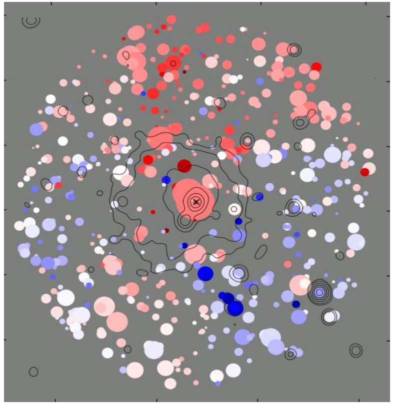
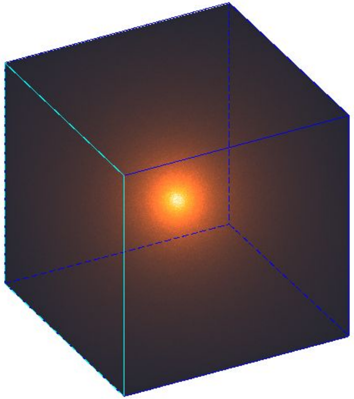
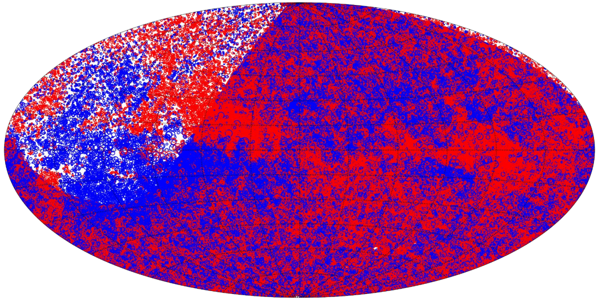
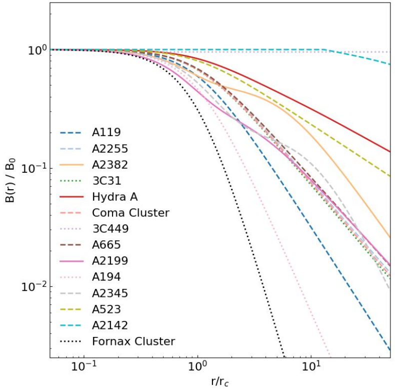
Revealing the Magnetic Landscape of Galaxy Clusters with SKA

Francesca Loi @ INAF-OAC







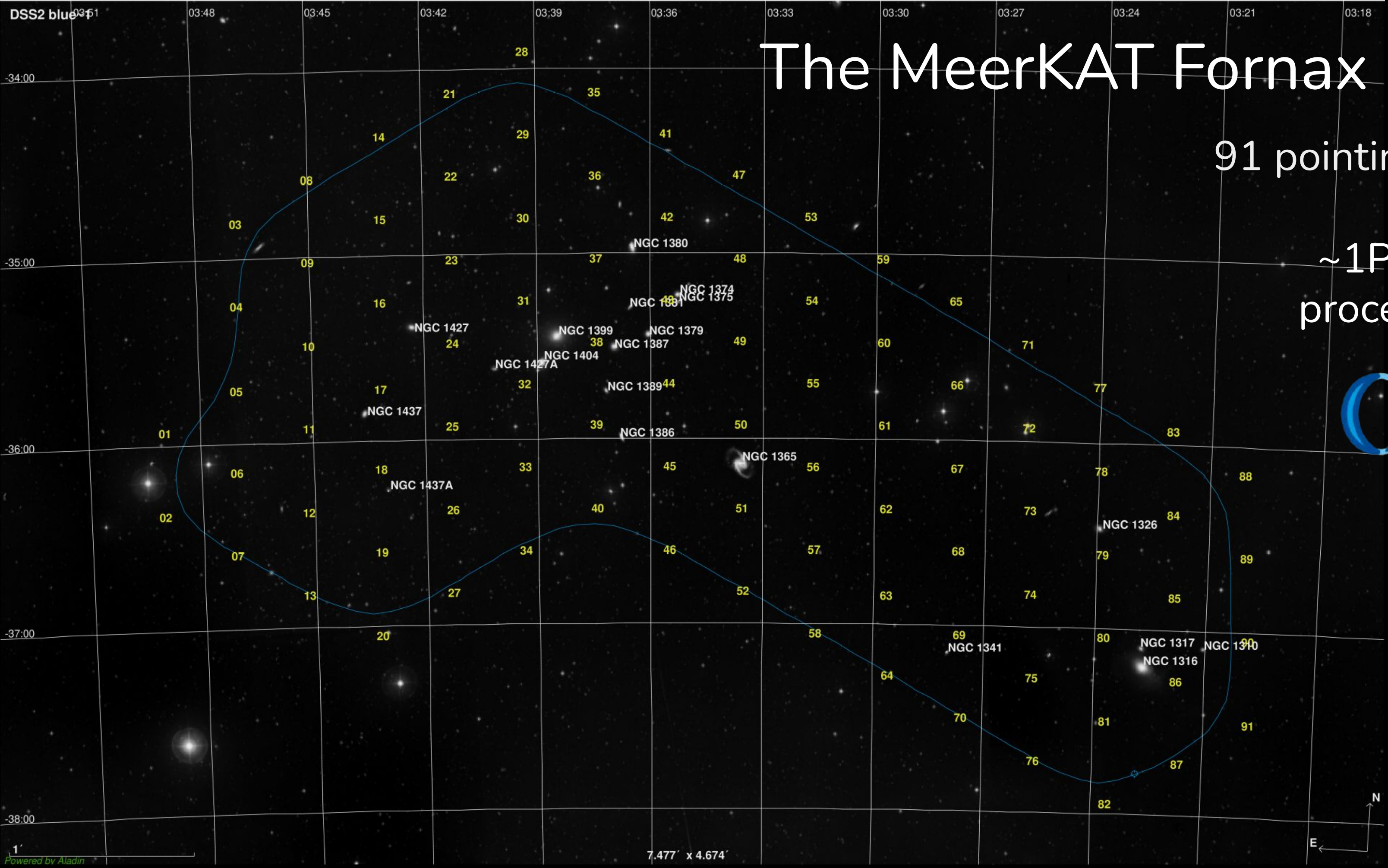


Collaborators: Federica Govoni, Matteo Murgia, Paolo Serra, Valentina Vacca, Filippo Maccagni, Craig Anderson, Annalisa Bonafede, Ettore Carretti, Shane O'Sullivan, Tessa Vernstrom, ...

Outline

- The MeerKAT Fornax Survey: an anticipation of the SKA-mid sky
- Why do we need to go so deep?
- Conclusion

The MeerKAT Fornax Survey



91 pointings (2x5hrs)

~1PB of data processed with

CARACAL

The MeerKAT Fornax Survey

91 pointings (2x5hrs)

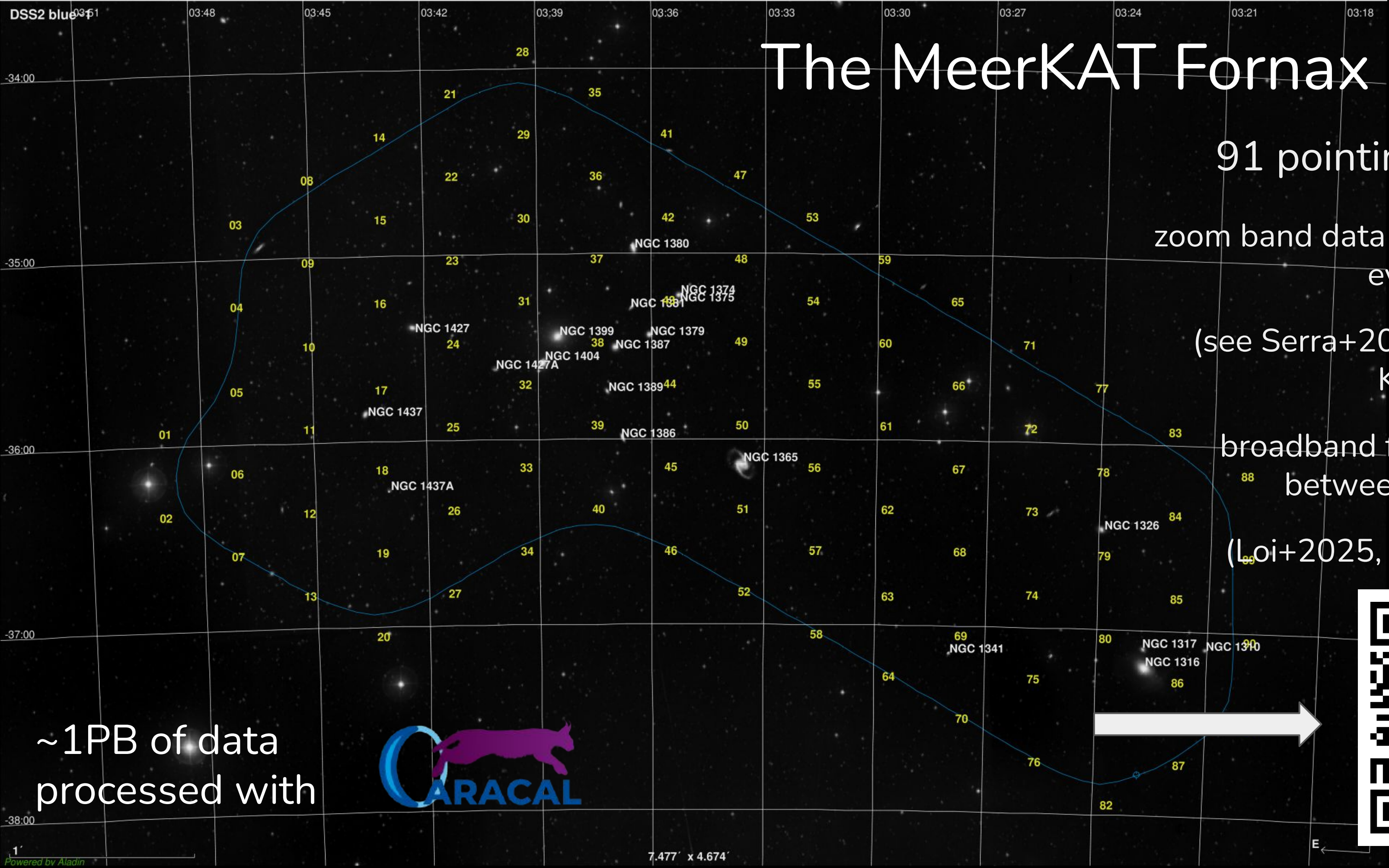
zoom band data to study galaxy evolution with HI

(see Serra+2023, Loni+2023, Kleiner+2023,…)

broadband full-Stokes data between 0.9 – 1.4 GHz

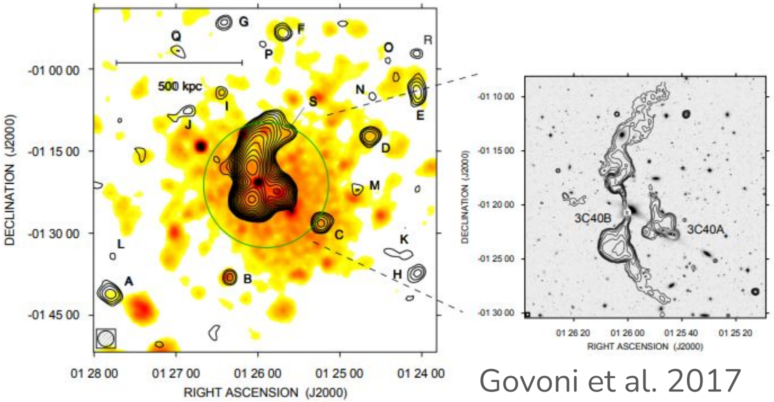
(Loi+2025, Loi+ in prep., …)

~1PB of data processed with CARACAL



The Faraday effect

A194 – SRT 6.6 GHz – VLA 1.4 GHz



Govoni et al. 2017

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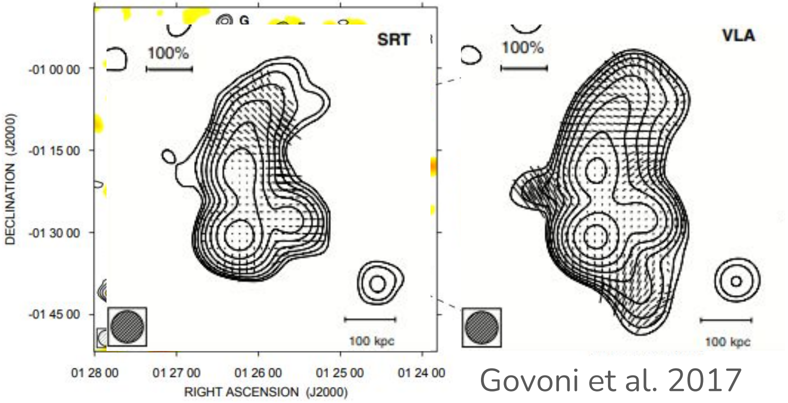

Govoni et al. 2017

x

The Faraday effect

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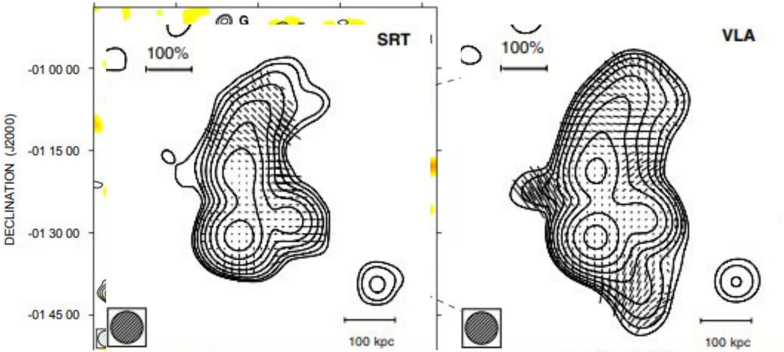
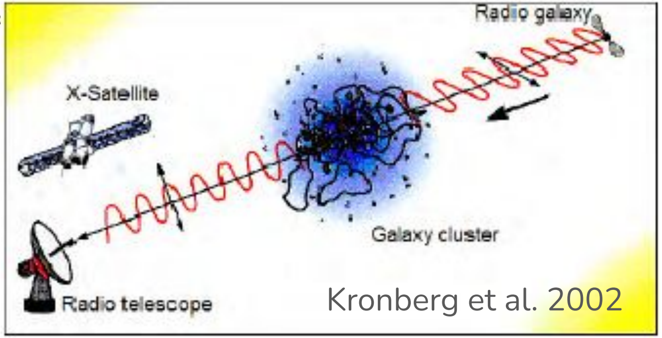
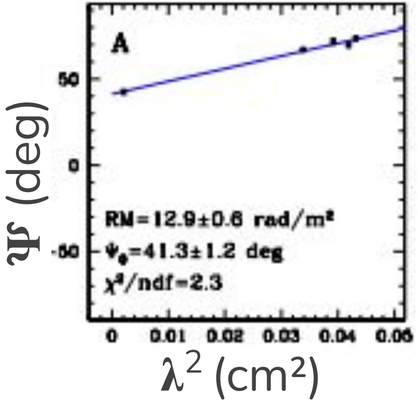




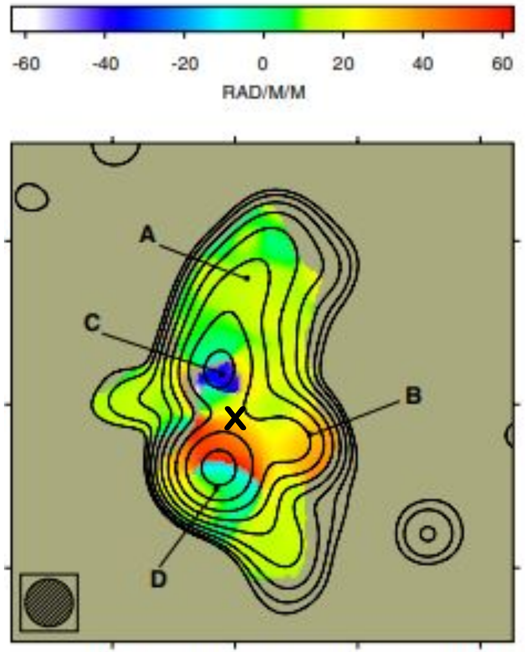
Kronberg et al. 2002

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

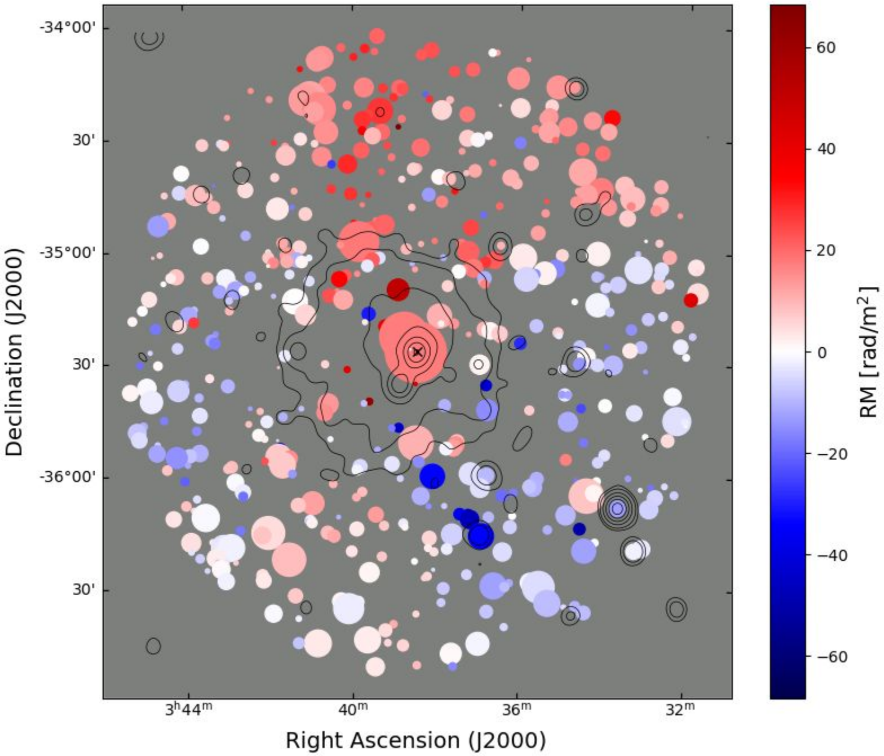
$$RM = \int B_{||} \cdot n_e \cdot dl$$



RM image



The MFS RM grid: an anticipation of the SKA-mid



Loi et al. 2021

r<1.42deg (~500 kpc) (r_c=173 kpc)

13 arcsec of resolution (~1 kpc)
σ ~ 2.6 μJy/beam (1.4–19 μJy/beam)

508 polarized sources detected in ~6.35 deg²
➔ 80 p.sources/deg²

SKA Cosmic Magnetism Science Working Group:

950-1760 MHz

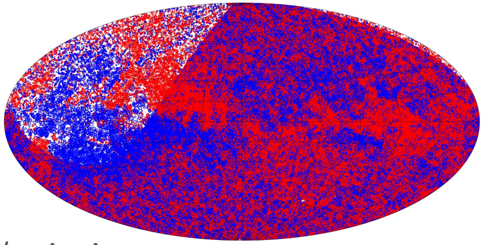
4 μJy/beam of sensitivity

2 arcsec of resolution

60–90 pol.sources/deg²

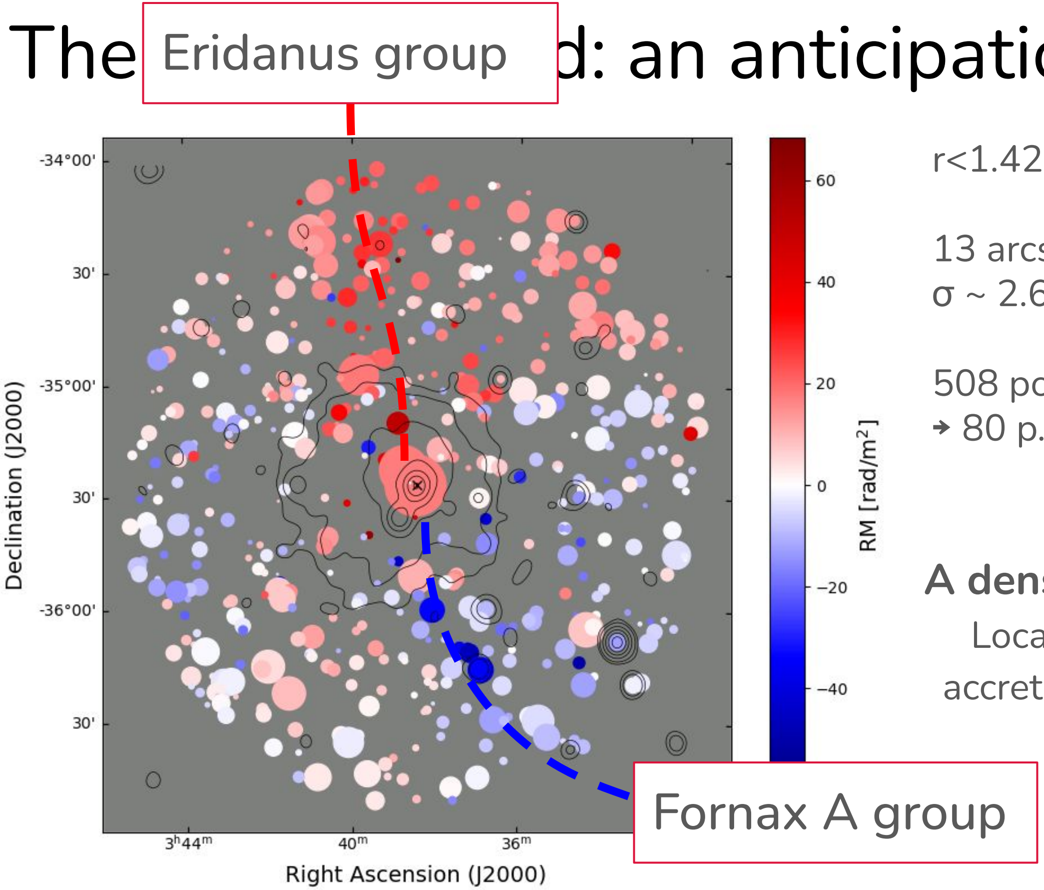
30'000 pointings, 15 min/pointing

The survey will last 2.5 years



Heald+2020

The d: an anticipation of the SKA-mid



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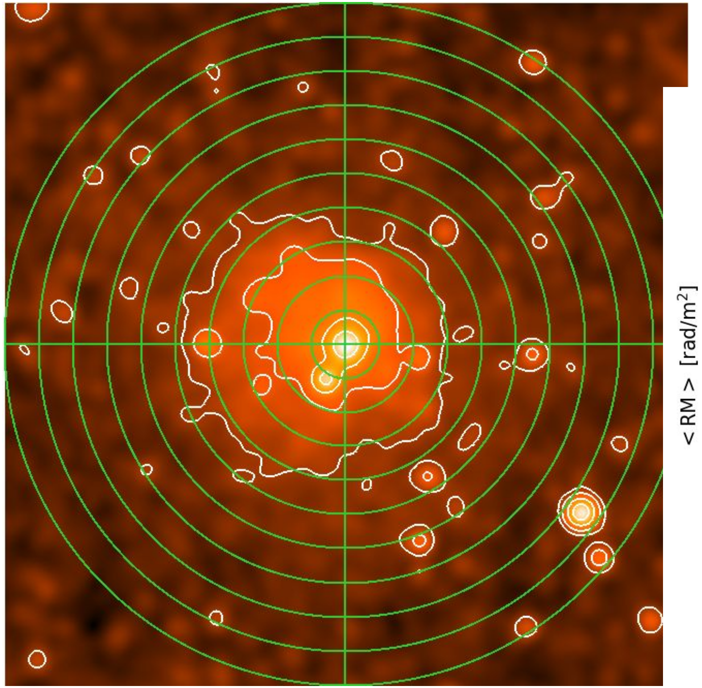
A dense RM grid reveals unexpected features

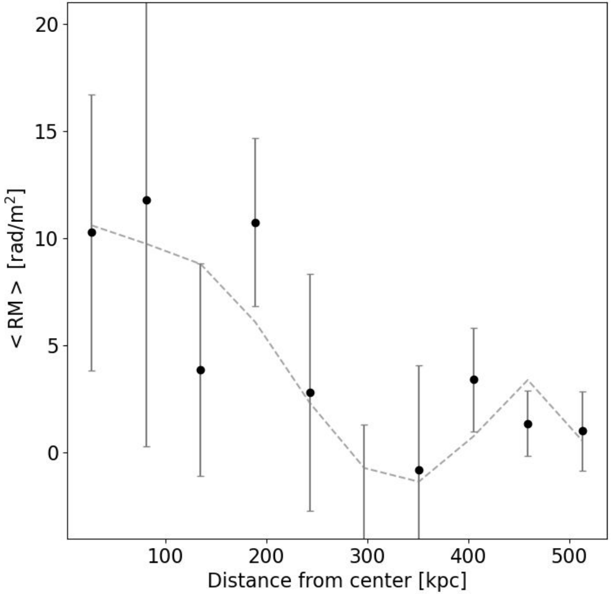
Localized RM enhancement as a consequence of accretion phenomena within the cluster virial radius

Better reconstruction of the RM profiles

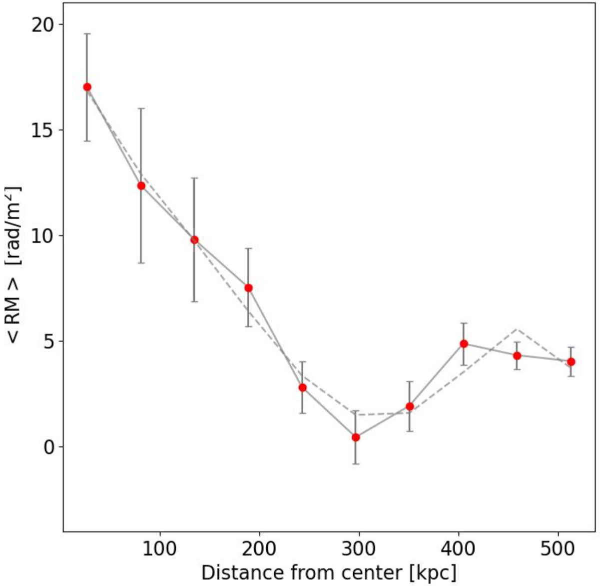


0.2–4 keV eROSITA/SRG X-ray image

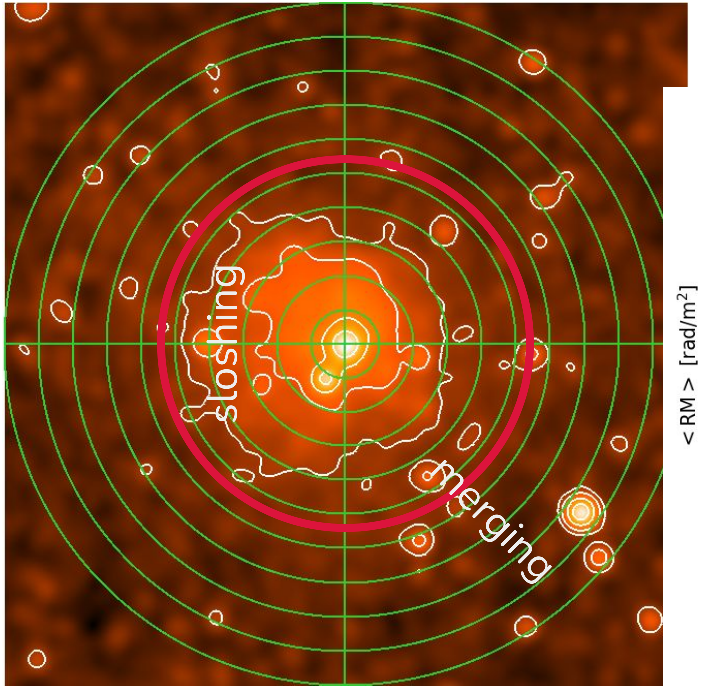
ASKAP RM grid with 25 p.source/deg²
based on Anderson et al. 2021



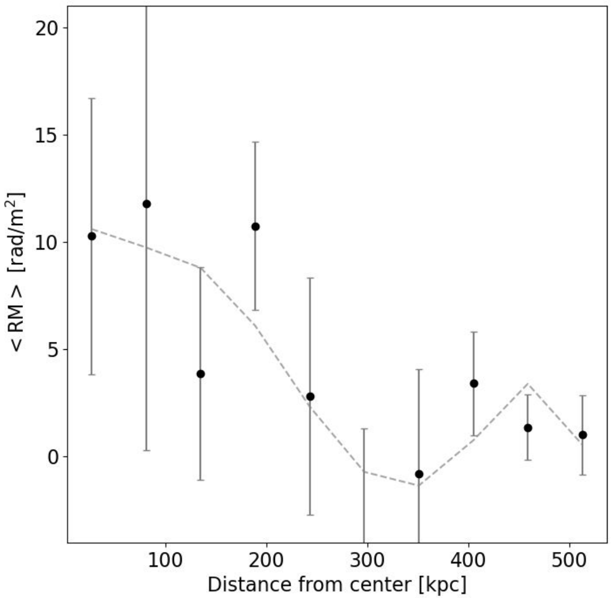
MFS RM grid with 80 p.source/deg²
based on Loi et al. 2025

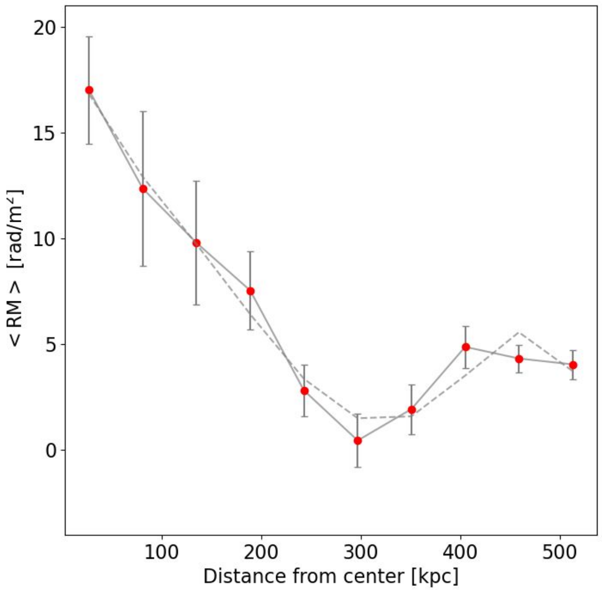


Better reconstruction of the RM profiles



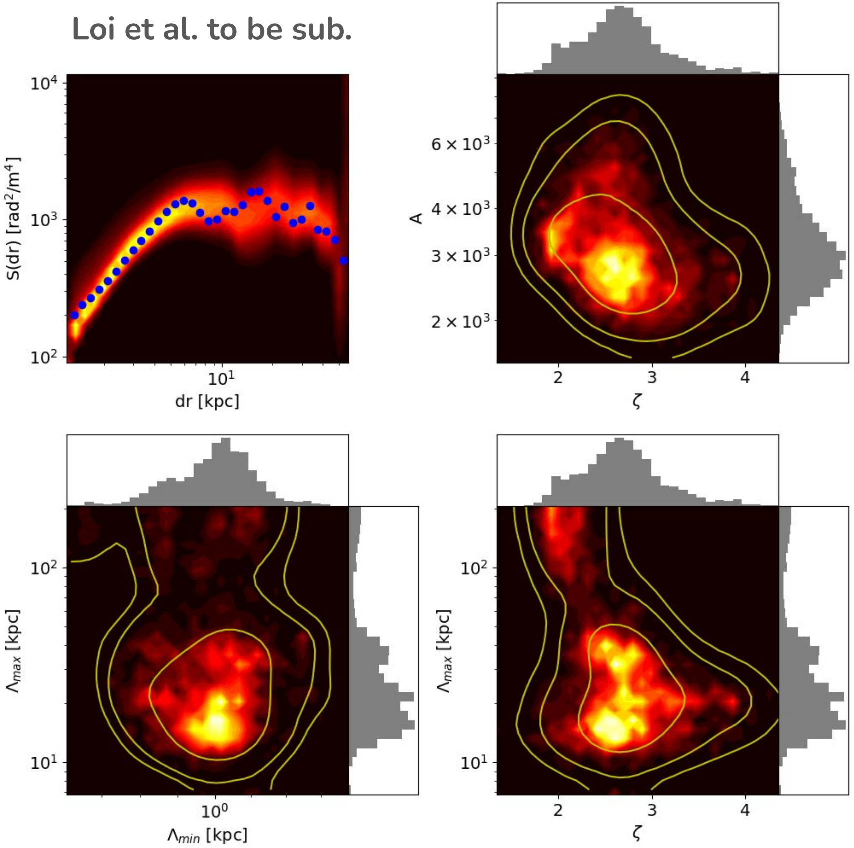
0.2–4 keV eROSITA/SRG X-ray image





B measurements

Loi et al. to be sub.



Simulations of the RM images with the FARADAY tool (Murgia et al. 2004):

bayesian inference to maximize the posterior probability of the observed **RM Structure function**

$$|B_k|^2 = A \cdot k^{-\zeta}$$

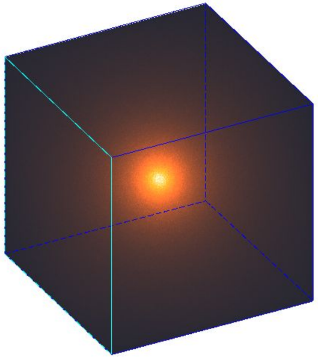
$n = 2.7 \pm 0.4$

$\Lambda_{min} = 1.01 \pm 0.02$ kpc

$\Lambda_{max} = 15 \pm 9$ kpc

$\Lambda_c = 3.4 \pm 1$ kpc

B measurements



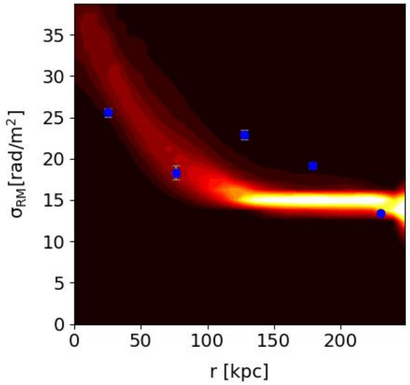
thermal plasma model

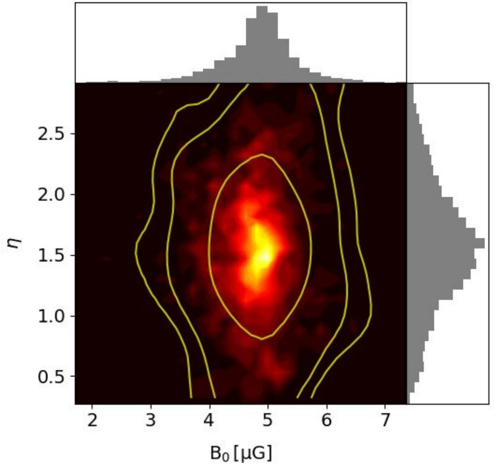
sim. RM

Simulations of the RM images with the FARADAY tool (Murgia et al. 2004):

bayesian inference to maximize the posterior probability of the observed **RM radial profile**

Loi et al. to be sub.

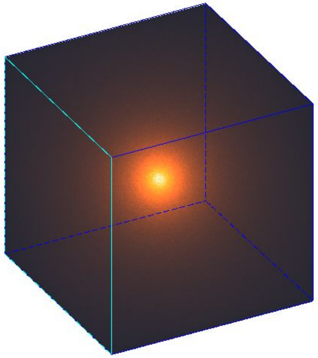




$$B(r) = B_0 \, (n(r)/n_0)^{\eta}$$

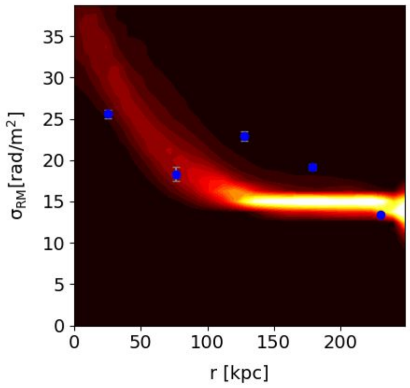
$$B_0 \simeq 5 \ \mu G$$
$$\eta \simeq 1.6$$

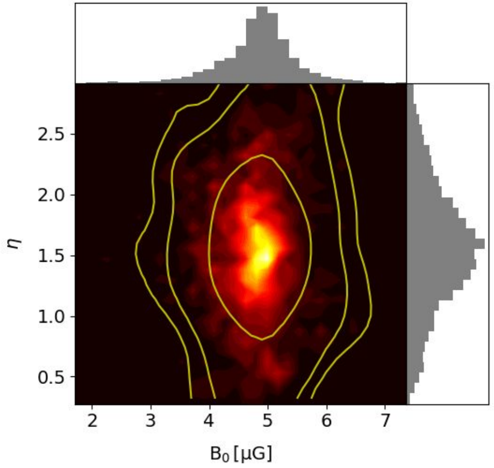
B measurements

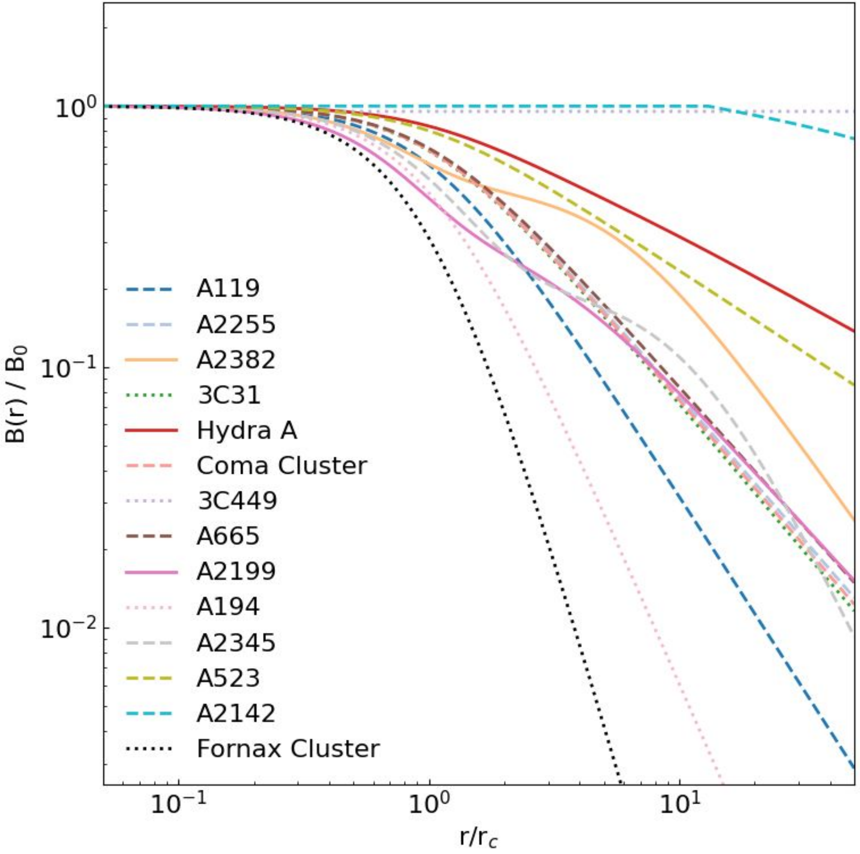


+ thermal plasma model = **sim. RM**

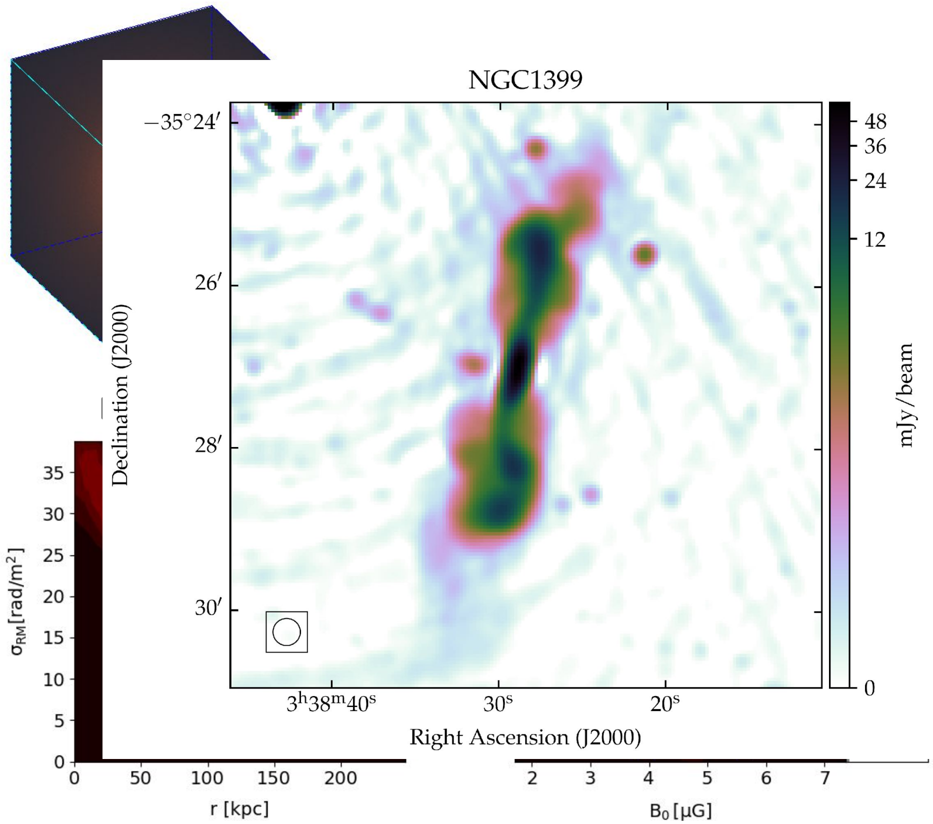
Loi et al. to be sub.

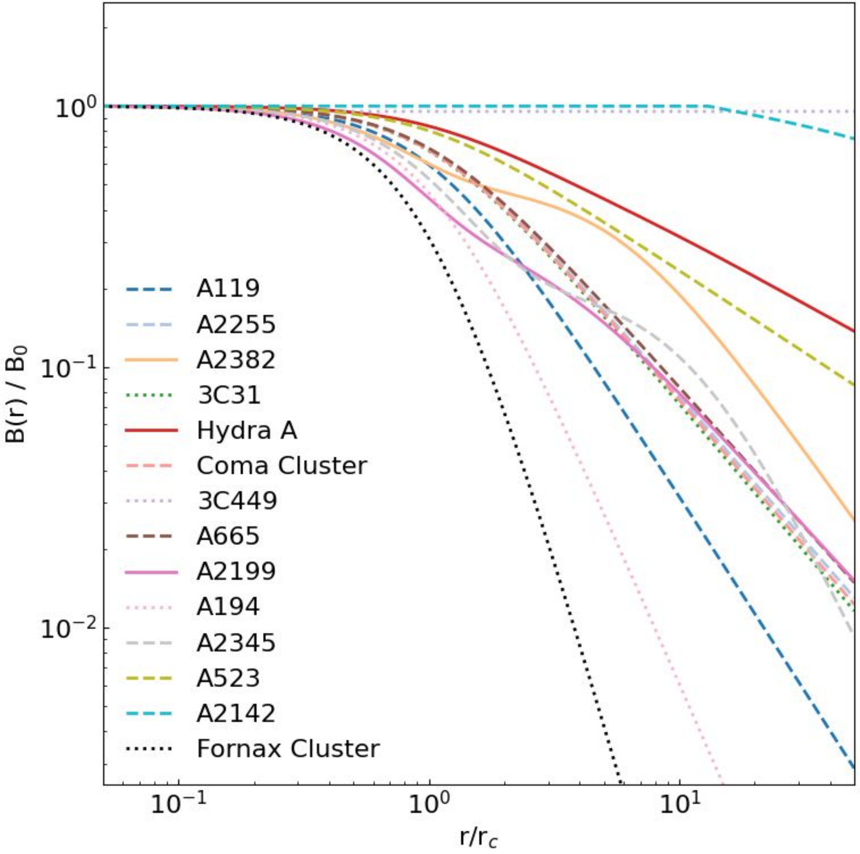






B measurements





A possible SKAO–AA* survey design

based on the SKAO sensitivity calculator

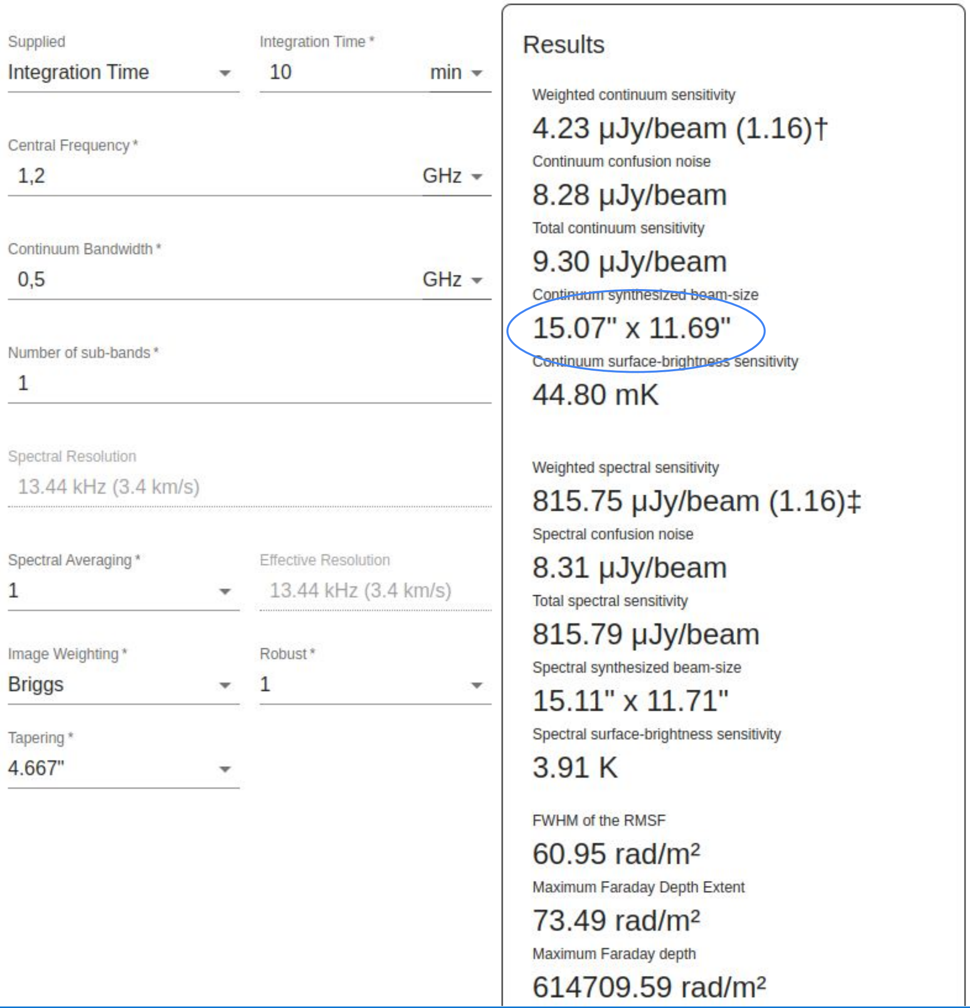
To detect ~ 80 pol. sources/deg² at 5σ we would need σ_{QU} ~3 μJy/beam

On the mosaic the rms will go down by a factor of 0.72

30’000 deg² to cover

THE ALL-SKY SURVEY WILL LAST 1-2 YEARS

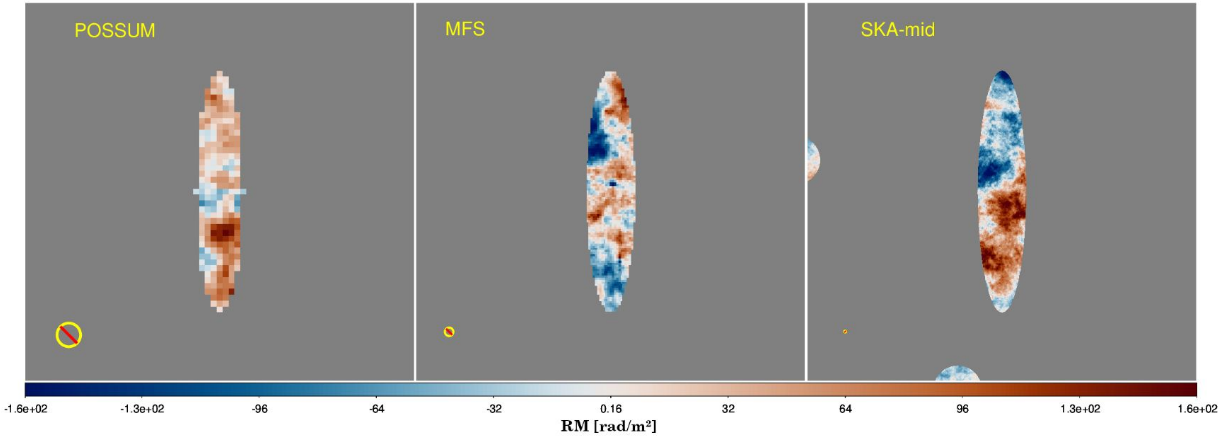
(up to ~2’’ with r=0 targeting the same sensitivity)



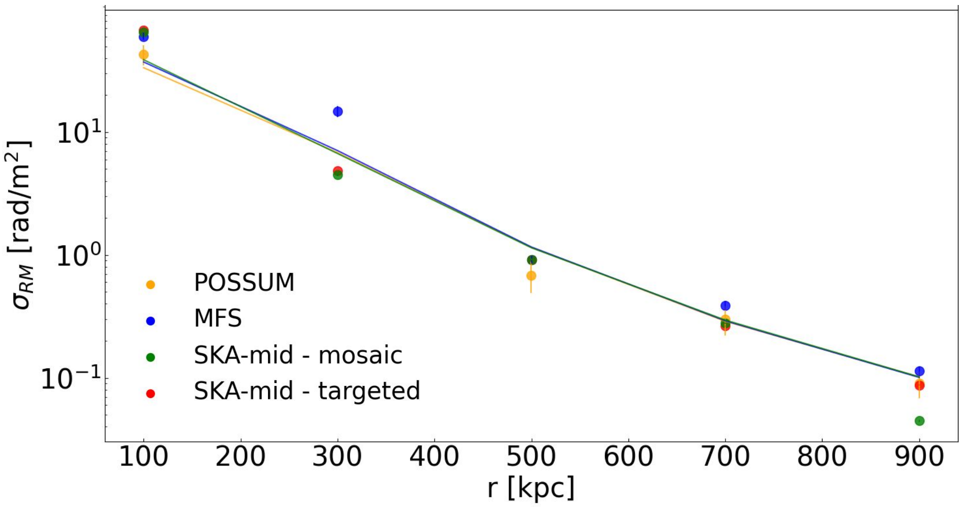
The impact of dense RM grids on the study of intra-cluster and intra-group magnetic fields

[Loi et al. SKA White Book]

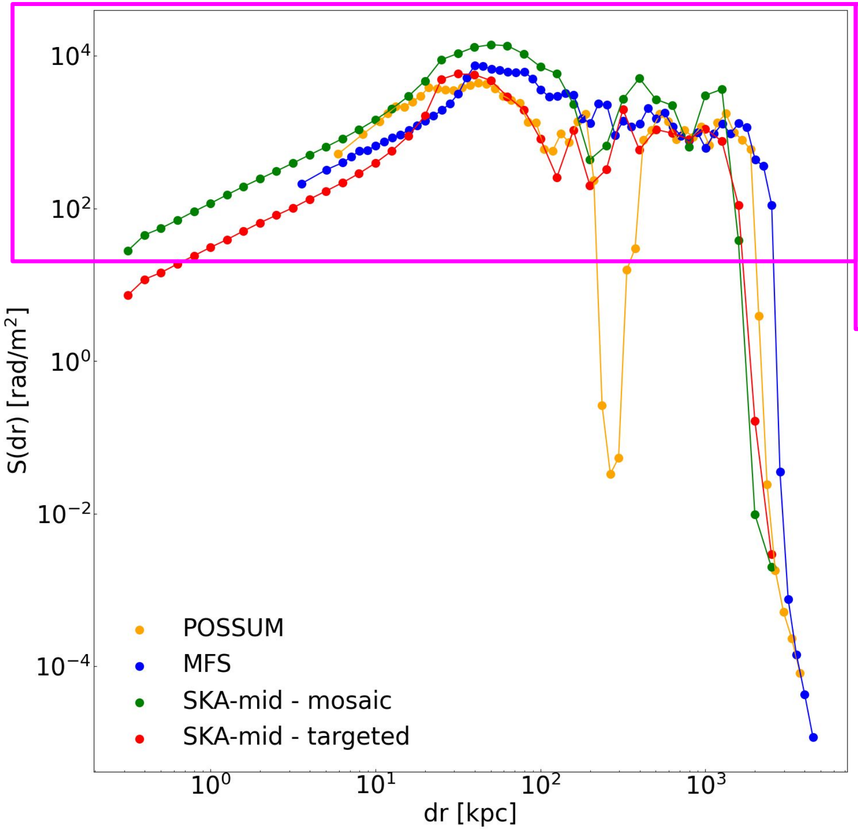
Simulations of RM images of a cluster at z=0.03 considering the sensitivity and resolution of four observational configurations

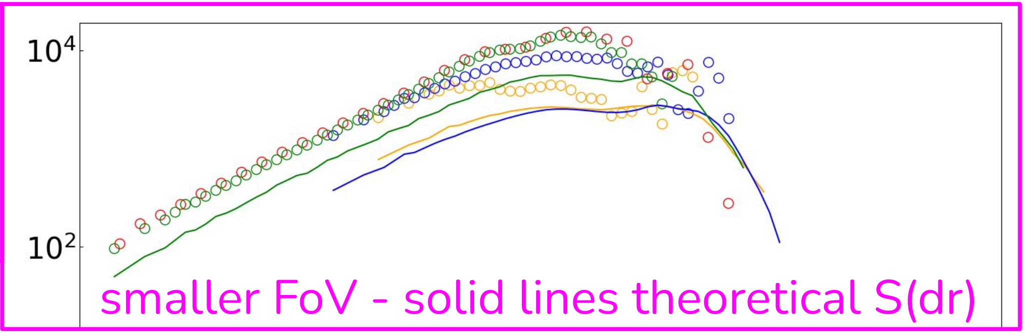


Survey	Bandwidth GHz	σ_{QU} [μJy/beam]	source density [number/deg^2]	resolution [arcsec]	
POSSUM	0.8–1.439	-	37	21	[Vanderwoude et al. 2024]
MFS (SKA-mid AA*)	0.9–1.4	3	80	13	[Loi et al. 2025]
SKA-mid mosaic	0.95–1.76	2.2	110	$\simeq$1	AA4 mosaic=15 min/points
SKA-mid targeted	0.95–1.76	0.5	414	$\simeq$1	AA4 targeted=10 hrs/points



Survey	
POSSUM	~
MFS (SKA-mid AA*)	ok
SKA-mid mosaic	ok
SKA-mid targeted	ok





Survey	
POSSUM	not enough
MFS (SKA-mid AA*)	~
SKA-mid mosaic	ok
SKA-mid targeted	ok

resolution matters!

Conclusion

Goal: accurate B reconstruction in a large sample of galaxy clusters

Methods: deep observations at high resolution (SKA-mid AA* and AA4)

The MFS strategy is good and accurate to trace B
<u>but</u> limited to nearby clusters if one is interested in the B structure (resolution matters), only deep observations can do this job

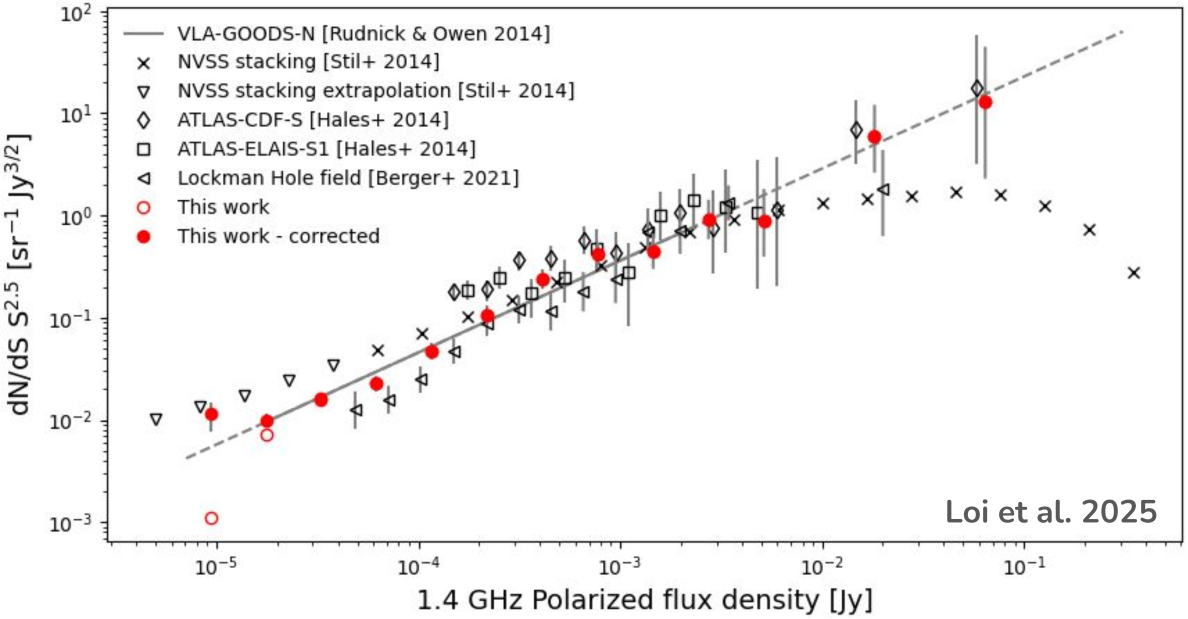
Fornax is ear (1 arcsec ~ 0.1 kpc)
At z=0.1 → 1 arcsec ~ 1.857 kpc
At z=0.5 → 1 arcsec ~ 6.169 kpc

Resolution matters!

Thank you

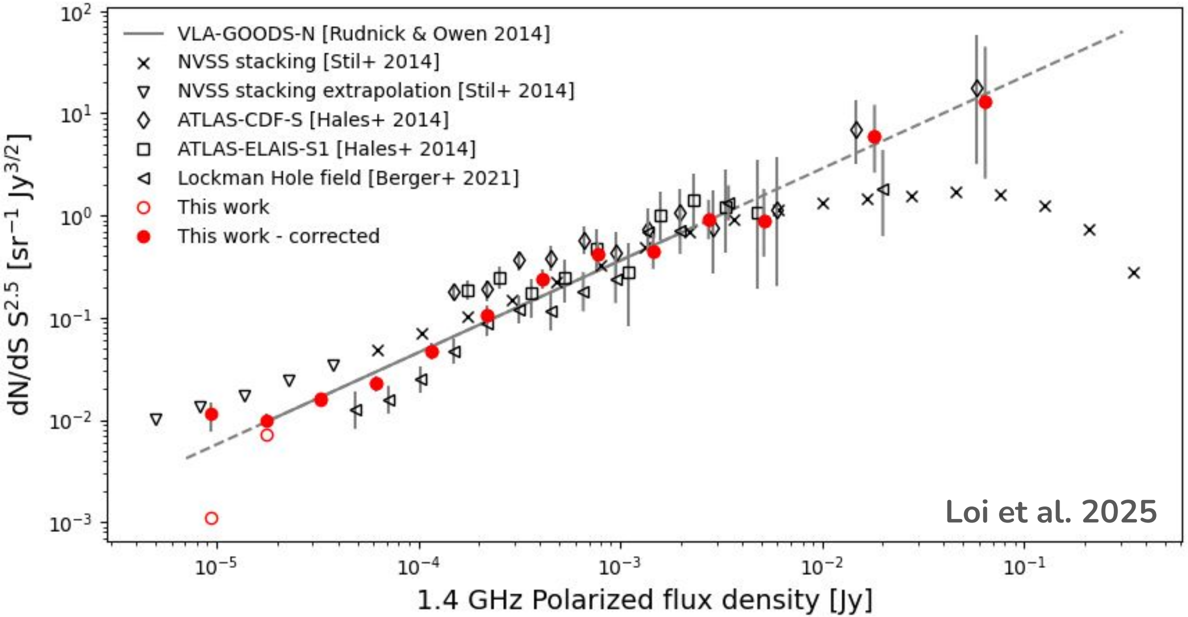
Backup slides

Euclidean normalized differential P source counts



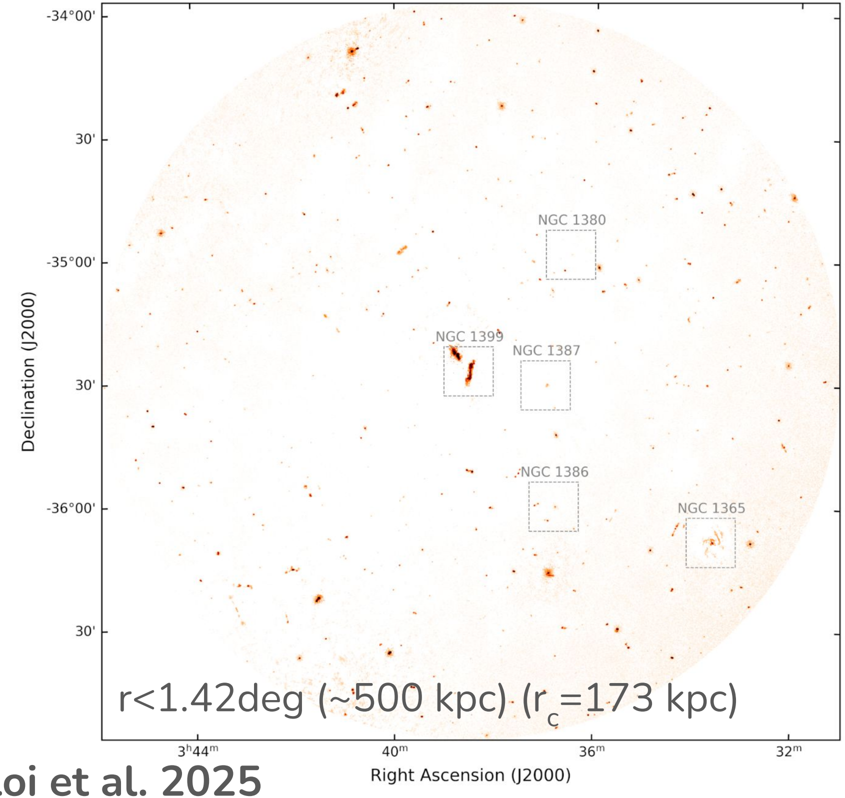
508 polarized sources detected (13 arcsec, σ_{QU} ~ 1.4÷19 μJy/beam)
⇝ **80 pol.sources/deg²**

Euclidean normalized differential P source counts



508 polarized sources detected (13 arcsec, σ_{QU} ~ 1.4÷19 μJy/beam)
⇝ 80 pol.sources/deg²
Considering the completeness correction there could be **1007 polarized sources**
⇝ 160 pol.sources/deg²

Polarized intensity mosaic (after RM synthesis)



Loi et al. 2025

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Polarized cluster galaxies