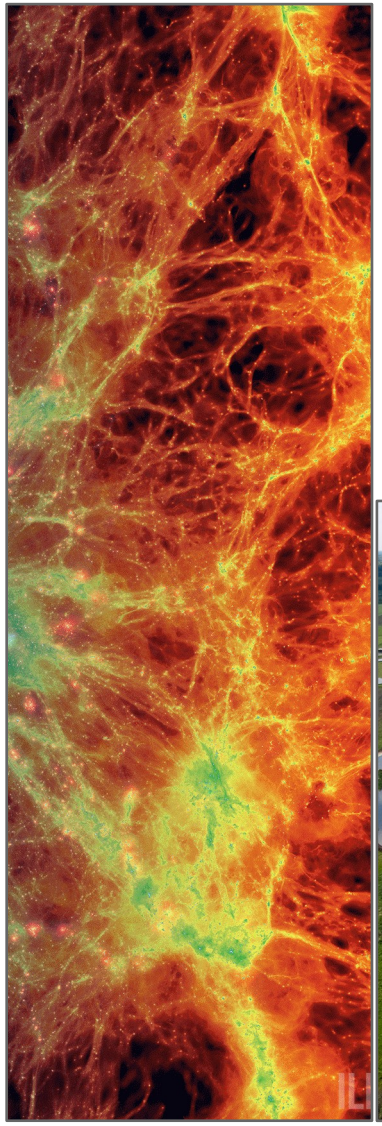


The Third National Workshop on the SKA Project
The Italian Route to the SKAO Revolution
4-8 October 2021

Large-scale magnetic fields unveiled by LOFAR

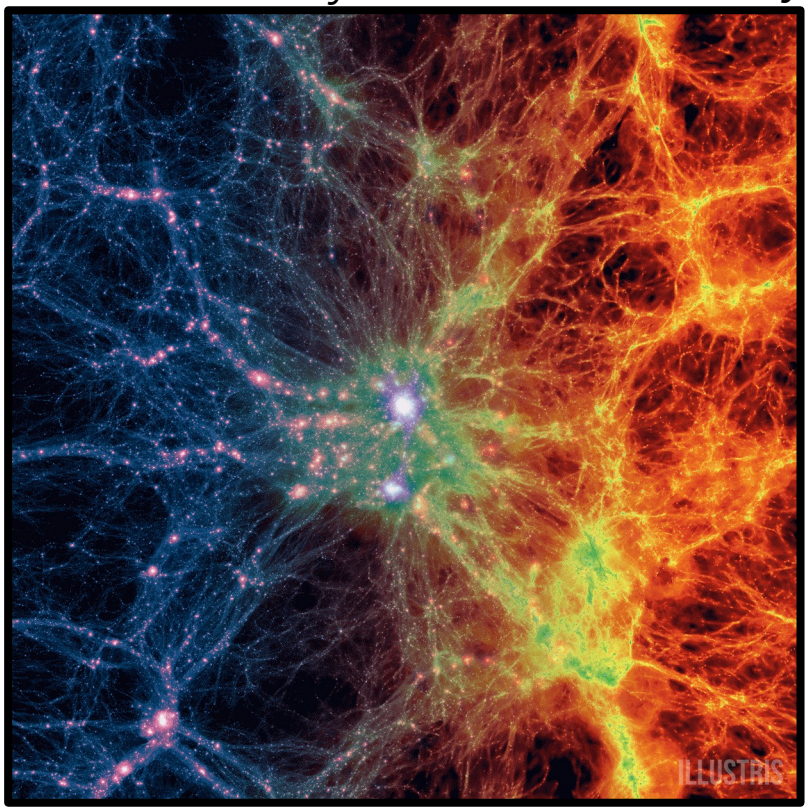
Chiara Stuardi
Università di Bologna
INAF – Istituto di Radioastronomia

Collaborators: A. Bonafede,
S. O'Sullivan, F. Vazza, S. Banfi et al.

DRANOEL
ERC - Stg16 714245
MIUR grant FARE SMS
LOFAR SURVEYS
LOFAR MAGNETISM
Key Science Project

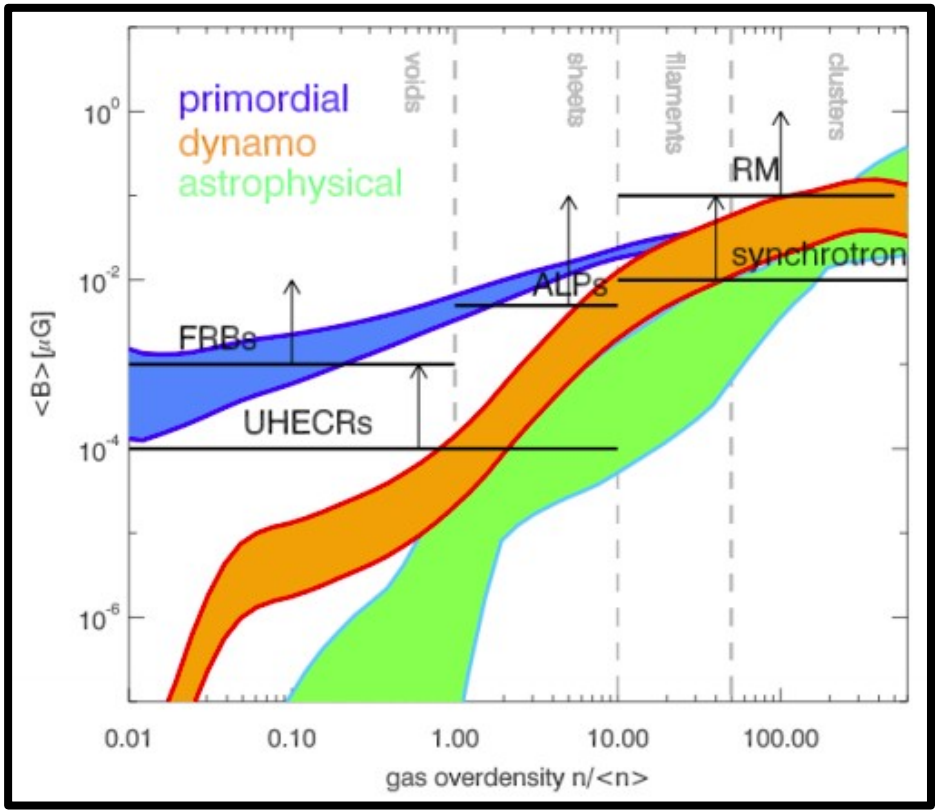
A magnetized Universe

Dark matter density Gas density



Vogelsberger+ 2014

Large-scale magnetic fields



Vazza+ 2017

A magnetized Universe

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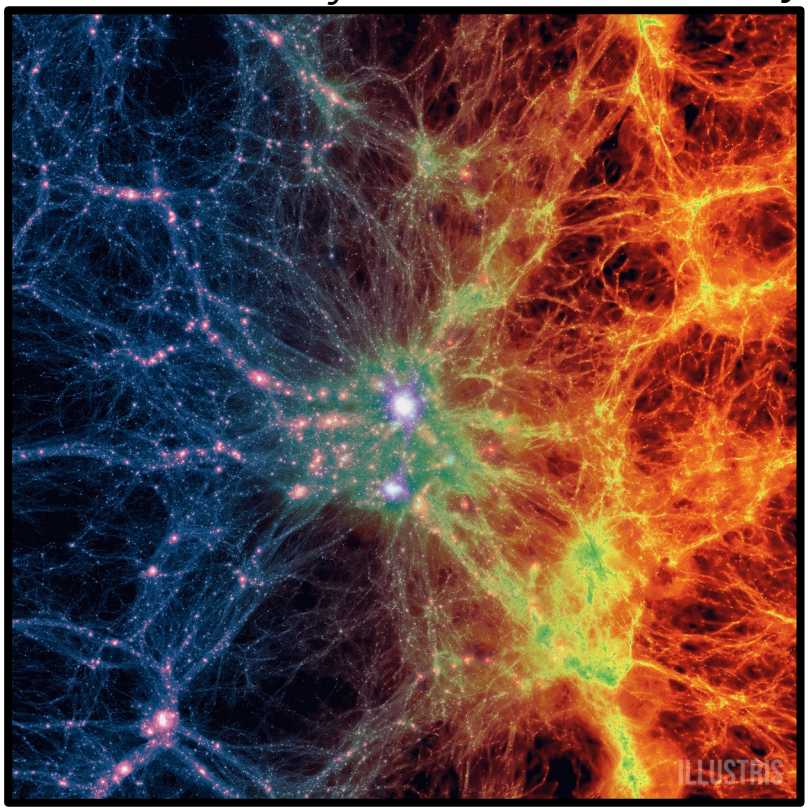

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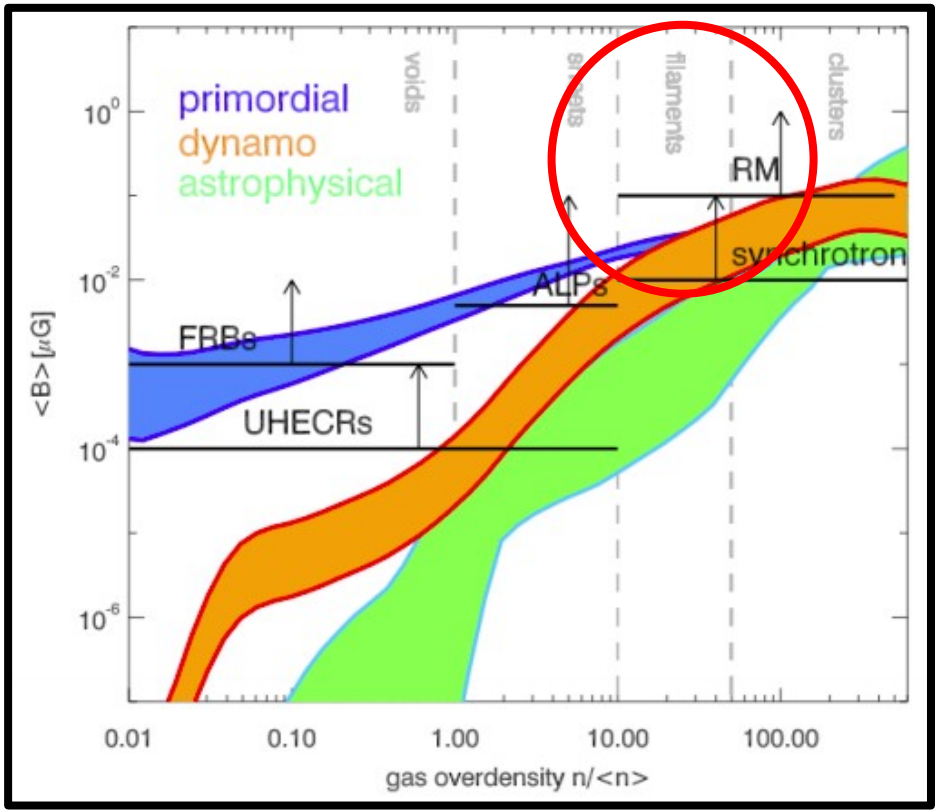
Large-scale magnetic fields

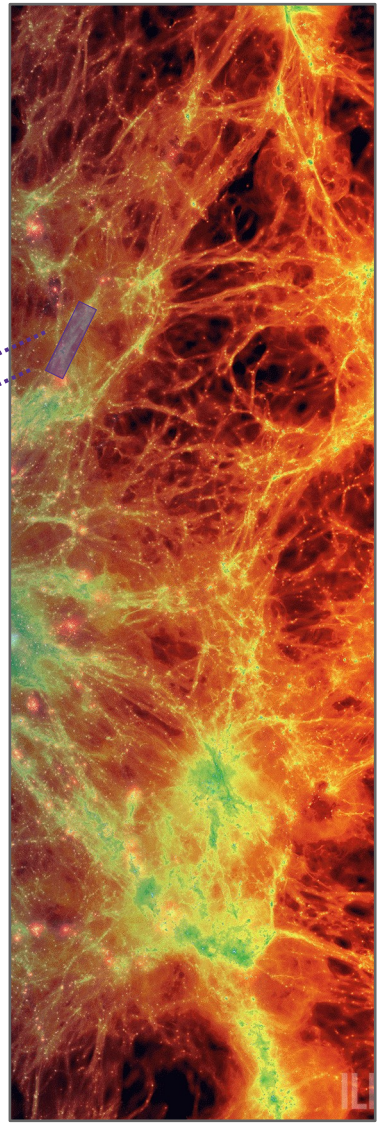


Vazza+ 2017

Radio observations

- Synchrotron emission

→ need for high sensitivity to low surface brightness diffuse emission

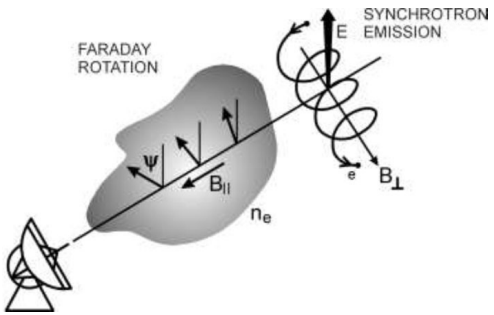


Radio observations

- Synchrotron emission

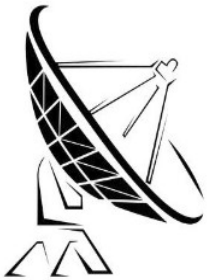
→ need for high sensitivity to low surface brightness diffuse emission

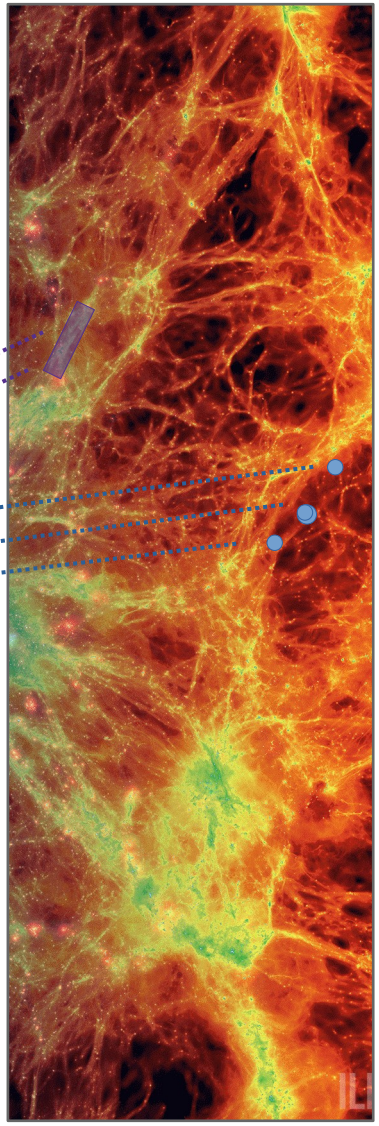
- Faraday rotation measure (RM)



$$\Psi_\lambda = \Psi_0 + RM\,\lambda^2$$

$$RM\,,\sigma_{RM} \propto \int_{source}^{observer} n_e B_\parallel dl_\parallel$$





→ need for a large number of polarized sources

Radio observations

- Synchrotron emission

→ need for high sensitivity to low surface brightness diffuse emission

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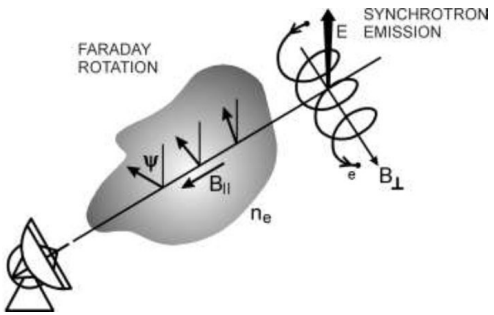

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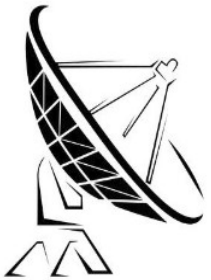
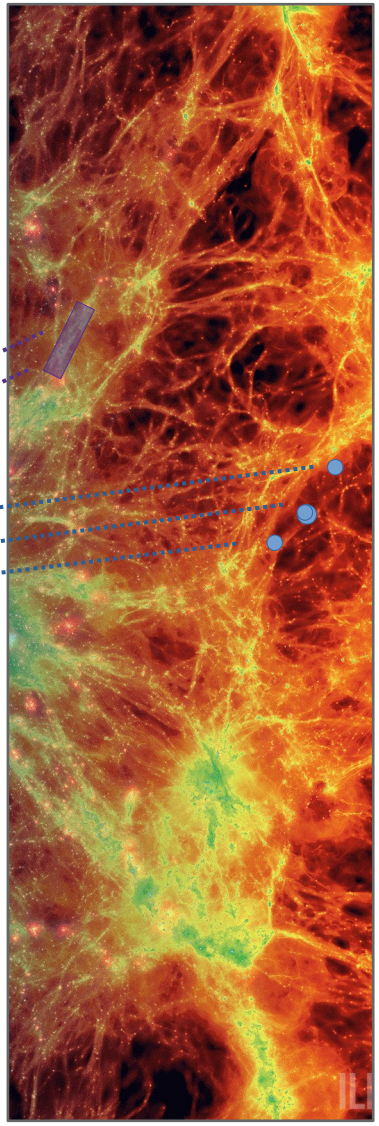


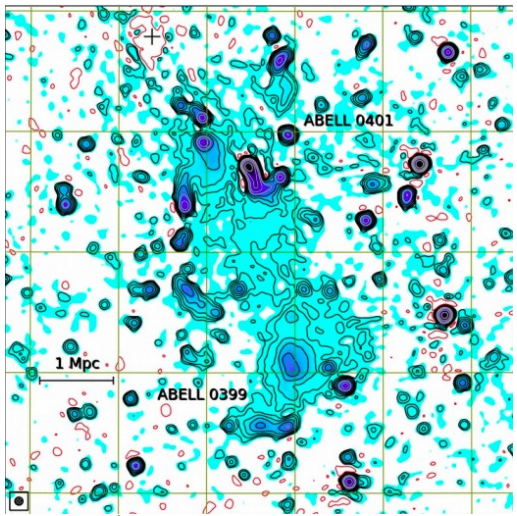


→ need for a large number of polarized sources

→ need for the SKAO revolution

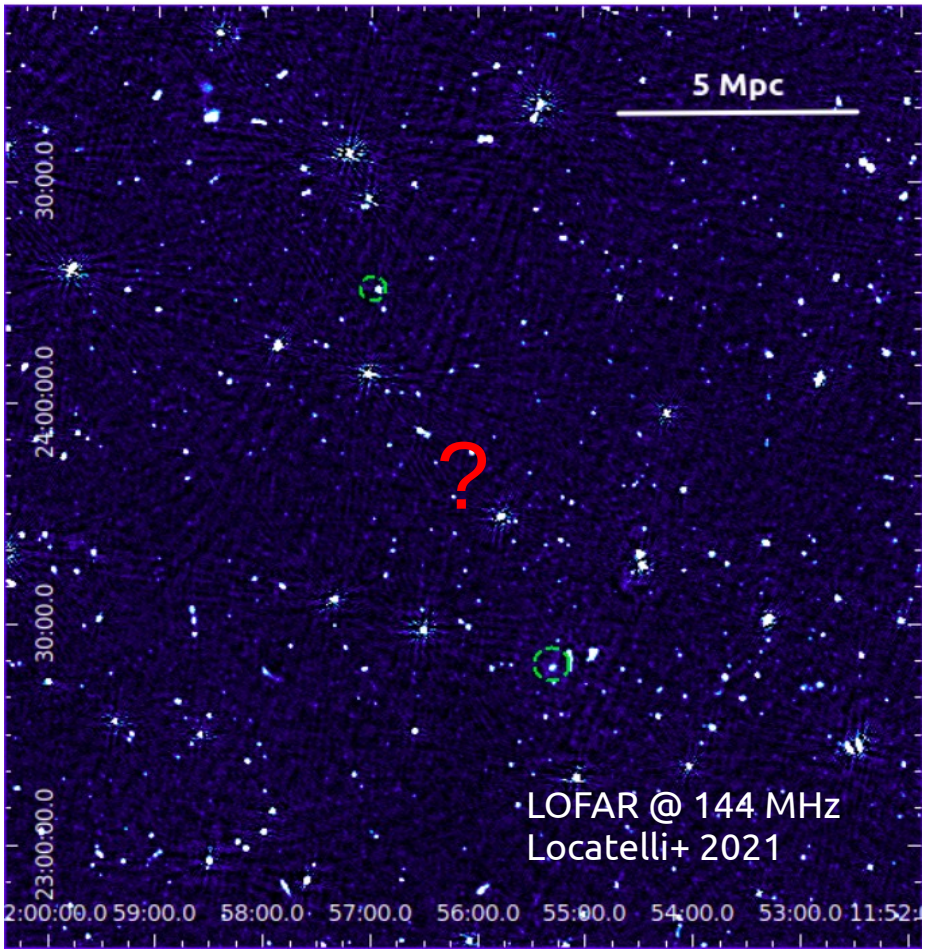
Radio observations: synchrotron emission

LOFAR @ 144 MHz



Govoni+ 2019

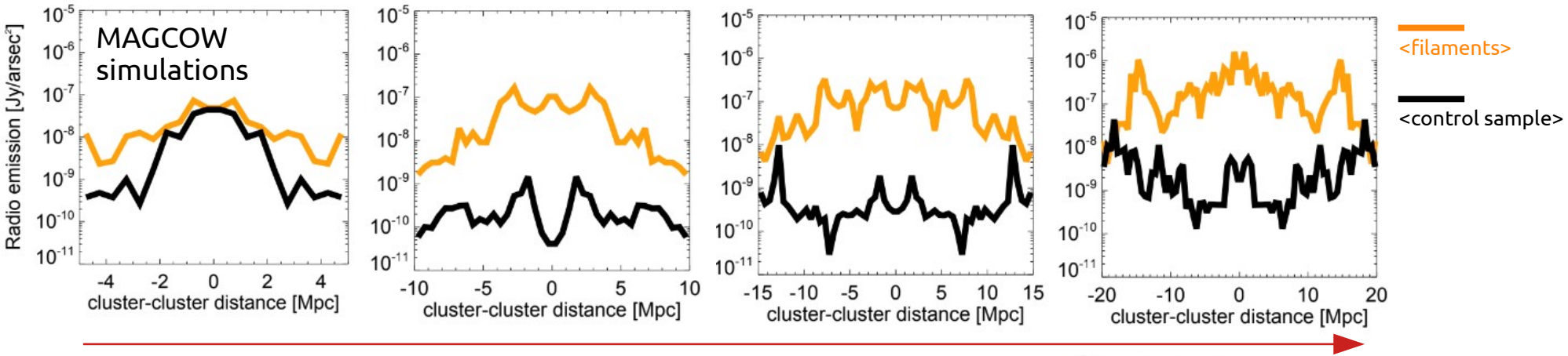
Observation of bridges (< 3Mpc) between clusters



Non detection of syncrotron emission from 10-20 Mpc filaments connecting two clusters → B <250 nG

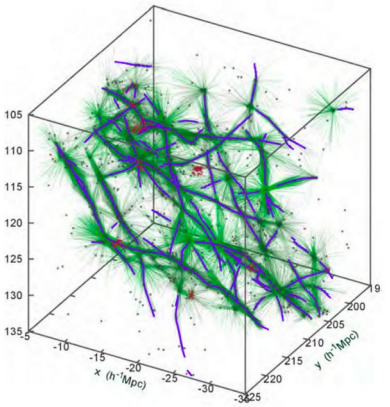
Radio observations: synchrotron emission

But longer filaments should have a higher chance to be detected



Tempel +2014: optically based (SDSS) filament catalog
Selection of the longest filaments: 40-60 Mpc

→ can LOFAR detect them?

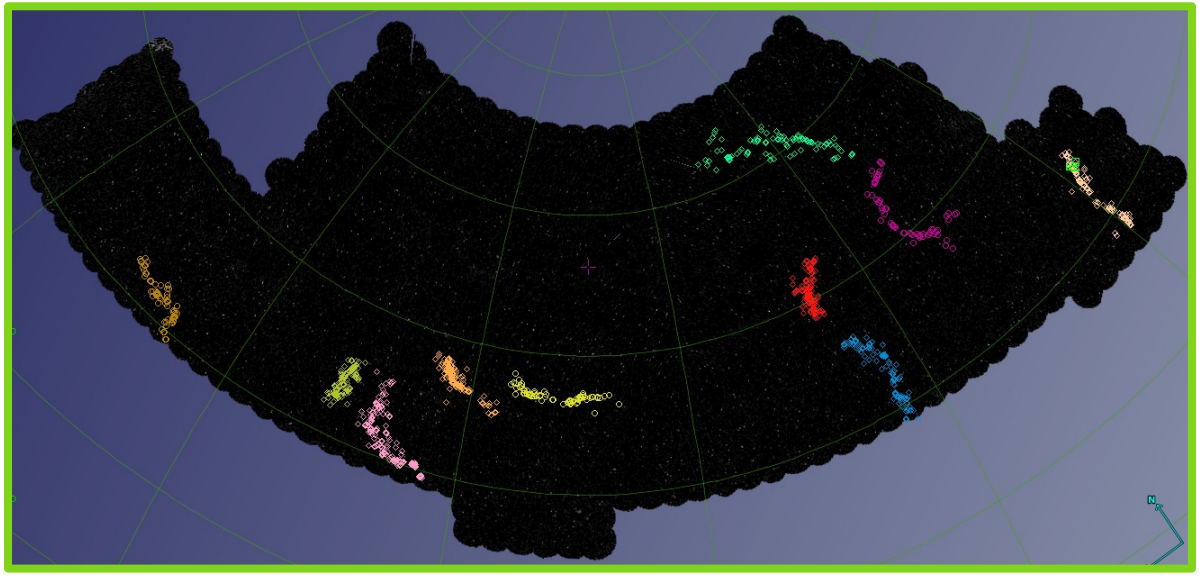


Radio observations: synchrotron emission

LOFAR Two Metre Sky Survey [Shimwell+ 2017,2019]

Why LoTSS?

- high sensitivity to low surface brightness diffuse emission @ 120-168 MHz
- broad sky coverage



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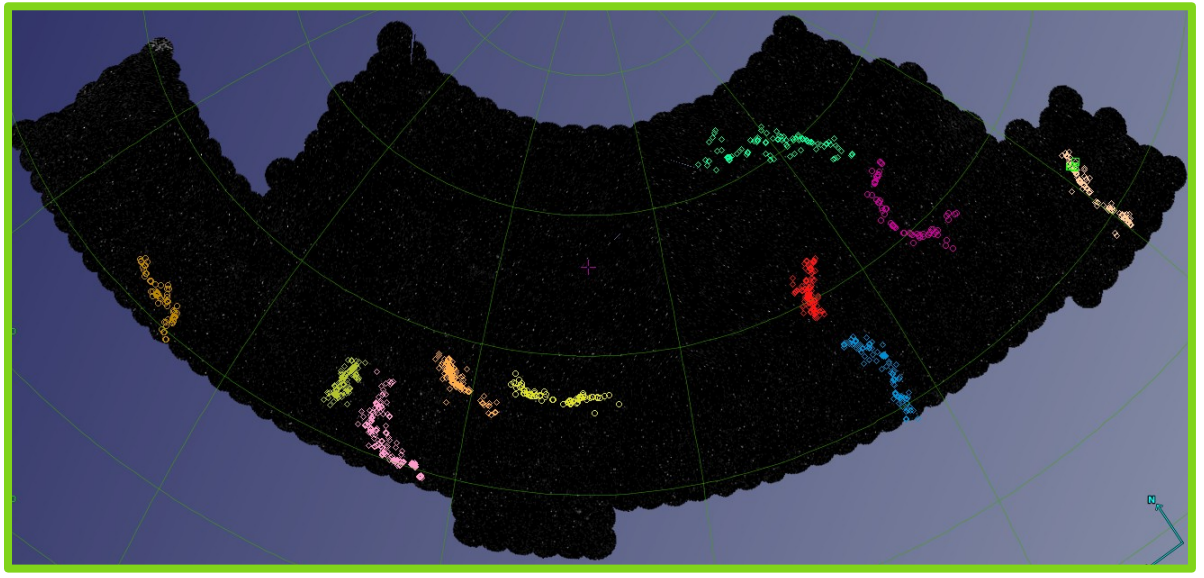

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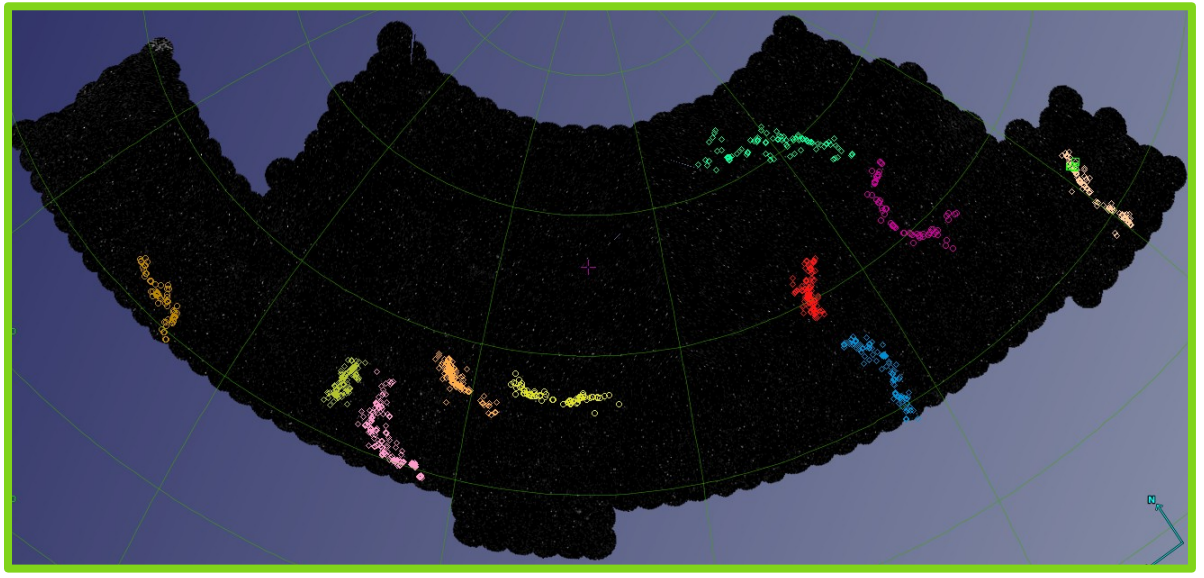

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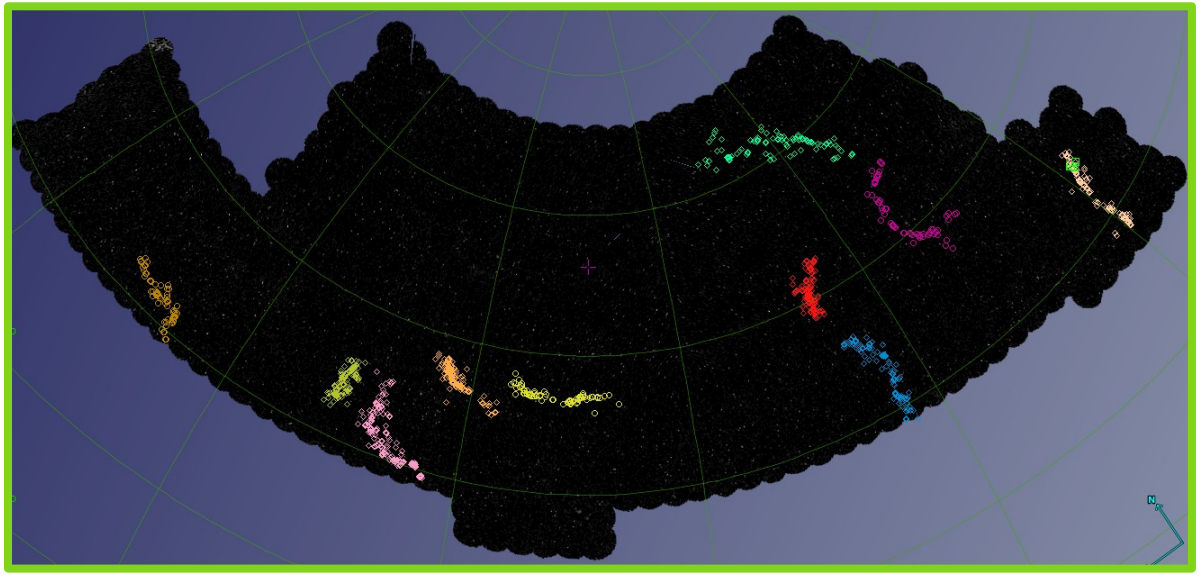
Stay tuned



Radio observations: Faraday rotation

LOFAR Two Metre Sky Survey [Shimwell+ 2017,2019]

Why LoTSS?

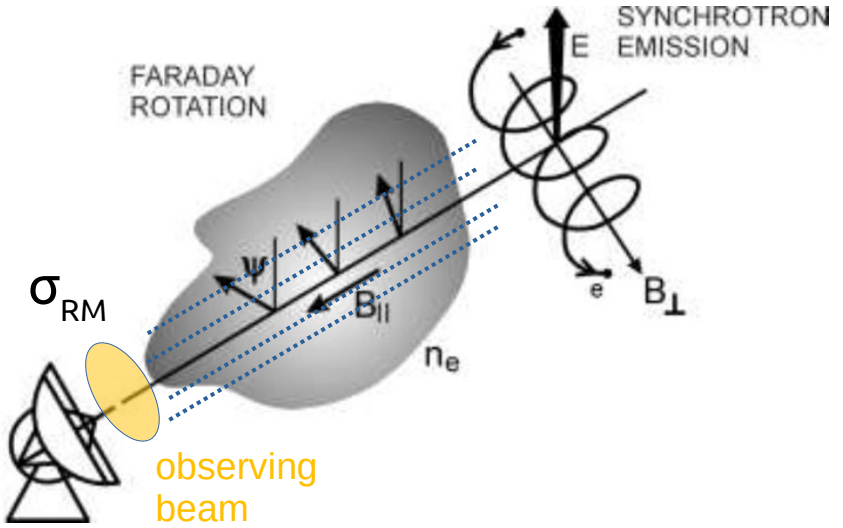
- High RM accuracy
- High sensitivity to small RM variations

- Strong Faraday depolarization

$$p(\lambda) \propto e^{-2\sigma_{RM}^2 \lambda^4}$$

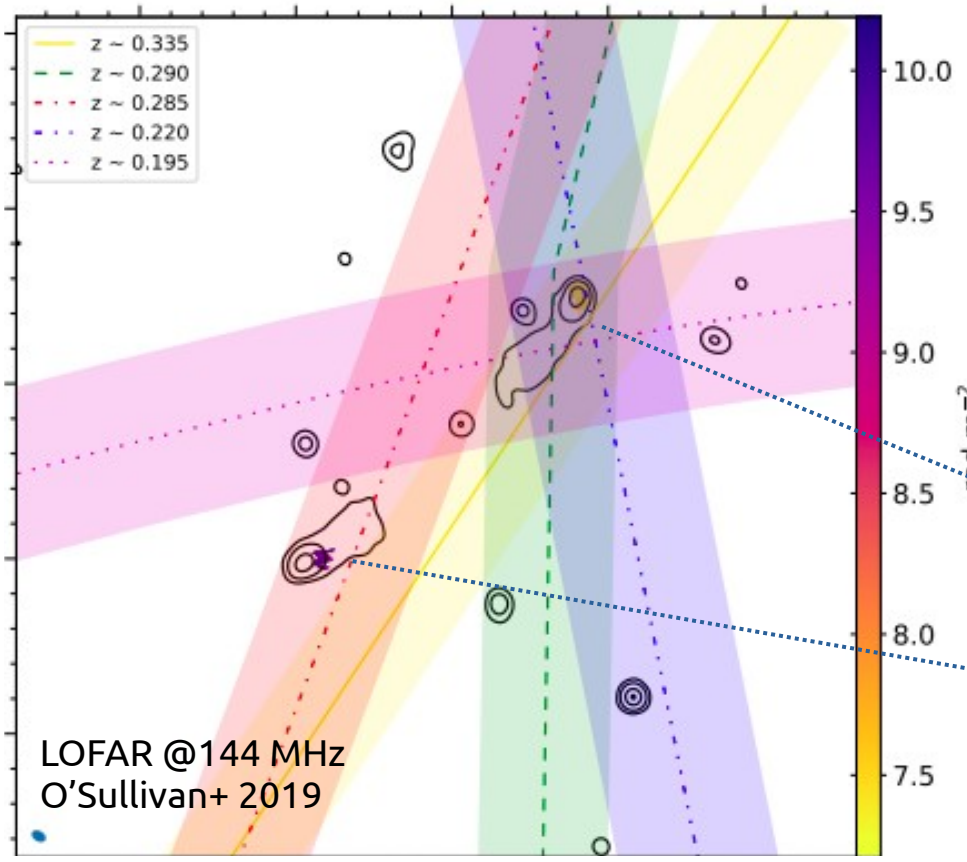
- few polarized sources

+ selection of sources in weakly magnetized environments

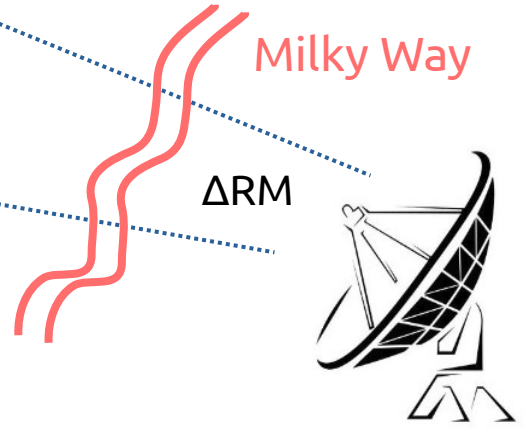


Radio observations: Faraday rotation

Observation of a single giant radio galaxy (> 700 kpc)

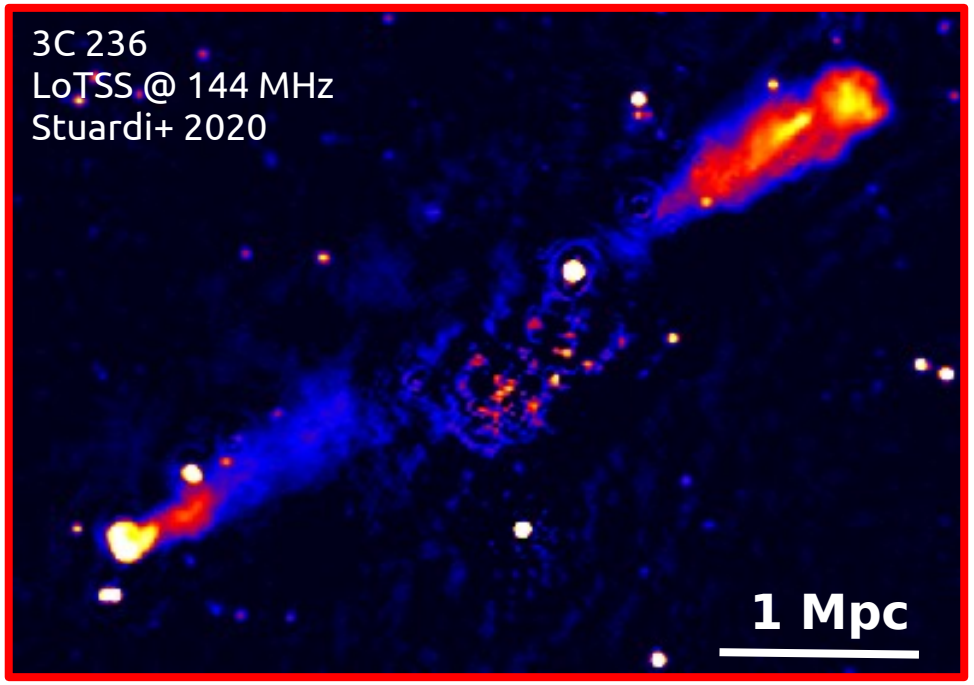


RM difference (ΔRM) possibly caused by interposed filaments → but also the MW can contribute

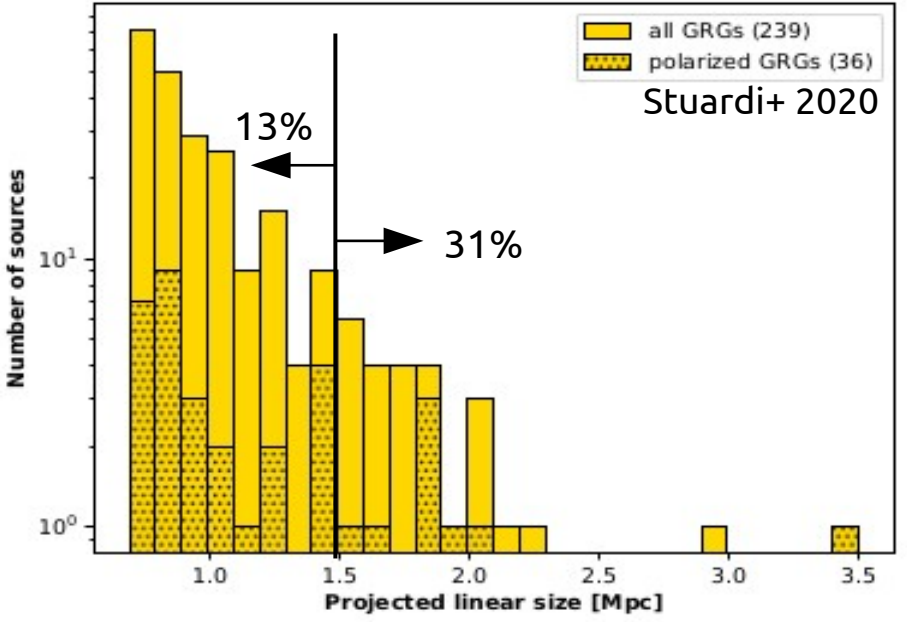


Radio observations: Faraday rotation

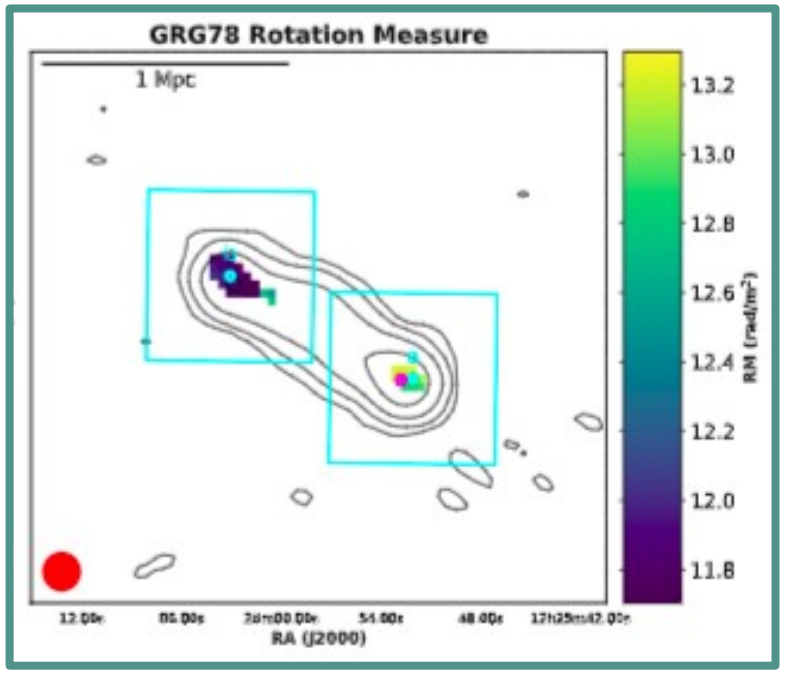
In deep study of a sample of giant radio galaxies (GRGs)



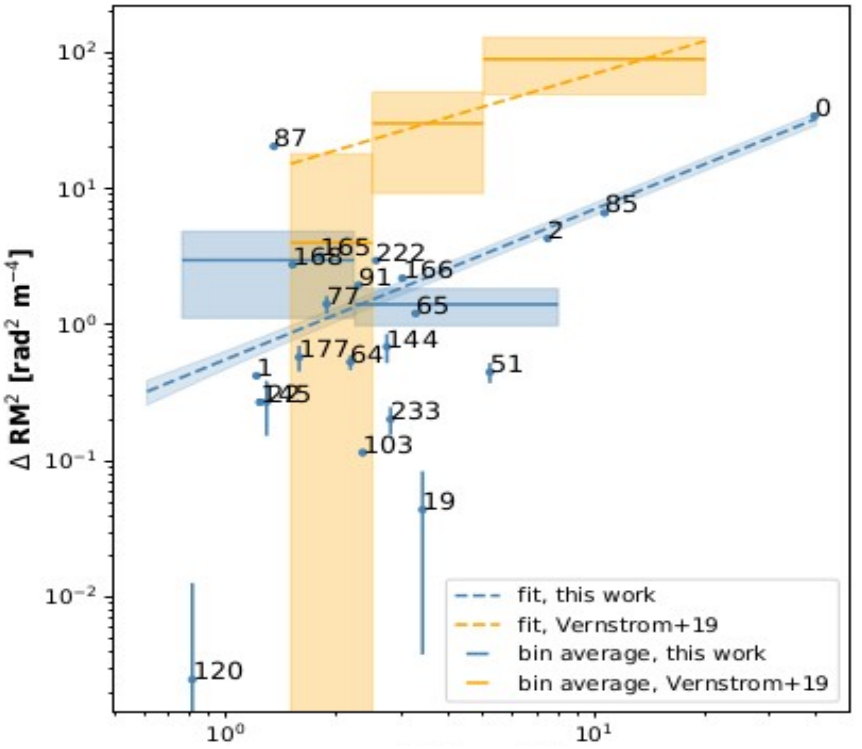
→ 36/239 GRGs detected in polarization (LoTSS dr1 based catalog [Dabhade+ 2020])
→ 20% S_{144MHz}>50mJy



Radio observations: Faraday rotation

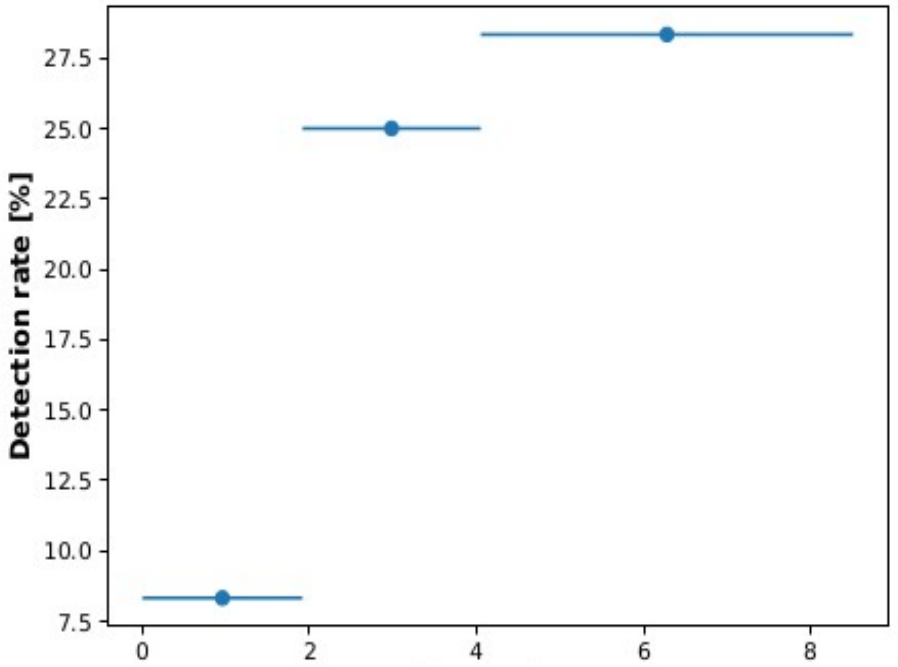


Expected ΔRM trend due to the Milky Way but large scatter



Radio observations: Faraday rotation

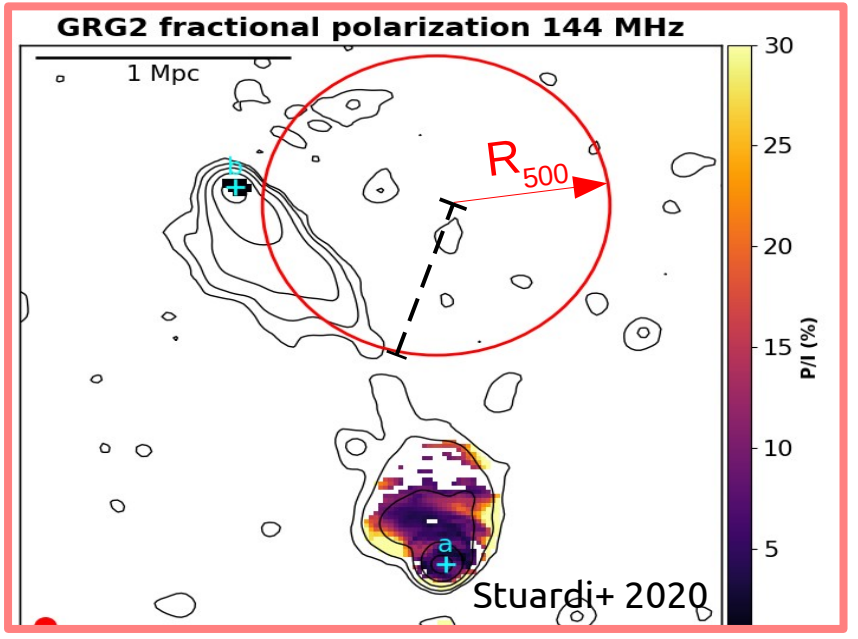
Depolarization effect due to the presence of *foreground* galaxy clusters



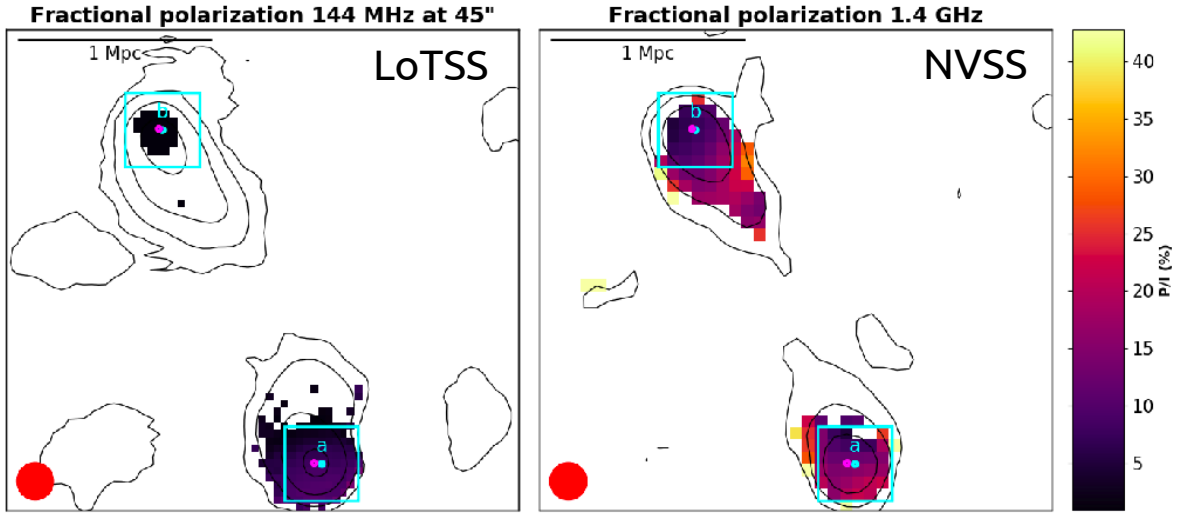
Distance from the closest *foreground* galaxy cluster (R_{500})

(SDSS based galaxy cluster catalog [Wen+2015])

→ selection of sources outside galaxy clusters



Radio observations: Faraday rotation

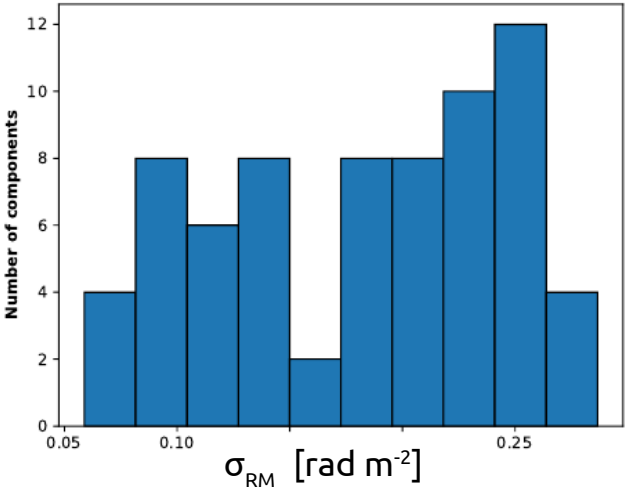


$$D^{144\,MHz}_{1.4\,GHz} = \frac{p_{144\,MHz}}{p_{1.4\,GHz}}$$

→ σ_{RM}

Assuming external Faraday screen

$$\sigma^2_{RM} = 0.812^2 \Lambda_c \int_{source}^{observer} (n_e B_\parallel)^2 dl$$

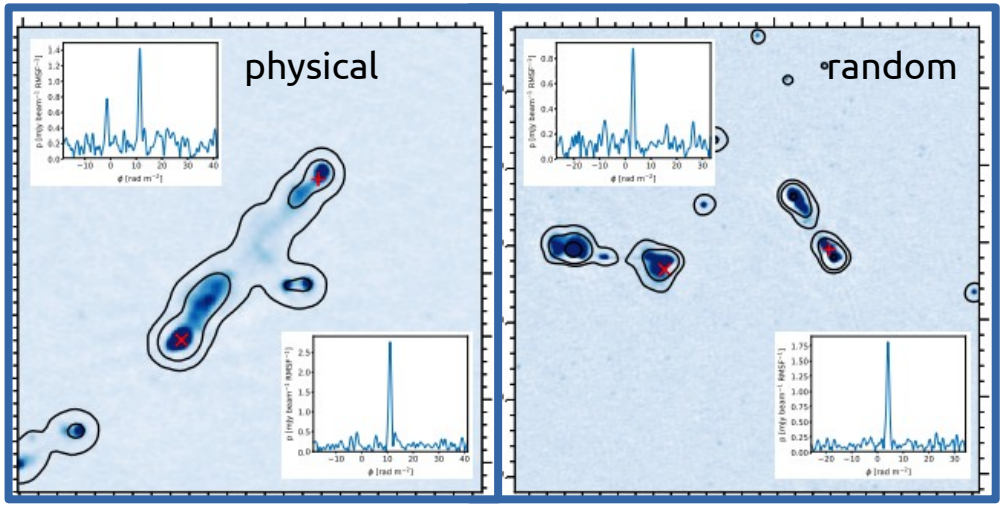


Local B fluctuations on 3-25 kpc scales (beam size)
GRG lobes expand in an under-dense environment: $n_{THe} \sim 10^{-5}$ cm^{-3} [Mack+ 1998; Malarecki+ 2015]

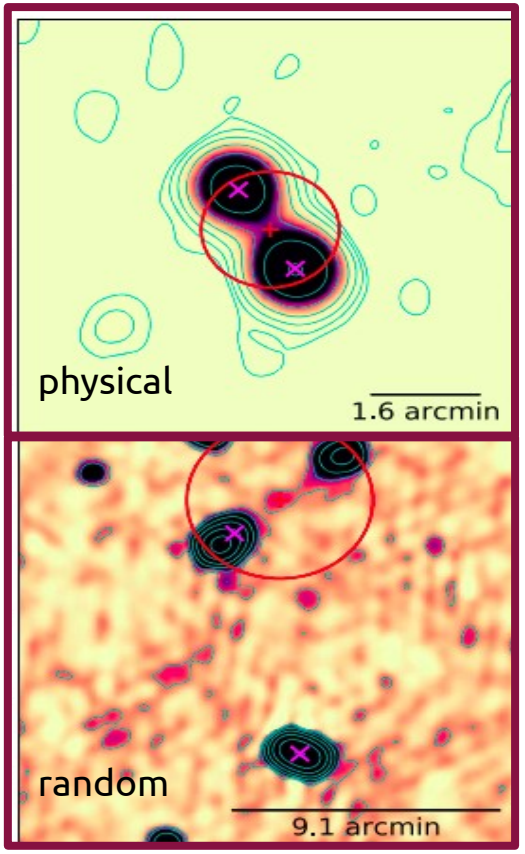
→ B < 100 nG

Radio observations: Faraday rotation

Observation of large sample of physical vs random pairs



LoTSS @ 144 MHz
O'Sullivan,...CS+ 2020



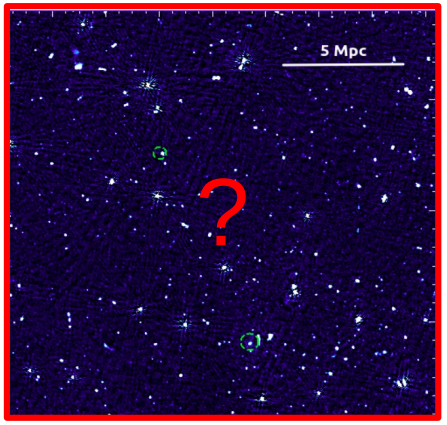
NVSS @ 1.4 GHz
Vernstrom+ 2019

Allow to isolate the extra-galactic contribution to ΔRM

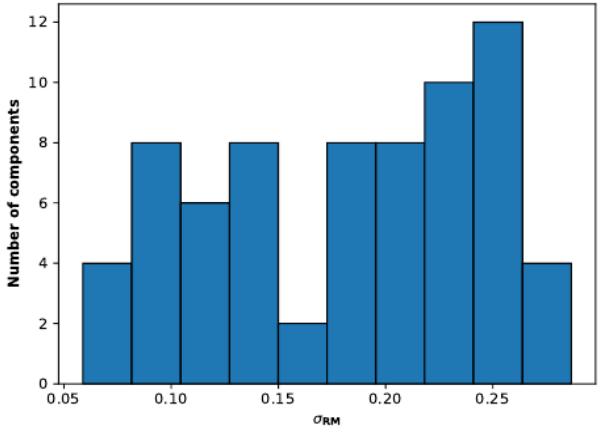
NVSS @ 1.4 GHz → B<40 nG
LoTSS @ 144 MHz → B<4 nG
} → selection effect

Conclusions

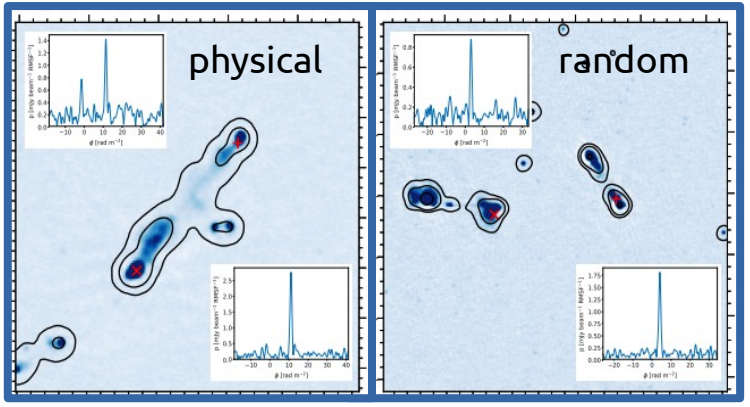
LOFAR has proven to be a great SKA pathfinder
for the study of large-scale magnetic fields



B<250nG



B<100nG



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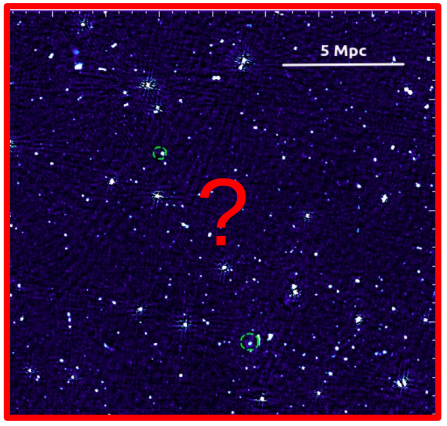
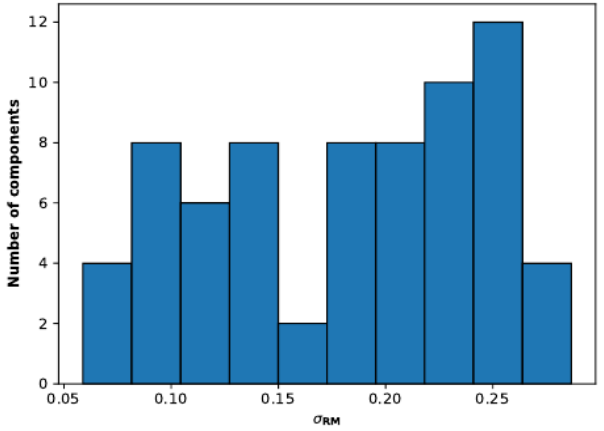
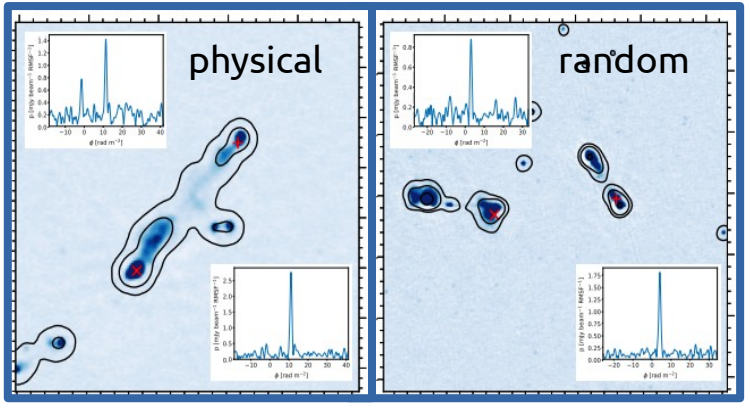


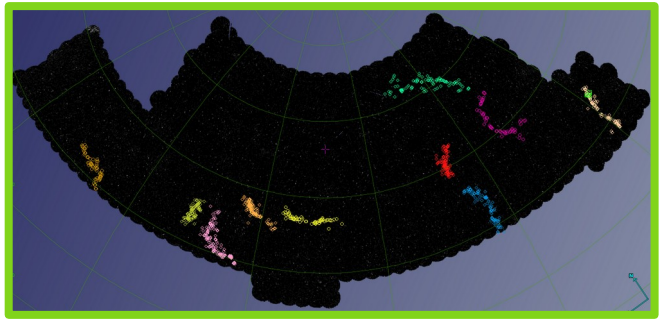
B<250nG



B<100nG



B<4nG



While waiting
for the SKAO revolution
...use LOFAR

Thank you!