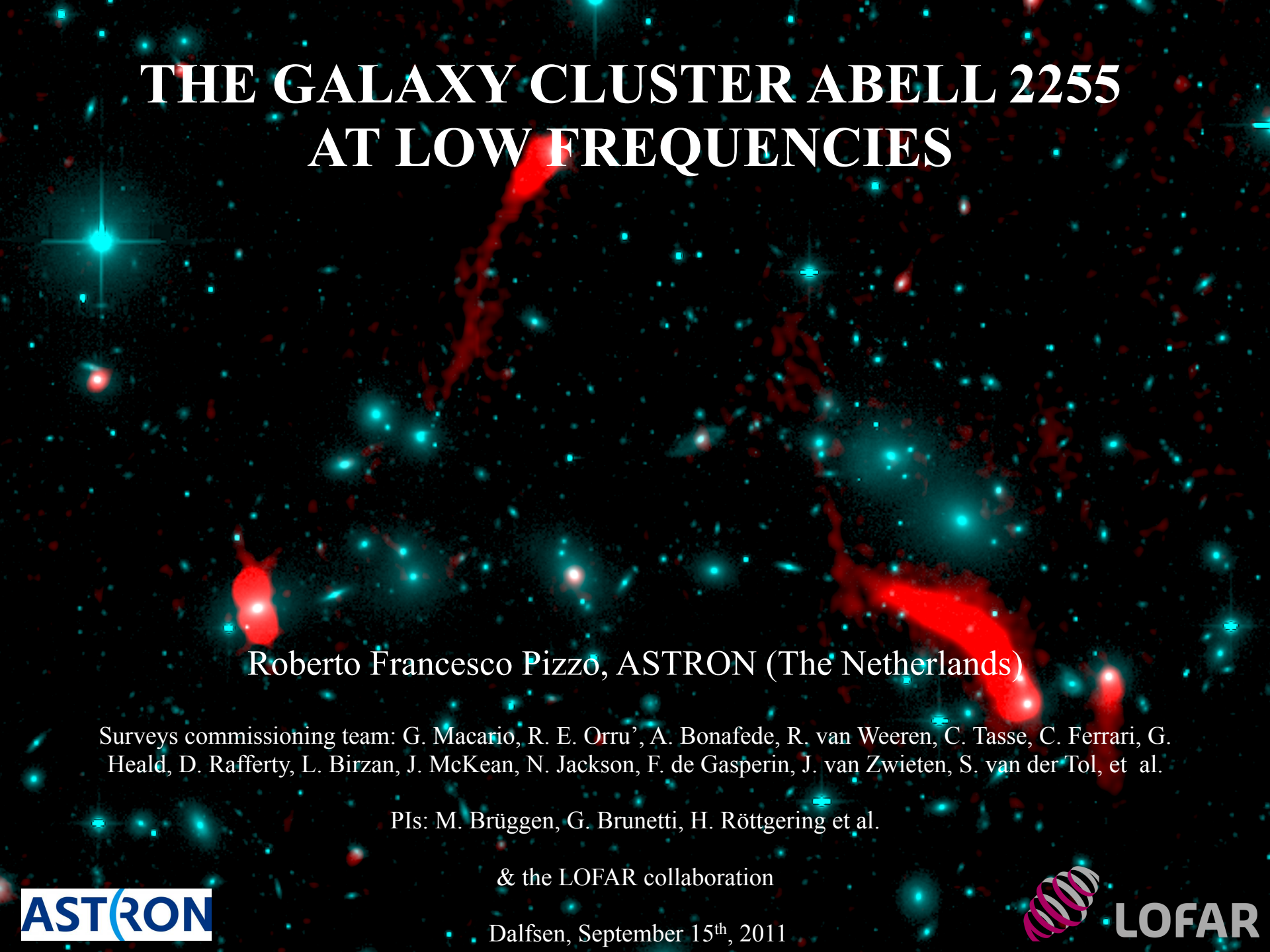
THE GALAXY CLUSTER ABELL 2255 AT LOW FREQUENCIES



Roberto Francesco Pizzo, ASTRON (The Netherlands)

Surveys commissioning team: G. Macario, R. E. Orru', A. Bonafede, R. van Weeren, C. Tasse, C. Ferrari, G. Heald, D. Rafferty, L. Birzan, J. McKean, N. Jackson, F. de Gasperin, J. van Zwieten, S. van der Tol, et al.

PIs: M. Brüggen, G. Brunetti, H. Röttgering et al.

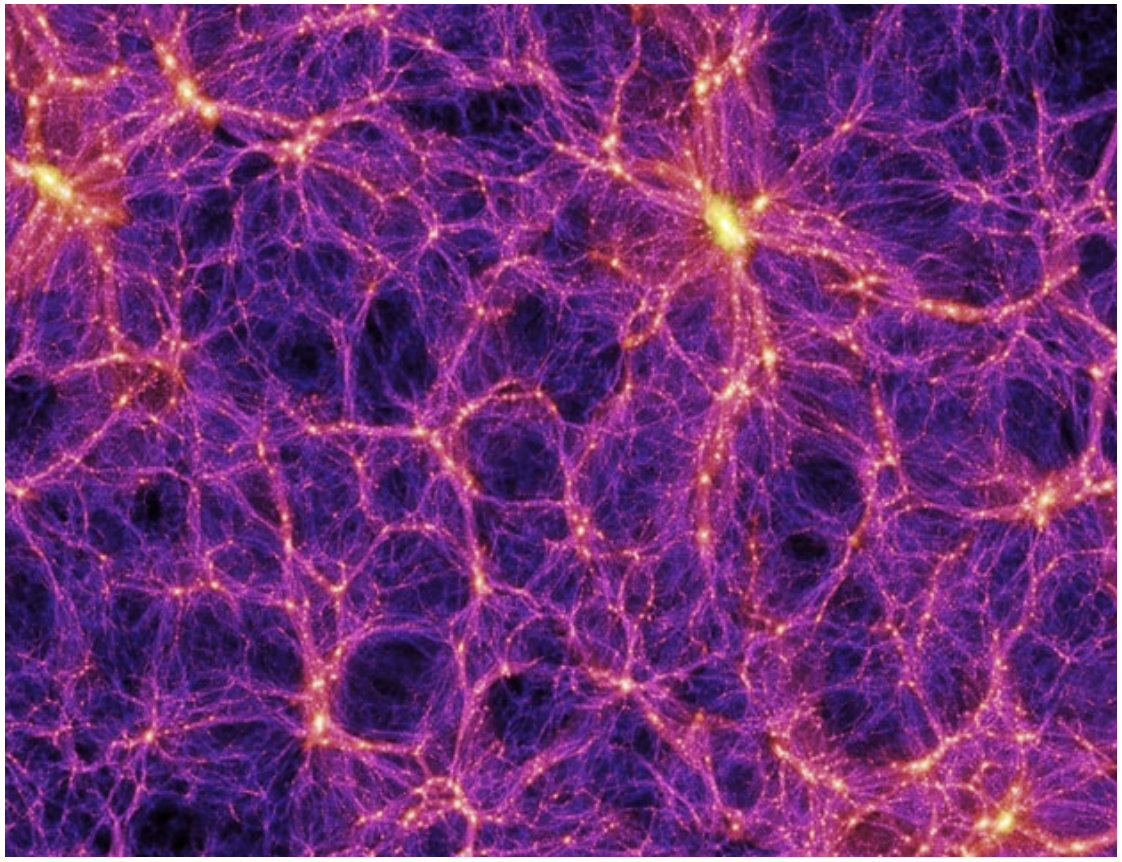
& the LOFAR collaboration

Dalfsen, September 15th, 2011

ASTRON

LOFAR

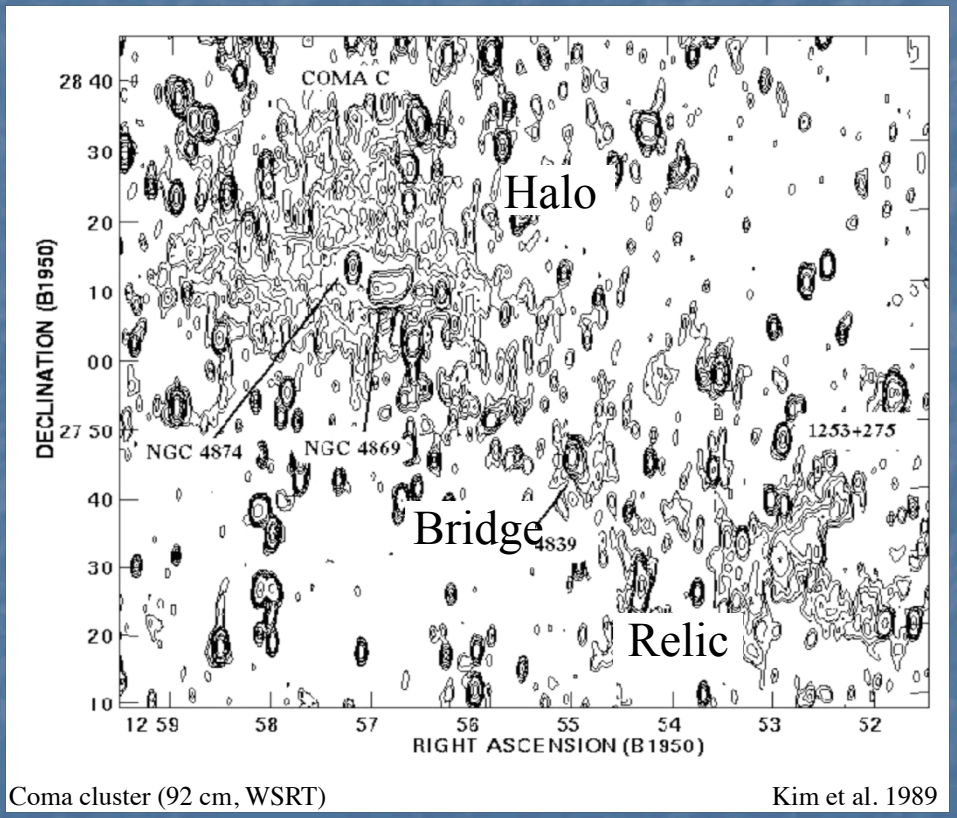
THE LARGE SCALE STRUCTURE OF THE UNIVERSE



Galaxy clusters lie at the nodes of the filamentary large-scale structure of the universe.

They grow by merger of smaller sub structures and continuous inflow of matter along the supercluster filaments

RADIO EMISSION FROM CLUSTERS: RADIO GALAXIES, HALOS, AND RELICS



Coma cluster (92 cm, WSRT) Kim et al. 1989

HALO:
- at the cluster center
- regular morphology
- steep spectrum ($\alpha < -1$, $S(\nu) \propto \nu^{\alpha}$), flattening towards the halo center
- unpolarized (< 10%)

RELIC:
- peripheral source
- elongated shape
- steep spectrum ($\alpha < -1$)
- highly polarized (20-40%)

HALOS AND RELICS:

- provide the evidence of the existence of magnetic fields (B ~1 μG) and relativistic particles ($\gamma >> 1000$) distributed over the cluster volume

- provide an important test for several theories concerning the origin of the relativistic particles and their propagation in astrophysical plasma

- indicate a perturbed dynamical state and can provide information on large-scale structure formation

- are the strongest extragalactic foreground radio sources and therefore they are related to complementary cosmological studies (e.g. EOR project)

HALOS AND RELICS:

The origin of halos and relics is associated with cluster mergers. The mechanisms that transfer energy to the electrons are

- HALOS: turbulence (Brunetti et al. 2001; Petrosian 2001; Fujita et al. 2003)

  1. the electrons are re-accelerated at several locations within the cluster (primary models)

  2. the electrons are the result of the collisions between the relativistic protons and the thermal ions present in the ICM (secondary models)

- RELICS: acceleration at shock waves (merger shocks or LSS shocks)

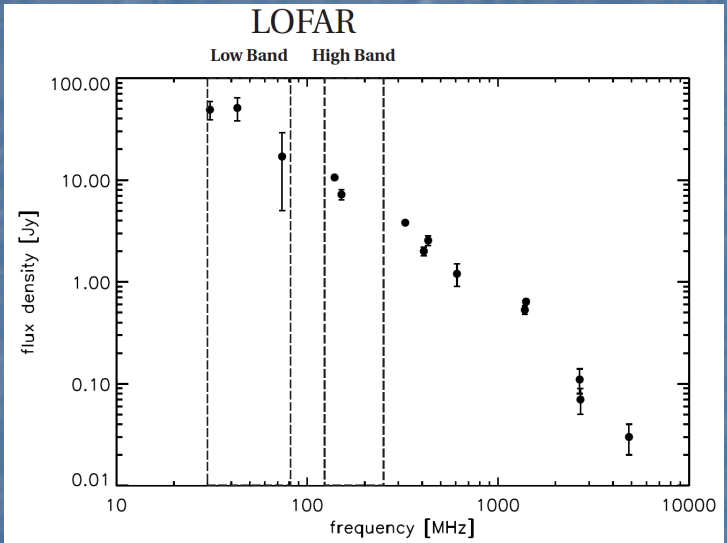
  1. Fermi-I diffuse acceleration of ICM electrons (Enblin et al. 1998; Keshet et al. 2004)

  2. adiabatic energization of relativistic electrons confined in fossil radio plasma ("ghosts"), released by a former AGN (Enblin & Gopal-Krishna 2001)

STUDYING HALOS AND RELICS

➢ An increased statistics and knowledge of the physics of halos and relics is required to properly answer the open questions regarding their origin. High resolution and sensitivity are important for this purpose.

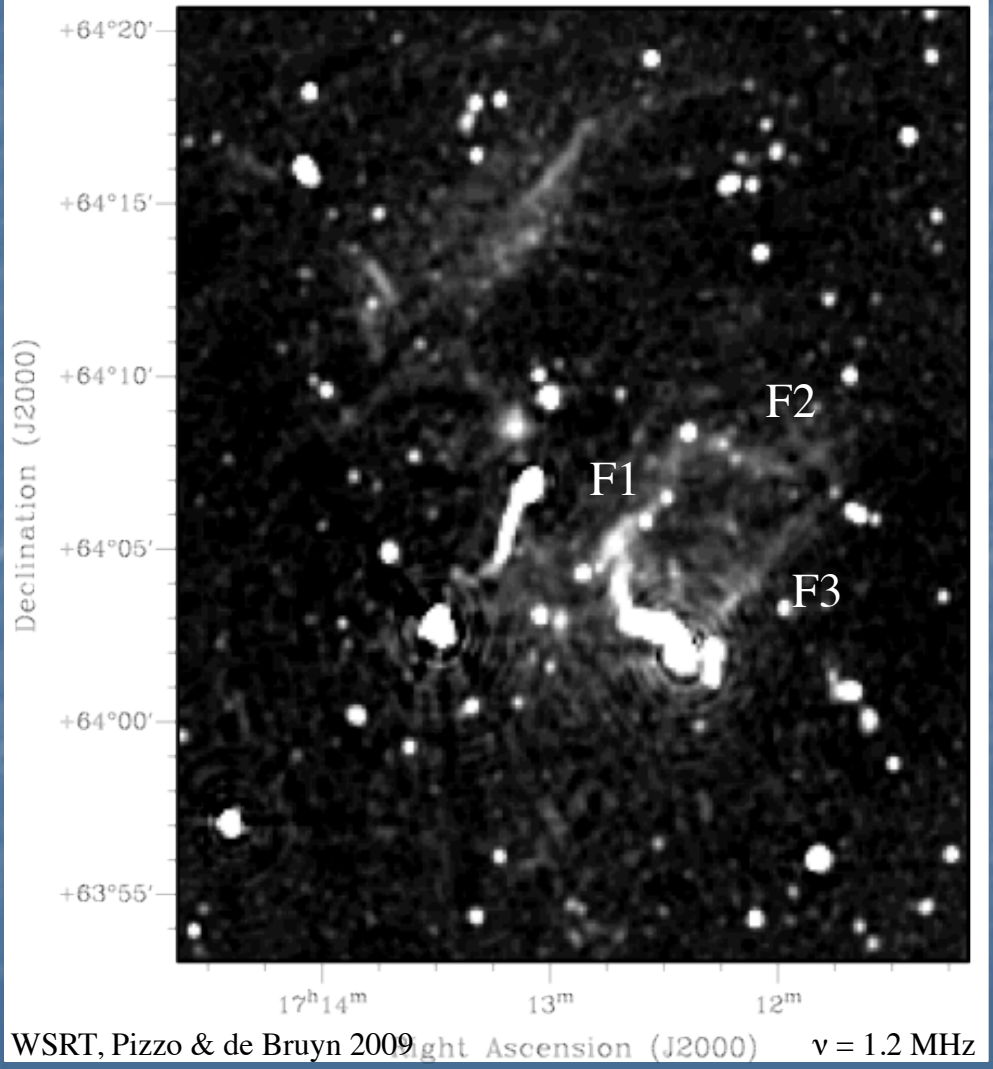
➢ Given the steep spectrum of halos and relics, low frequencies are the key for their detection



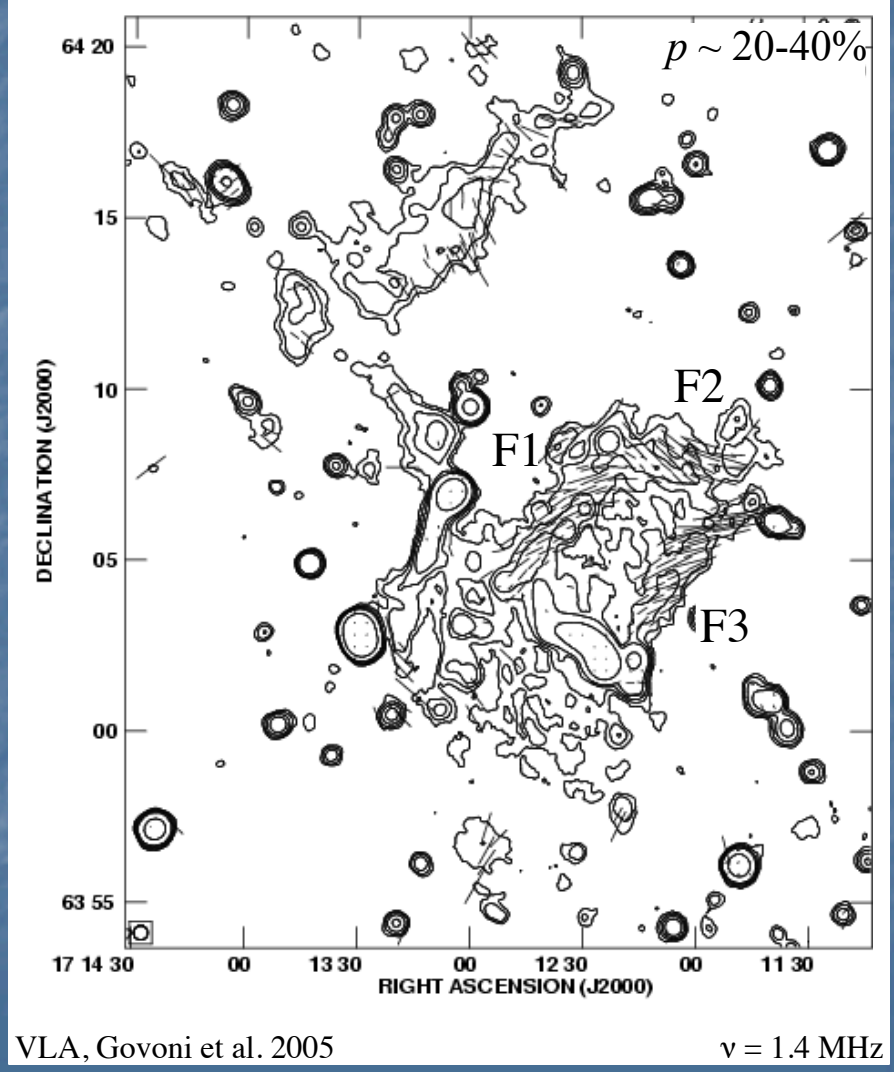
The spectrum of Coma C with superimposed the frequency range domain of LOFAR

➢ Large statistical samples of halos and relics will be studied by LOFAR, which will detect 500 halos/relics up to z=1 at 120 MHz (Röttgering 2003)

SCIENCE CASE: ABELL 2255 (z = 0.08)



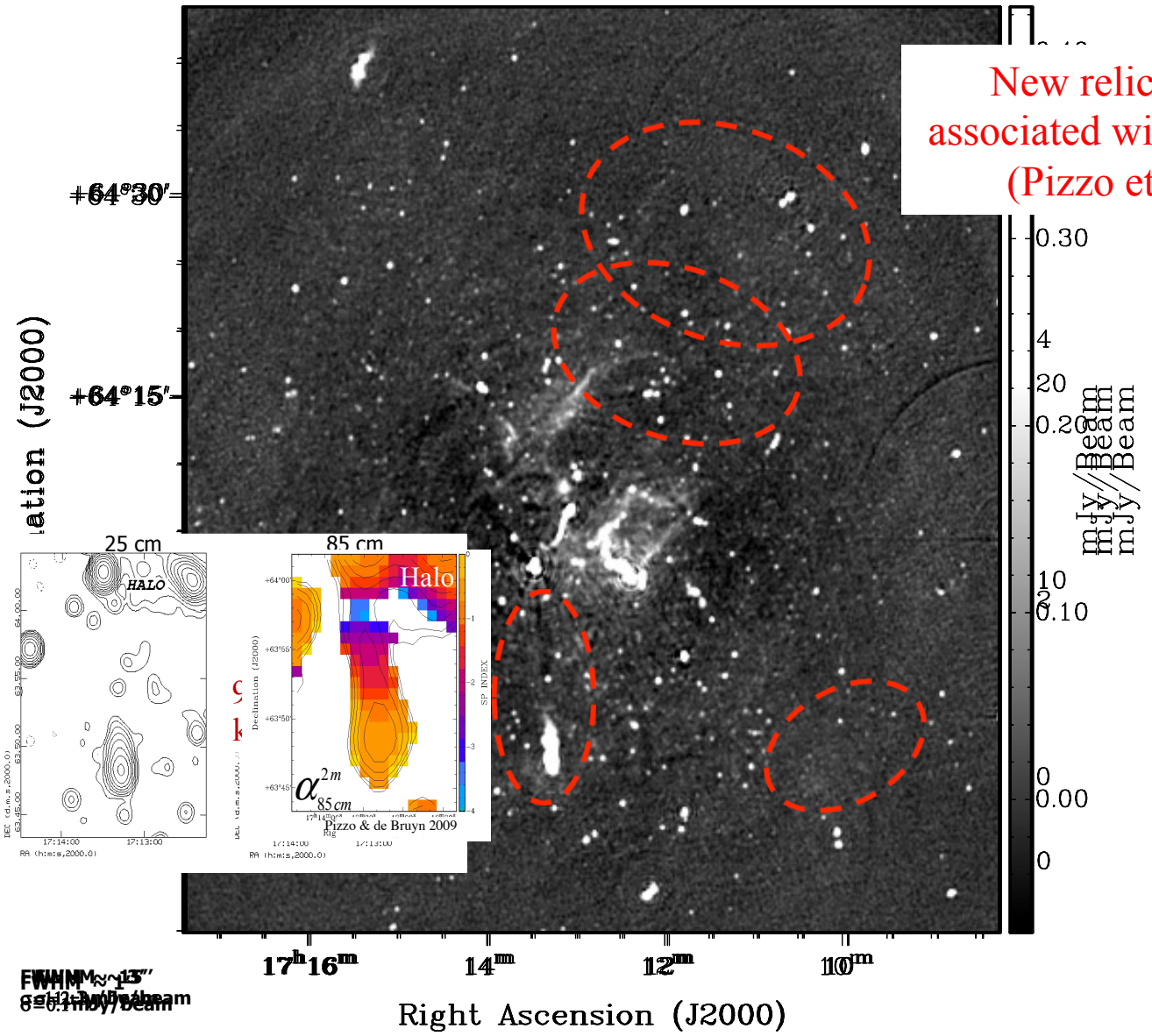
WSRT, Pizzo & de Bruyn 2009 ν = 1.2 MHz



VLA, Govoni et al. 2005 ν = 1.4 MHz

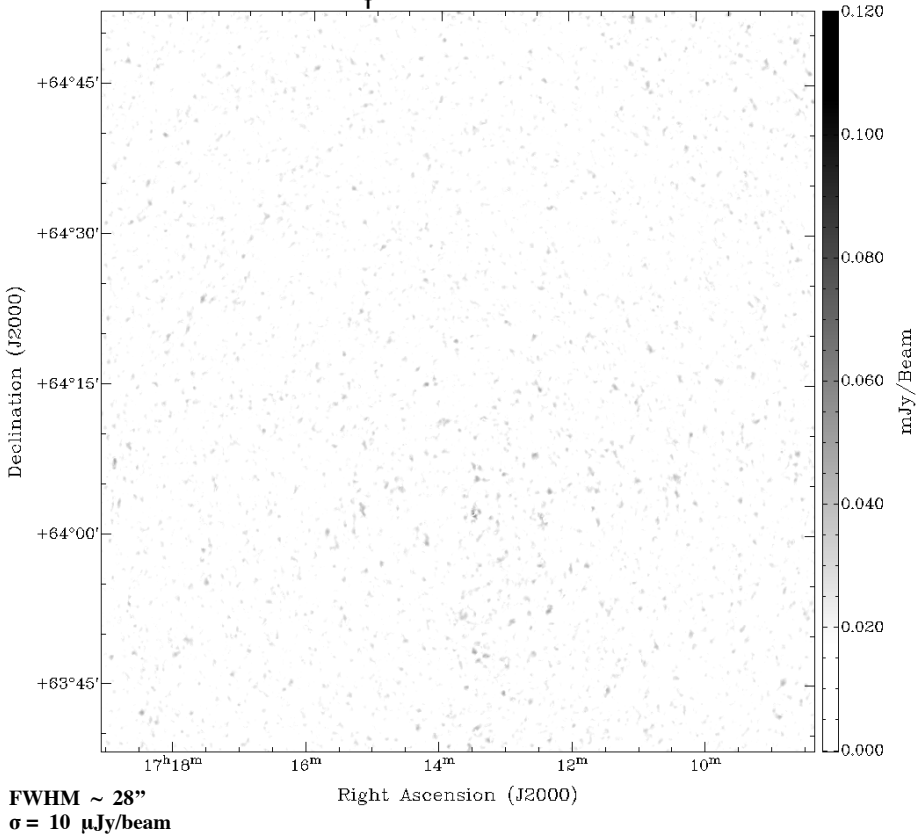
WSRT RESULTS

At 85cm



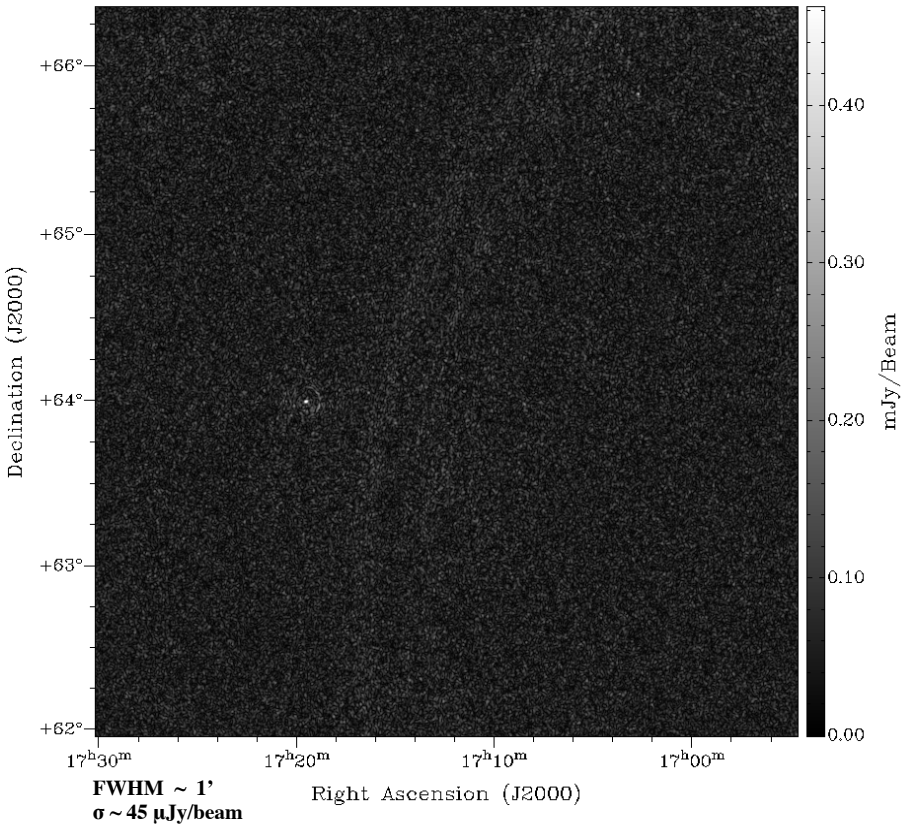
POLARIMETRIC RESULTS (WSRT)

ν= 1200-1400 MHz,
- 1000 < ϕ < + 1000 rad m^{-2}



FWHM ~ 28"
σ = 10 μJy/beam

ν= 350 MHz,
- 200 < ϕ < + 200 rad m^{-2}

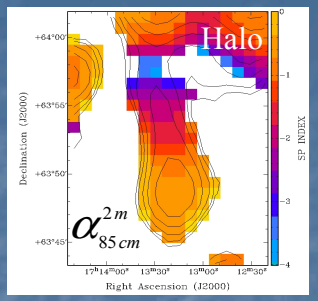


FWHM ~ 1'
σ ~ 45 μJy/beam

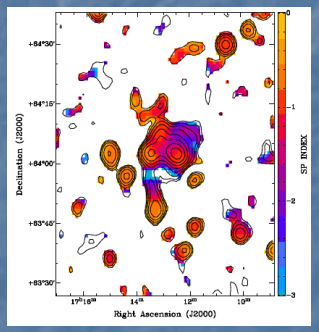
The halo is not polarized. The 3 bright filaments at the edge of the halo are located in the foreground of the cluster.

For more details, see Pizzo et al. 2011

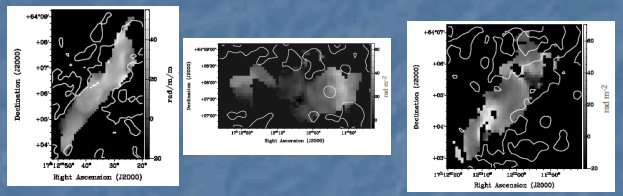
REMAINING OPEN QUESTIONS



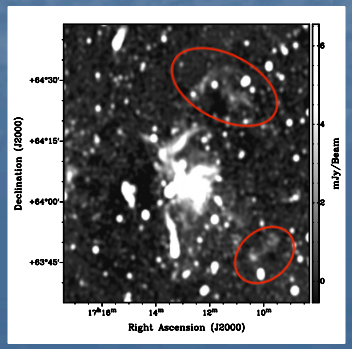
➢ Understanding the origin of the relativistic particles of the radio halo (radio galaxies?) ➔ better resolution needed;



➢ origin of the radio halo compatible with primary or secondary models? ➔ better resolution needed;



➢ distance of the polarized filaments from the center of the cluster ➔ RM variance and fractional polarization at low frequencies;

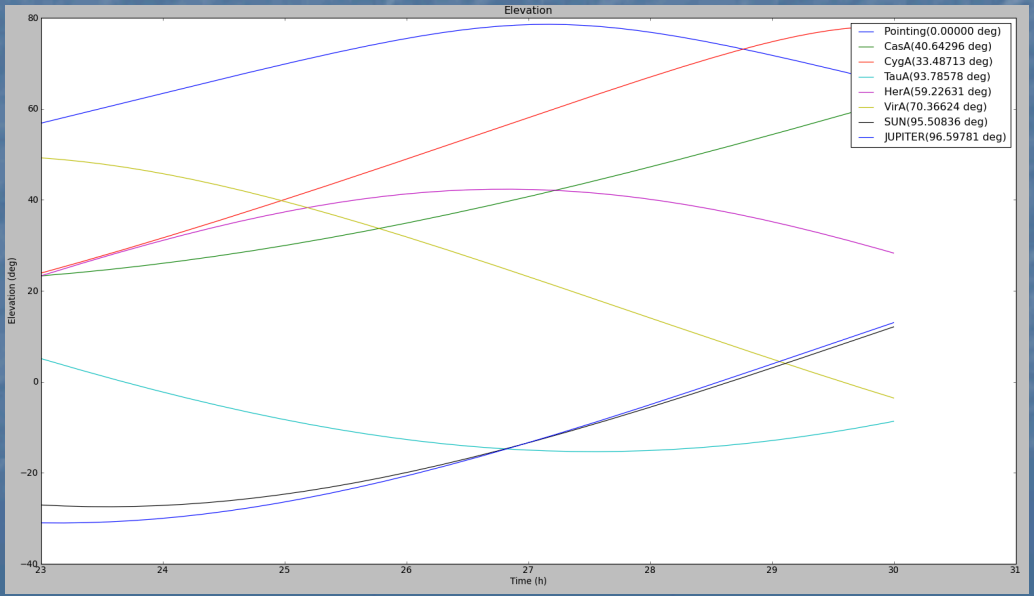


➢ study the physical and spectral properties of the new relics (detection of polarization).

LOFAR OBSERVATIONS: HBA

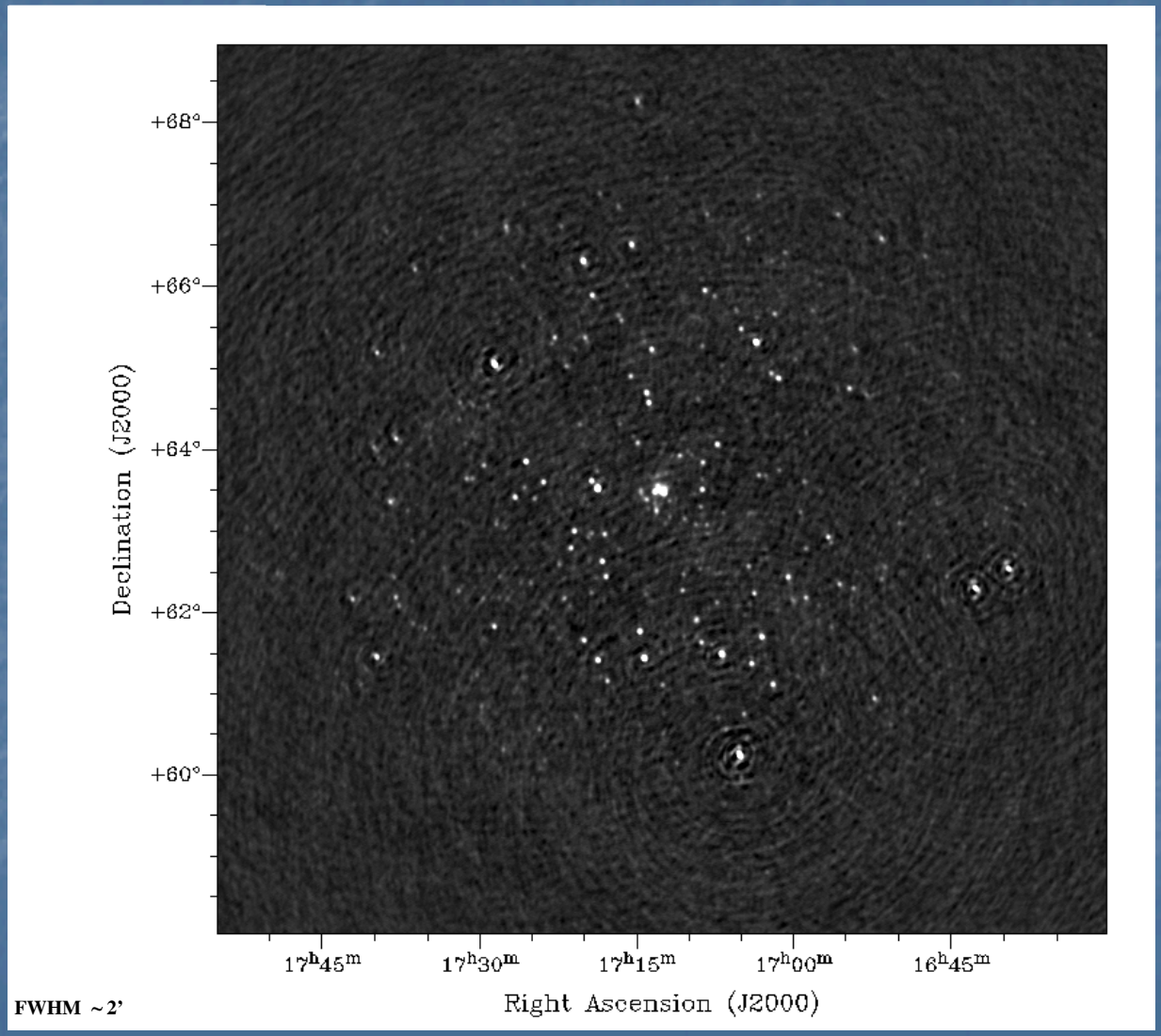
- HBA LOW (110-190 MHz), 15-16 Apr 2011, 23 pm – 6 am, 7 hours
- HBA DUAL, 45 stations, 38 CS + 7 RS
- 244 sub bands, 64 channels, 2 seconds integration

- The A-team:



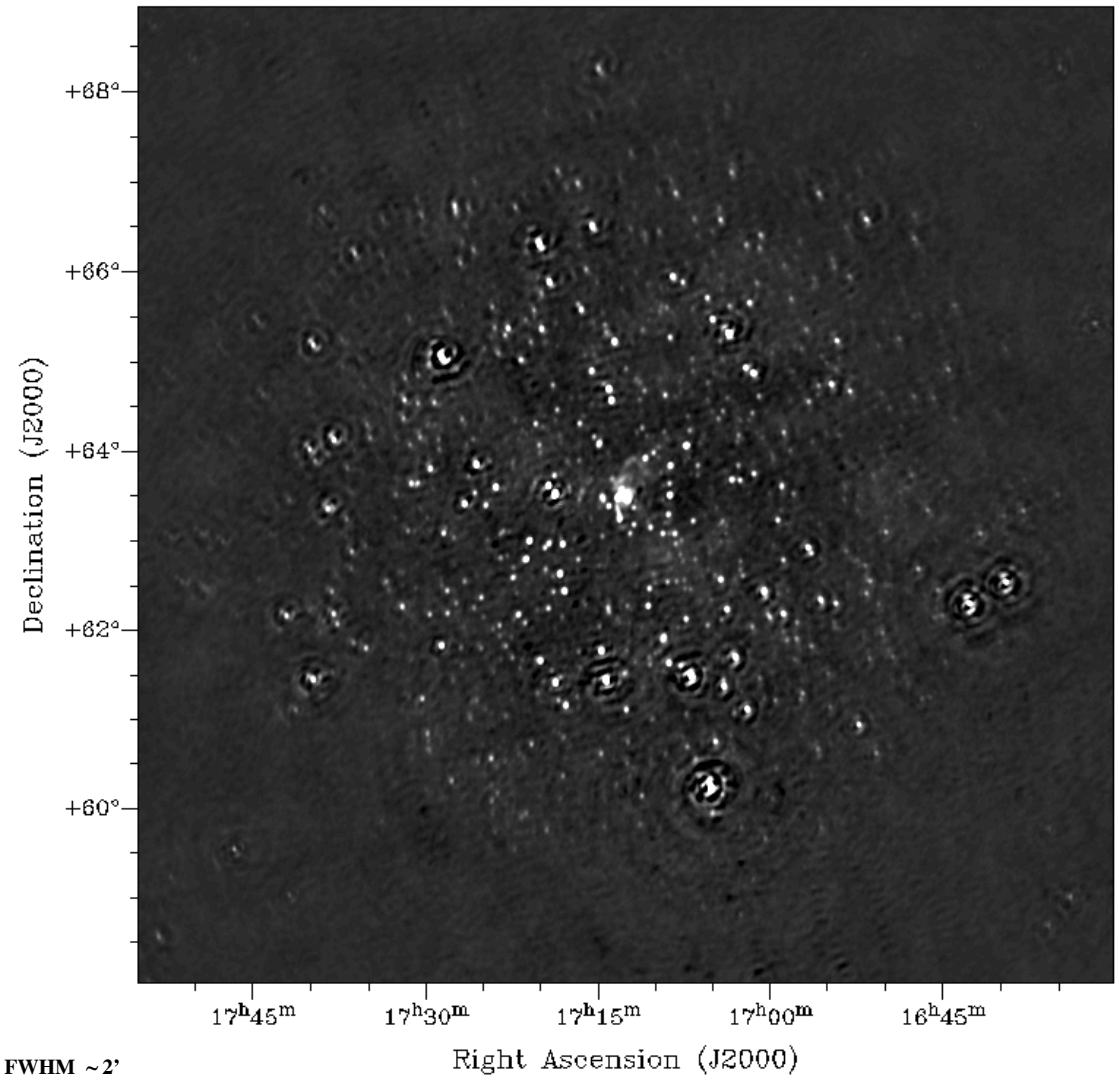
Cas A and Cyg A nearby (<40°) and at high elevation !

STOKES I CUBE (189 SBs)

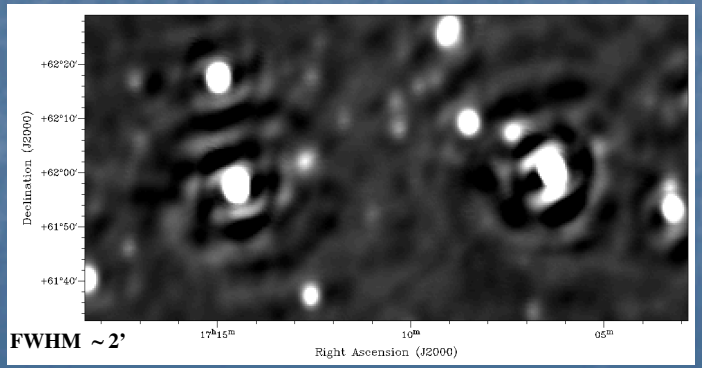


- ✓ 189 frames from 110 to 190 MHz
- ✓ Global calibration applied; model extracted from WENNS (350 components)
- ✓ Residual low level RFI left after clipping after the calibration (still need to be investigated)
- ✓ Primary beam effect clearly visible
- ✓ Off-axis errors at the location of strong off-axis sources. Need Awimager – work in progress

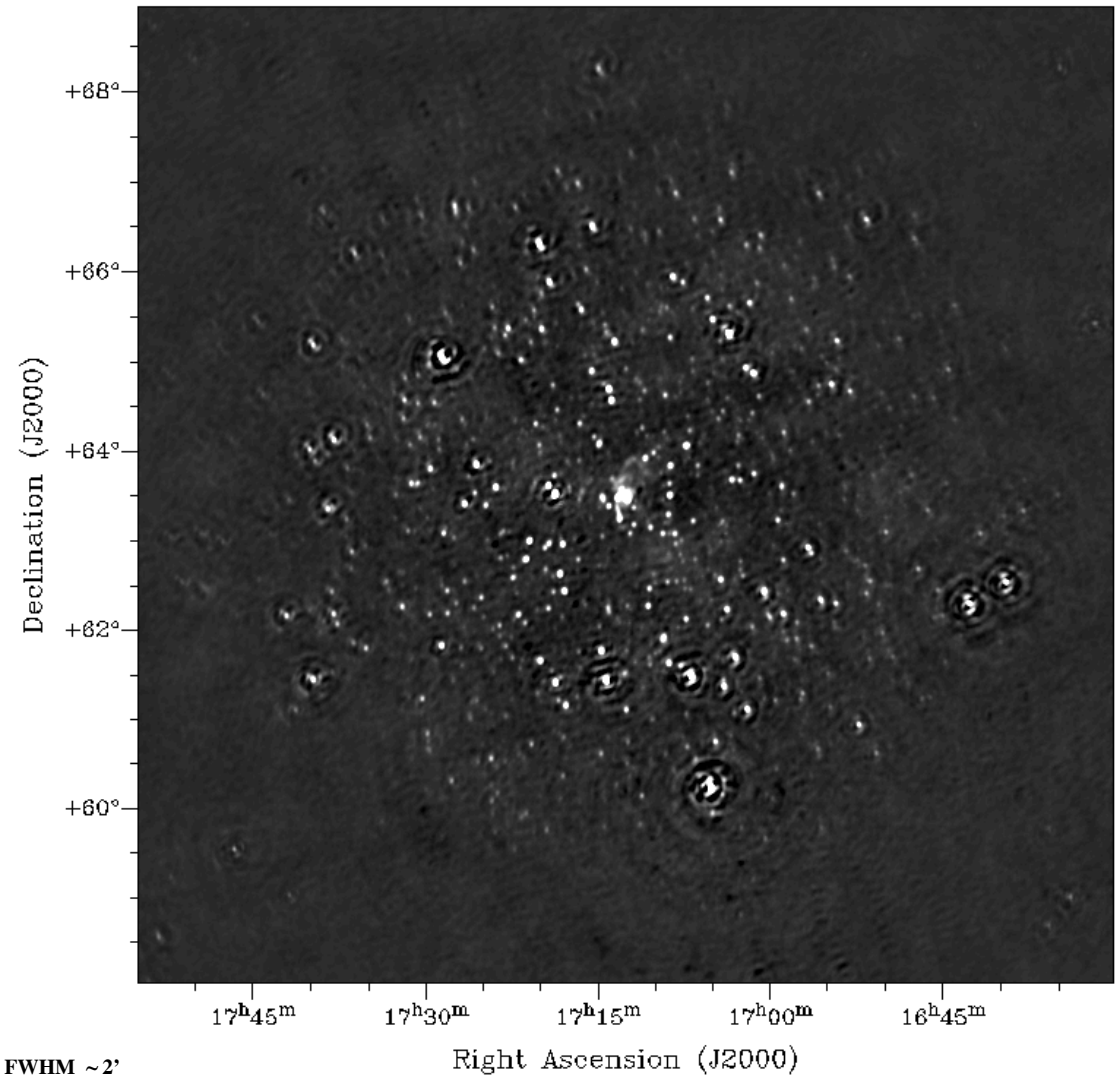
THE FINAL MAP (189 SBs)



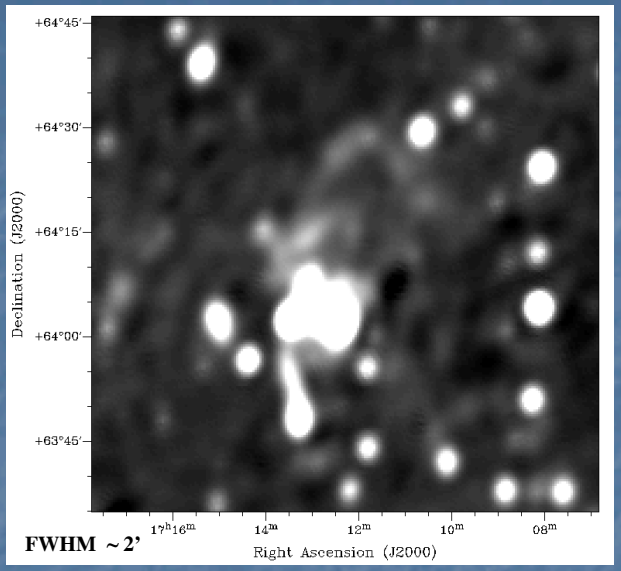
- ✓ Dynamic range ~ 3000
- ✓ σ = 1.5 mJy/beam (15 x σ_{therm})
- ✓ Thousands of sources detected in the field
- ✓ RS still need to be included. Imaging is in progress
- ✓ Off-axis problems still need to be taken care of



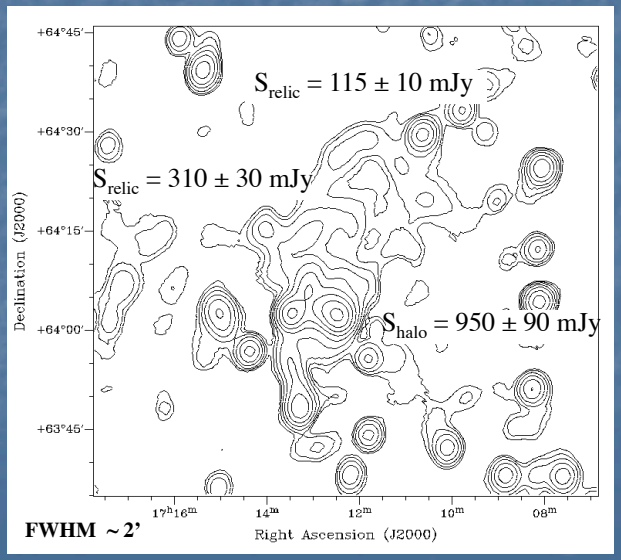
THE FINAL MAP (189 SBs)



FWHM ~2'

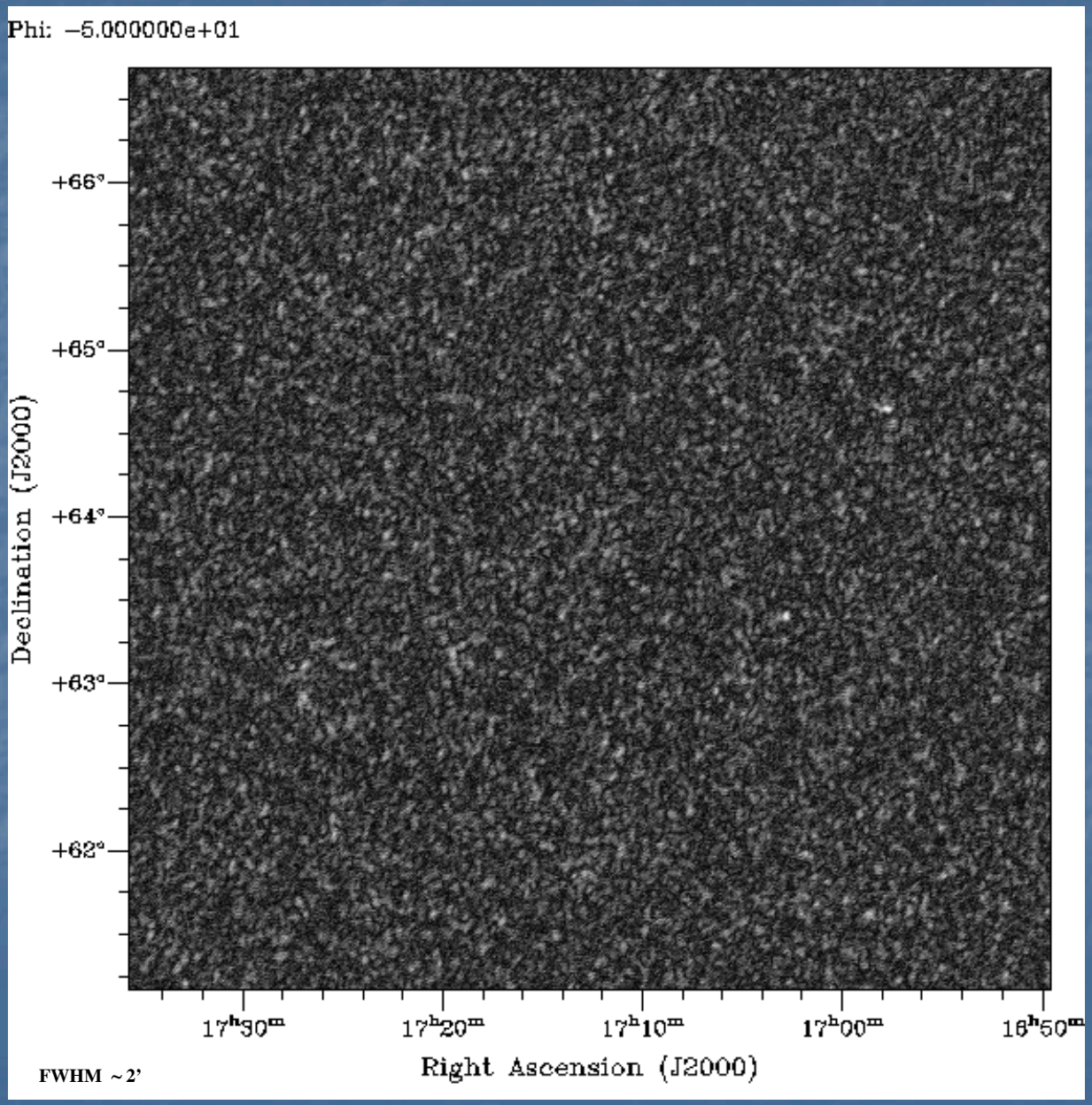


FWHM ~2'



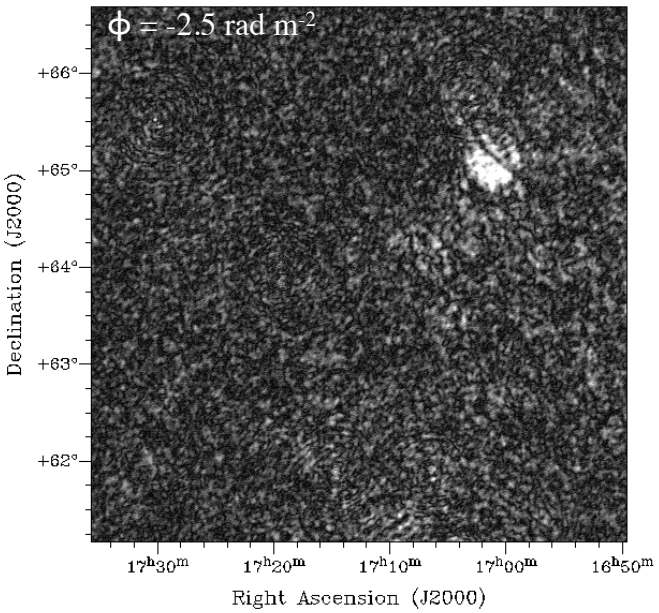
FWHM ~2'

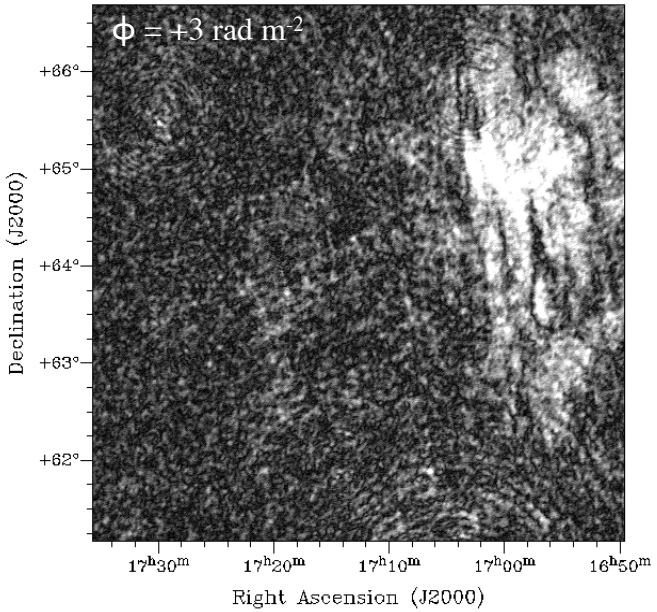
POLARIZED EMISSION: RM CUBE

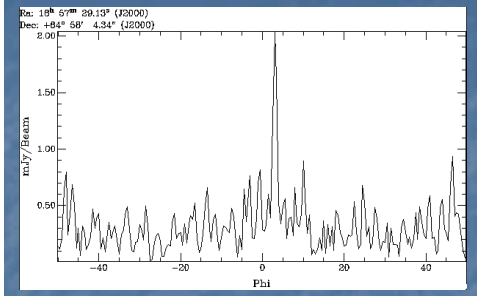


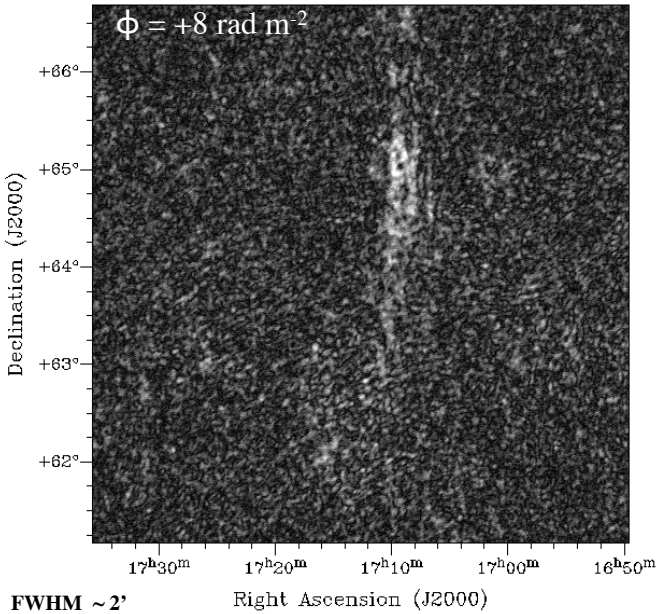
- ✓ $-50 < \phi < +50$ rad m^{-2} with step of 0.5 rad m^{-2}
- ✓ $\sigma = 0.2$ mJy/beam!!
- ✓ Polarized emission detected at $-5 < \phi < +15$ rad m^{-2}

POLARIZED EMISSION AT INTERESTING ϕ

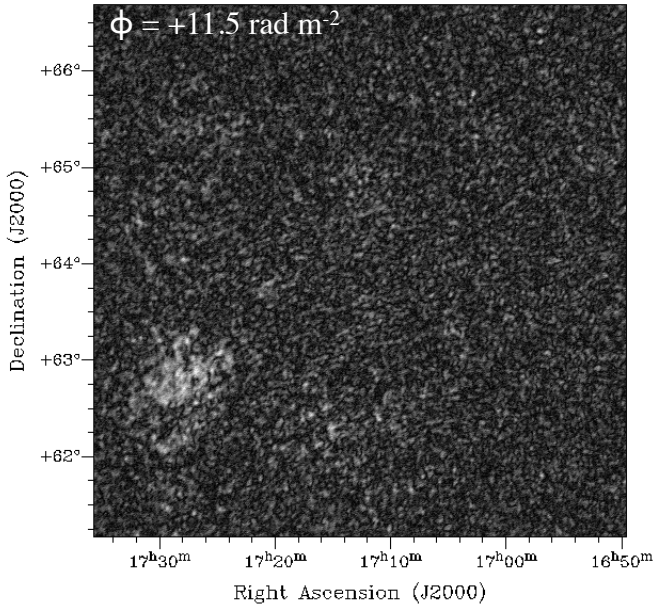








FWHM ~2'



- ✓ Various polarized features with no counterpart in Stokes I
- ✓ Brightness temperature ~ 4 K
- ✓ Instrumental origin unlikely, as they do not happen at $\phi = 0$ rad m^{-2} are not symmetric w.r.t this Faraday depth

SUMMARY AND FUTURE WORK

- ✓ A2255 represents a very interesting science case for LOFAR. Several open questions can be answered through the new sensitive high resolution data provided by this instrument;
- ✓ The preliminary results from HBA imaging show that the data are of very good quality;
- ✓ In Stokes I, the final map is more sensitive than the best available WSRT map (factor of 2);
- ✓ The emission from halo, relics and head-tail radio galaxies is fully recovered. More extended emission to the south of the cluster is detected;
- ✓ In polarization, the final RM cube is the most sensitive cube made with LOFAR data to date. Several extended polarized features are detected. They are likely associated with the Galaxy;
- ✓ Including the RS is crucial for both total intensity and polarimetric study (imaging currently in progress);
- ✓ LBA frequency are very interesting for this target.