

The background of the slide is a detailed map of the Cosmic Microwave Background (CMB) radiation. It shows a complex pattern of temperature fluctuations across the sky, with a color scale ranging from dark blue (cooler regions) to bright yellow and red (warmer regions). The pattern is highly irregular, with many small-scale features and larger-scale structures. The text is overlaid on this background.

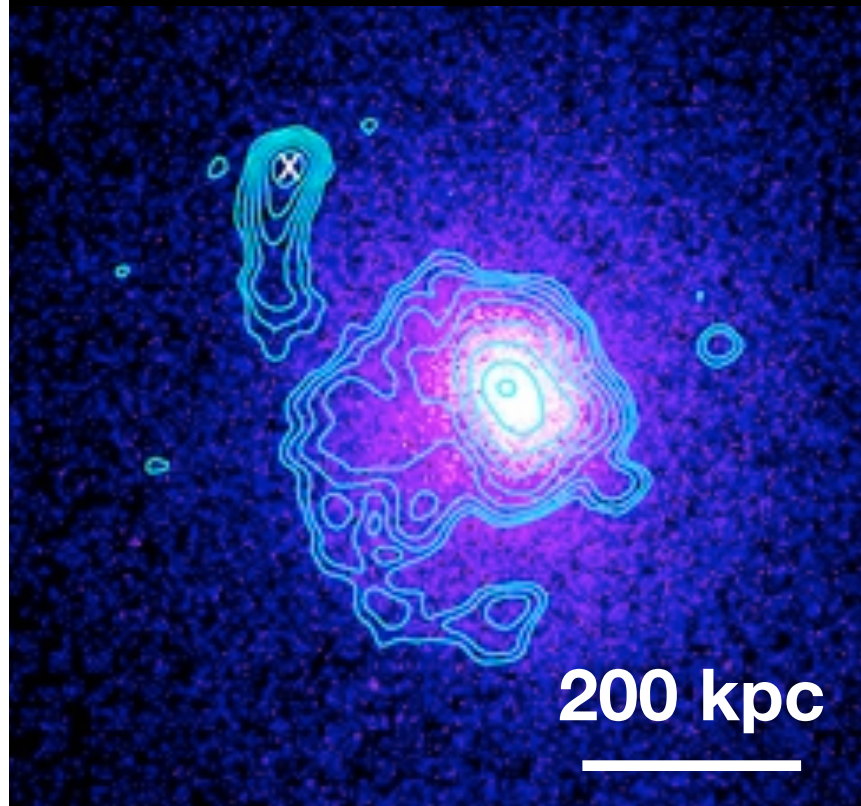
Magnetic fields and relativistic electrons in  
galaxy clusters:  
first results from LOFAR

Annalisa Bonafede



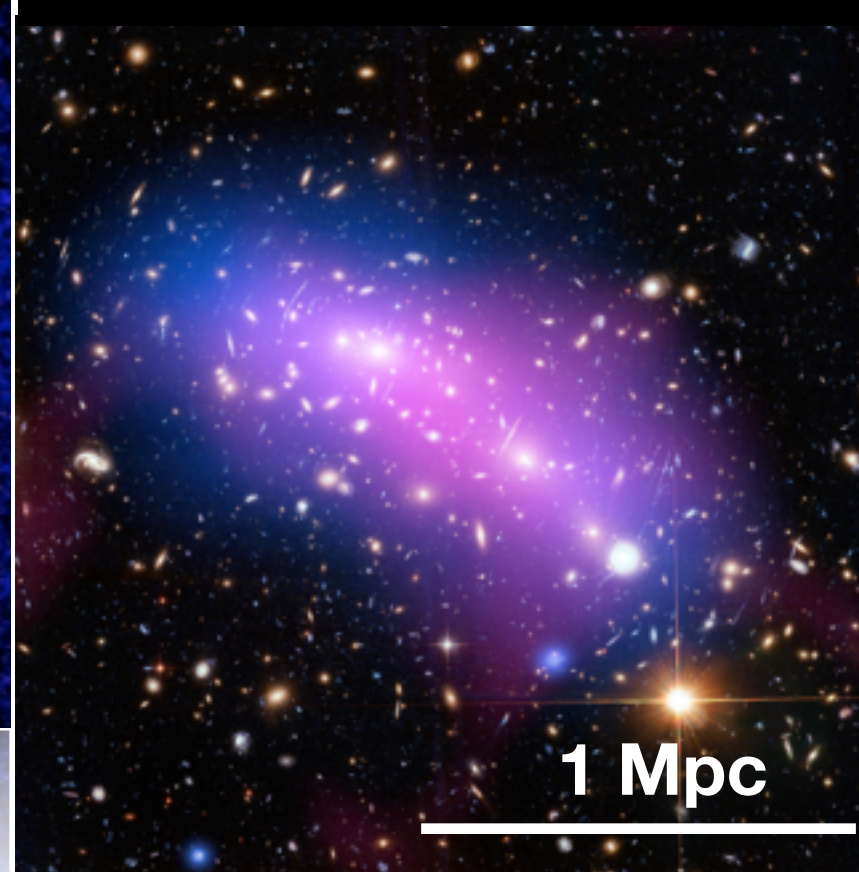
# Galaxy clusters: radio emission

Radio contours  
X-ray (gas) colours



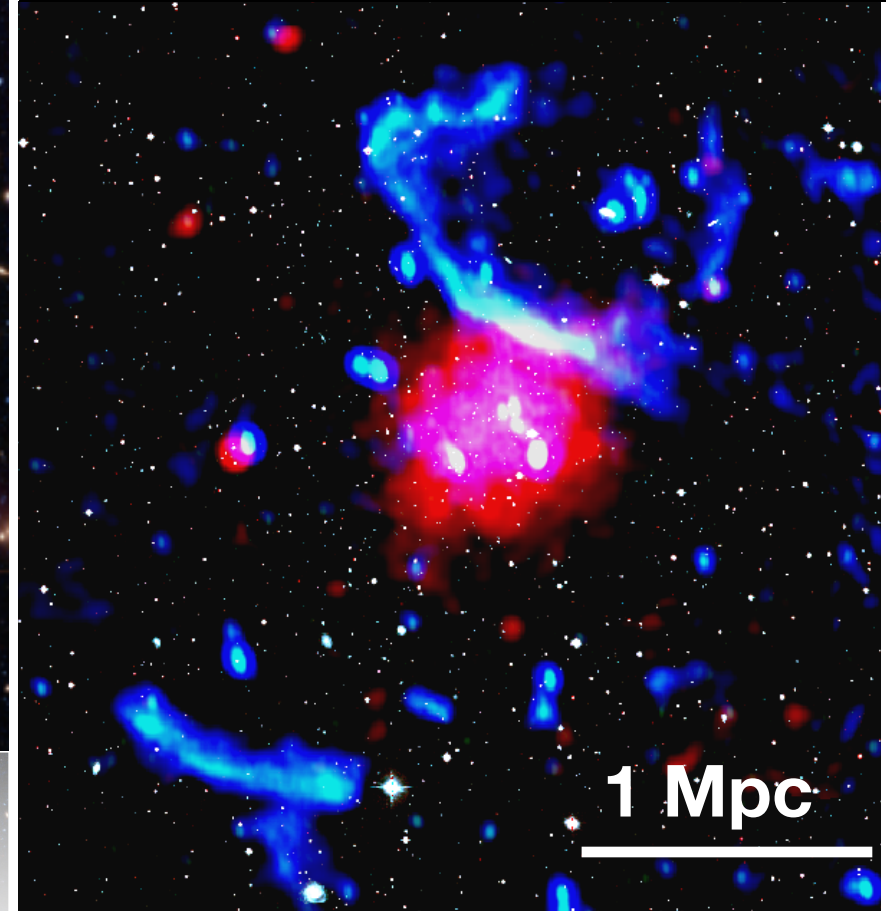
The cluster RXCJ 1721  
Giacintucci et al. (2012)

Radio  
X-ray (gas)



The cluster MACSJ0416  
Ogrean et al. (2015)

Radio  
X-ray (gas)



The cluster PLCKG287 -  
Bonafede et al. (2014)

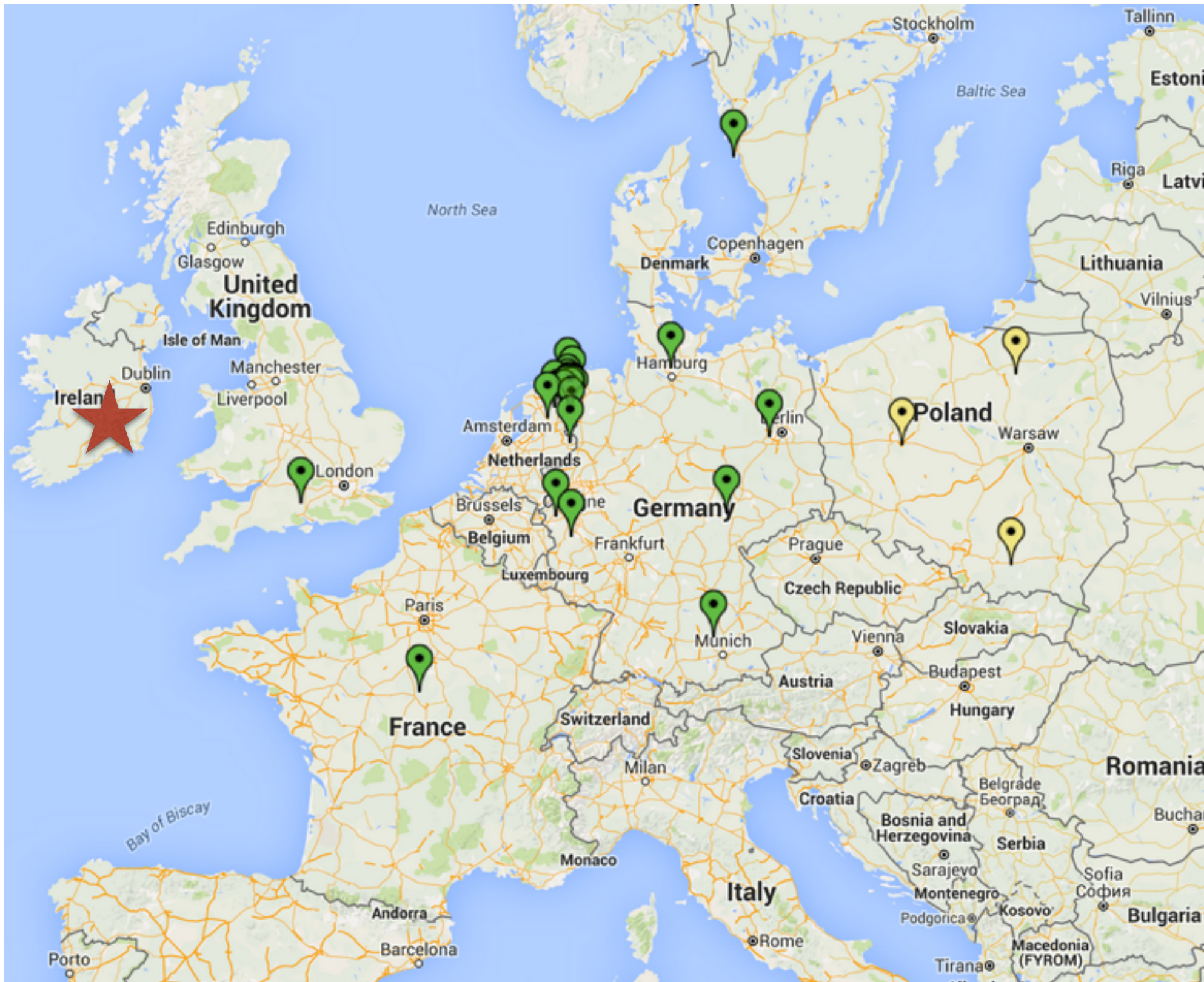
▶ Link with **cluster dynamical status**

▶ **(re)acceleration** processes at work!



# The LOw Frequency ARray

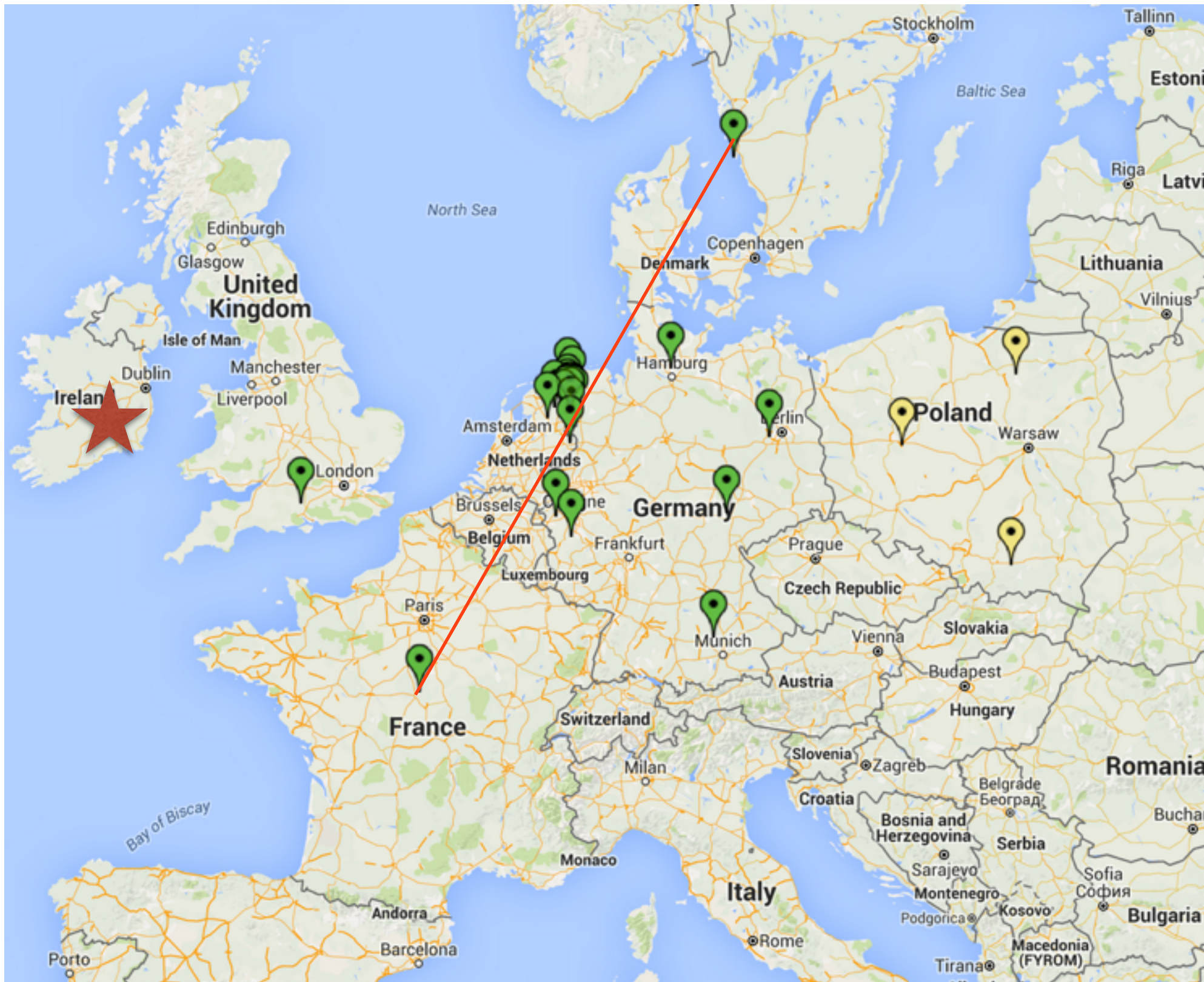
- New observational window 15-250 MHz





# The LOw Frequency ARray

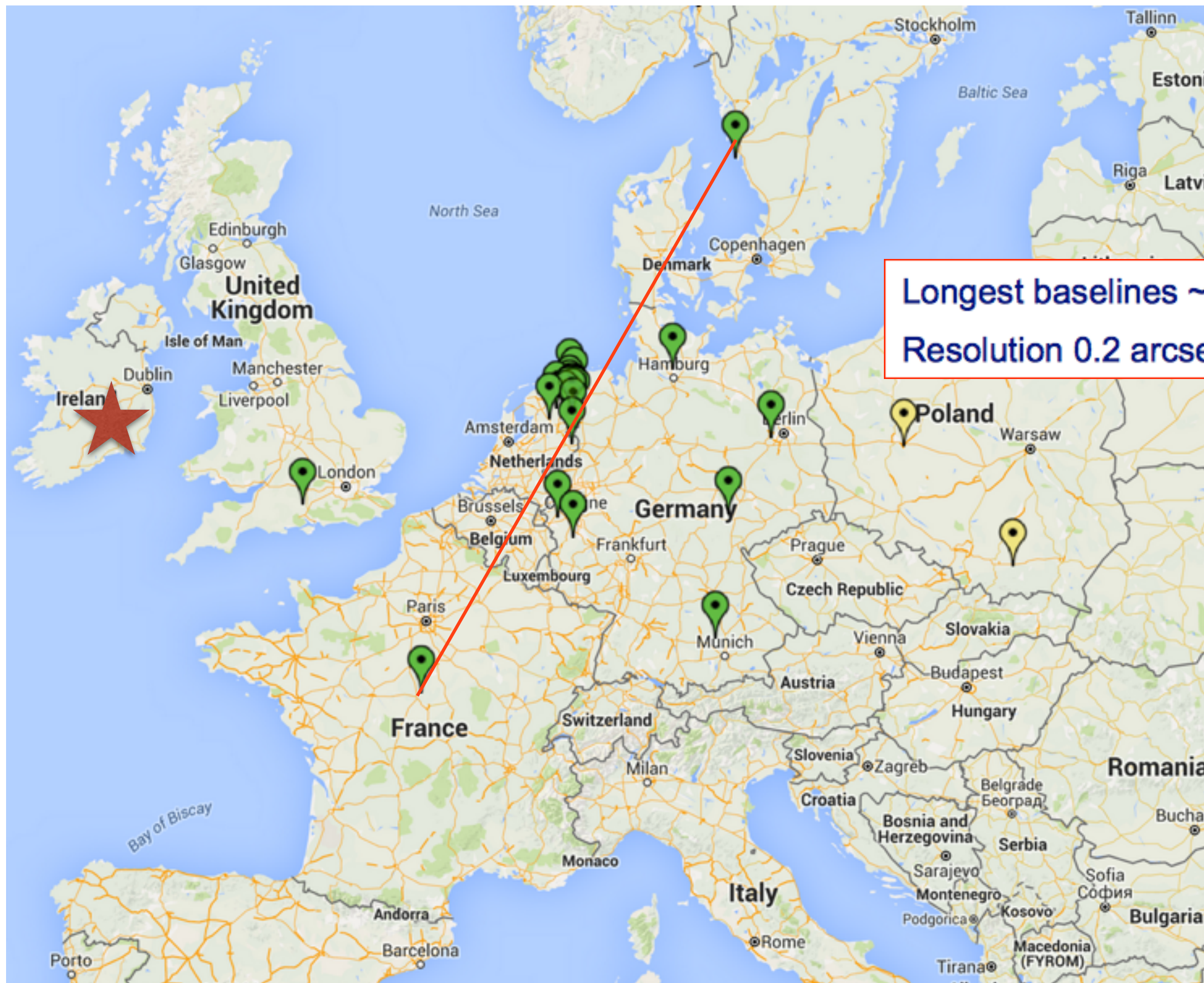
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# The LOw Frequency ARray

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# The LOw Frequency ARray

- New observational window 15-250 MHz



The LOFAR super terp

6 stations, 320 m

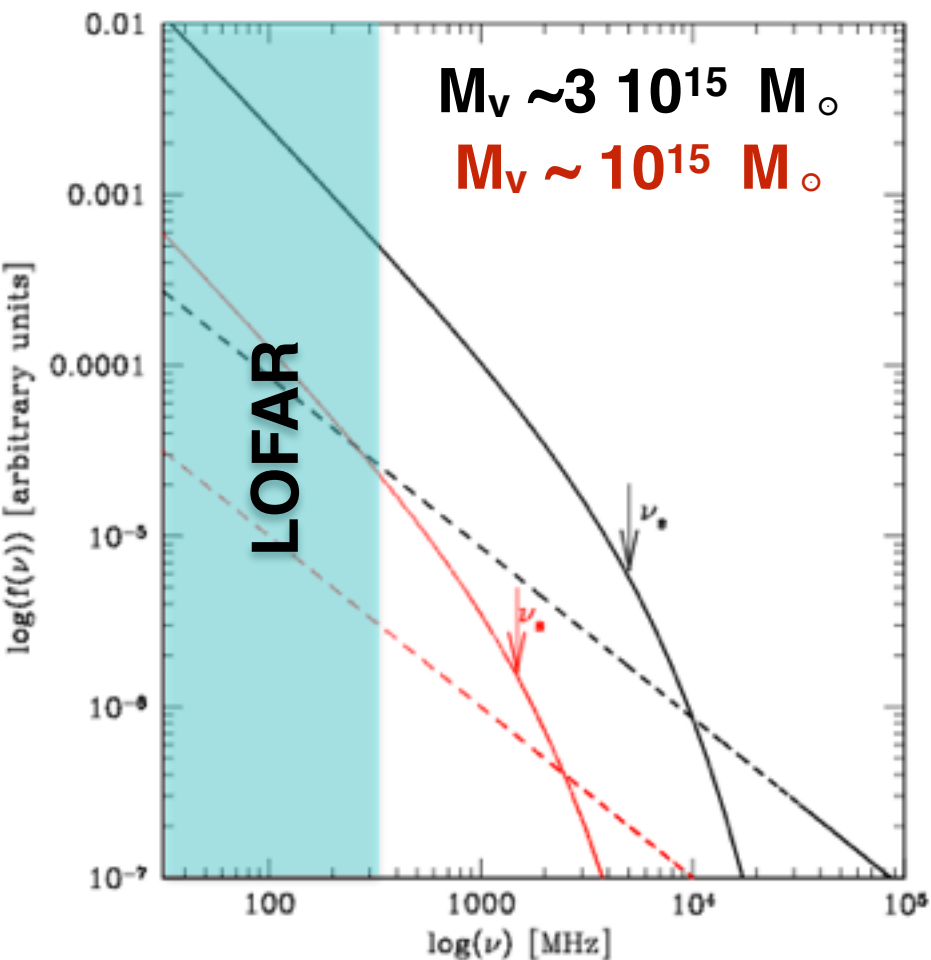
Sensitivity to Large angular scale



# Galaxy clusters: why low frequency?

1

Insights into the re-acceleration process



— re-acceleration  
- - - hadronic injection

**Cassano et al (2012)**



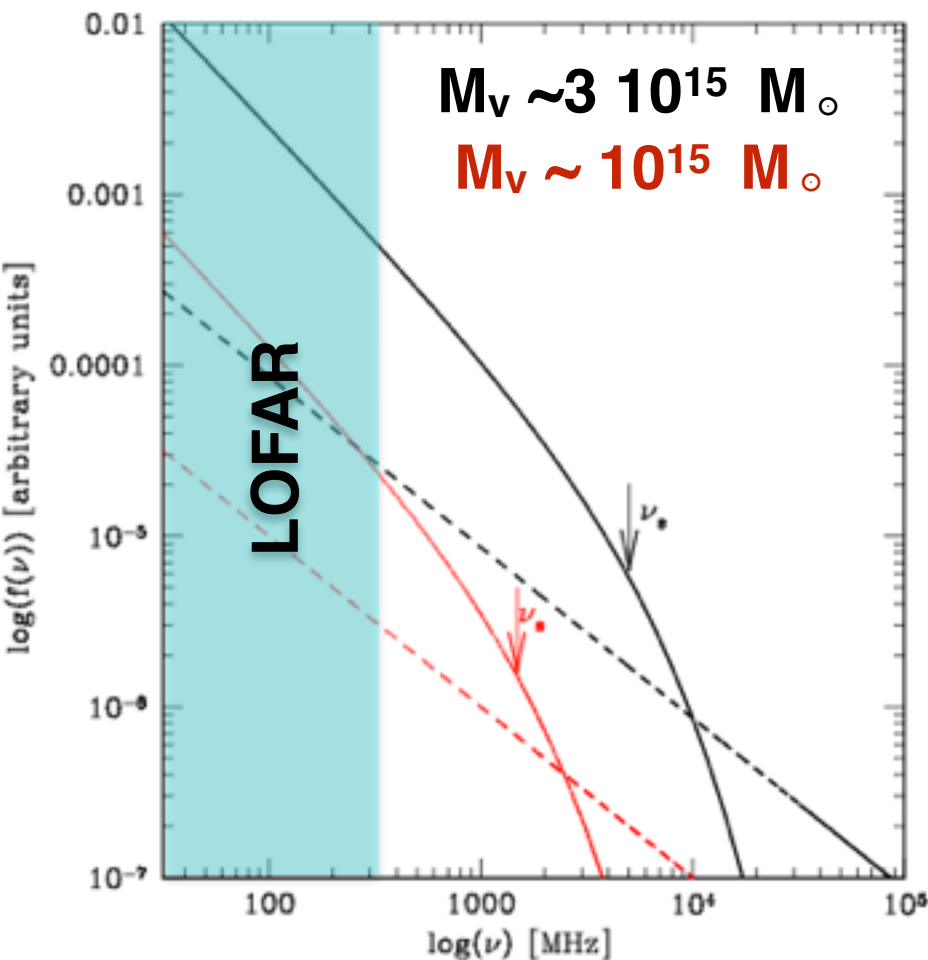
# Galaxy clusters: why low frequency?

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Insights into the re-acceleration process

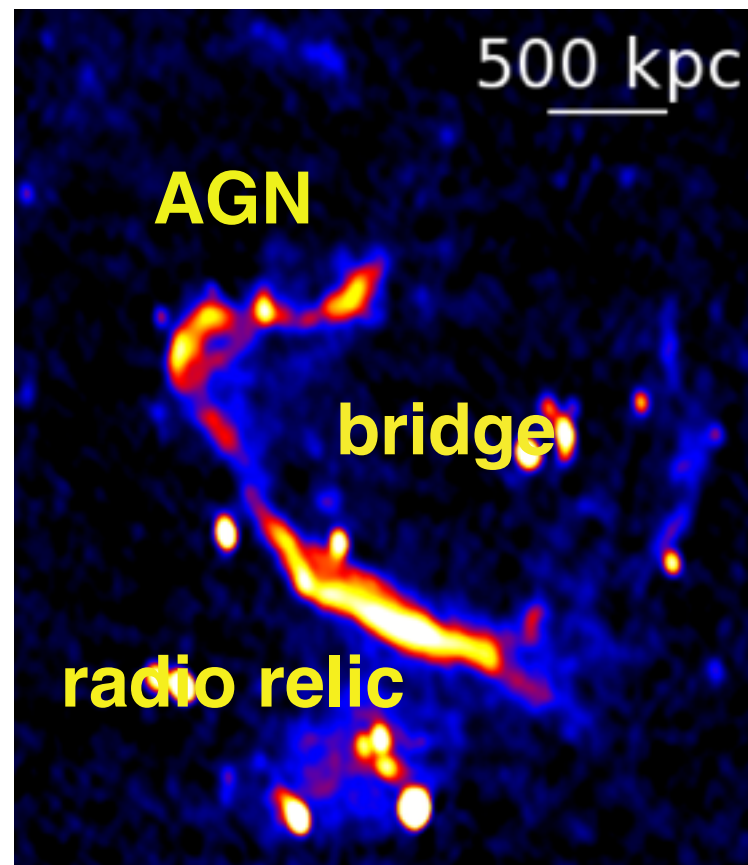
2

Unravelling the seed particles



— re-acceleration  
- - - hadronic injection

**Cassano et al (2012)**



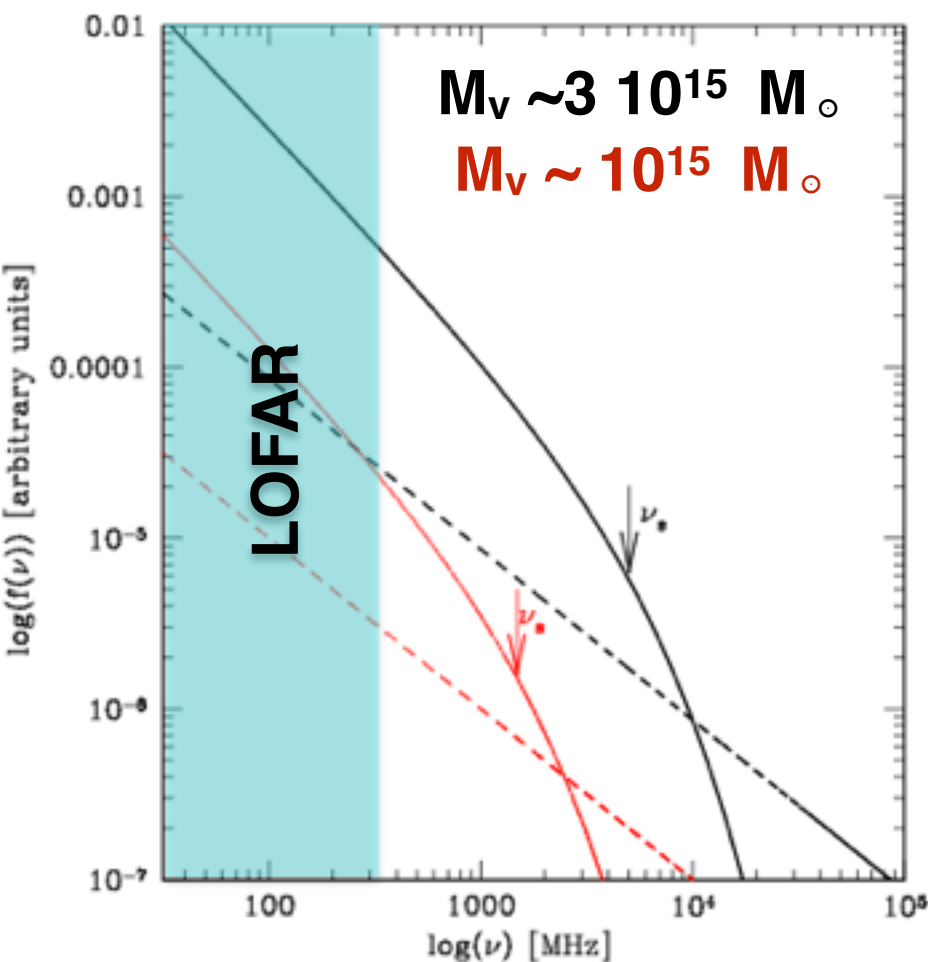
**Bonafede et al. (2014)**



# Galaxy clusters: why low frequency?

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Insights into the re-acceleration process

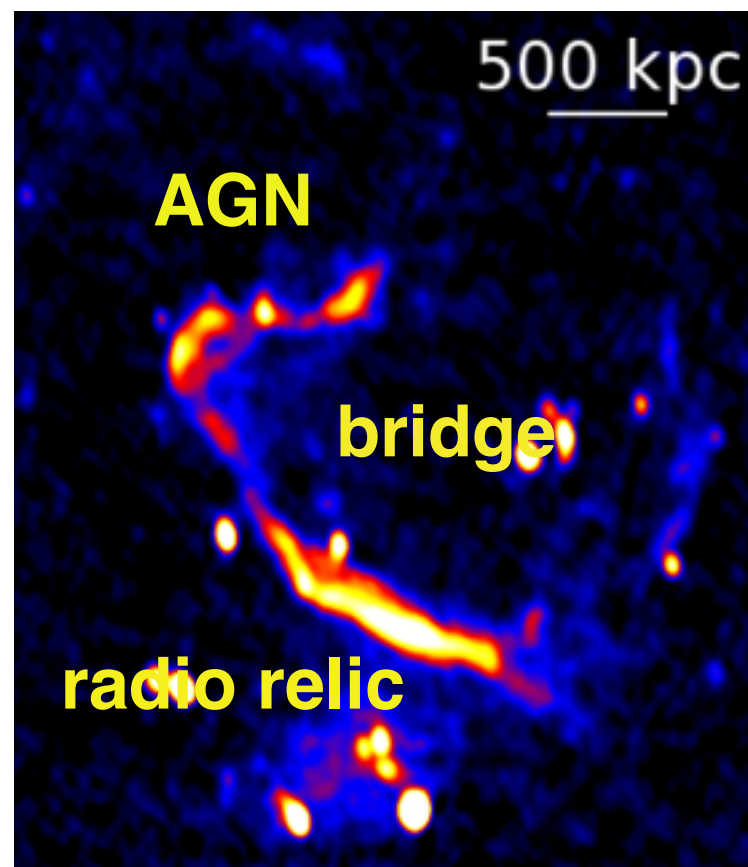


— re-acceleration  
- - - hadronic injection

**Cassano et al (2012)**

2

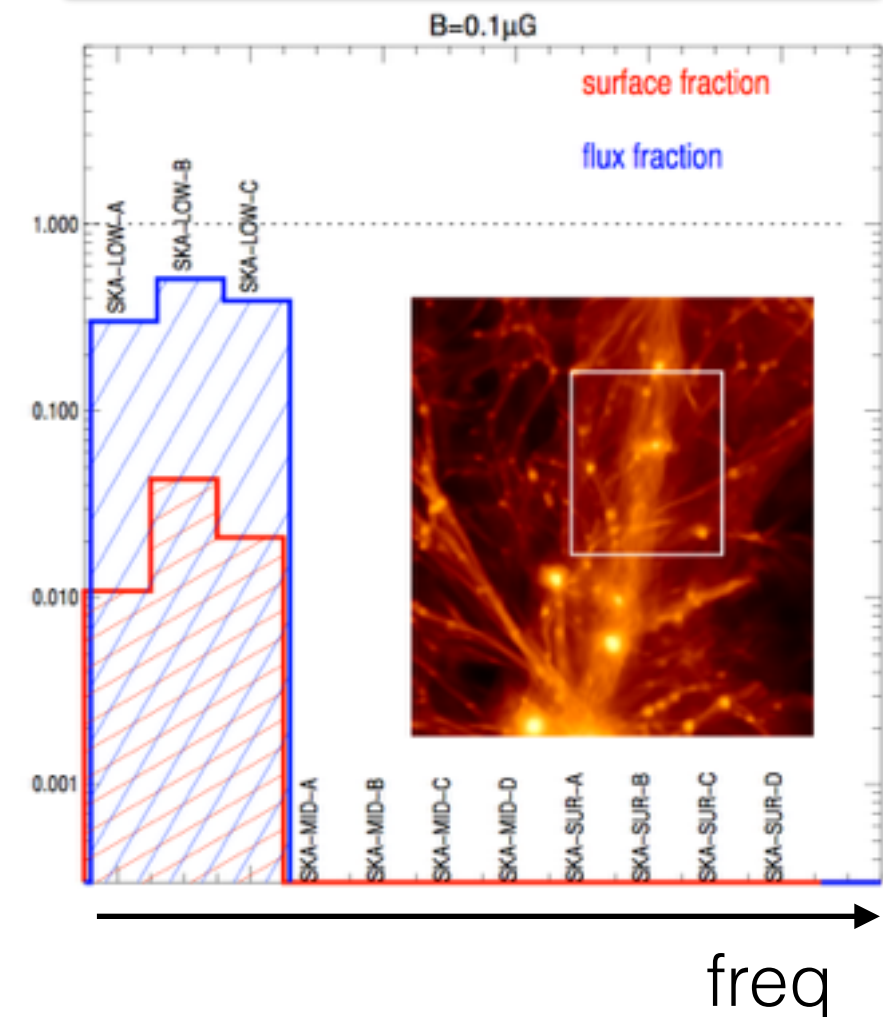
Unravelling the seed particles



**Bonafede et al. (2014)**

3

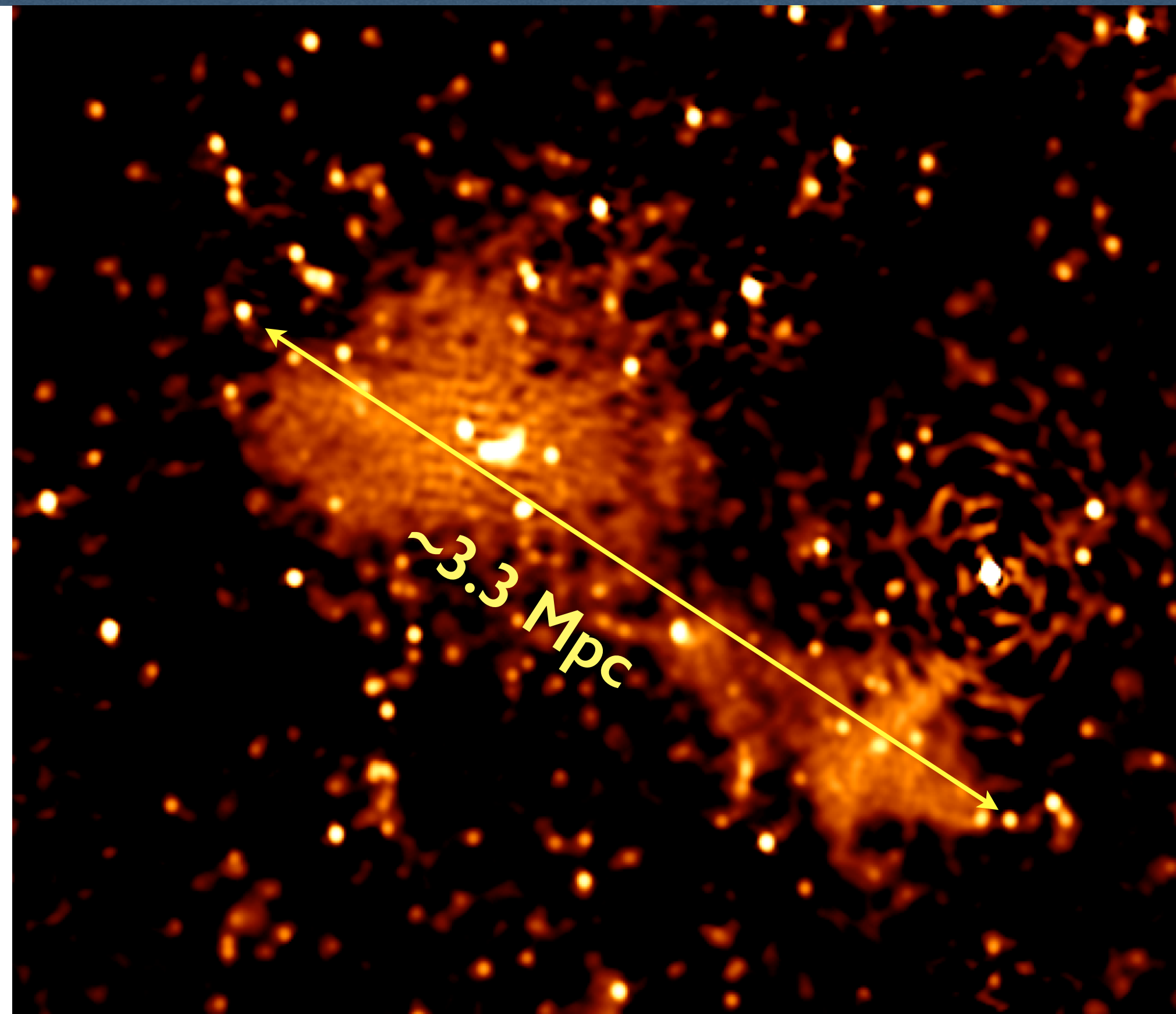
Beyond clusters: the cosmic web



**Vazza et al. (2015)**



# Coma - so far



LOFAR image  
at 140 MHz

30 arcsec resolution

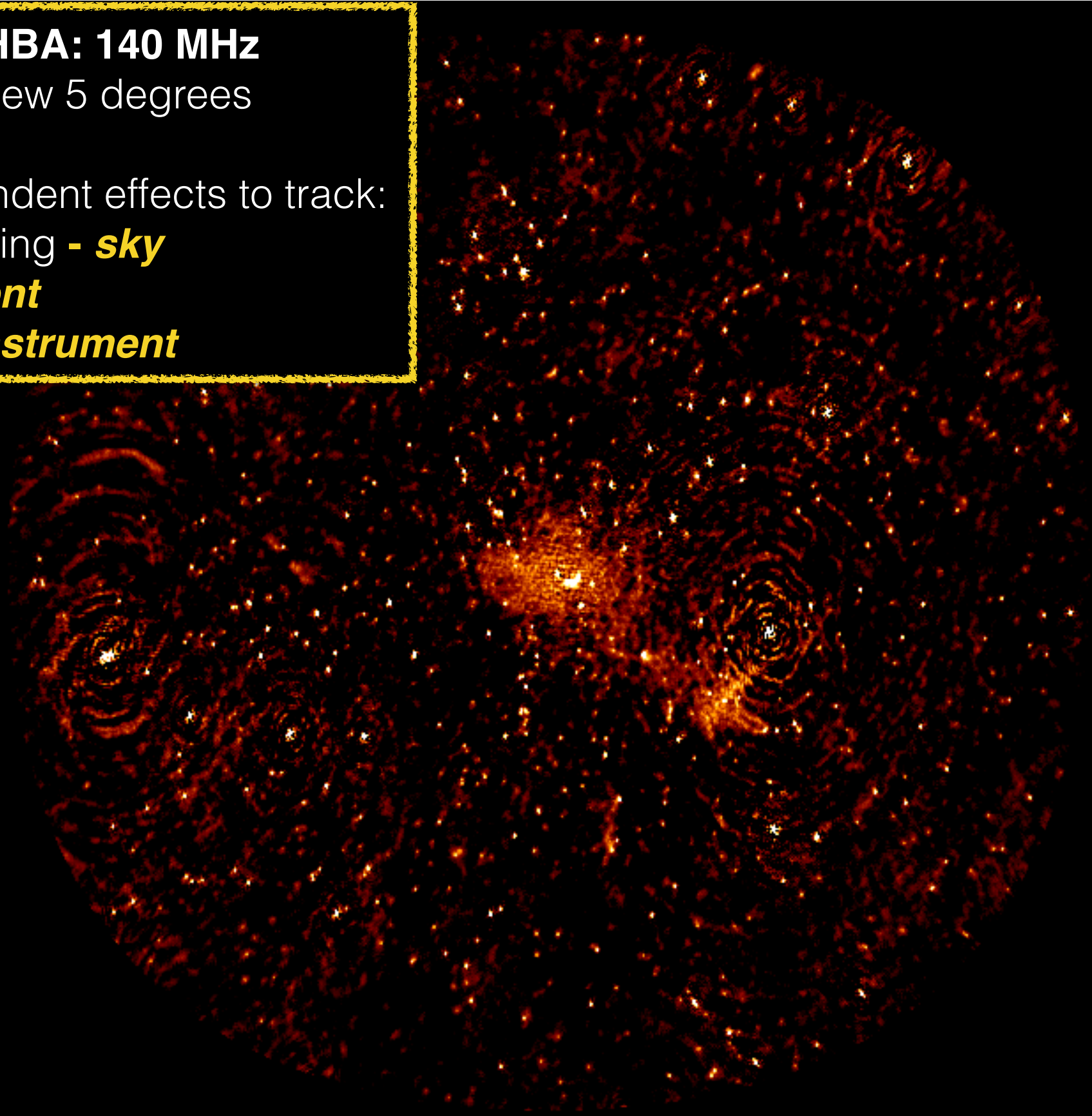
no direction-  
dependent  
calibration

# Direction-dependent effects

**LOFAR HBA: 140 MHz**

field of view 5 degrees

directional dependent effects to track:  
ionospheric blurring - **sky**  
gains - **instrument**  
station beam - **instrument**





# New technique: facet calibration

**LOFAR HBA: 140 MHz**

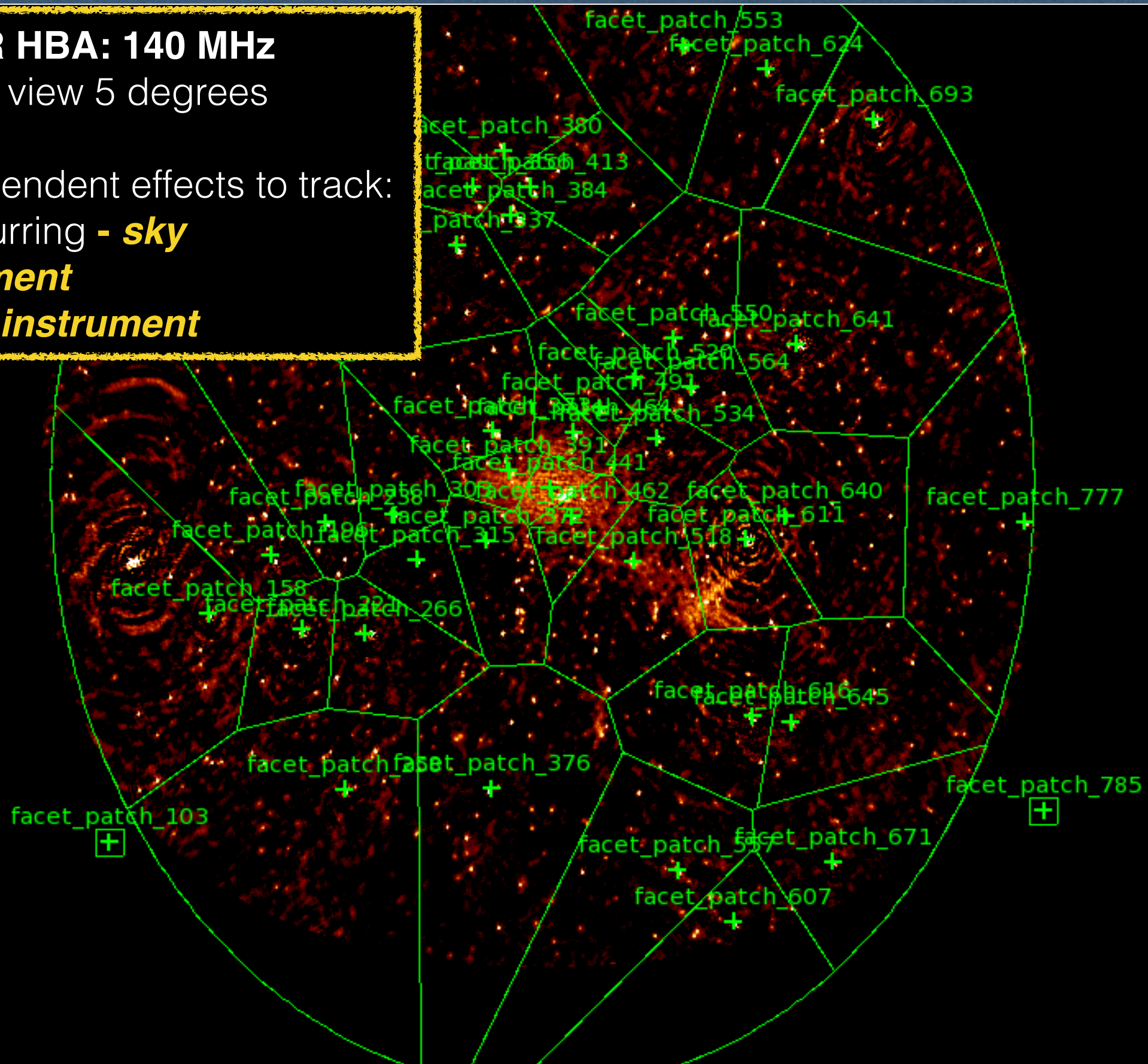
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directional dependent effects to track:

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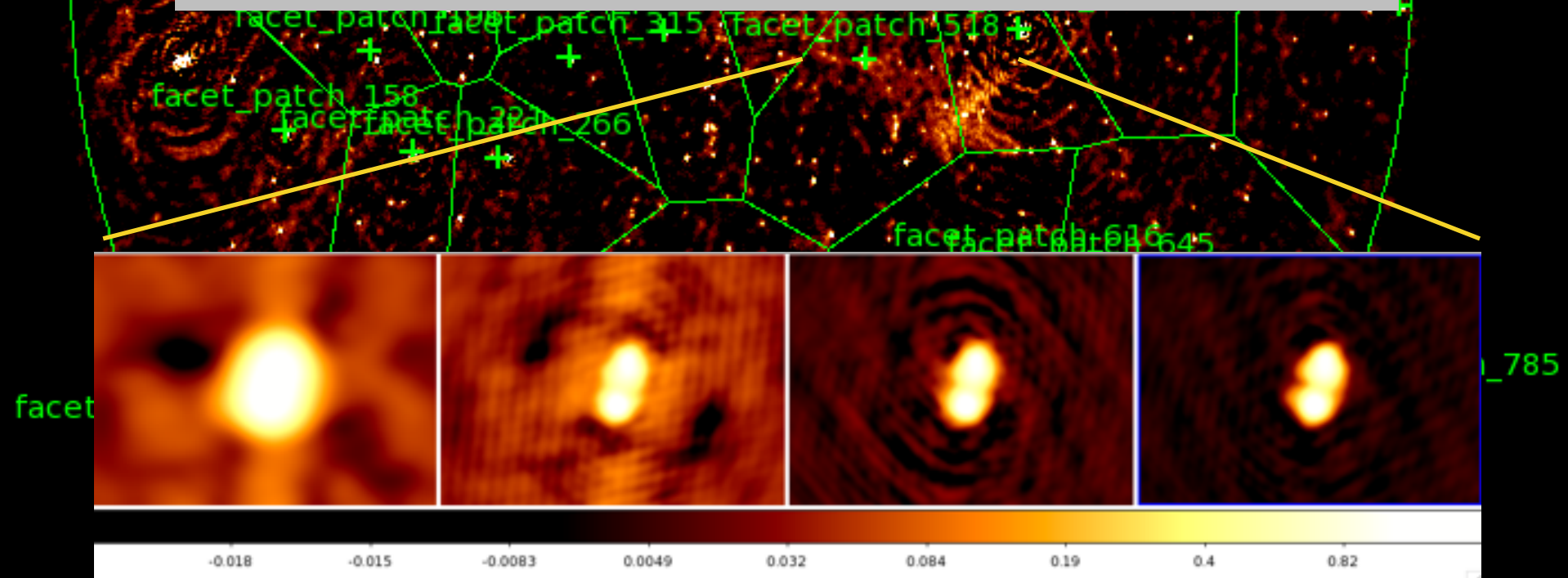
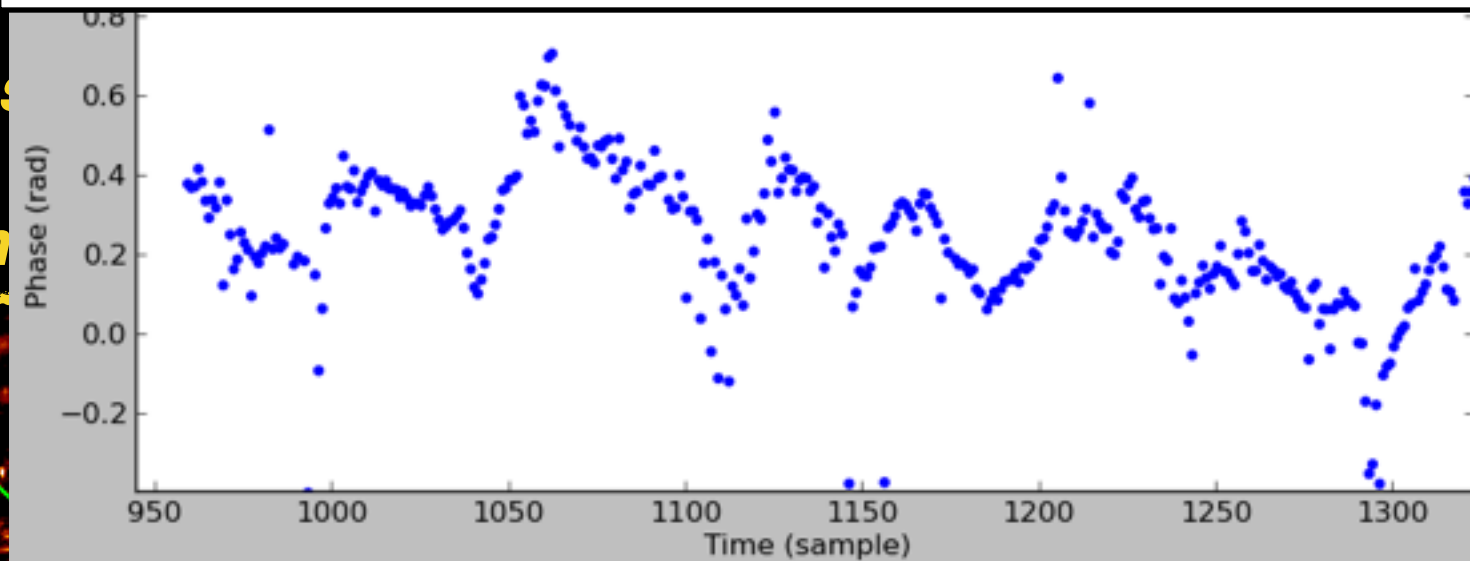
# New technique: facet calibration

**LOFAR HBA: 140 MHz**

field of view 5

directional dependent  
ionospheric blurring -  
gains - **instrument**  
station beam - **instrum**

Tracking the variation in total electron content  
in the atmosphere on 5-sec scale



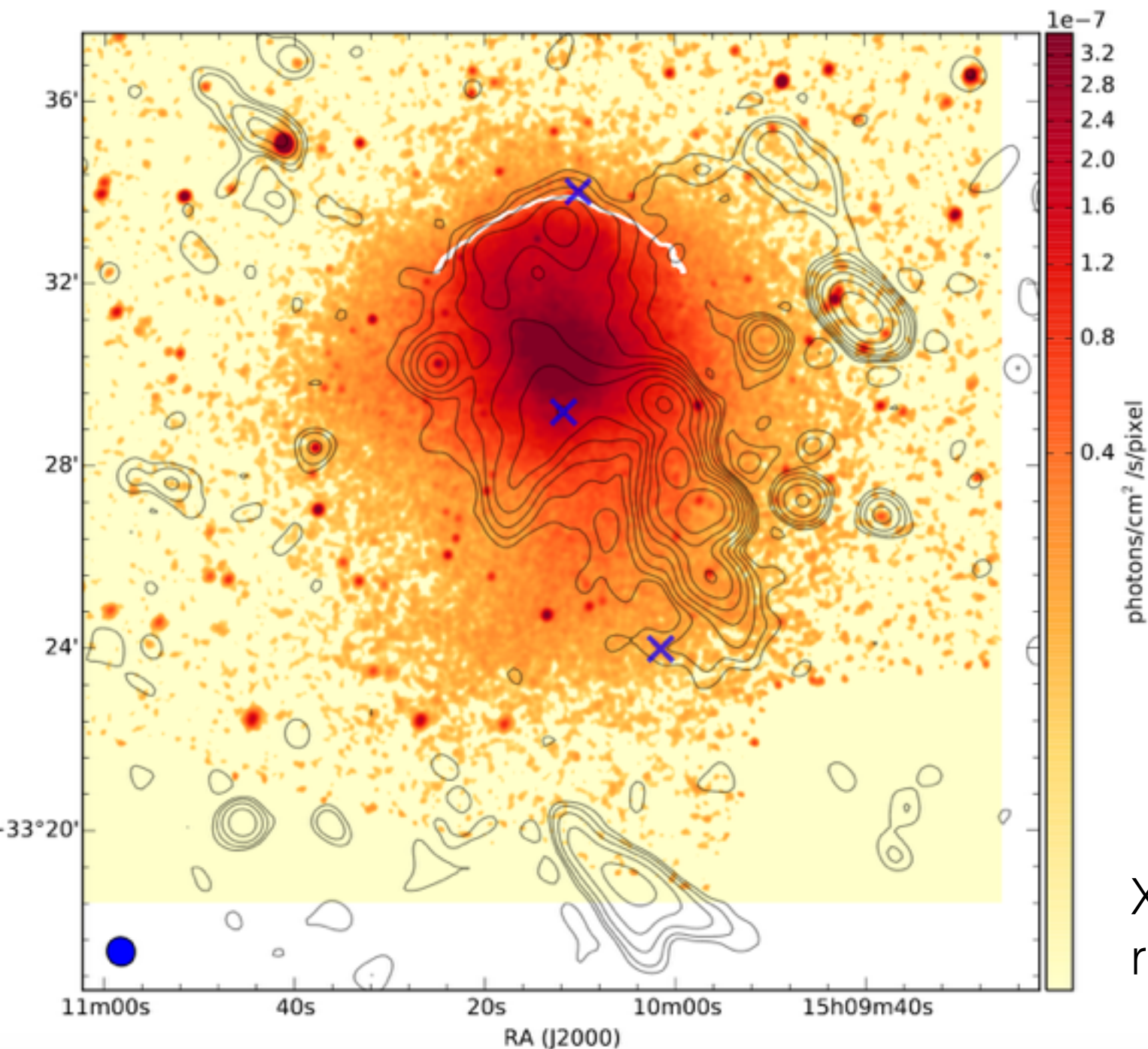
10x sensitivity improvement!



# First LOFAR results

Abell 2034

Shimwell & LOFAR cluster group (2016)



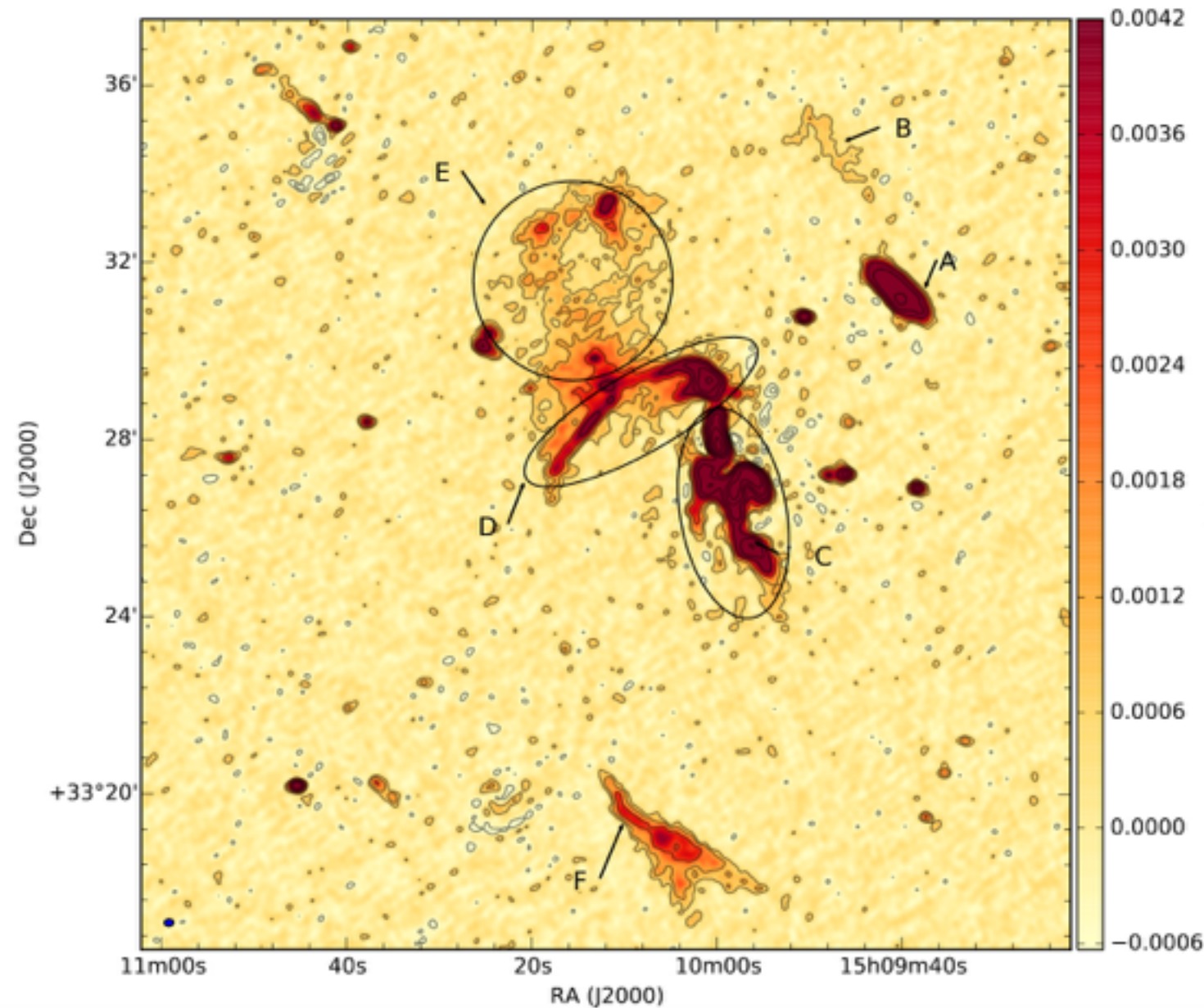
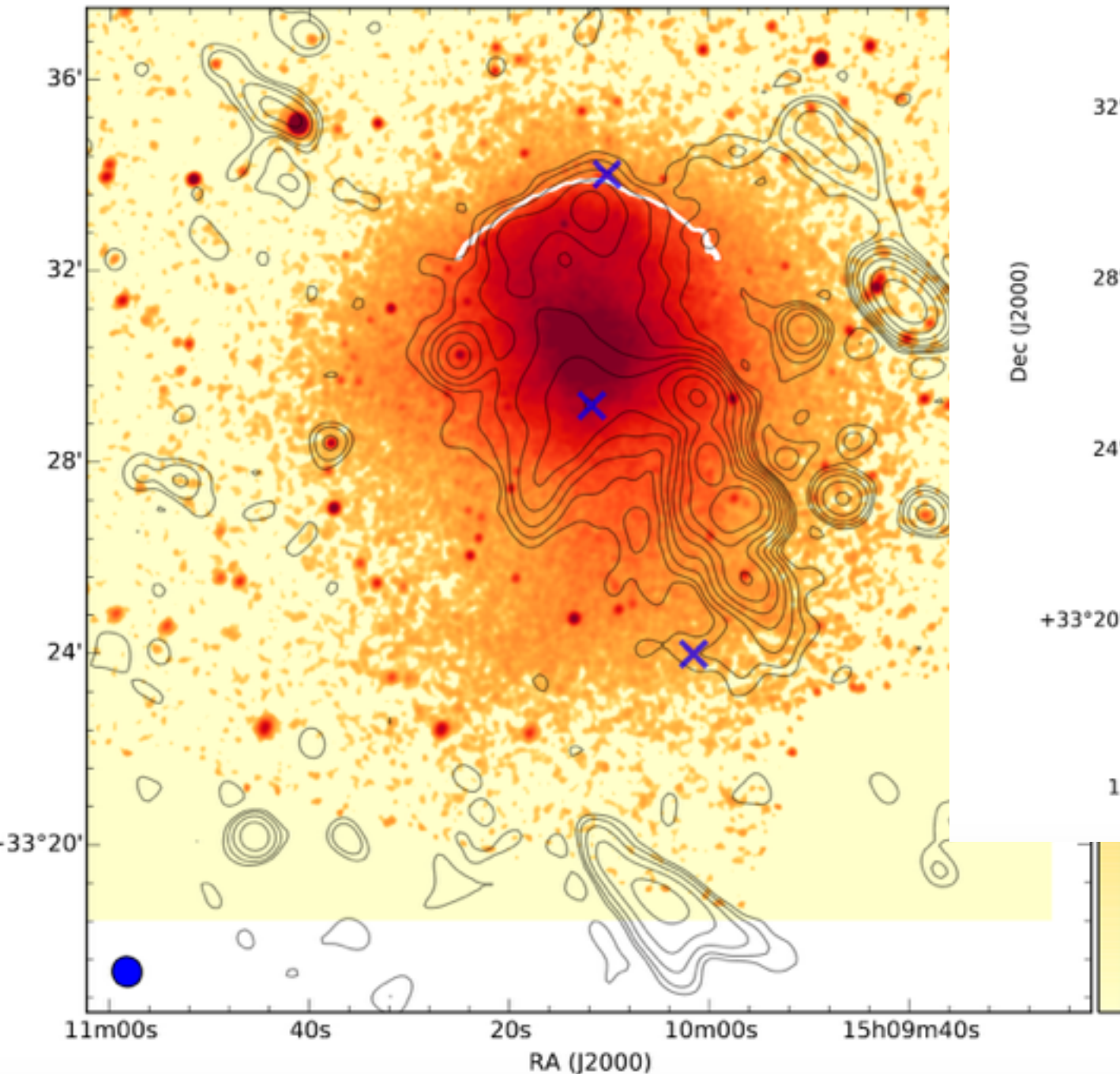
X-ray (Chandra 0.5 - 7 keV) in colours  
radio (LOFAR 120-190 MHz)



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Abell 2034

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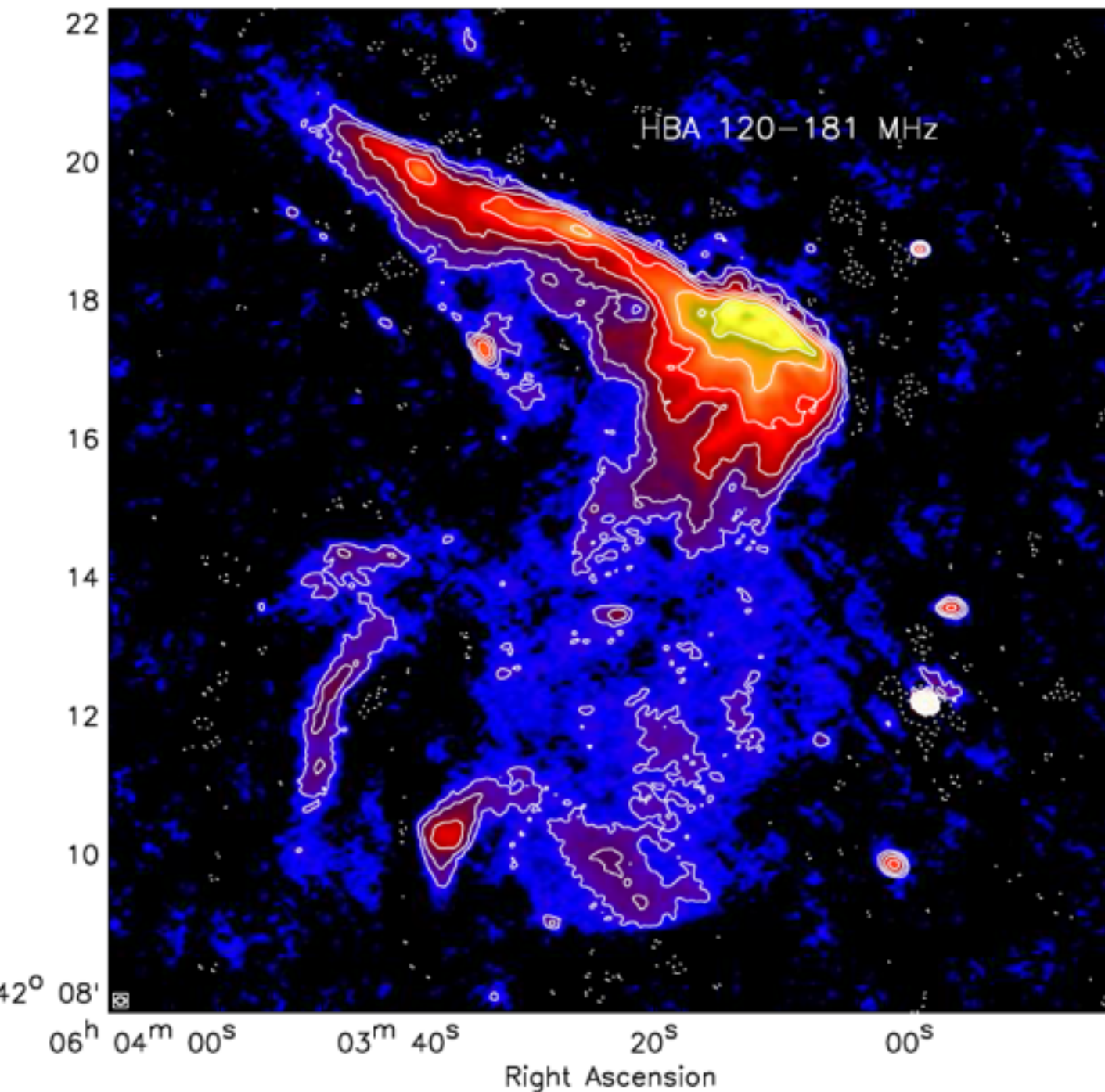


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# First LOFAR results

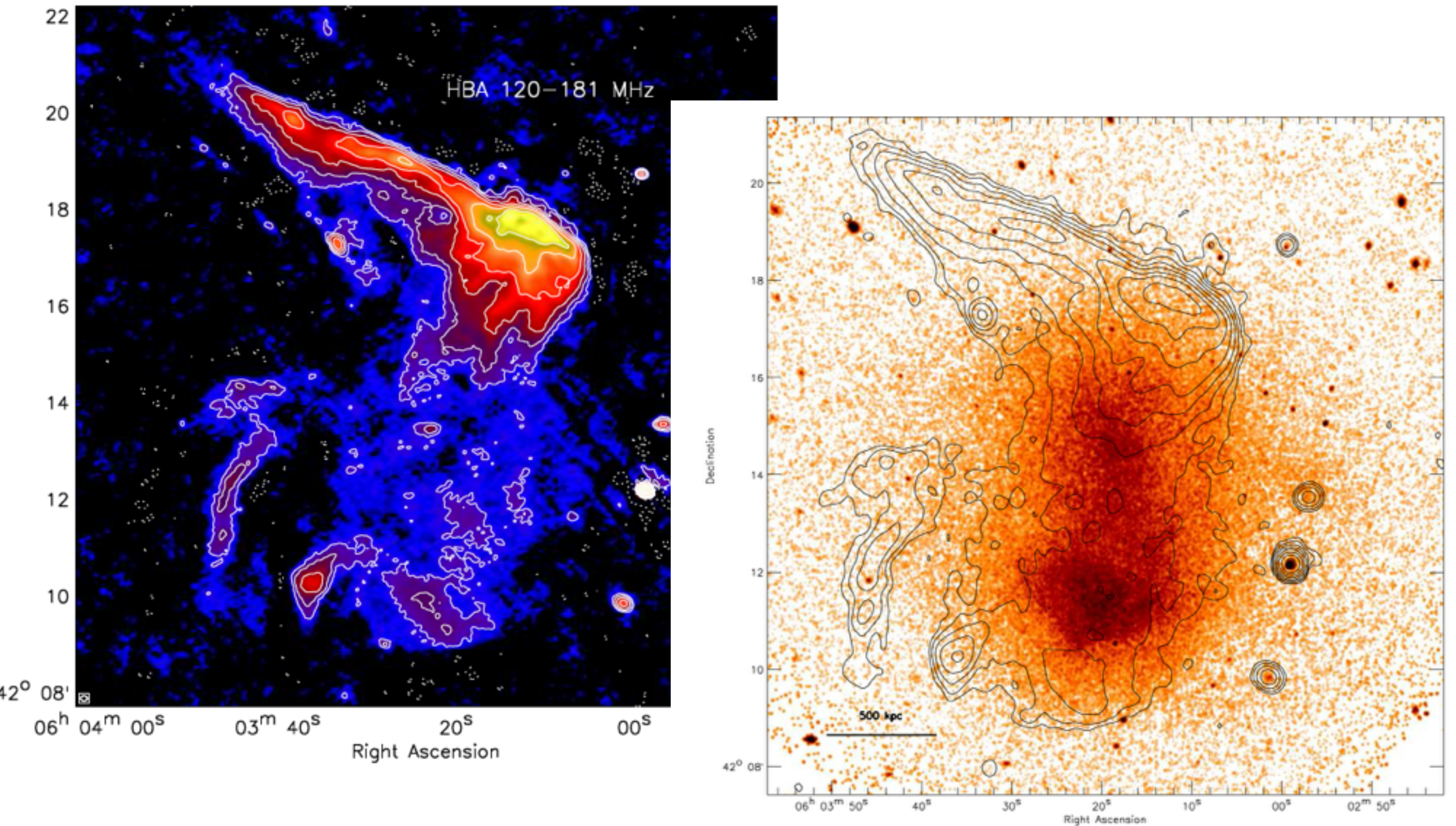
The “toothbrush” cluster  
van Weeren & LOFAR cluster group 2016





# First LOFAR results

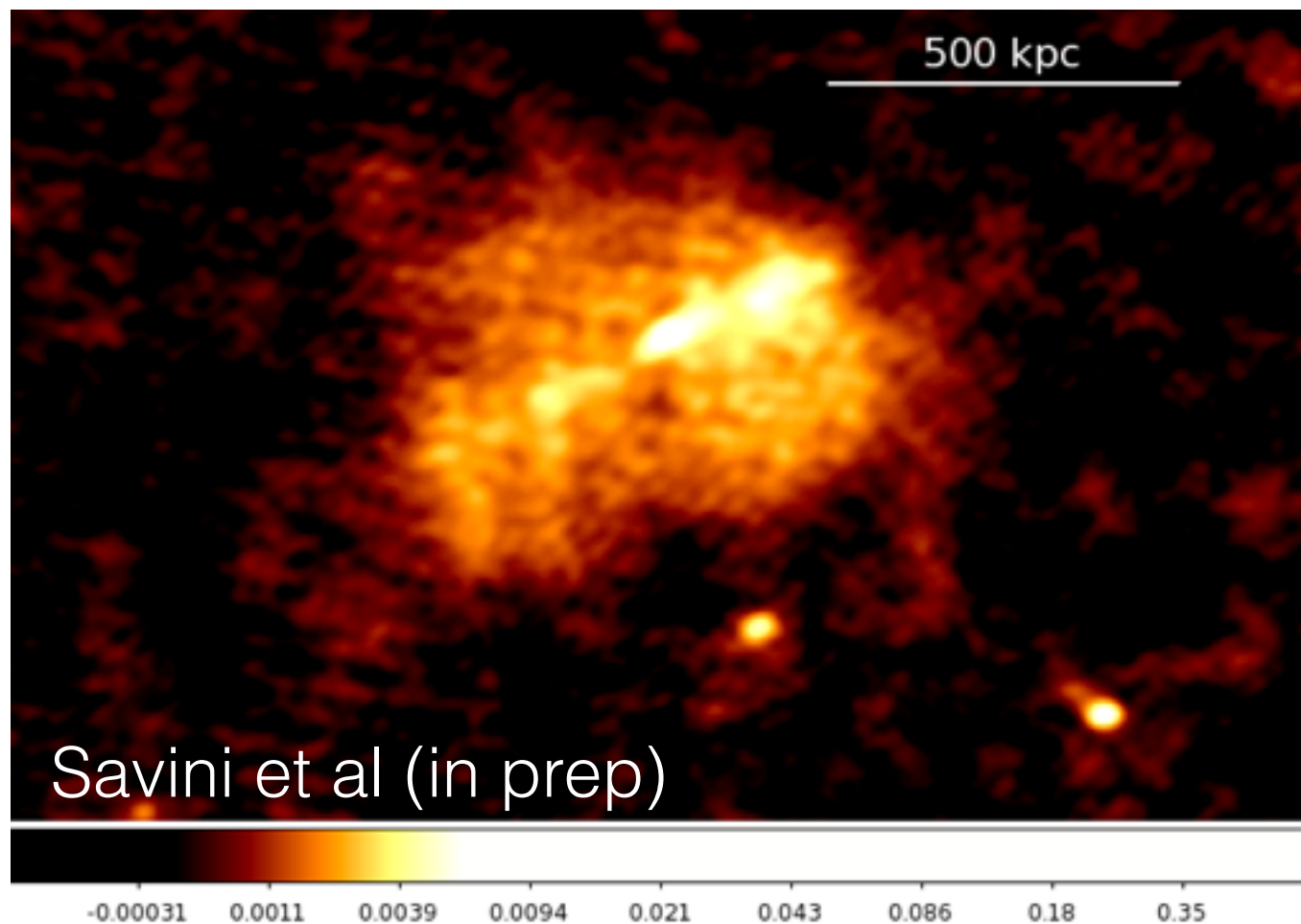
The “toothbrush” cluster  
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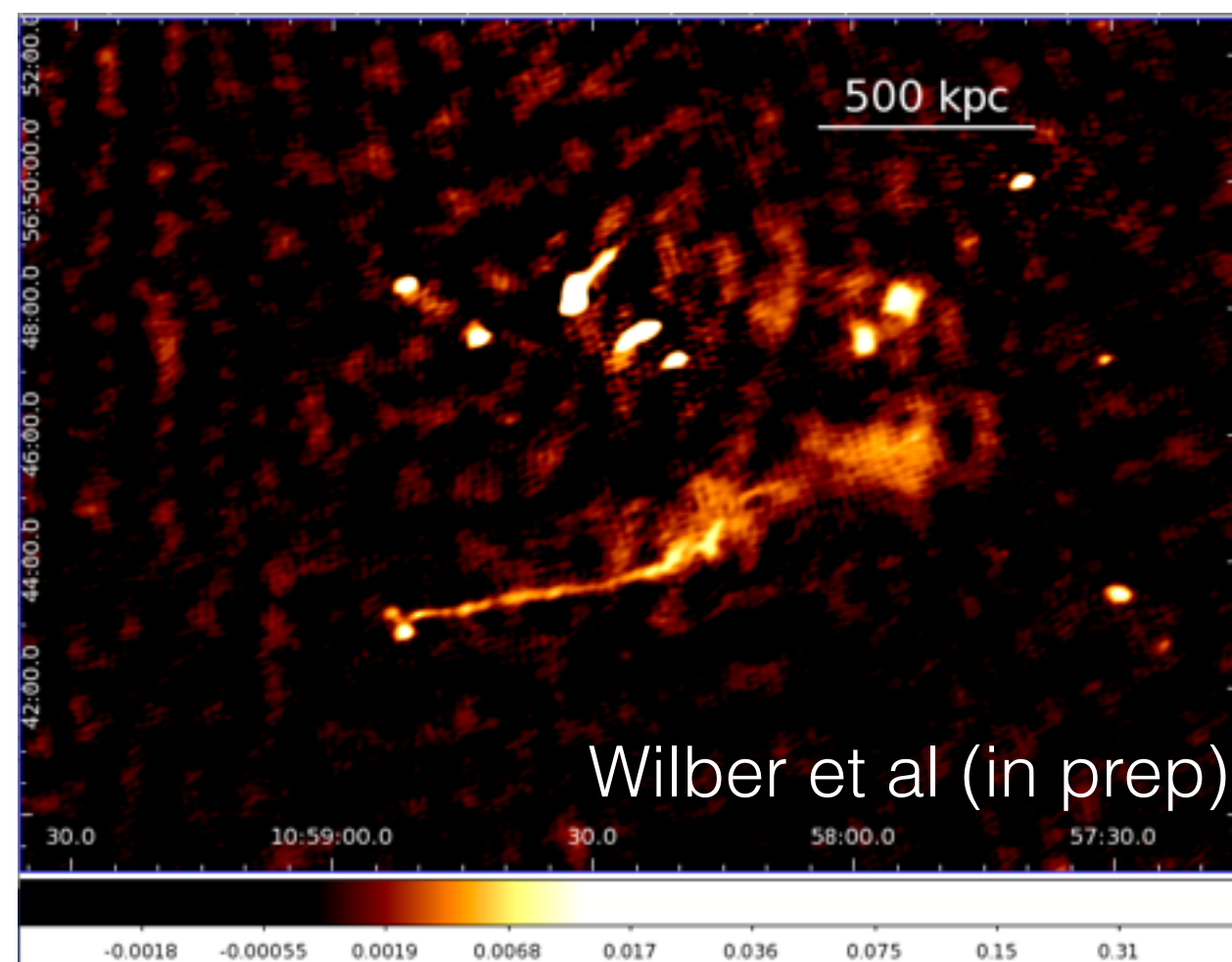
# More LOFAR results

2MASX J13171639+5143303,  $z=0.188$



Total emission  $\sim 800$  kpc!

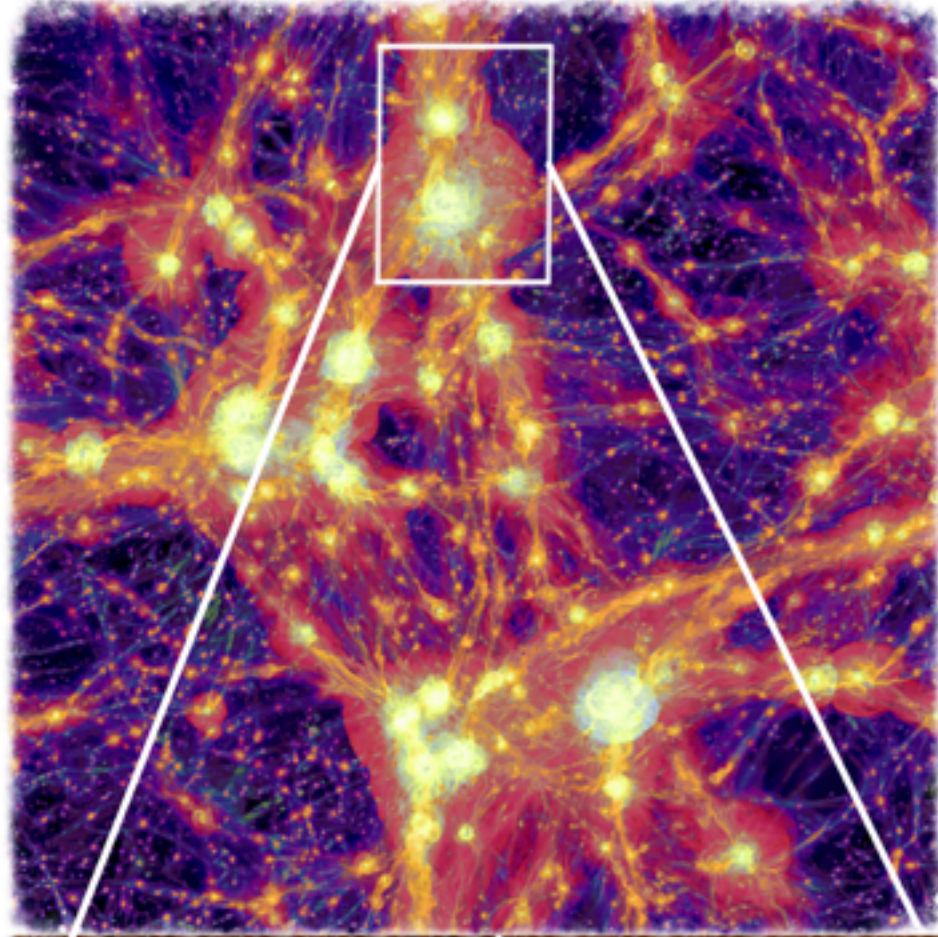
Abell 1132,  $z=0.1363$



Head tail? 1.5 Mpc long!



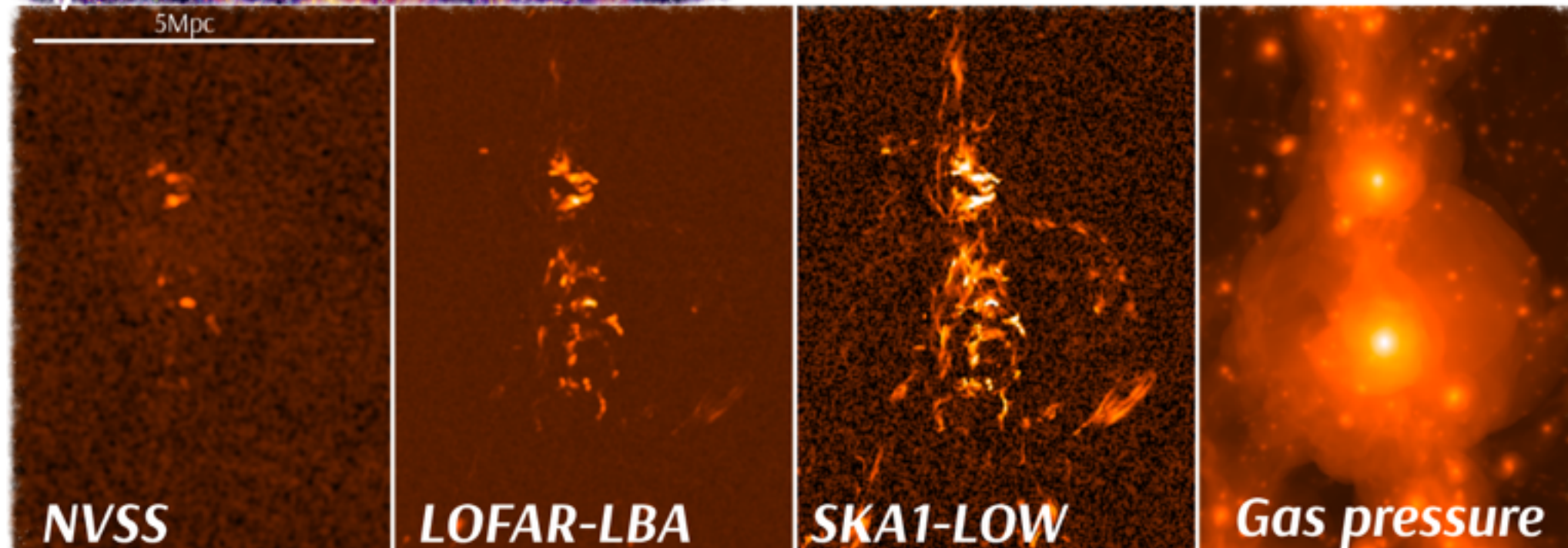
# Beyond clusters: detecting the cosmic web?



The radio cosmic web: a window on magneto genesis

Synchrotron from shock accelerated electrons  
—> radio survey

Low frequency probe large scale ( $1^\circ$  at low  $z$ )



Side courtesy of F. Vazza (Vazza et al. 2015,2016)



# Summary

- ✓ Low frequency + large surveys —> insights on **plasma acceleration processes & magnetic field**.
- ✓ **New approach** to observational data, new techniques required.
- ✓ Interferences are NOT a problem. One needs a perfect knowledge of the **instrument** and methods to **track ionospheric variations**
- ✓ LOFAR/ASKAP/Meerkat —> **unavoidable step** towards the SKA