The 4th National Workshop on the SKA Project - Sharpening the Italian science case for the SKAO
Catania - 29/11/2023

The magnetized Universe

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INAF-OAC
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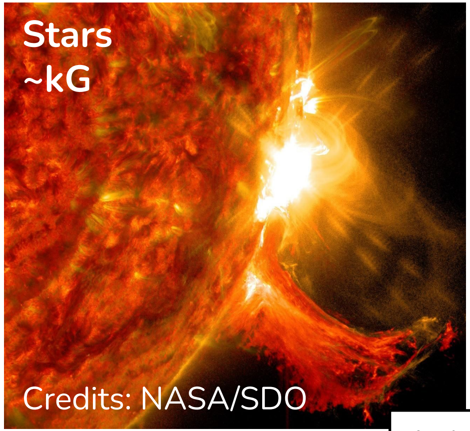
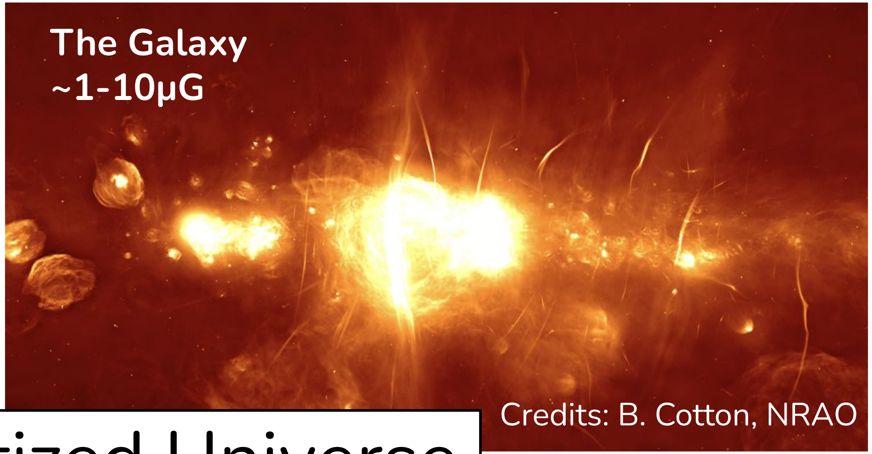
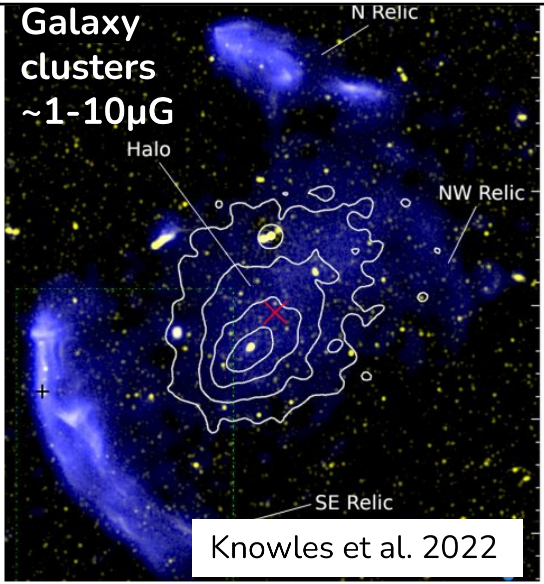
Outline

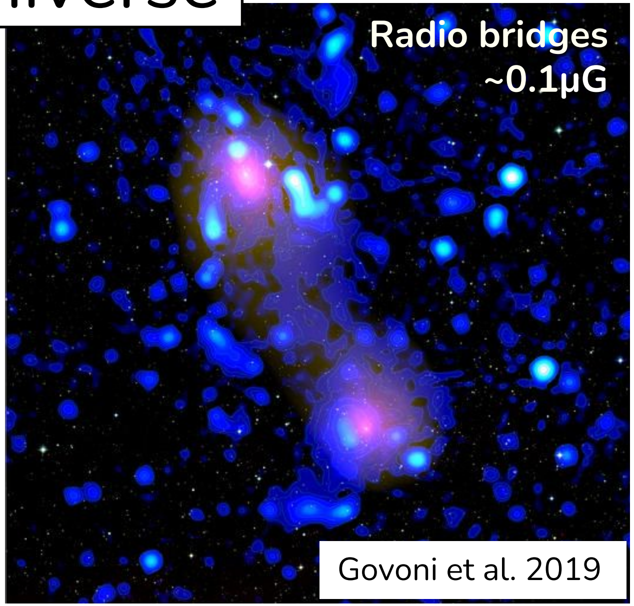
- Scientific introduction
- Open questions
- Ongoing surveys and projects
- Future SKA survey

We all live in a magnetized Universe







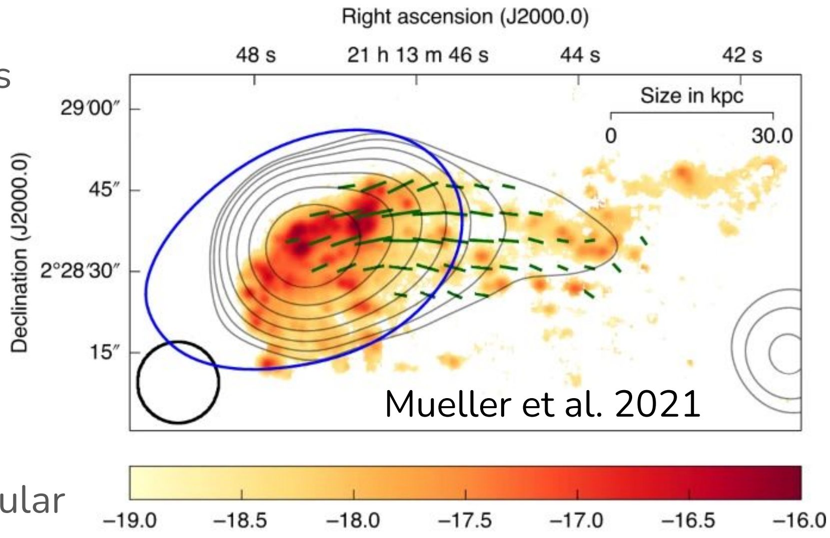


The impact of magnetic fields at different scales

1. Cosmology:
   - Structure formation [see e.g. Subramanian et al. 2016]
   - duration of the EoR
2. Cluster physics:
   - heat conduction, propagation of relativistic particles, gas mixing, star formation of cluster galaxies
3. Galaxy physics and evolution:
   - SFR, feedback, outflows
   - accretion around AGN
   - formation of relativistic jets in AGN
4. Milky Way:
   - morphology of SNR, planetary nebulae, HII region, globular clusters, life in exoplanets
   - formation and collapse of dense molecular clouds

talk by A. Bonafede on Wed.

talk by C. Trigilio on Thu.



Hα flux (erg/s/cm), log scale

talk by M. Padovani & A. Traficante on Wed.

Open questions

1. What is the origin of large-scale magnetic fields?

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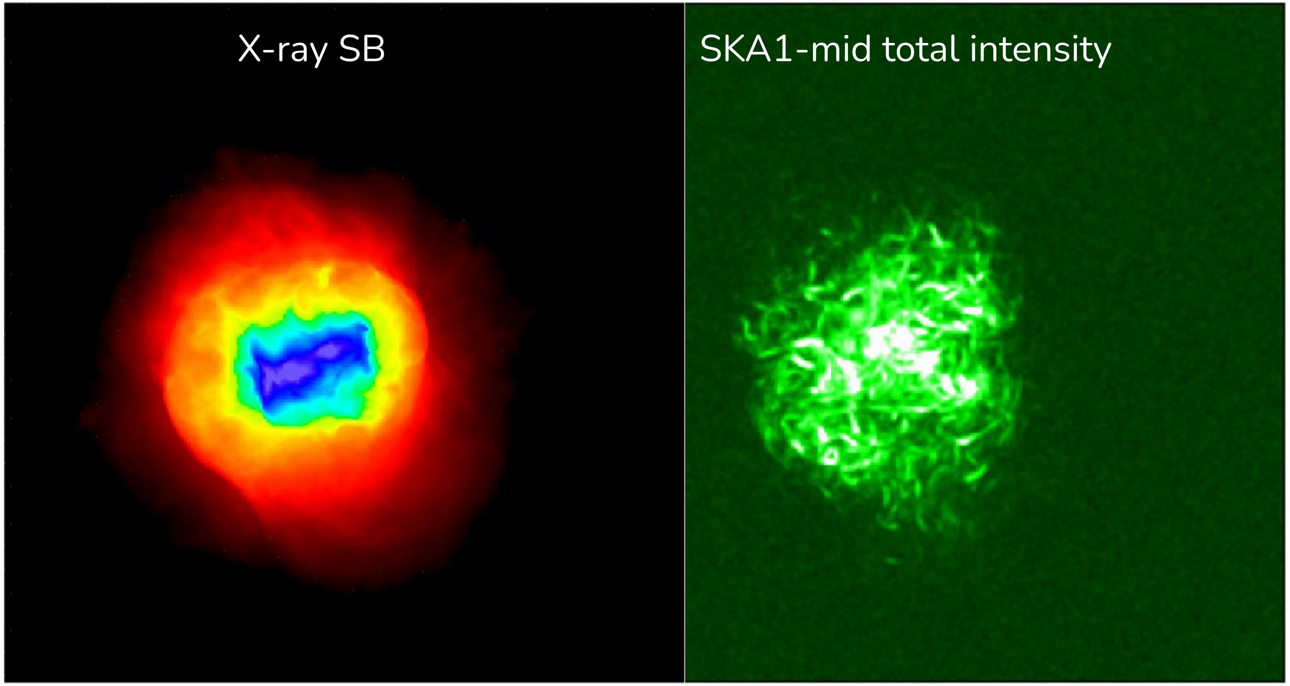


Loi et al. 2019a,b

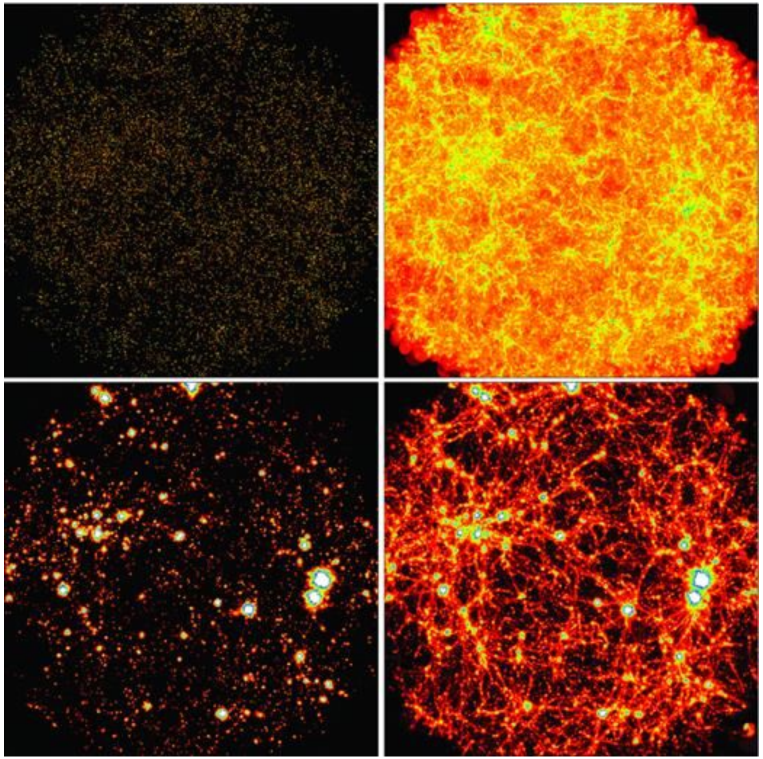
Open questions

1. What is the origin of large-scale magnetic fields?

ASTROPHYSICAL PRIMORDIAL

z=4.1

z=0



Donnert et al. 2009

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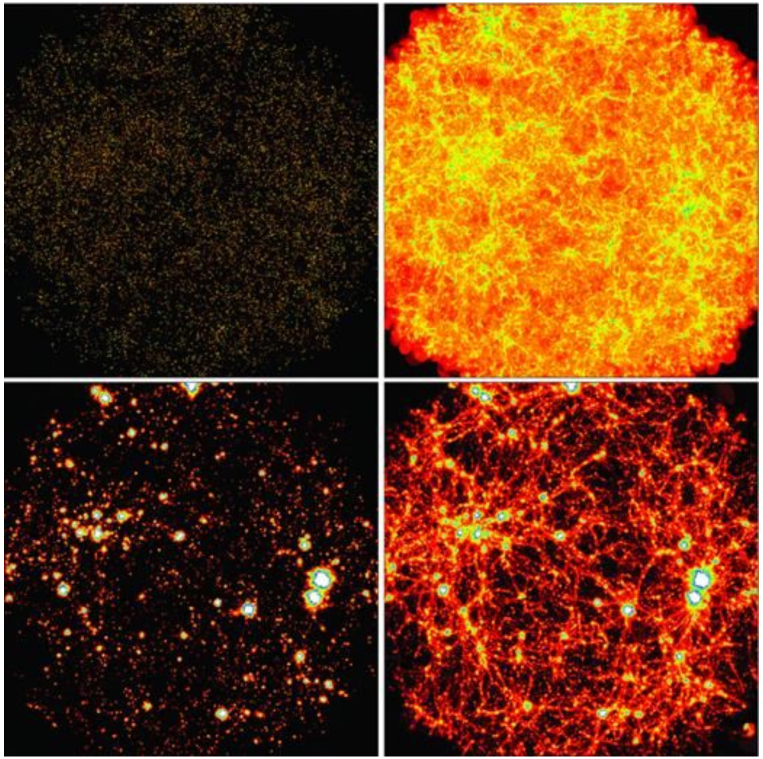

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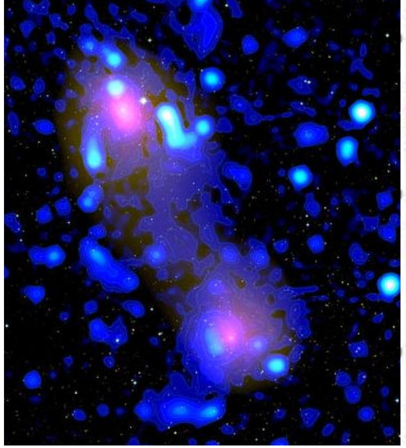
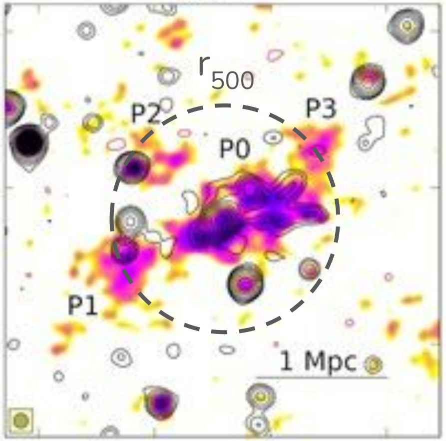
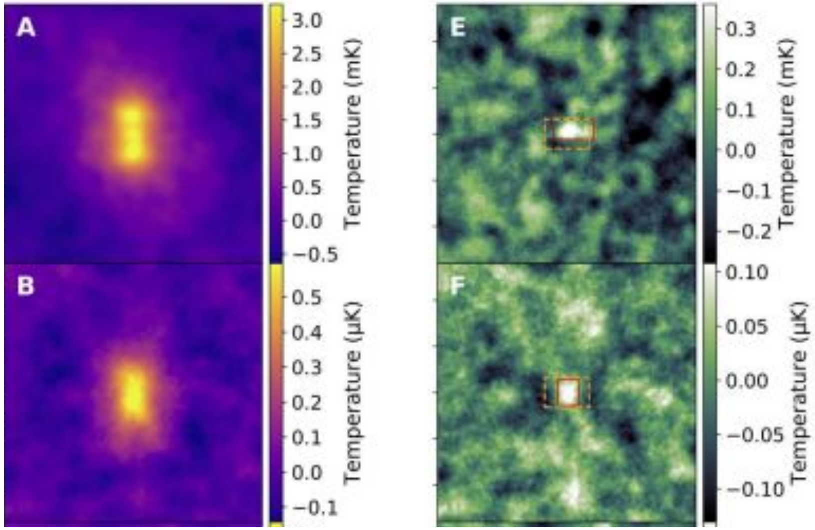


A399-A401
[Govoni et al. 2019]



A523
[Vacca et al. 2022]



[Vernstrom et al. 2023]

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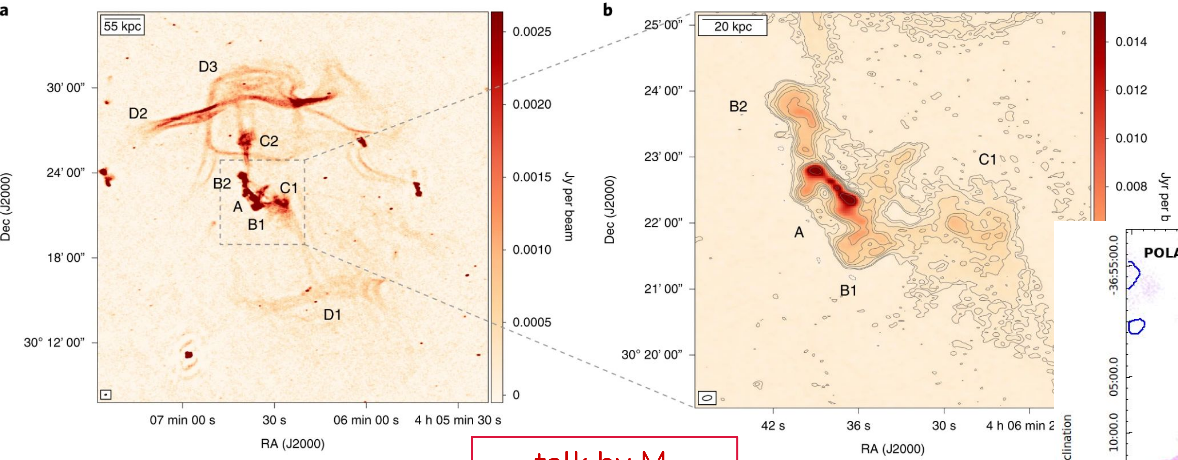
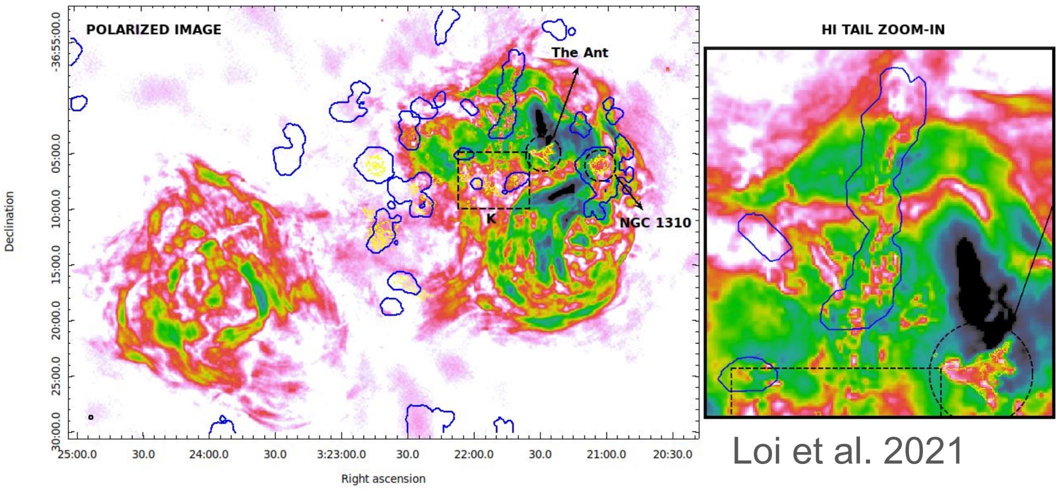


Brienza et al. 2022

talk by M. Brienza on Wed.



Loi et al. 2021

Open questions

1. What is the origin of large-scale magnetic fields?
   - level of dynamo amplification in filaments, memory of B “seed”
   - duration of EoR (if B seeding by EoR)
2. What are the properties of intracluster magnetic fields?
   - ICM turbulence scale
   - evolution of the magnetic field?
3. How AGN/SFG interact with the environment?
4. Why large-scale magnetic fields are present in SFG?
   - large-scale dynamo models
5. What are the properties of the turbulent interstellar magnetic field?
6. What is the structure and the strength of the Milky Way magnetic field? (implications on measurements)

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SKA: The telescope to understand cosmic magnetism

SKA magnetism working group

<u>Chairs:</u>
V. Vacca (INAF) and T. Vernstrom (Western Australia Univ.)

<u>65 members, 14 working in Italy:</u>
A. Bonafede*, E. Carretti*, L. Feretti*, F. Govoni*, C. Riseley*, G. Brunetti, G. Giovannini, F. Loi, F. Marchegiani, M. Murgia, M. Padovani, M. Regis, R. Paladino, F. Vazza.

*core members

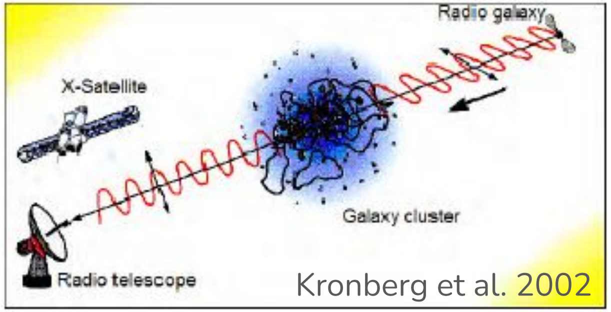
Techniques & strategies

Diffuse emission in total and polarized intensity

Faraday effect

Zeeman effect (clouds)

The Rotation Measure grid



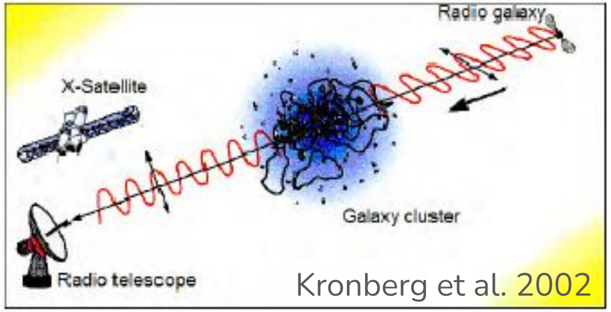
Faraday effect

$\Delta\Psi = RM \cdot \lambda^2$

$RM = \int B_{||} \cdot n_e \cdot dl$

- Bandwidth
- Sensitivity
- Space and frequency resolution

The Rotation Measure grid



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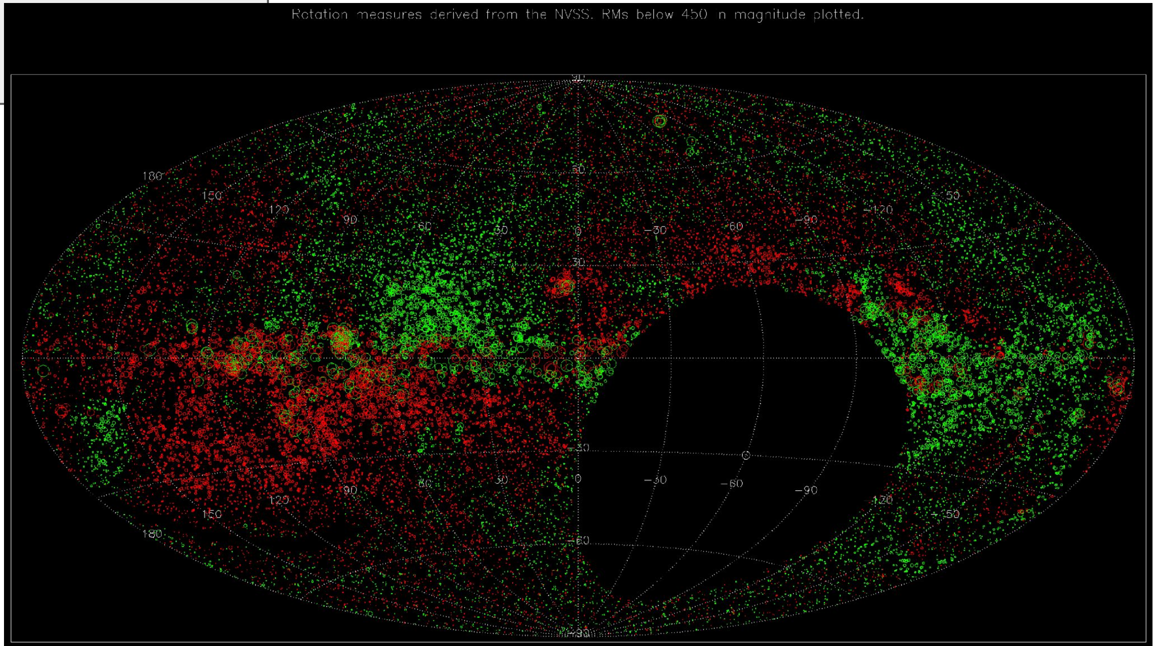
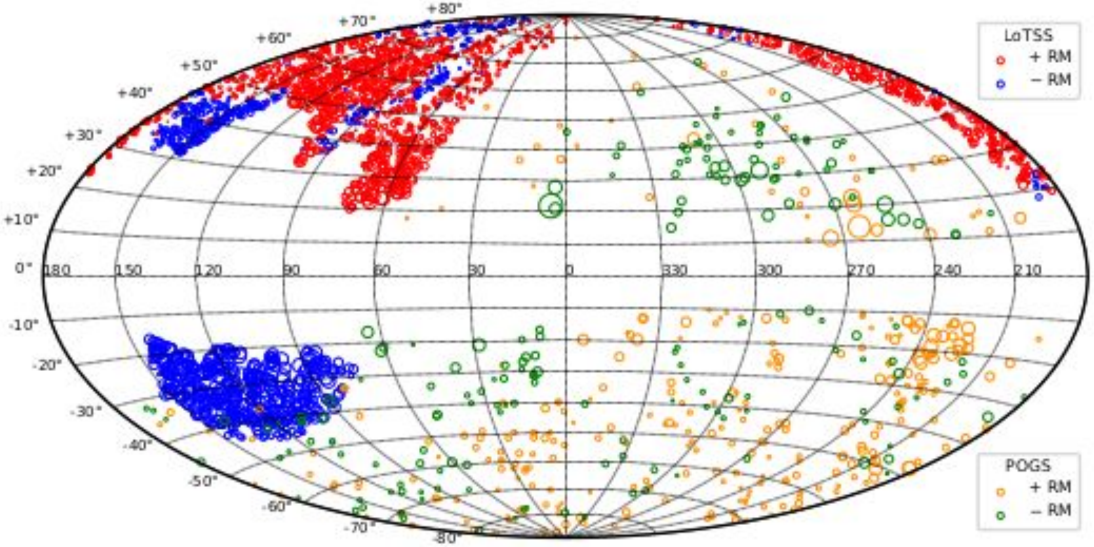
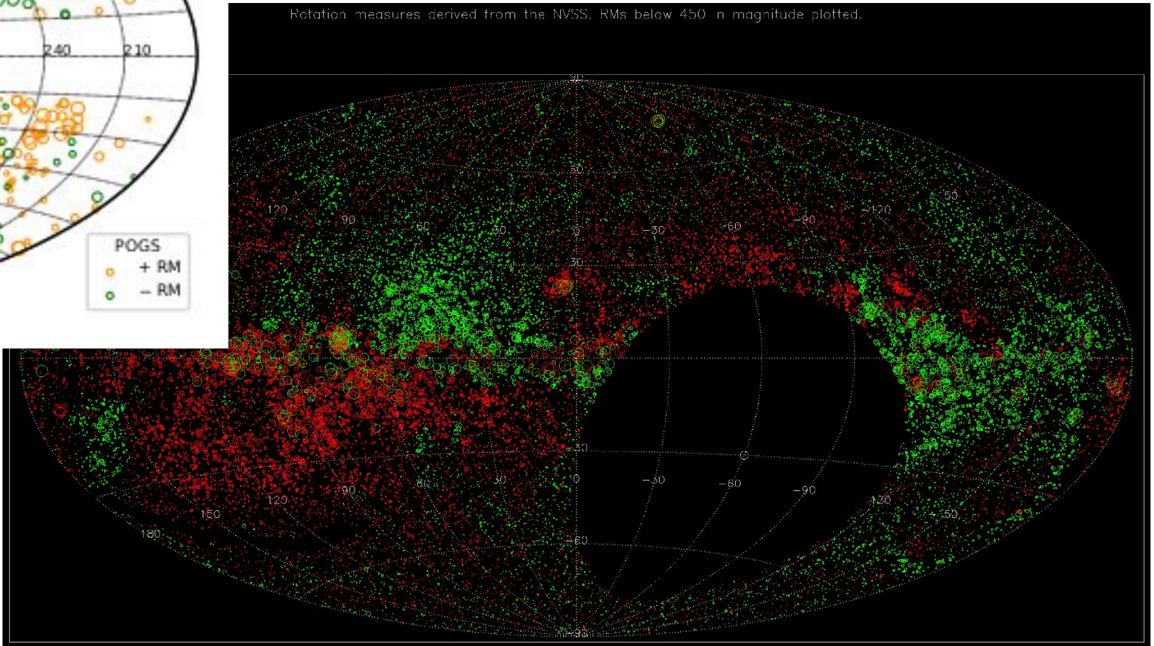


1.4 GHz NVSS [Taylor+2009]: 1-2 polarized sources/deg²

The Rotation Measure grid



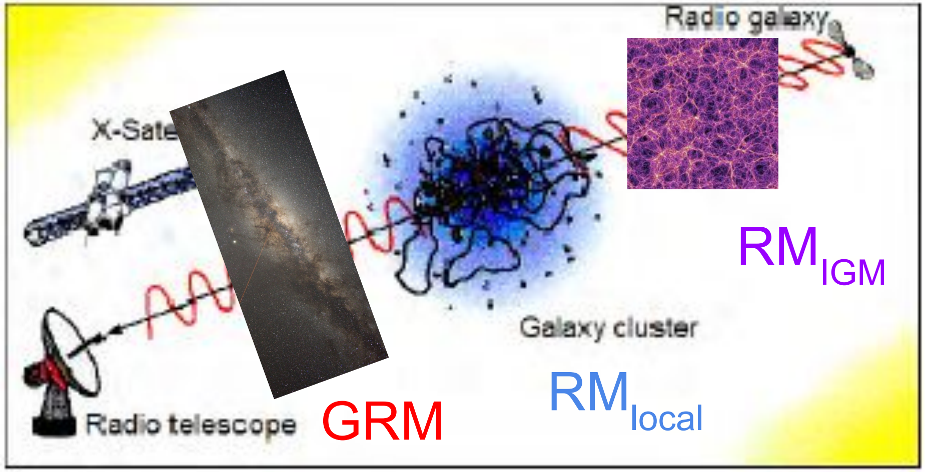
144 MHz LoTSS [O'Sullivan et al. 2023]:
0.29-0.48 p.s./deg²
200 MHz POGS [Riseley et al. 2020]:
0.019 p.s./deg²



1.4 GHz NVSS [Taylor+2009]: 1-2 polarized sources/deg²

Magnetic fields in cosmic filaments with LoTSS-DR2

(Carretti et al. 2022-2023)



$\Delta\Psi$ = RM $\cdot\ \lambda^2$; large $\Delta\Psi$ within a frequency channel destroys the polarization

$$RM = GRM + RM_{local} + RM_{IGM} + RM_{noise}$$

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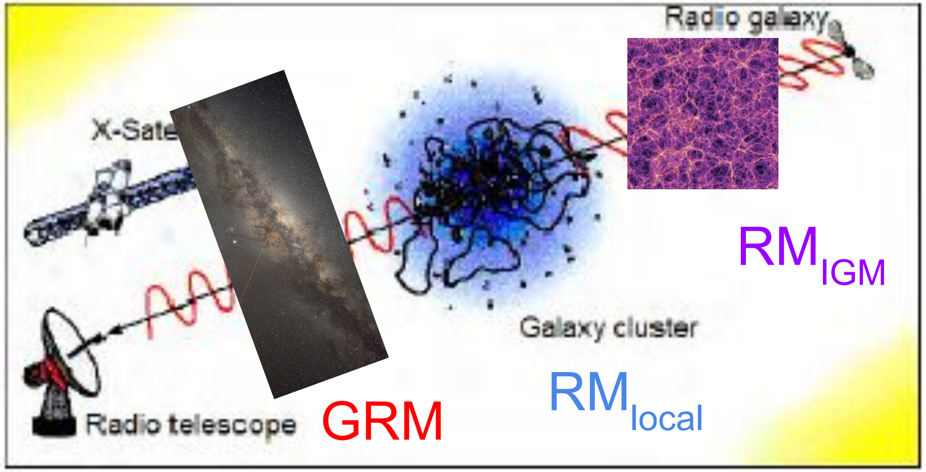

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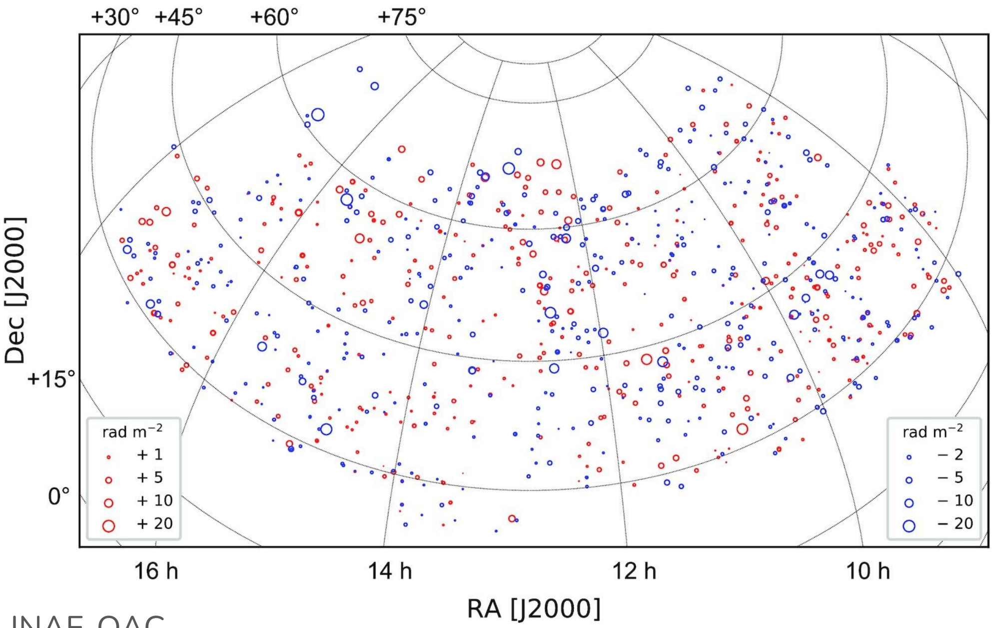
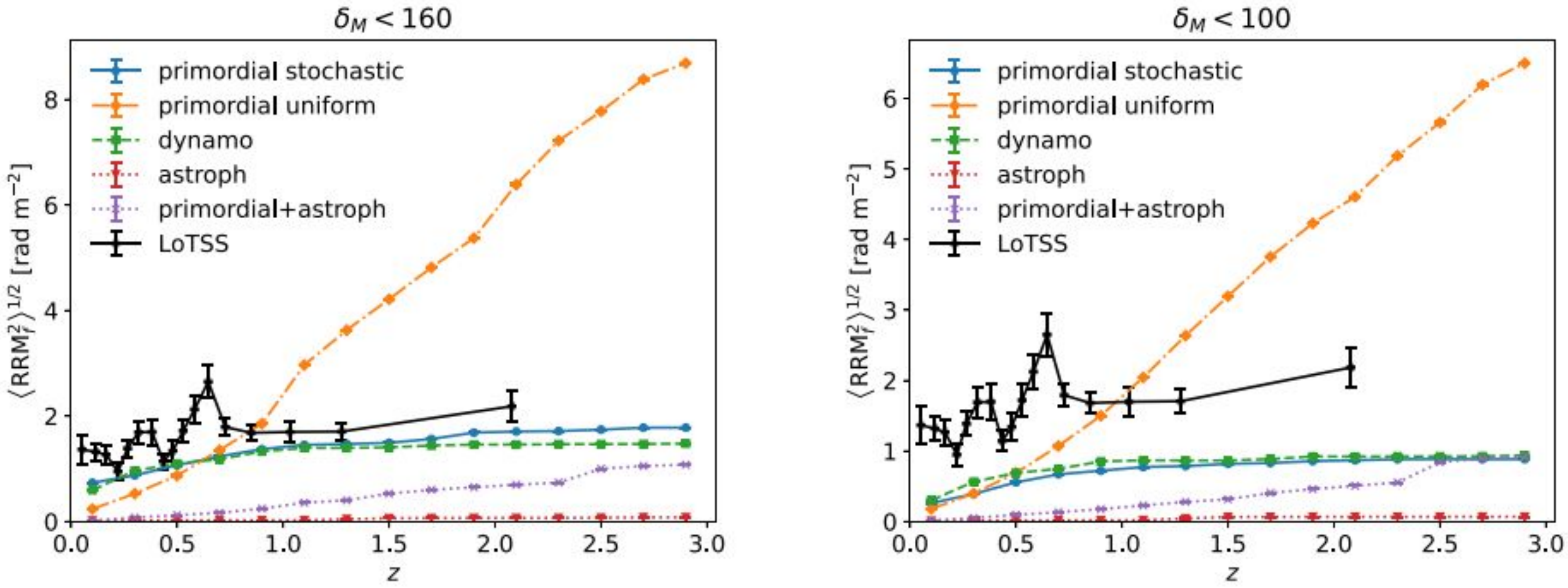


Residual RM: RRM=RM-GRM

more than 90% is due to filaments!

Magnetic fields in cosmic filaments with LoTSS-DR2
(Carretti et al. 2022-2023)



Primordial uniform model excluded.

Primordial stochastic magnetic field model with comoving B=0.04-0.11 nG

Consistent with CMB u.l. of 0.12–0.13 nG (Paoletti & Finelli 2019; Paoletti et al. 2022).

The MeerKAT Fornax Survey (P.I. Paolo Serra)

Goals:

Studying the evolution of galaxies

talks by P. Serra and A. Loni on Wed.

Mapping the Fornax cluster magnetic field

talk by me on Wed.

Methods:

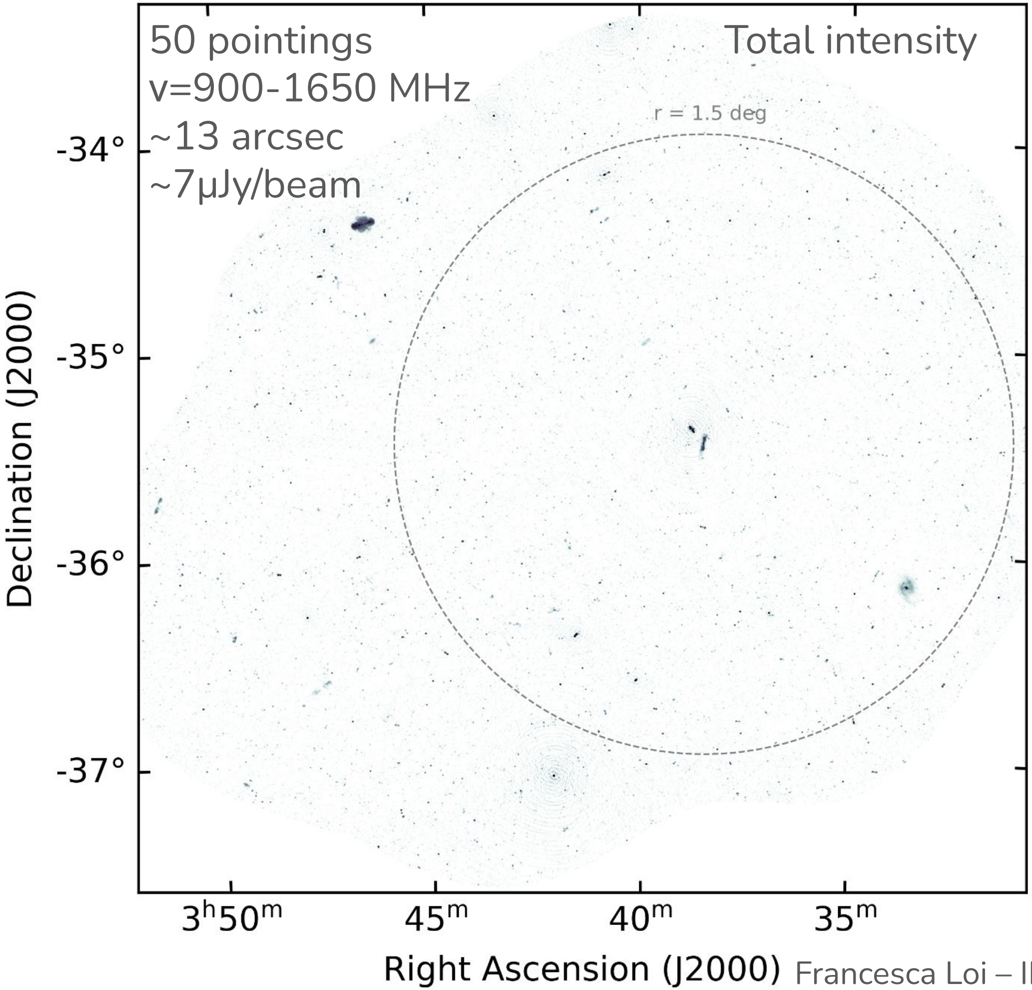
HI detection

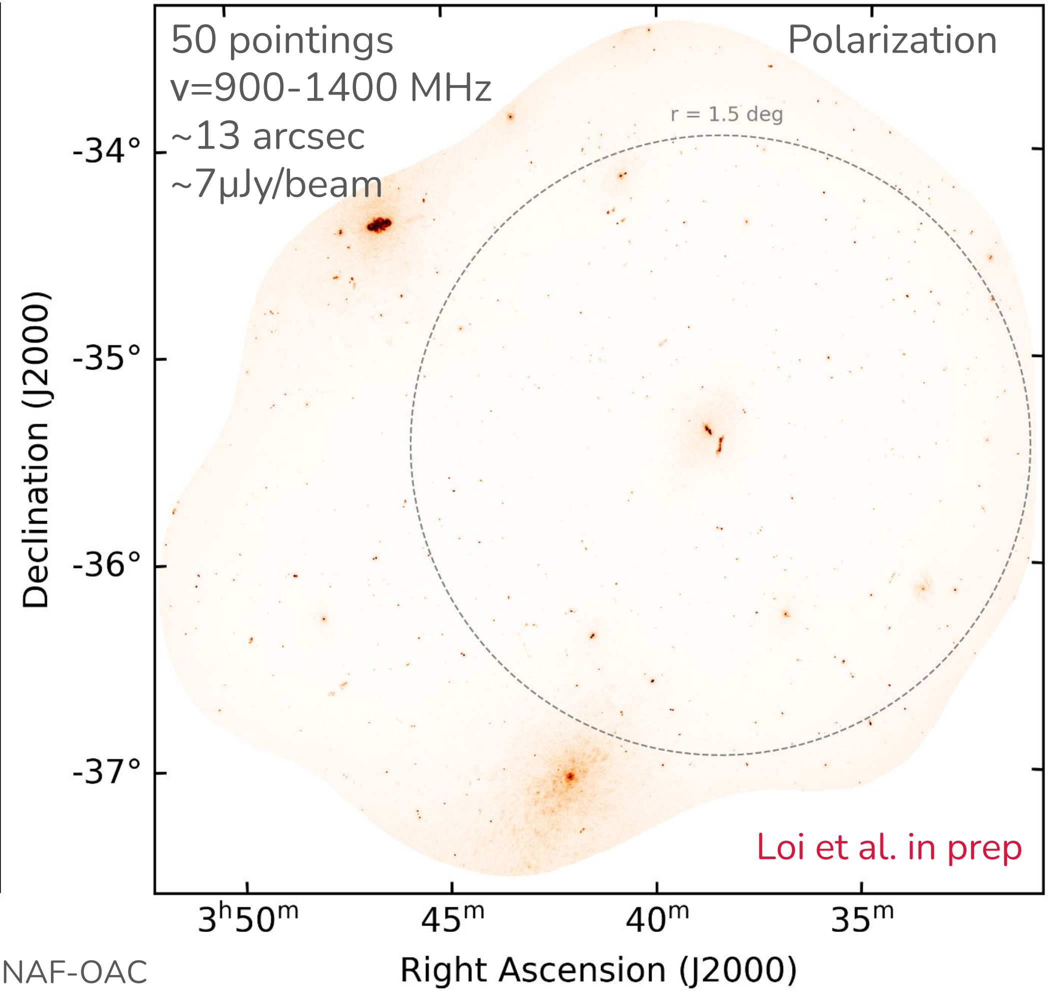
Broad band spectro-polarimetric observations (ν=900-1650 MHz)

Why Fornax?

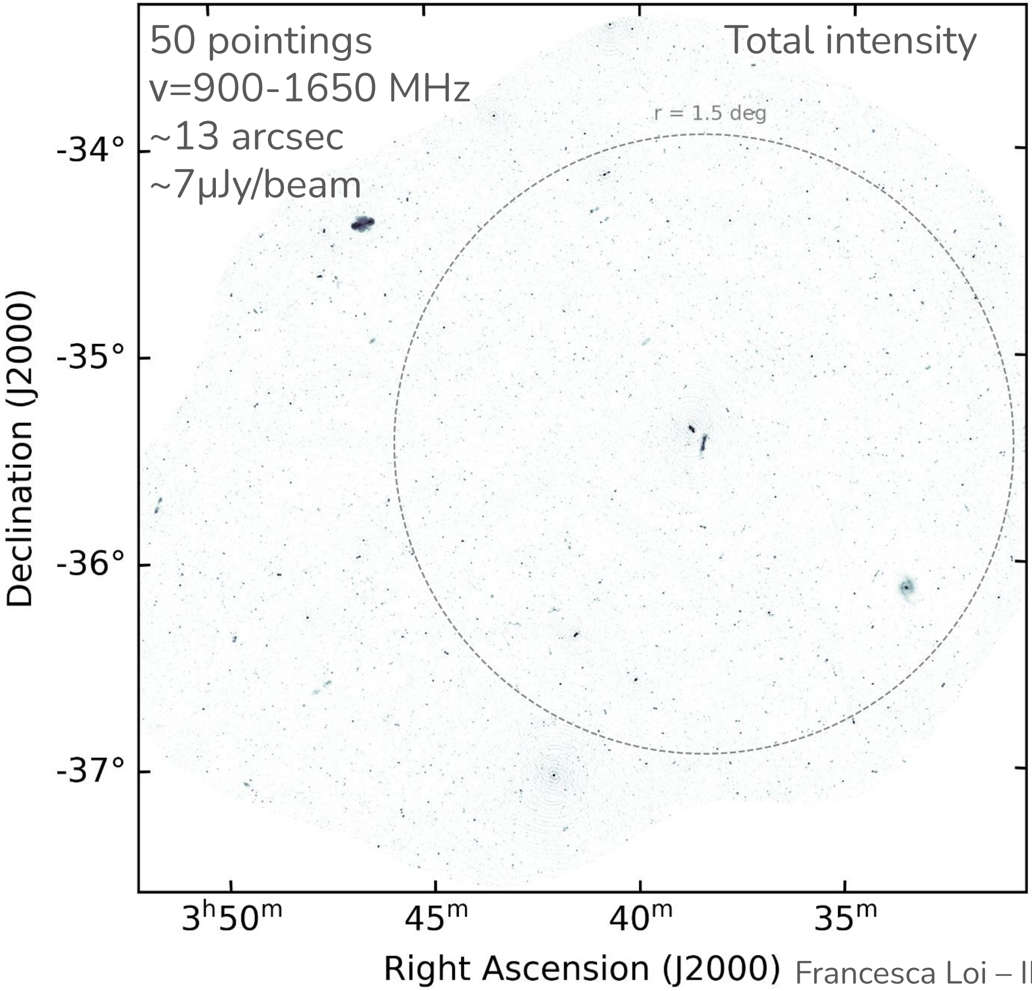
Nearby(~20 Mpc) low-mass cluster ($M \sim 6 \cdot 10^{13}\ M_{sun}$) with substructures.

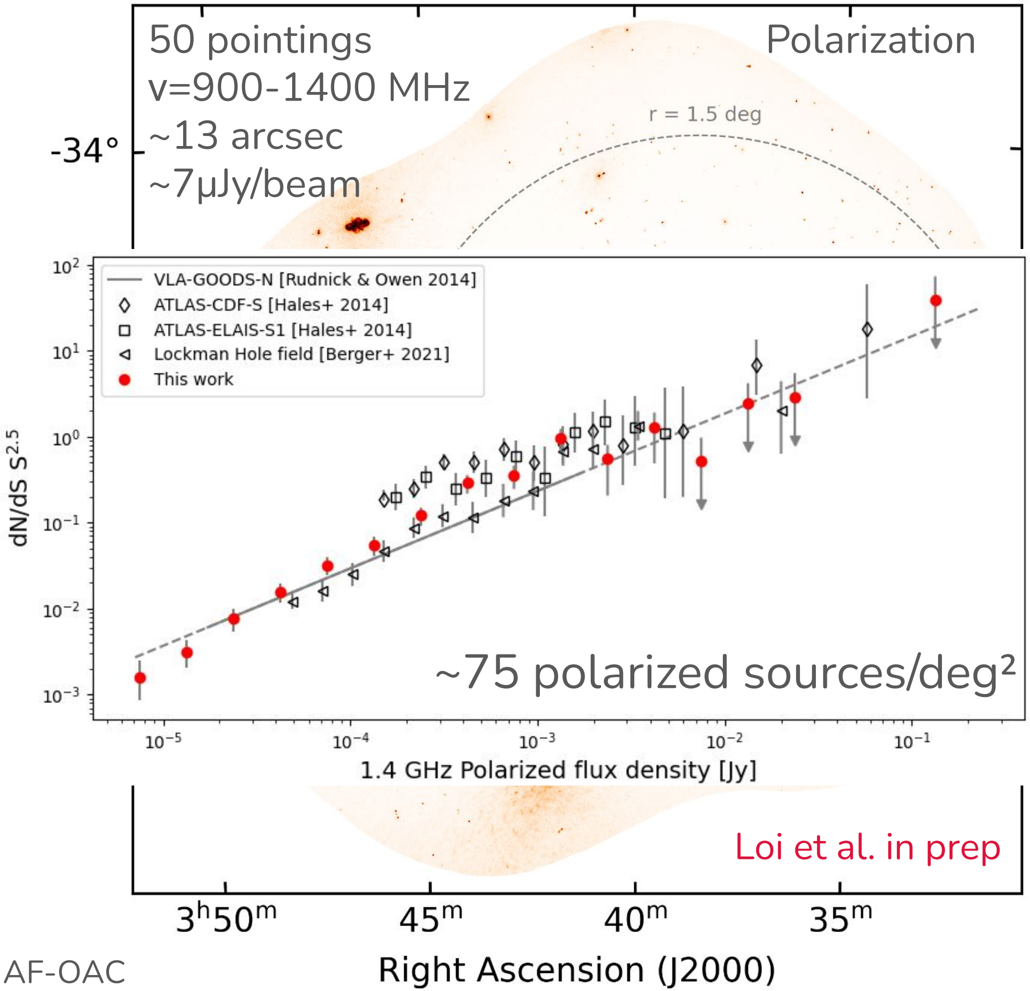
MeerKAT Fornax Survey





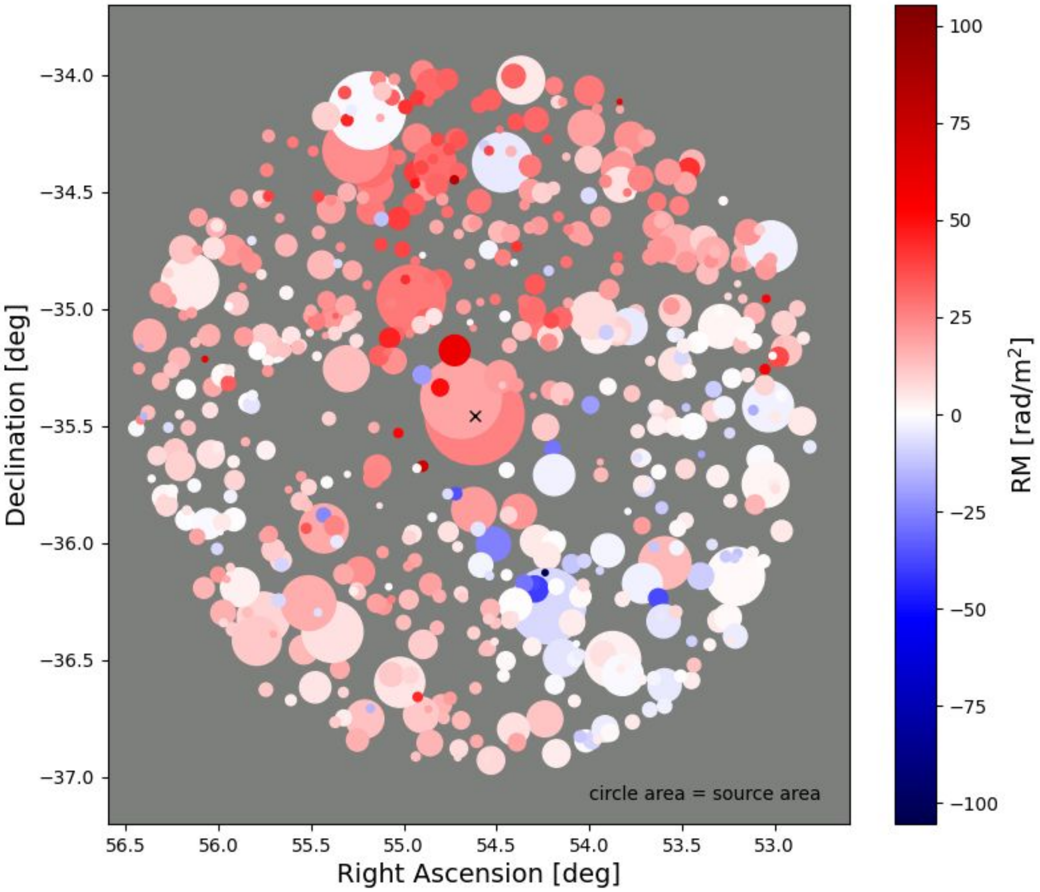
MeerKAT Fornax Survey

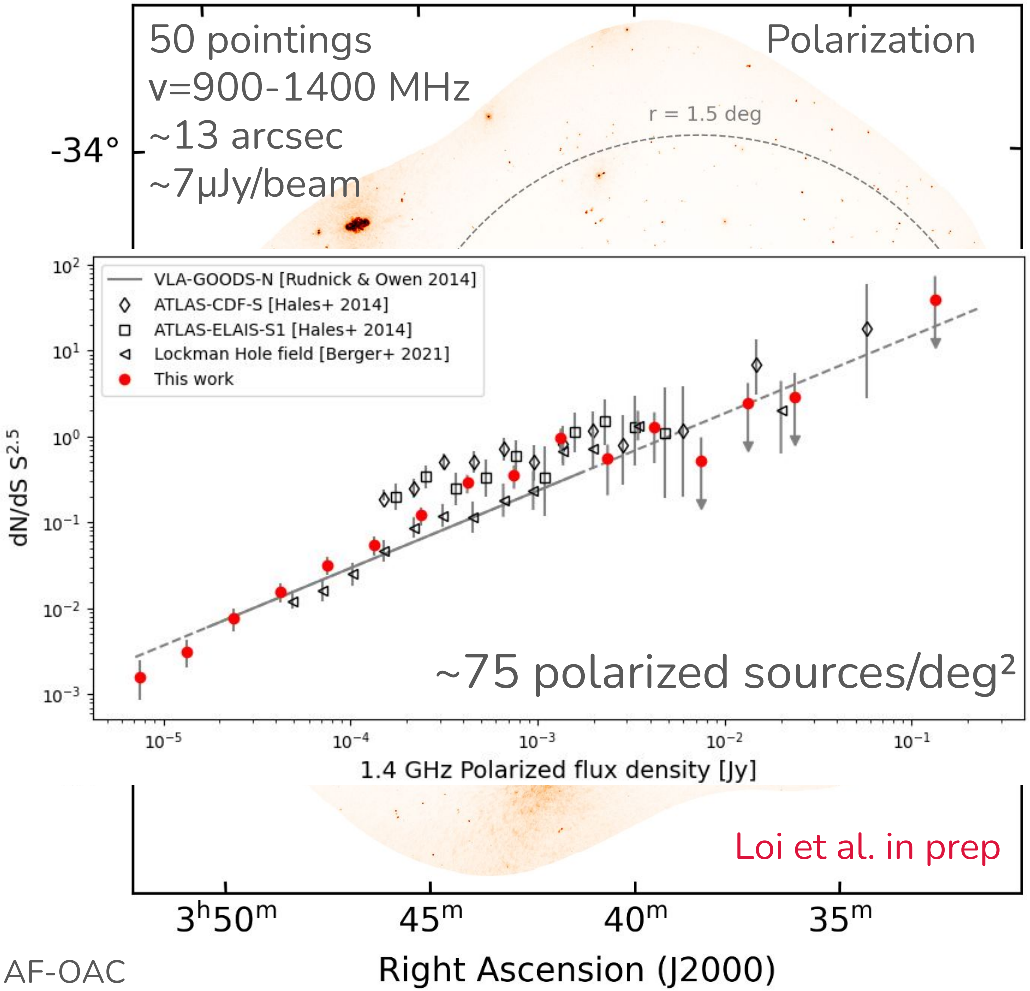




Francesca Loi – INAF-OAC

MeerKAT Fornax Survey





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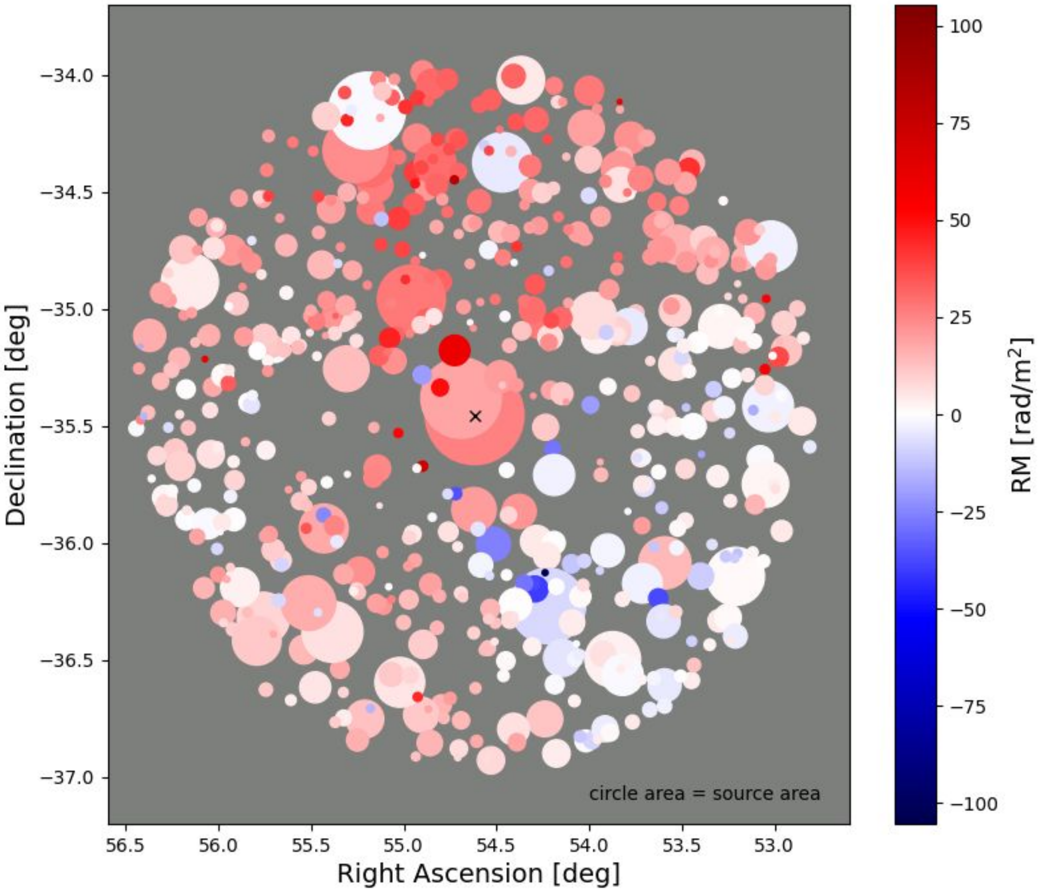
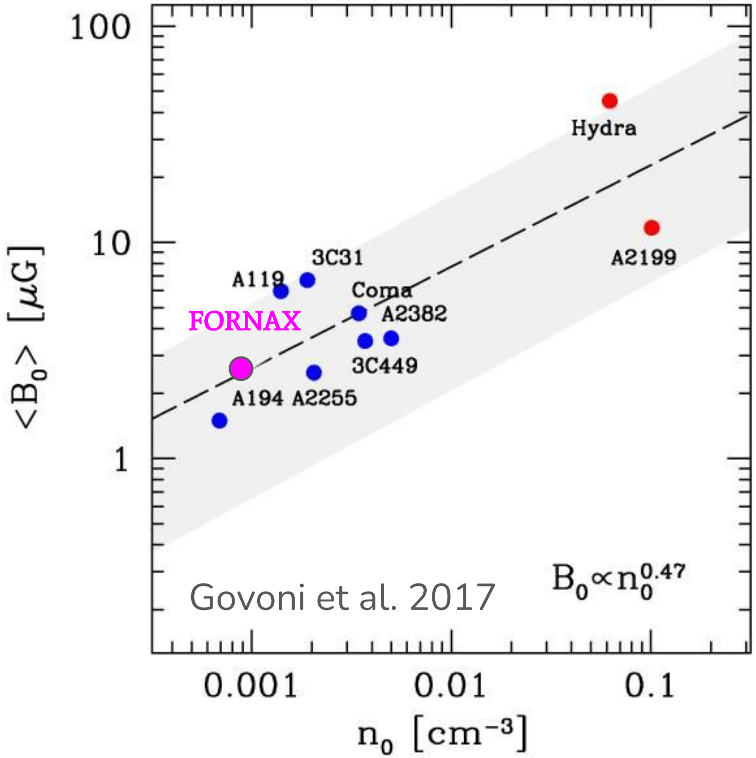
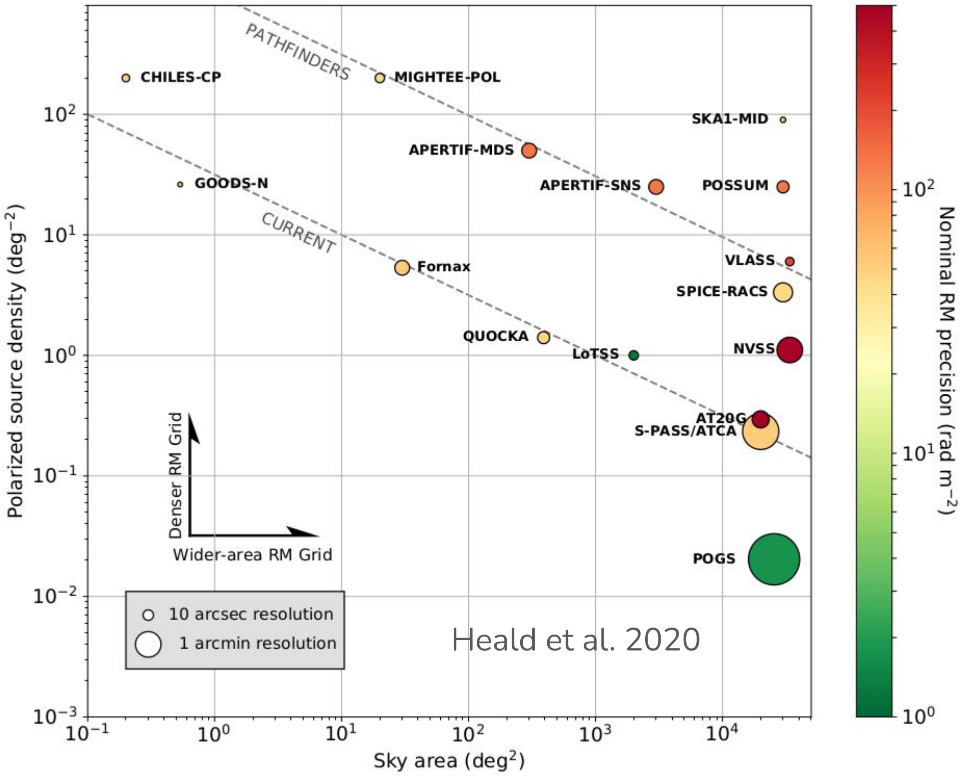


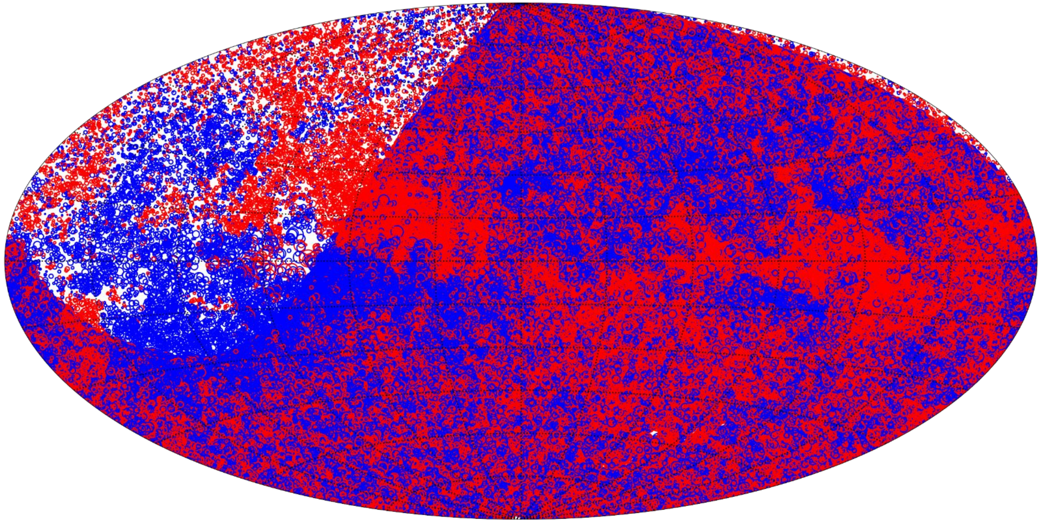


Loi et al. in prep

The Future: SKA1-mid Survey



950-1760 MHz
4 μJy/beam of sensitivity
2 arcsec of resolution
60-90 pol.sources/deg²
LAS ~ 0.5-1 degree
30'000 pointings, 15 min on each
The survey will last 2.5 years.



credits: S.A. Mao, using data from Oppermann et al (2015) and Schnitzeler et al (2018)

Conclusion

SKA1-mid is going to explore the Universe in polarization

Its unprecedented capabilities will help us to better understand cosmic magnetism

A lot of commensality projects will be carried out with the same data

Thank you

Magnetism projects with SKA pathfinders at low frequency

LOFAR	Magnetism Key Science Project	P.I.: O' Sullivan and V. Heesen
	Milky way	Chairs: M. Iacobelli (ASTRON) and V. Jelić (Ruđer Bošković Institute)
	Nearby galaxies	Chairs: **R. Paladino** (INAF) and K. Chyzy (Jagiellonian University)
	Radio galaxies	Chairs: E. Orrú (ASTRON) and M. Jamrozy (Jagiellonian University)
	IGM & LLS	Chairs: **A. Bonafede** (INAF) and **E. Carretti** (INAF)
	Deep fields	Chairs: **V. Vacca** (INAF) and **I. Prandoni** (INAF)
	RM grid task force	P.I.: S. O' Sullivan (Madrid University)
	GOODS-N deep field	P.I. **V. Vacca** (INAF)

Magnetism projects with SKA precursors at mid frequency*

ASKAP projects	POSSUM collaboration	P.I. C. Anderson (NRAO), G. Heald (CSIRO), N. McClure-Griffiths (ACT)
	P009: Magnetic fields in the LSS with a Bayesian approach	P.I. **E. Carretti** (INAF)
	P004: A detailed RM study of the poorly known Abell 3718 galaxy cluster	P.I. **F. Loi** (INAF)
	M010: Rise of a phoenix in Hickson Compact Group (HCG) 15: shocked fossil plasma revealed by ASKAP, LOFAR, and the GMRT	P.I. **C. Riseley** (INAF)
MeerKAT key science projects	The MeerKAT Fornax Survey - polarization	P.I. **P. Serra** (INAF)
	MIGHTEE - polarization working group	Chairs: A. Scaife (Manchester Univ.) & R. Taylor (UCT)

*project related to polarization/RM with an italian PI-ship

Open questions

1. What is the origin of large-scale magnetic fields?

Polarized accretion shocks from the cosmic web
[Vernstrom+2023]

Organization of local magnetic fields by strong shock waves