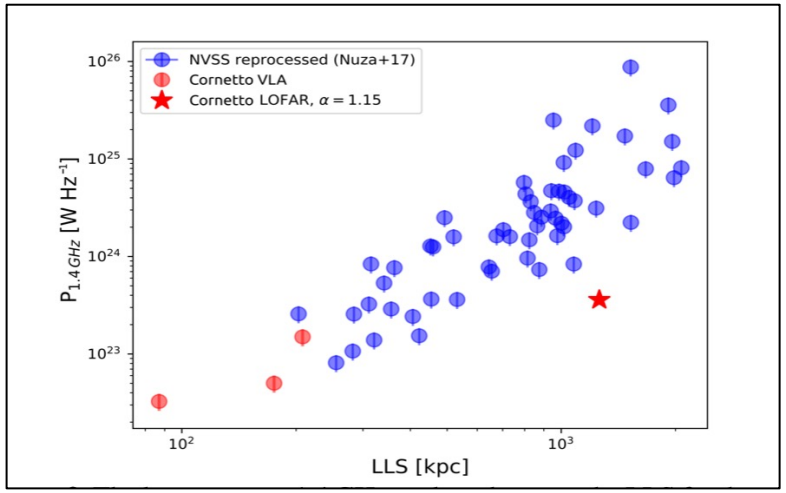


The case of the «Cornetto Relic» in A2249 (faint, MPc scale, DSA enough to explain its origin)

Locatelli et al. 2020

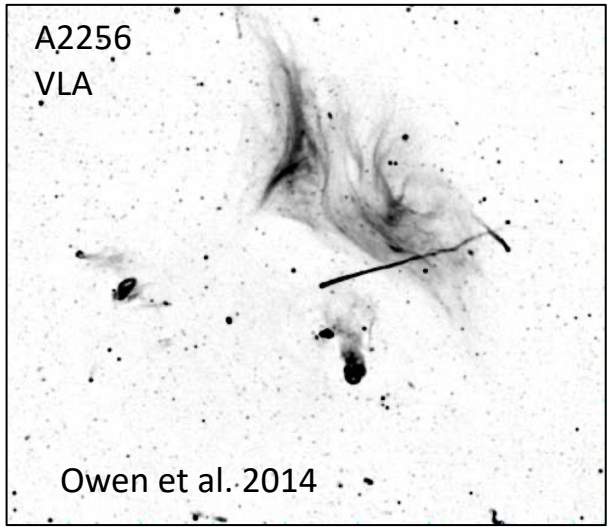
New region of the parameter space for relics

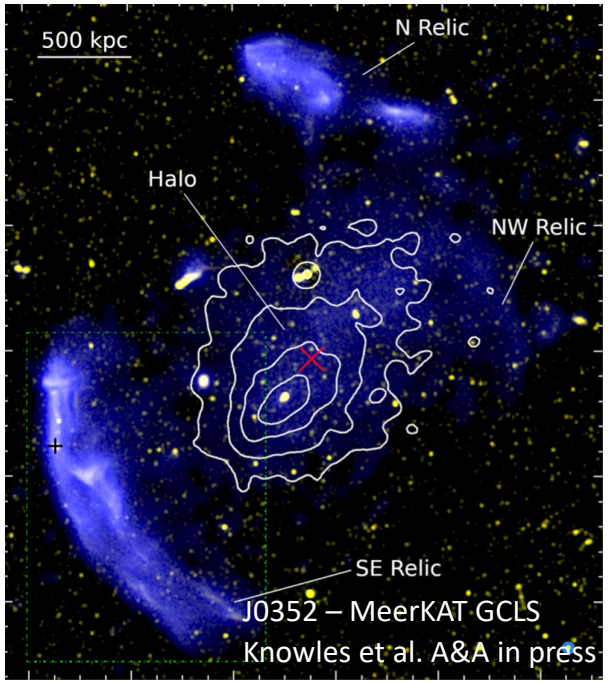




The case of the «Cornetto Relic» in A2249 (faint, MPc scale, DSA enough to explain its origin)
Locatelli et al. 2020

Filamentary structure of relics more and more common
Need for **polarization information at low frequency** to constrain the magnetic field properties

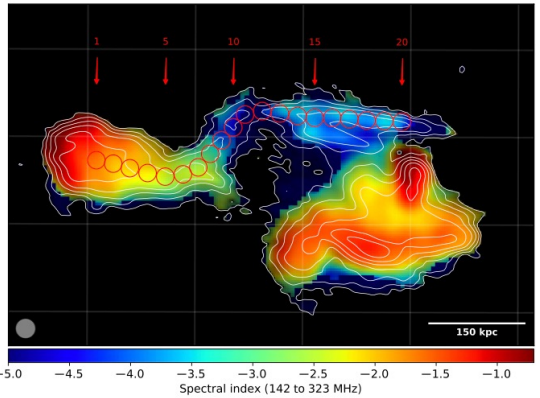


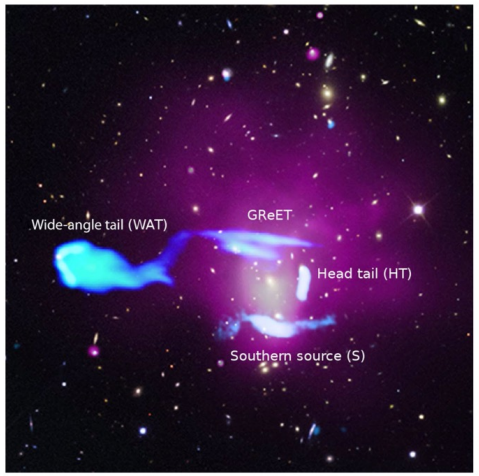


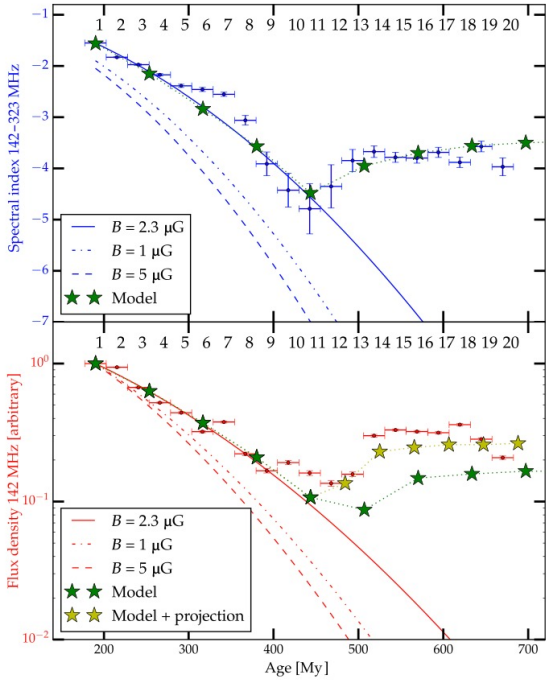
Radio sources in galaxy clusters

New areas of investigation for radio galaxies in clusters

- **Radio galaxies - where AGN science and galaxy cluster science meet**



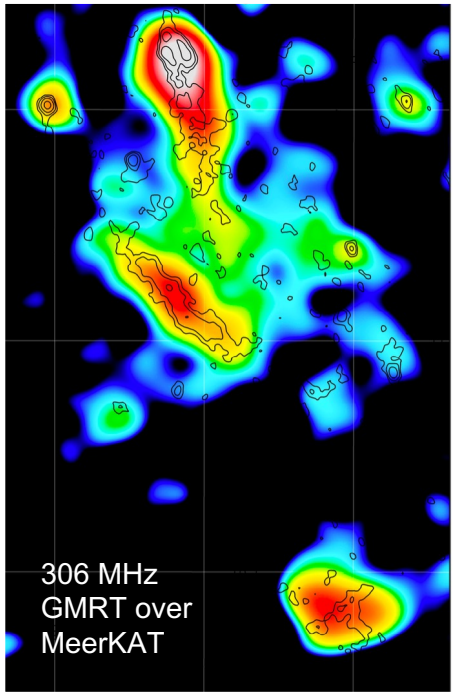




LOFAR and uGMRT

The case of A1033 and **Gentle Re-acceleration** in radio tails

de Gasperin et al. 2017

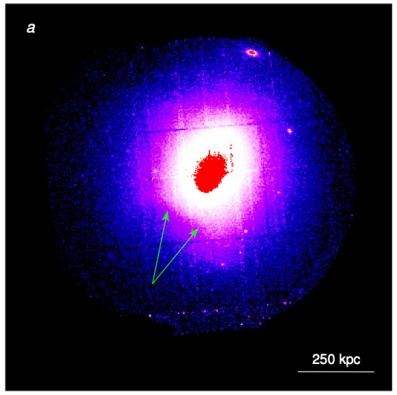


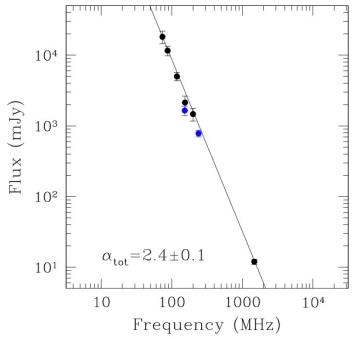
GMRT and MeerKAT

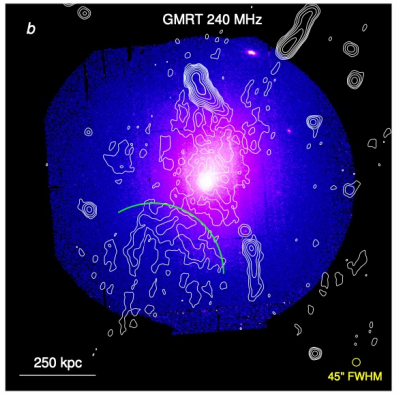
Broken head-tail and bar in the Shapley Concentration

Radio galaxy – ICM shock interaction?

Venturi et al. submitted







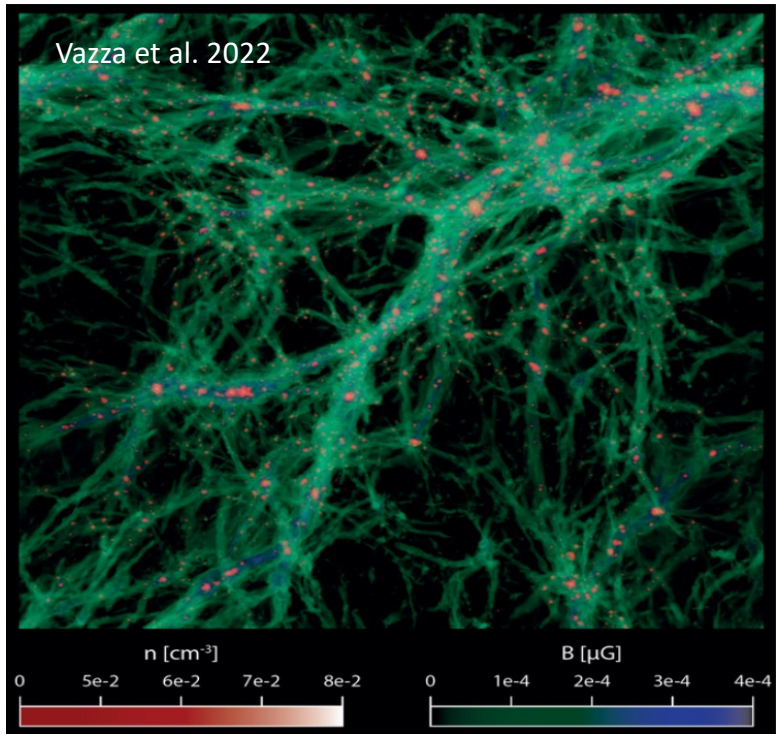
The extreme outburst at the centre of the Ophiucus cluster

$pV \sim 5 \times 10^{61}$ erg

A case of **fossil extraordinary powerful AGN outburst** with dramatic implications on the cluster itself

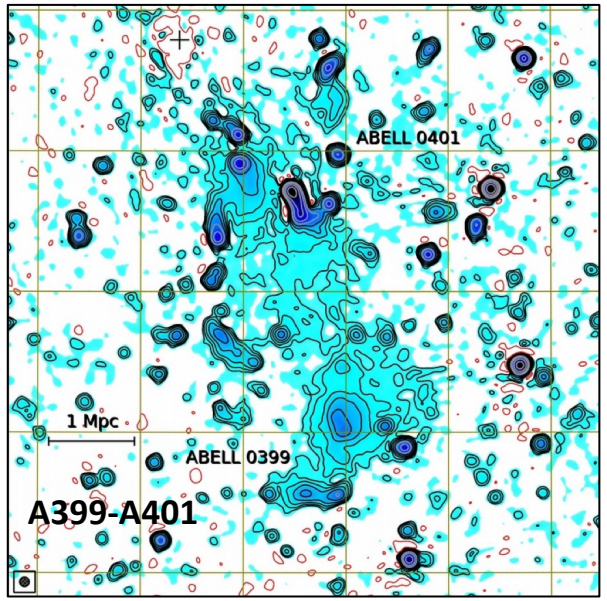
Giacintucci et al. 2020

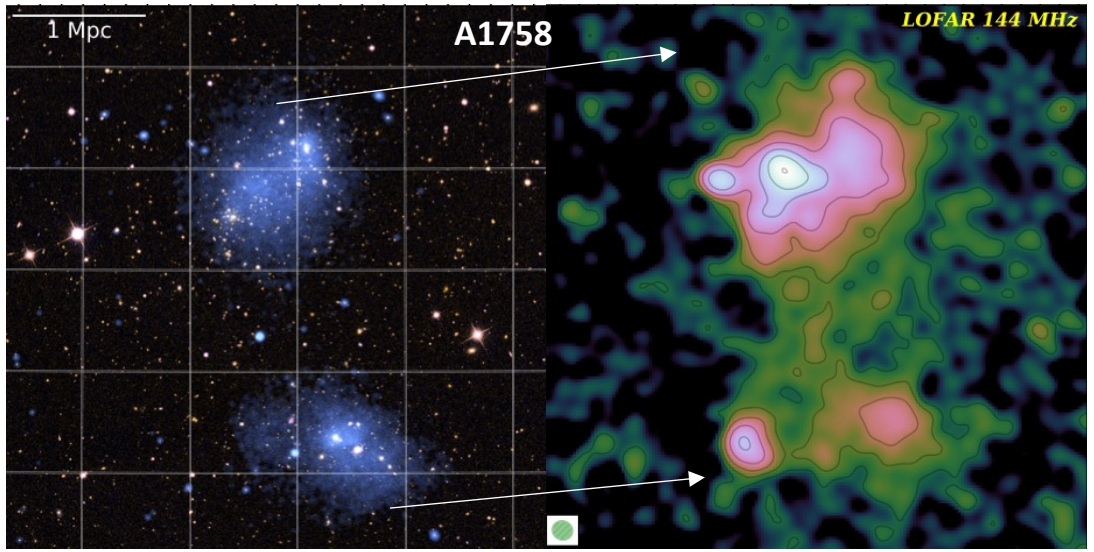
Main SKA challenge: radio detection from the cosmic web

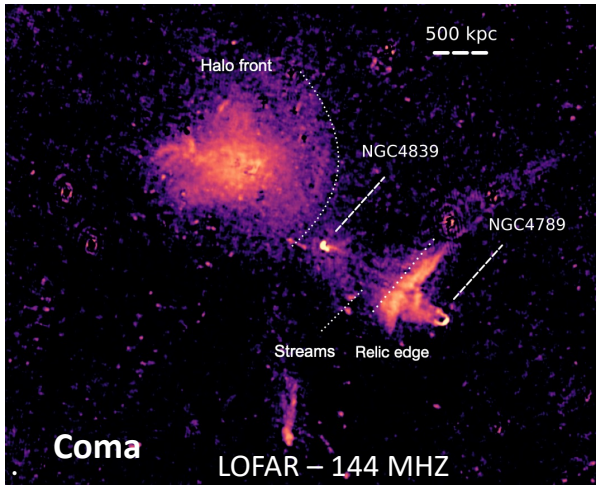


Only very few cases of detection of radio emission beyond the cluster scale, so far at low frequencies

- Coma cluster (Kim+,1989, Bonafede+, 2021)
- A1758 (Botteon+ 2020)
- A399-A401 (Govoni+ 2019)





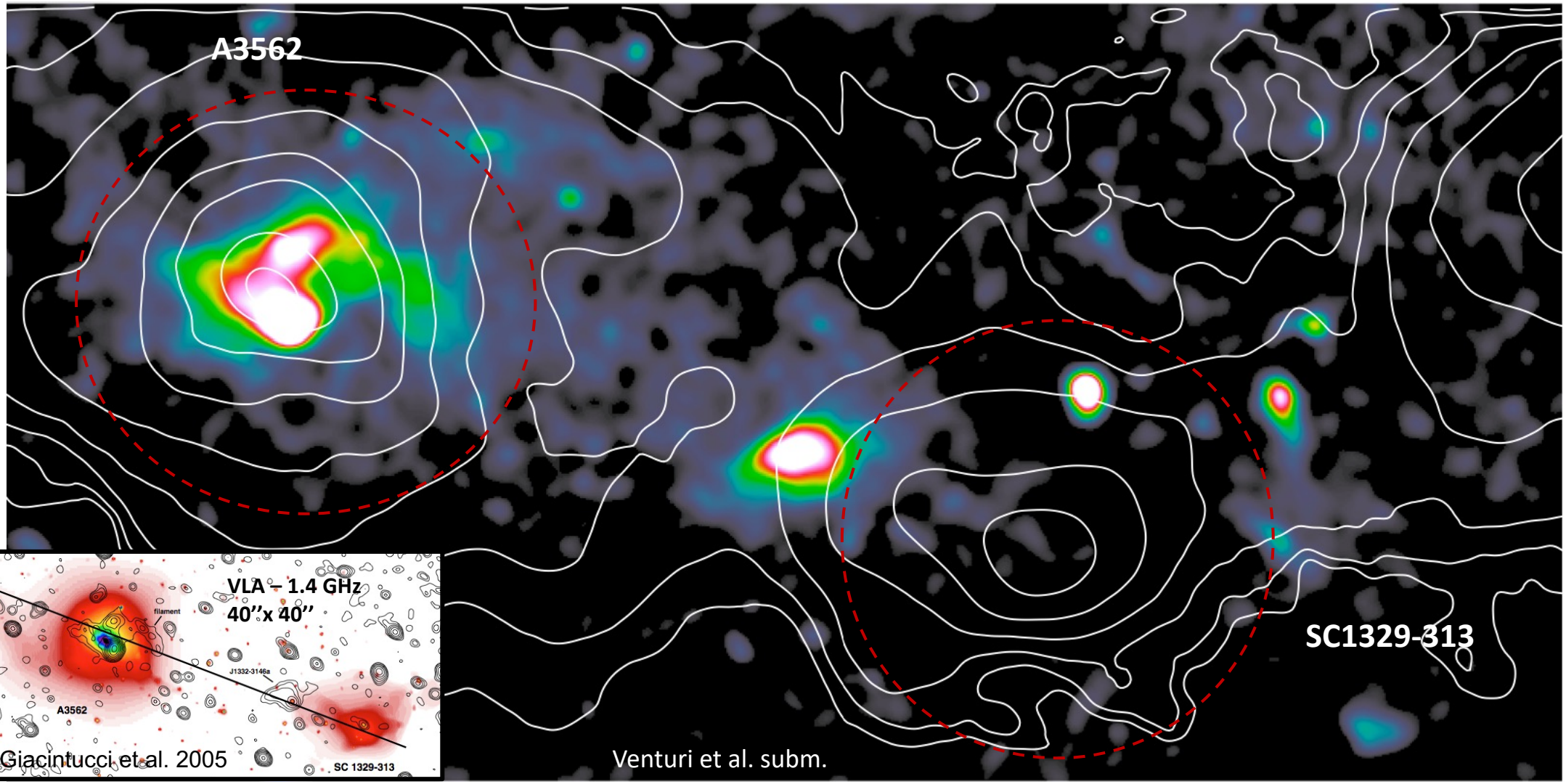


Key question – **detection of radio emission on scales beyond galaxy clusters**, in regions where $B_{eq} \lesssim 0.1$ μG to explore the **origin of primordial magnetic fields.**

Strong **synergy among observations, simulations, HPC**

Intercluster filament in the **Shapley Concentration** detected at 1.2 GHz with MeerKAT

A key target for SKA1-LOW



White contours show the XMM emission

Filament barely detected with ASKAP

B_{eq} ~ 0.8μG

MeerKAT – 1.283 GHz
43.0''x42.2'' - Point source subtracted
rms ~ 30 μJy/b

The need for an institutional framework

Italy and Australia have a long standing tradition of cooperation in science and technology

- Bilateral agreements of cooperation between IRA (CNR) and CSIRO have been active and very successful from 1995 to 2003, and have spread the seeds of the present collaborations
- Mutual growth in the development towards SKA1-low
- Italian scientific community very active and well represented in the exploitation of ASKAP (EMU, POSSUM, WALLABY and Early Science, such as **Scorpio** and **Shapley Concentration**, both also accepted for Pilot II Survey)
- Italian postdocs in Australia
- Shared supervision of PhD thesis making use of the Australian radio facilities

Moreover

- ✓ A bilateral agreement of scientific, technological and innovation cooperation exists between Italy and Australia, signed on May 22nd, 2017 in Canberra and ratified in May 2021
- ✓ The Italian Ministry of Foreign Affairs supports the agreement with a budget of 461kEuro/year

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The scientific programmes in both countries and all the scientific and technological cooperations would greatly benefit from the implementation of such bilateral agreement

THANK YOU FOR YOUR ATTENTION