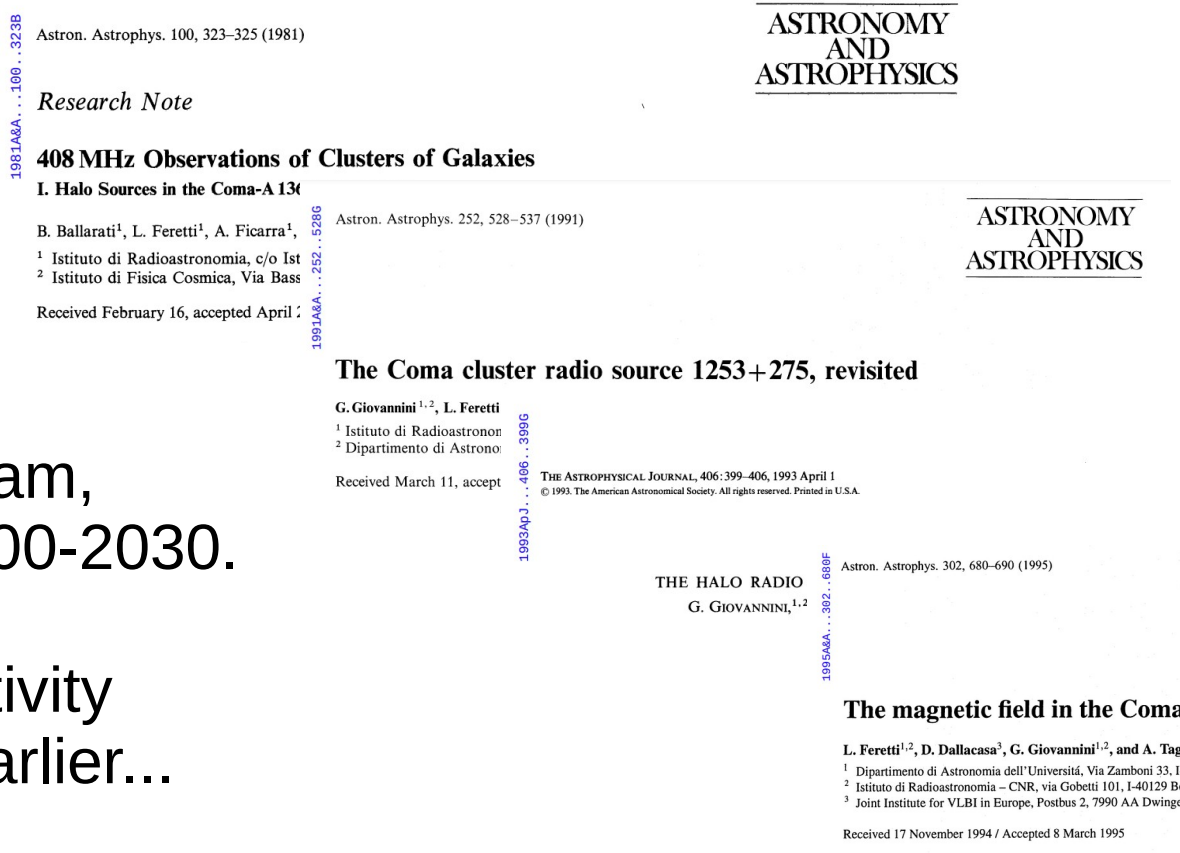
METEORA ★

Valentina Vacca – INAF OAC

METEORA: **M**agnetism in **E**xtragalactic sys**T**ems with multi-fr**E**quency **O**bse**R**v**A**tions



Scientific Program,
Time range: 2000-2030.

Actually this activity
started much earlier...

SCIENTIFIC BACKGROUND

ORIGIN & **EVOLUTION** OF COSMOLOGICAL MAGNETIC FIELDS

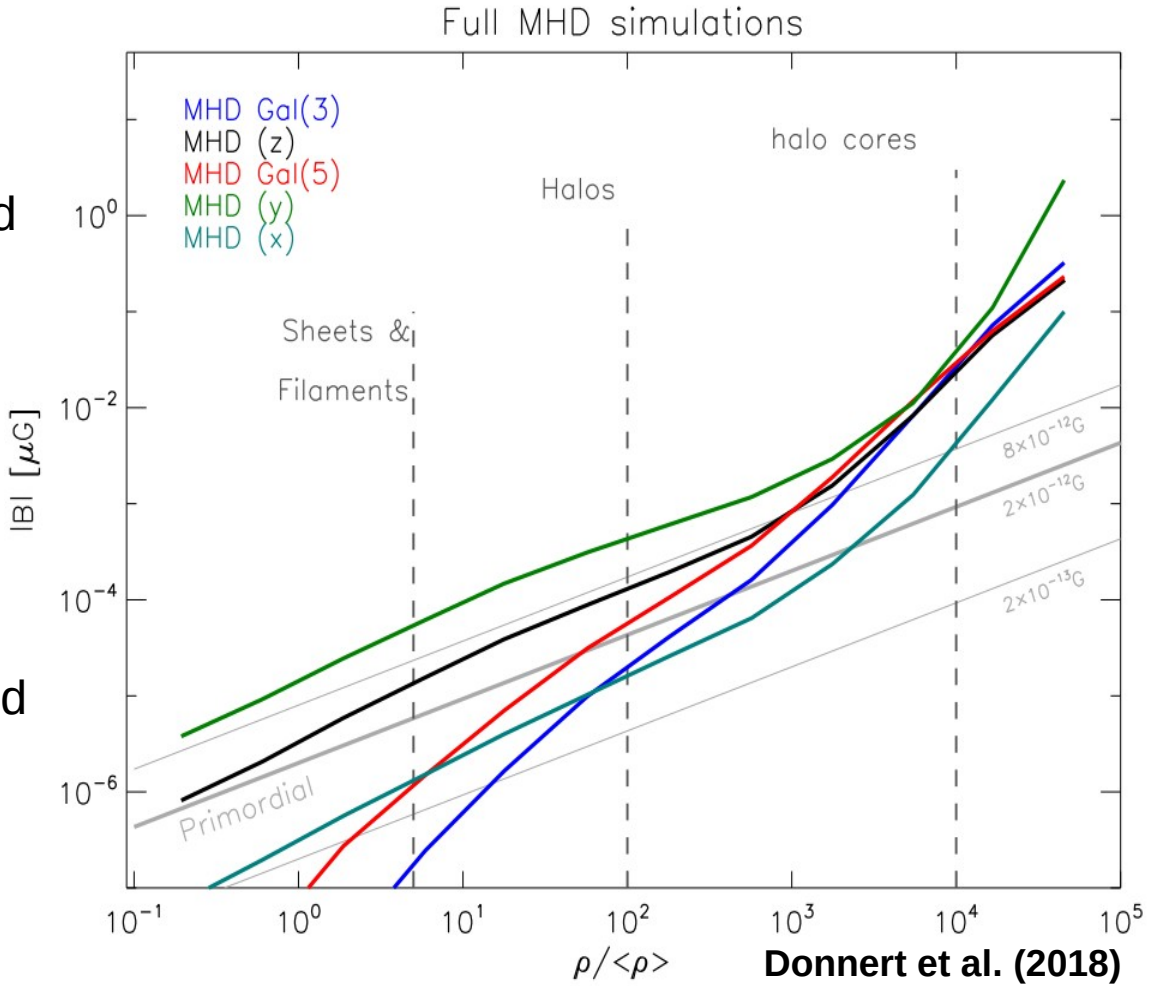
1) *Primordial scenarios*: seed fields created either during inflation or during post-inflationary epoch;

2) *Astrophysical scenarios*: seed fields injected by feedback events related to the evolution of galaxies and of their black holes (z≤10).

B ≤ 1 nG, amplification mechanism required that modifies strength and geometry.

Filaments and Voids: origin

Galaxy clusters: evolution



Donnert et al. (2018)

SCIENTIFIC BACKGROUND

Cosmic magnetism is a **key science project** for the SKA telescope

The new radio telescopes currently available are enabling large progress in this field.

TEAM

Diverse expertise: Observational, Numerical and theoretical

Valentina Vacca
Ricercatrice
INAF - OAC

Elia Battistelli
Prof. Associato
Univ. La Sapienza

Walter Boschin
Head of Astronomy
TNG

Ettore Carretti
Primo Ricercatore
INAF - IRA

Luigina Feretti
Associato INAF

Gabriele Giovannini
Associato INAF

Marisa Girardi
Prof. Associato
Univ. Trieste

Myriam Gitti
Prof. Associato
Univ. Bologna

Federica Govoni
Ricercatrice
INAF - OAC

Matteo Murgia
Primo Ricercatore
INAF - OAC

Rosita Paladino
Ricercatrice
INAF - IRA

Isabella Priandoni
Primo Ricercatore
INAF - IRA

TEAM

Diverse expertise: Observational, Numerical and theoretical

Valentina Vac
Ricercatrice
INAF - OAC

e Giovannini
ciato INAF

Total FTE: 3.9 during 2022 -3.8 during 2023

INAF: 2.5 FTE

Universities & other institutions: 1.4 FTE

Marisa Girardi
Prof. Associato
Univ. Trieste

Myriam Gitti
Prof. Associato
Univ. Bologna

Federica Govoni
Ricercatrice
INAF - OAC

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INAF - IRA

TEAM

Diverse expertise: Observational, Numerical and theoretical

Valentina Vacc
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ıbriele Giovannini
Associato INAF

Plus collaborators from all over the world

Marisa Girardi
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Ricercatrice
INAF - IRA

Isabella Priandoni
Primo Ricercatore
INAF - IRA

TEAM & INAF LEADESHIP

Cosmic Magnetism SKA Working Group
Carretti, Feretti, Giovannini, Govoni (core-team members),
Murgia, Paladino (members),
Vacca (*co-chair*);

LOFAR Magnetism Key Science Project (MKSP)
Feretti, Paladino (members),
Carretti, Prandoni e Vacca (members of the MKSP
Management Council and working group co-chairs);

ASKAP
Polarisation Sky Survey of the Universe's Magnetism (POSSUM)
Carretti (*member of the builders list and co-chair of activities*);

Evolutionary Map of the Universe EMU
Carretti (member), Prandoni (*working group leader*).

TEAM & INAF LEADESHIP

Significant expertise of the team and leadership recognized at an international level.

However, new instruments bring new competitors.

To keep international leadership we need on a short time scale:

1. man power
2. computational time
3. training of young researchers

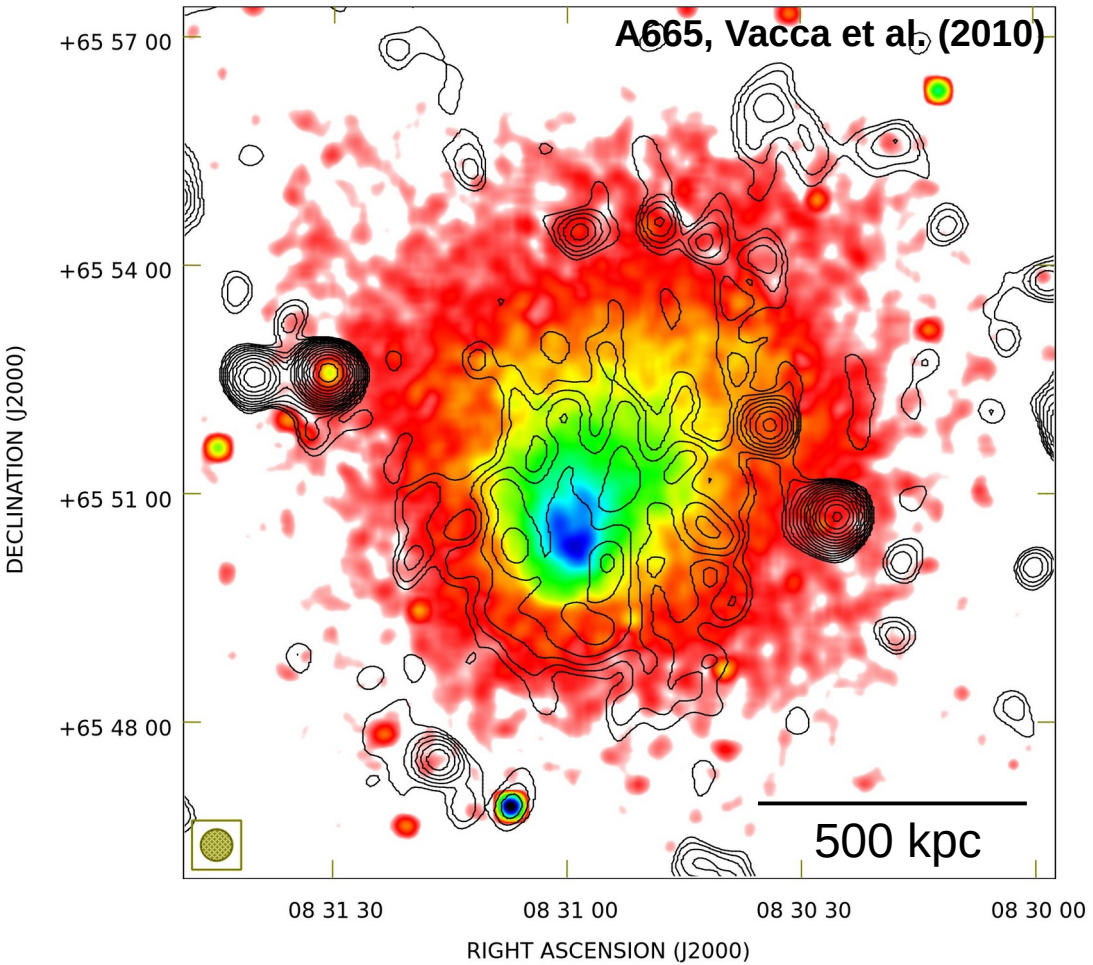
QUESTIONS TO ADDRESS

(i) What are properties of magnetic fields in galaxy clusters in different dynamical states and in galaxies embedded in different environments?

(ii) How common are magnetic field in filaments? What is the chance to detect them with the new radio instruments? What models of magneto-genesis do they support?

(iii) Does the magnetic field strength of intergalactic environments evolve with cosmic time? Are voids of the cosmic web magnetized?

METHODS



Central large-scale diffuse synchrotron sources direct probe of magnetic fields and relativistic particles in galaxy clusters.

Total intensity: magnetic field strength

Polarization: magnetic field order

Polarization provides strong constraints of the properties of the magnetic fields but its detection is hindered by observational limitations.

Feretti et al. (2012), van Weeren et al. (2019)

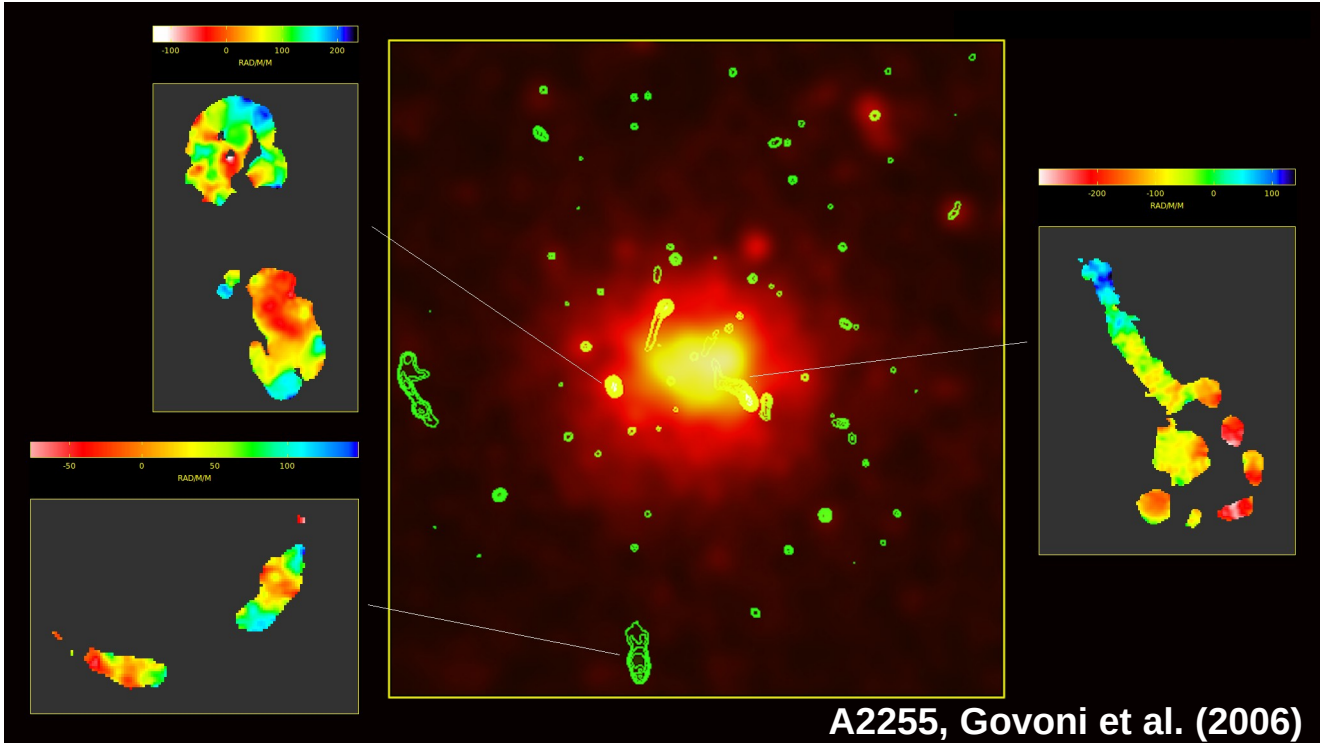
METHODS

$$\mathrm{RM} = 812 \int_0^{\mathrm{L}} n_{\mathrm{e[cm^{-3}]}} \mathbf{B}_{[\mu\mathrm{G}]} \cdot \mathbf{dl}_{[\mathrm{kpc}]} \quad \mathrm{rad\ m^{-2}}$$

Rotation Measure (RM) of background/embedded radio sources represents a complementary technique to probe magnetization.

A detailed characterization of magnetic field properties comparison of observations with numerical simulations.

Govoni & Feretti (2004)



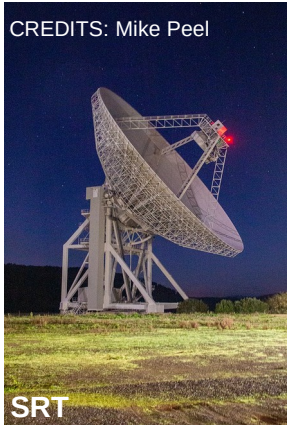
A2255, Govoni et al. (2006)

INSTRUMENTS AND MAIN RESULTS

ν << 1 GHz

ν ~ 1 GHz

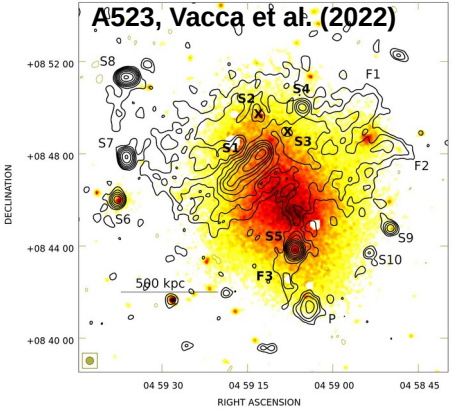
ν >> 1 GHz

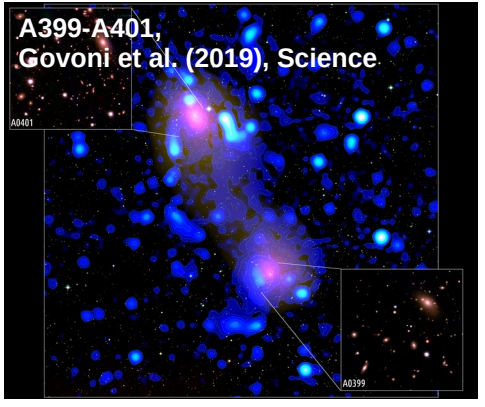


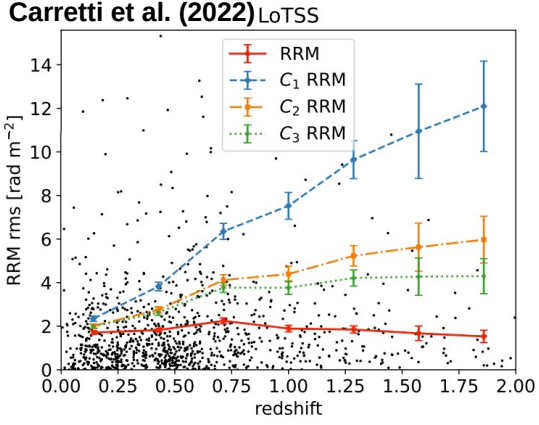
Steep spectrum sources

$S(\nu) \propto \nu^{-\alpha}$ α = 1-1.4

Extremely high RM Precision (≤ 0.1 rad/m²)







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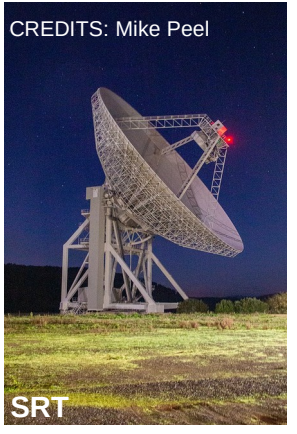
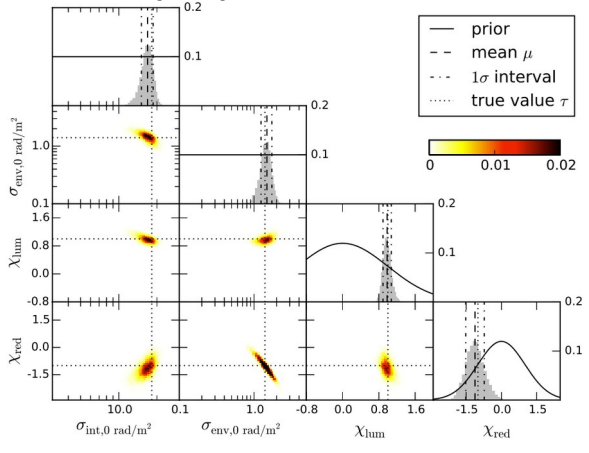


Vacca et al. (2016)

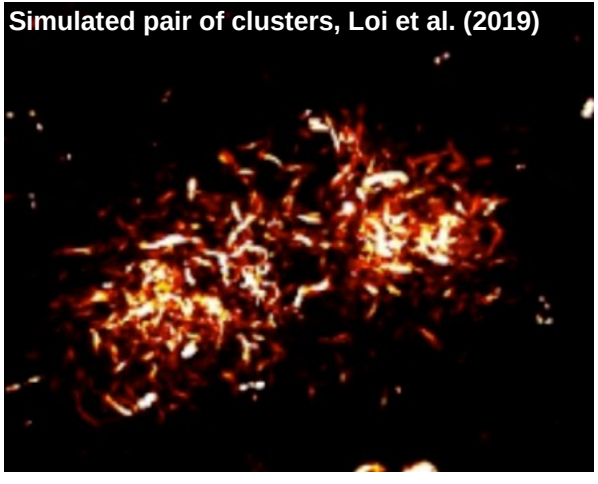


Detailed RM studies

Large RM catalogs (up to 25-30 pol sources/deg^2)

Polarized emission from diffuse synchrotron sources

Simulated pair of clusters, Loi et al. (2019)



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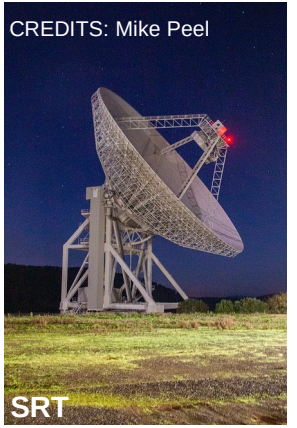
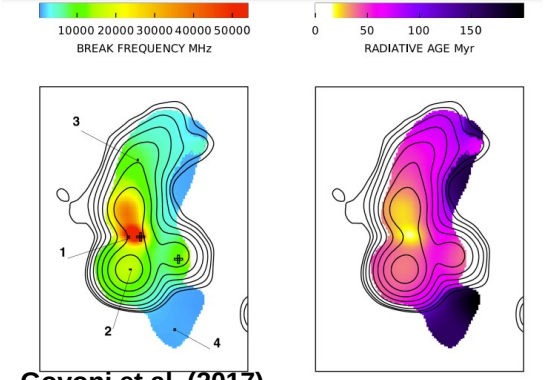
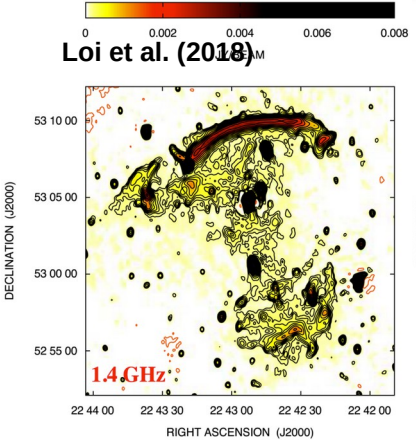
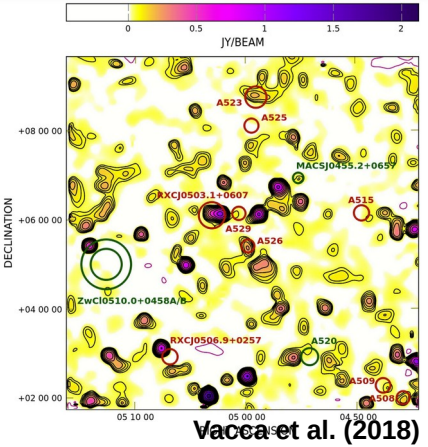




Govoni et al. (2017)

Loi et al. (2018)





Vacca et al. (2018)

Spectral break, precious hints about emitting radio plasma

Recovery of large angular scales

INSTRUMENTS AND MAIN RESULTS

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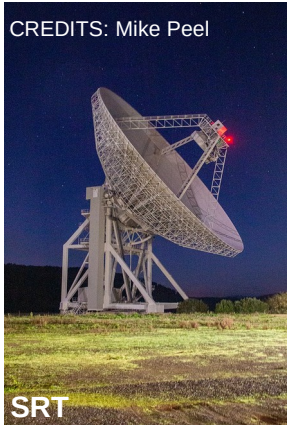

ν = 50 MHz – 1.76 GHz

ν = 4.6 – 15.3 GHz

Plus instruments in optical, X-rays, mm/sub-mm (e.g., SKA-Athena synergy)

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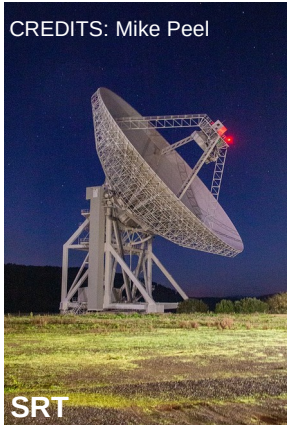

ν = 50 MHz – 1.76 GHz

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Plus instruments in optical, X-rays, mm/sub-mm (e.g., SKA-Athena synergy)

MAIN RESULTS

Summary of main results:

- Intracluster magnetic fields fluctuating on a wide range of spatial scales (~1-500 kpc), Kolmogorov power spectrum and central strengths of ~1-10 microG;

- Magnetic field strength proportional to a function of the thermal gas density;

- Hints of a link with the dynamical state of the system;

- First detection of magnetization along filaments of the cosmic web;

- First detection of RM excess evolving with redshift associated with the intergalacting medium;

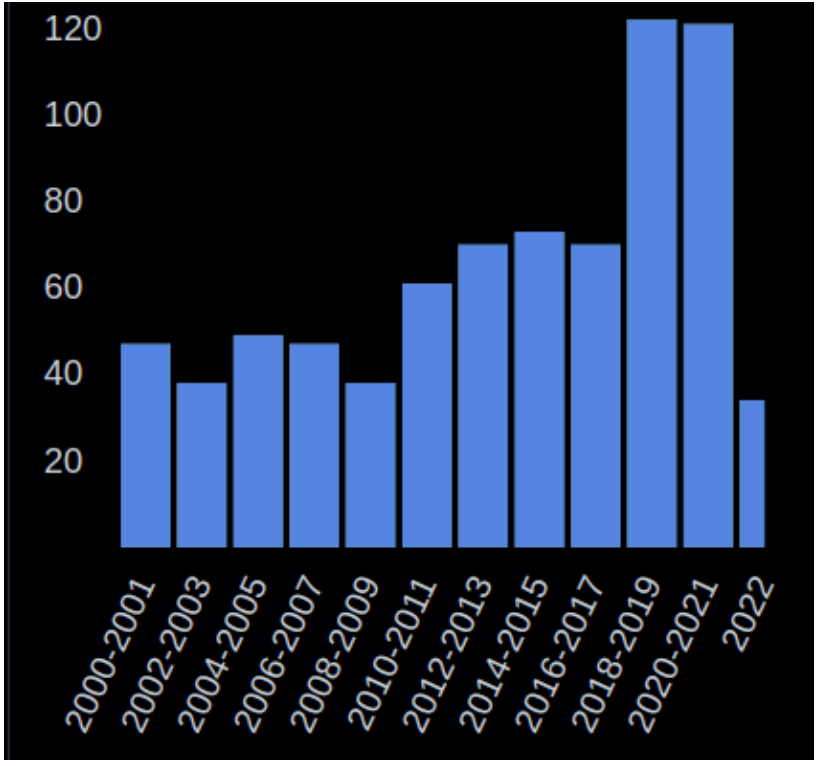
- Development of statistical tools to study magnetic fields.

MAIN RESULTS

Very active collaboration
~ 800 referred papers in the last decades
~ 32,000 citations
(not only magnetism!)

Several reviews, Books, Organization of conferences

International leadership



Source: ADS

WHAT’S NEXT?

PERSPECTIVES

FUNDING

CRITICALITY

WHAT'S NEXT?

PERSPECTIVES | FUNDING | CRITICALITY

Telescope	Hours	Project ID	Targets
JVLA	>300h	18A-325, 18A-072, 18B-231, 17A-243, 13A-168, 12A-253 ...	Collection of 11 galaxy clusters in different dynamical state
LOFAR	>400h	LC15_015, LC15_006, LC14_007, LC13_030, LC13_023, LC11_013, LC11_010, LC10_024, LC09_033, LC07_012, ...	GOODS-N, Collection of nine massive galaxy clusters, A2147-A2152, Sample of field and cluster nearby galaxies
MeerKAT	5h	MKT-20115	A399-A401
ASKAP	200h	POSSUM and EMU Pilot Survey, P004-PS41, P009	About 300 deg2 including also several systems of interest
SRT	>400h	50-20, 40-19, S0001, ...	A399-A401, A2147-A2152, collection of 19 galaxy clusters in different dynamical state

Datasets available to the collaboration as PIs or Co-Is

WHAT'S NEXT?

PERSPECTIVES | FUNDING | CRITICALITY

- Probe the average low-frequency polarization and Faraday rotation measure properties of low power radio galaxies and of star-forming galaxies and radio-quiet AGN (not-yet detected) - **WP1**;

- Detect of polarized diffuse large-scale radio emission from galaxy clusters and filaments to derive firm constraints on magnetic field properties – **WP2 & WP3**;

- Develop and apply advanced algorithms to new RM catalogs in order to detect magnetization from the largest scales (e.g., voids) and characterize its properties versus cosmic time - **WP3**.

WHAT'S NEXT?

PERSPECTIVES | FUNDING | CRITICALITY

- **WP1:** Study of magnetic field in a sample of nearby galaxies both in undisturbed environments as well as in galaxy clusters & investigation of average polarization properties of low power radio galaxies as a function of redshift with low frequency data.

- **WP2:** Characterization of magnetic field power spectrum in a sample of galaxy clusters by combining single-dish and interferometric data (*postdoc*);

- **WP3:** Determination of the best observing strategy to investigate the presence of diffuse emission along filaments of the cosmic web and its application & development and application of statistical tools to investigate magnetic fields in the large scale structure and its redshift evolution from RM catalogs (*postdoc*);

- **WP1, WP2, WP3:** Analysis of multi-wavelength data to understand the link between the dynamical state and the thermal properties with the non-thermal components.

WHAT'S NEXT?

PERSPECTIVES | FUNDING | CRITICALITY

- 2009-2013, we obtained funding support from PRIN INAF, PRIN MIUR and ASI (~35kEuro).

- In this years, we could carry out breakthrough research with results of impact at an international level thanks to "ricerca di base" funding support from our own institutes (up to about ~200kEuro up to now).

WHAT'S NEXT?

PERSPECTIVES | FUNDING | CRITICALITY

Significant expertise of the team and leadership recognized at an international level. To keep international leadership we need on a short time scale:

(i) man power
(ii) computational time
(ii) training of young researchers

WHAT'S NEXT?

PERSPECTIVES FUNDING CRITICALITY

- Obtain optical, X-rays and mm/sub-mm data;

- Development and application of new algorithms and advanced techniques (computational time & expertise);

- Training of young students (master and PhD) and researchers.

THANKS!