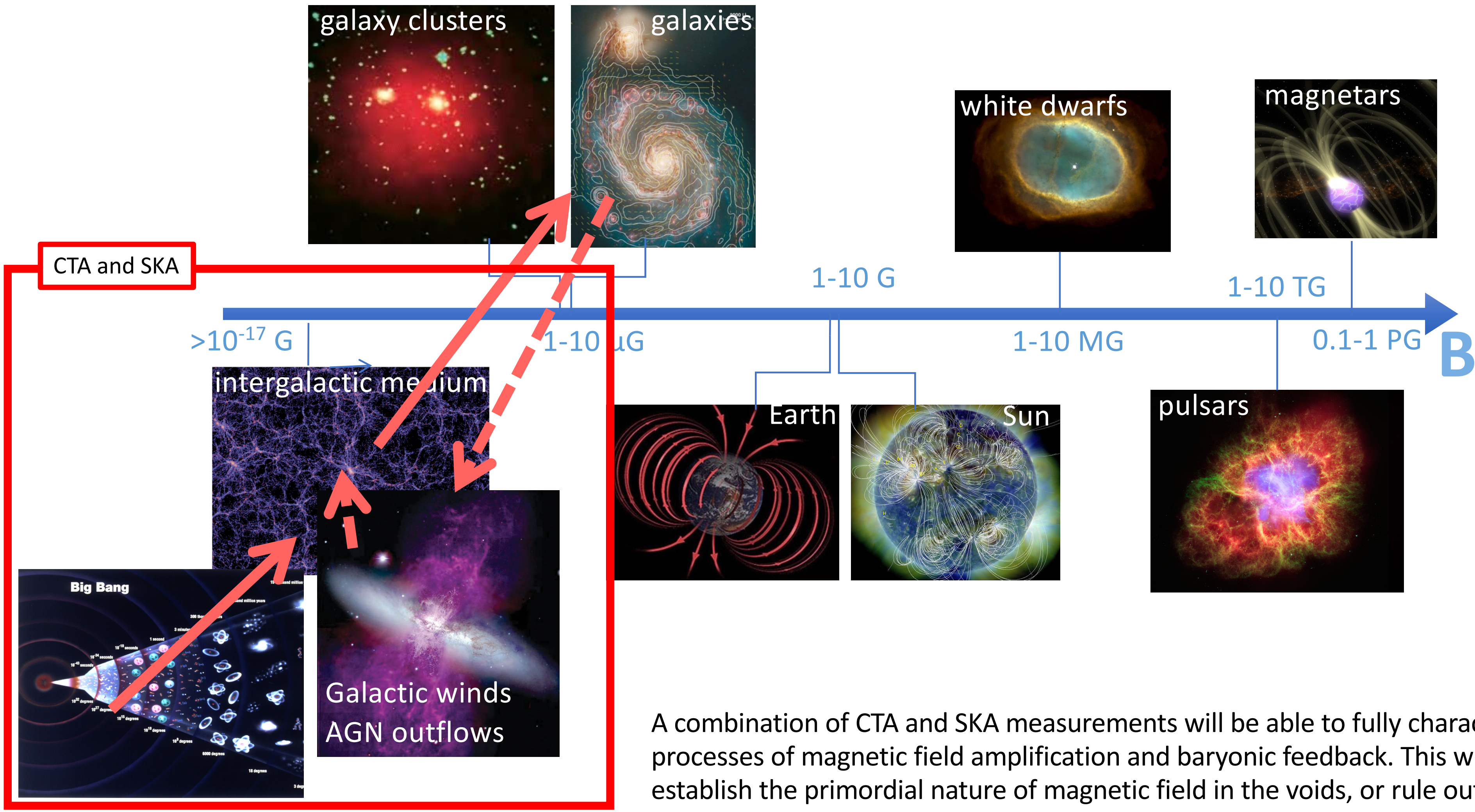
Intergalactic magnetic fields with CTA and SKA

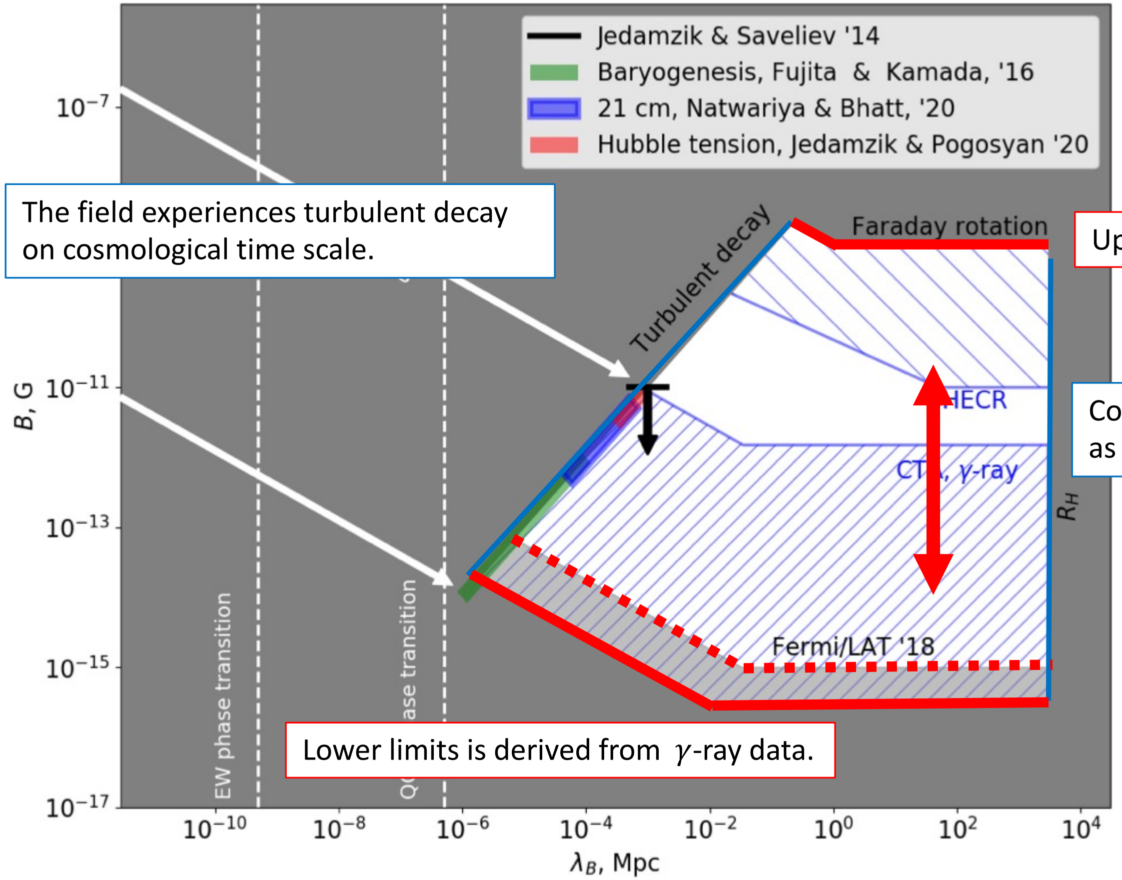
Andrii Neronov
APC Paris



A combination of CTA and SKA measurements will be able to fully characterise the processes of magnetic field amplification and baryonic feedback. This will allow to establish the primordial nature of magnetic field in the voids, or rule out this possibility.

Known constraints on IGMF

Korochkin, Kalashev, AN, Semikoz 2007.14331



The field experiences turbulent decay on cosmological time scale.

Upper limits is imposed by radio data

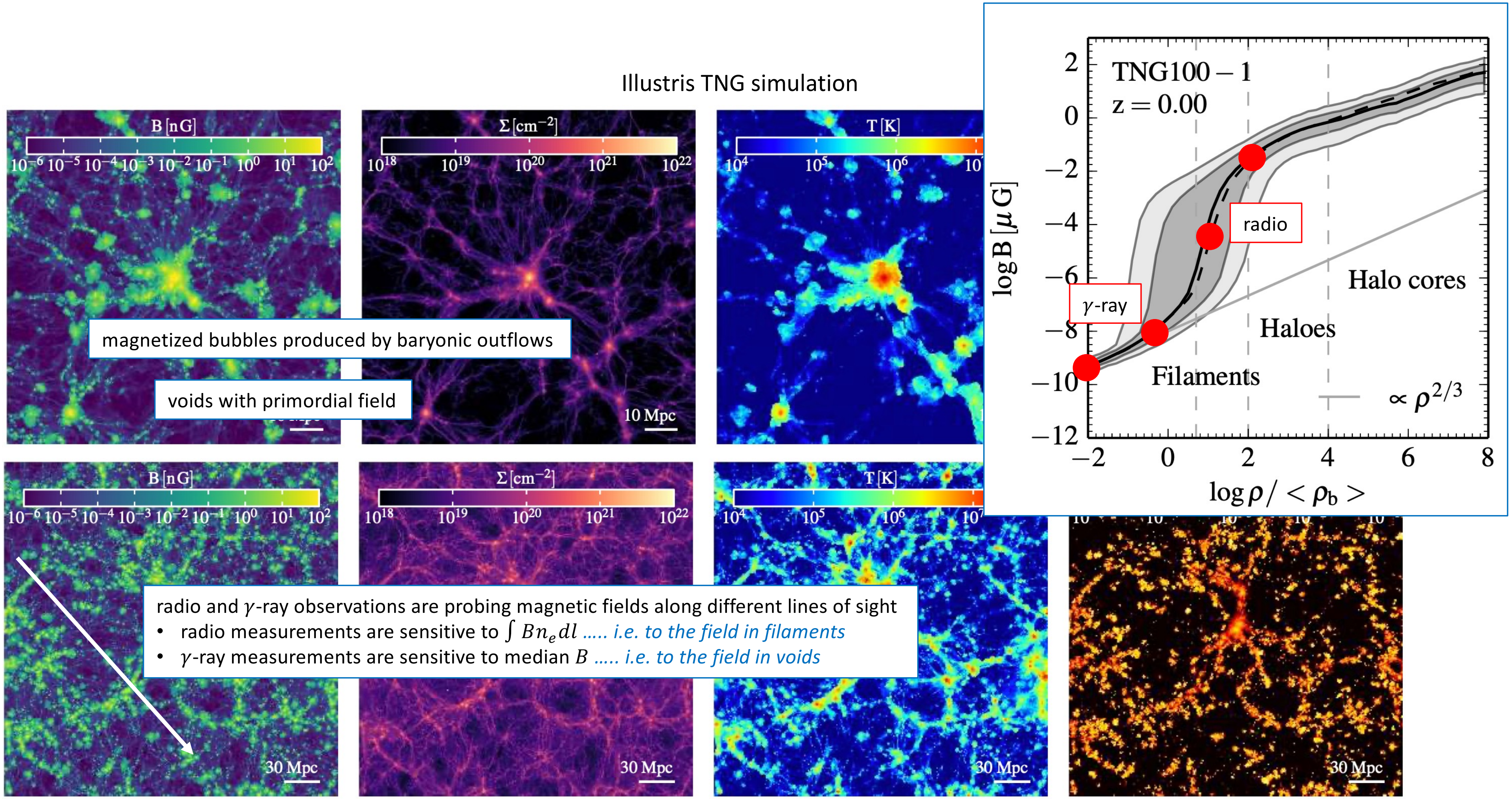
Correlation length could be as large as the size of the Universe

Lower limits is derived from γ-ray data.

Intergalactic magnetic field does not have fixed strength and / or correlation length. Its properties are different in voids and filaments of the Large Scale structure.

Magnetic field structure in intergalactic medium

Illustris TNG simulation

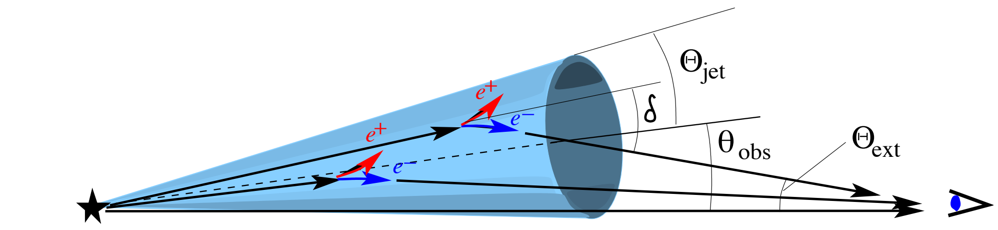


radio and γ-ray observations are probing magnetic fields along different lines of sight

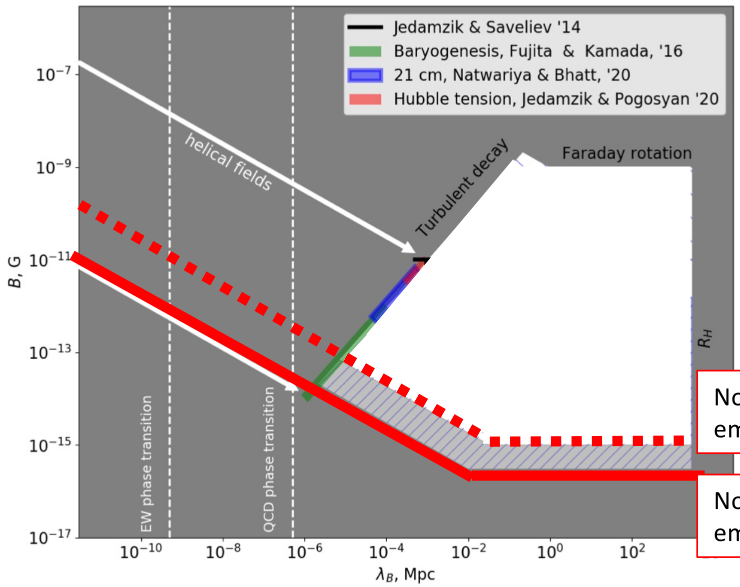
- radio measurements are sensitive to $\int B n_e dl$ *..... i.e. to the field in filaments*
- γ-ray measurements are sensitive to median B *..... i.e. to the field in voids*

γ-ray measurement method

γ-rays with energies above TeV produce electron-positron pairs in interactions with visible light photons. Electrons positrons re-generate γ-rays of lower energies via inverse Compton scattering of Cosmic Microwave Background photons. The "secondary" γ-rays emission from e^+e^- in intergalactic medium is sensitive to the magnetic field.

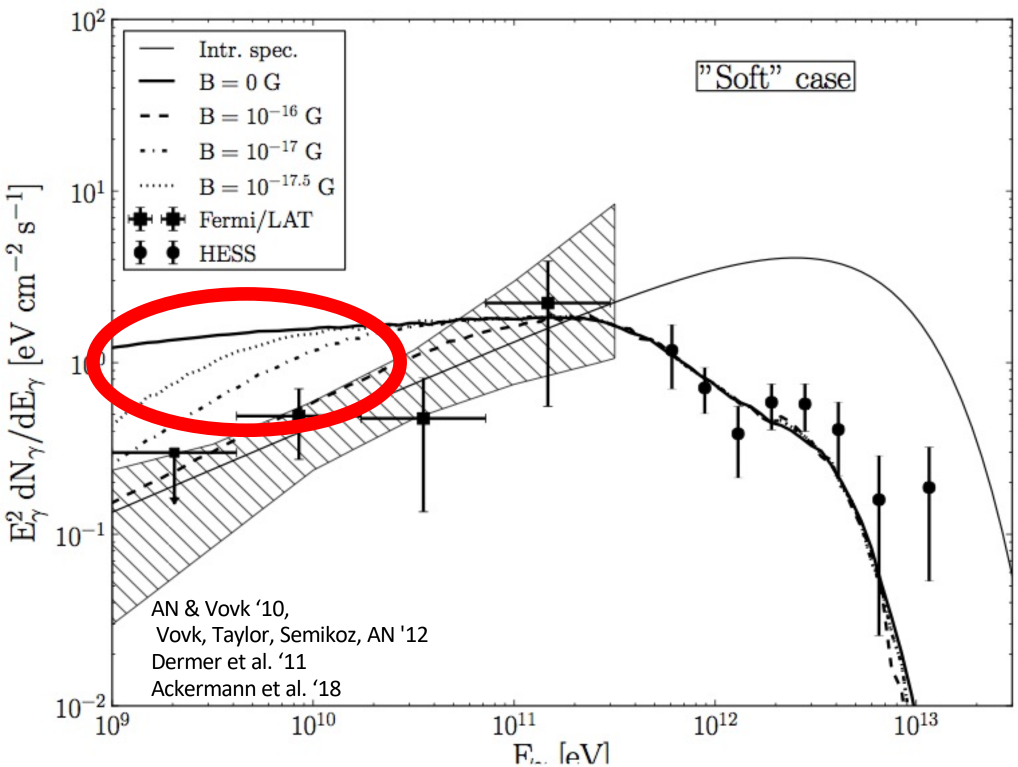


Plaga '95
Neronov & Semikoz '07, '09



Non-detection of extended emission around distant AGN

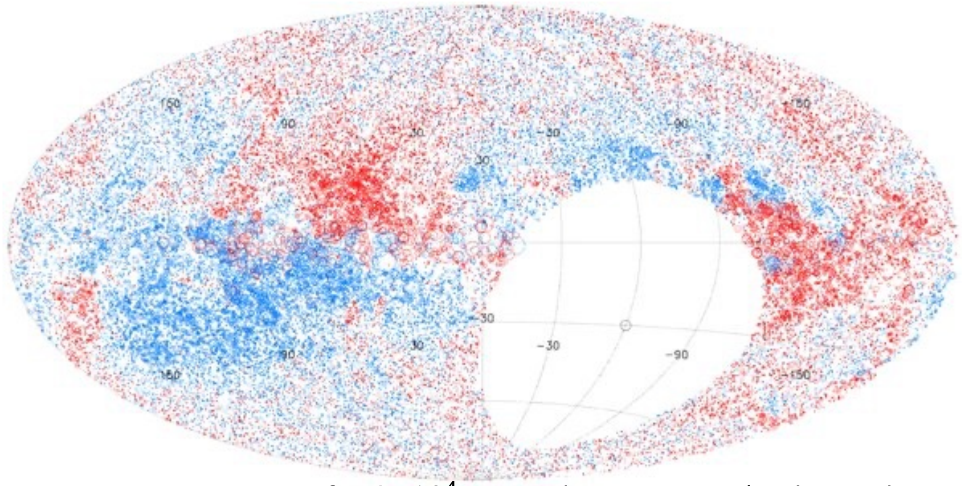
Non-detection of delayed emission from AGN flares

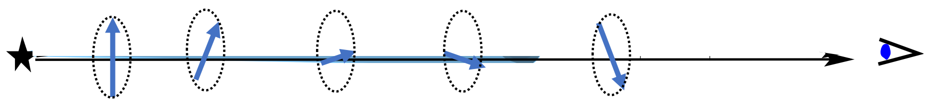


IGMF measurement using Faraday rotation

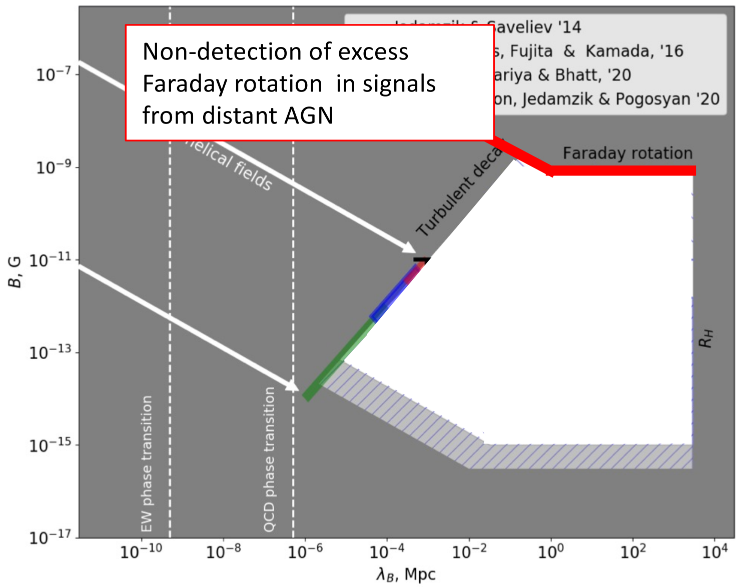
Constraints on IGMF strength were derived from non-observation of rotation of polarisation plane of radio waves from distant AGN.

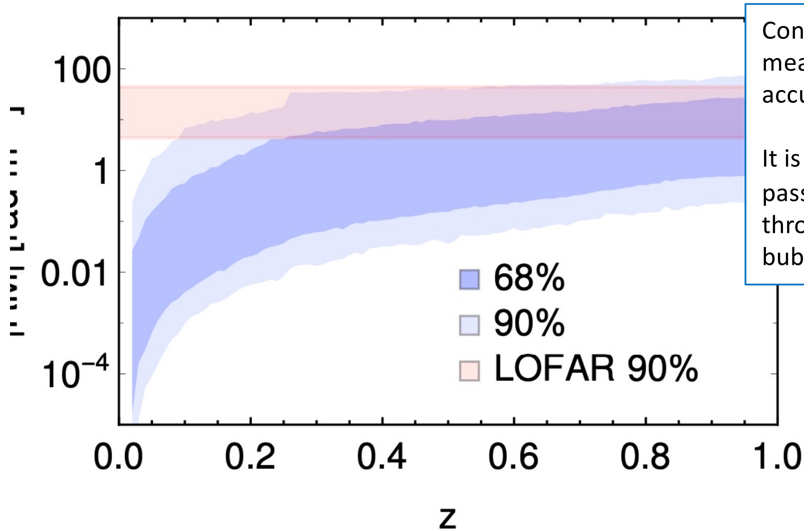
Faraday rotation measure signal along different lines of sight is dominated by the effect of radio wave propagation through the Galactic magnetic field. The rotation accumulated during propagation through the intergalactic medium is largely sub-dominant.





Rotation measure for 4×10^4 extragalactic sources (Taylor et al. 2009)





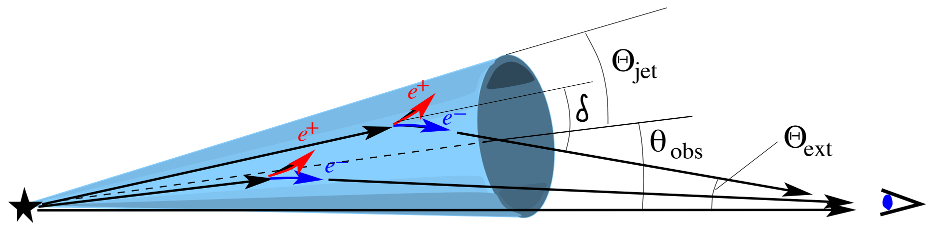
Contrary to Galactic Rotation measure, extragalactic RM accumulates with redshift.

It is mostly accumulated at passages of the lines of sight through filaments and magnetized bubbles around galaxies.

Blasi et al. '99
AN et al., '13
Garcia et al. '20

CTA sensitivity reach

γ-rays with energies above TeV produce electron-positron pairs in interactions with visible light photons. Electrons positrons re-generate γ-rays of lower energies via inverse Compton scattering of Cosmic Microwave Background photons. The "secondary" γ-rays emission from e^+e^- in intergalactic medium is sensitive to the magnetic field.



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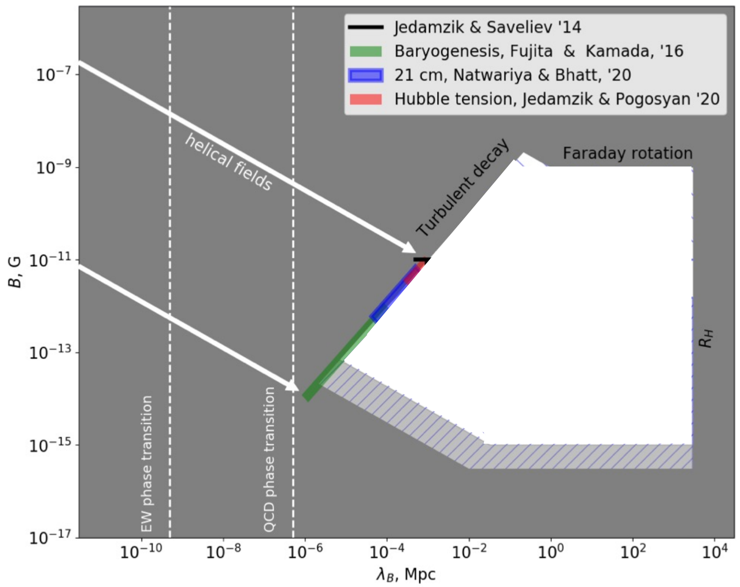

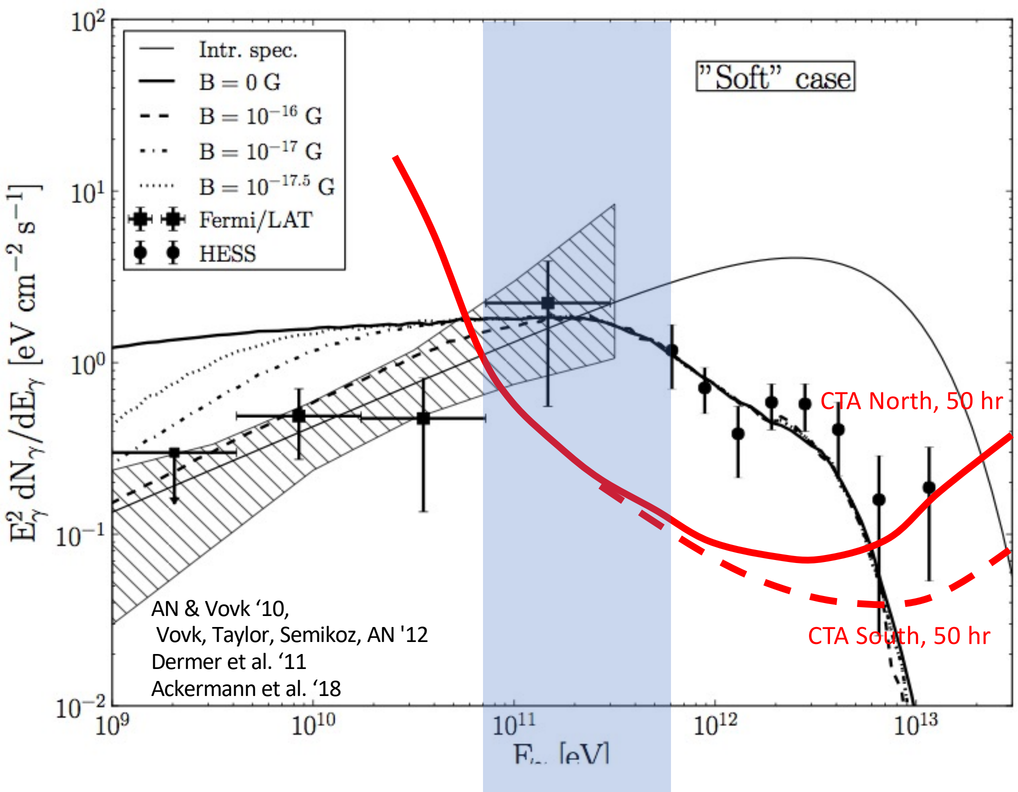

CTA will be able to probe stronger IGMF that efficiently deflects higher energy electrons. These higher energy electrons produce secondary emission in 100 GeV band in which the extended emission signal is currently not accessible.

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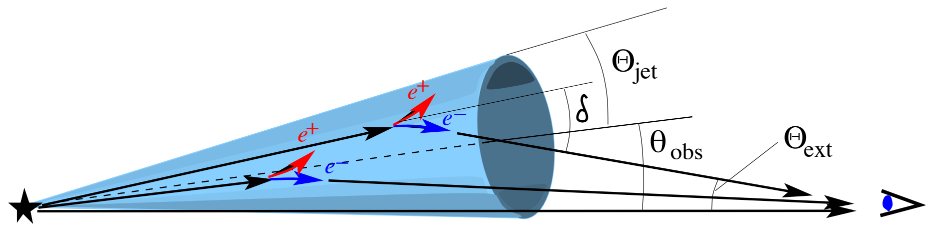

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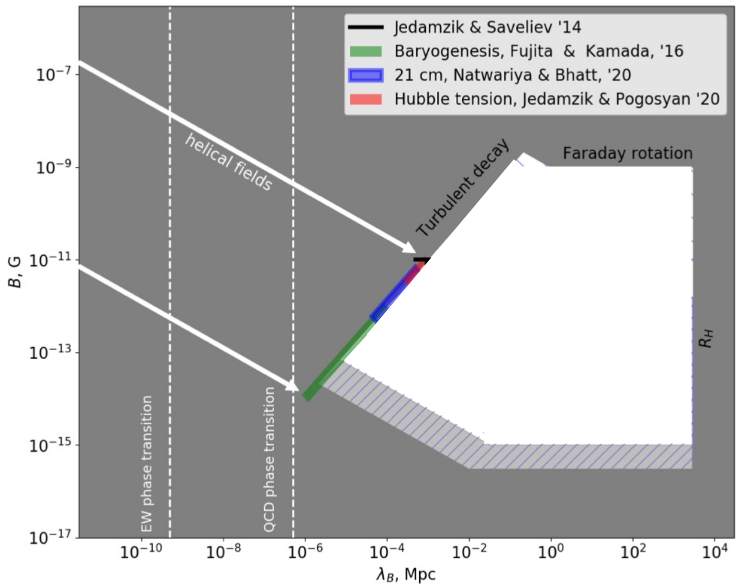

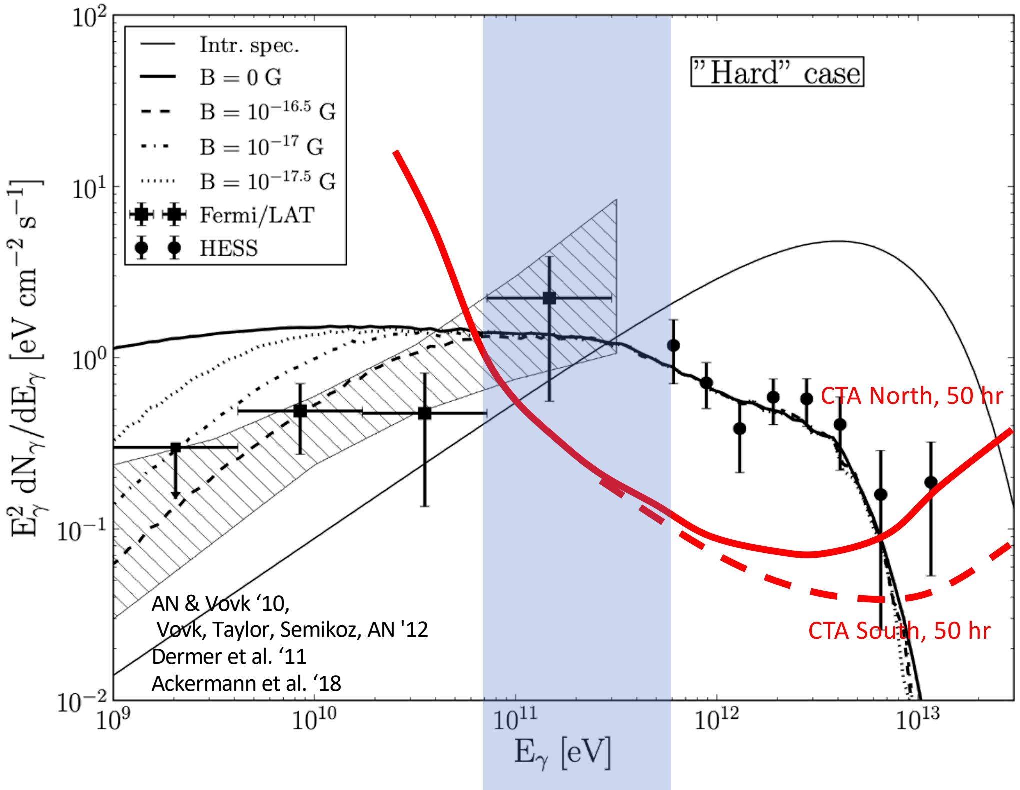

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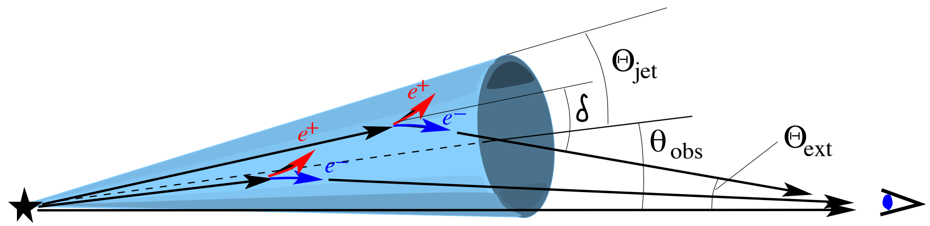

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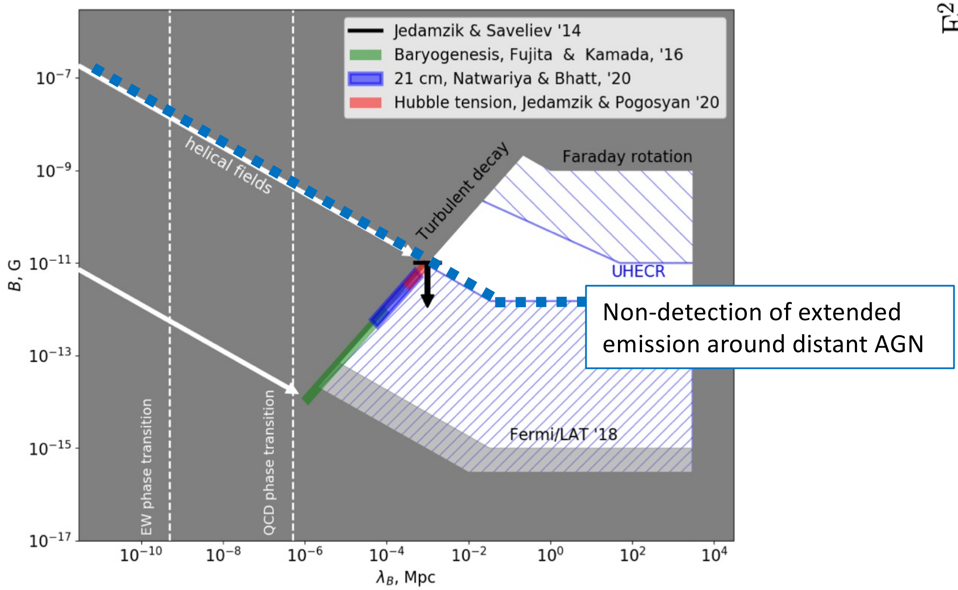

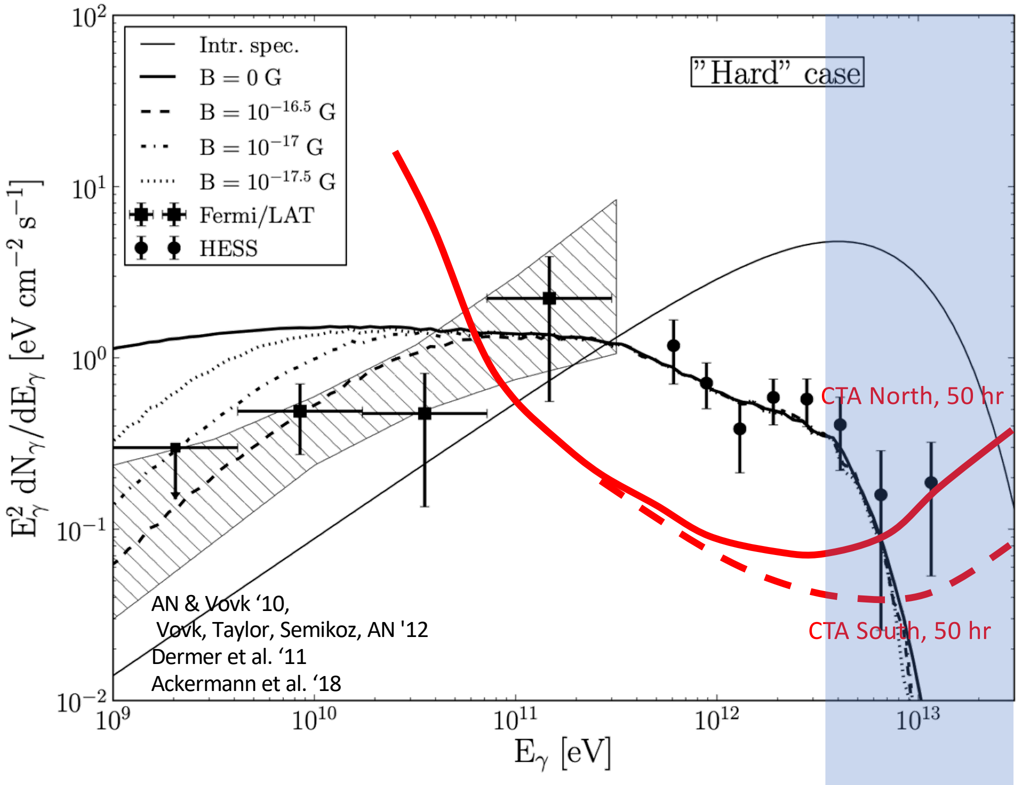

CTA will be able to increase precision of measurements of intrinsic luminosity of distant sources in the 10 TeV range, where current generation telescopes run out of statistics.

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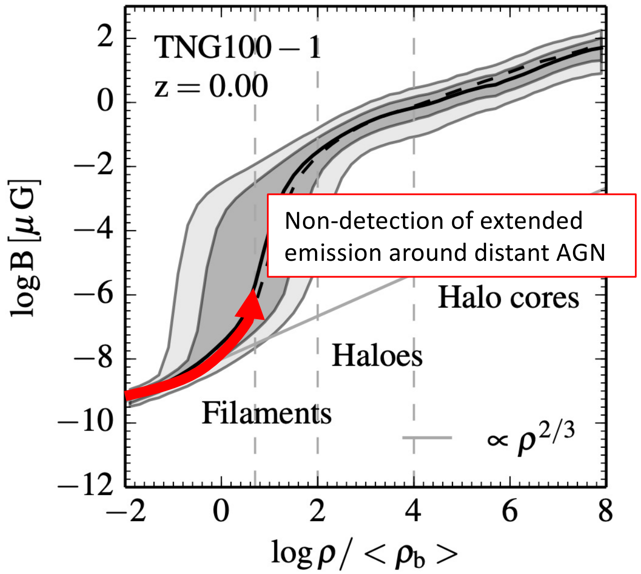

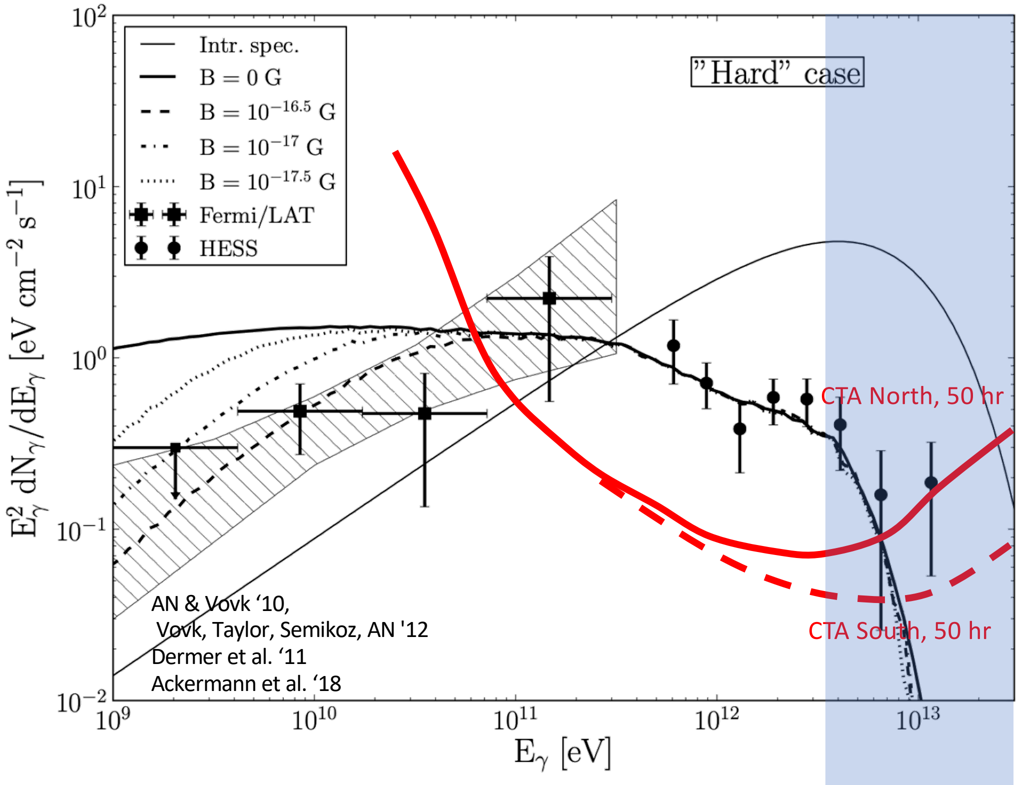

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SKA sensitivity reach

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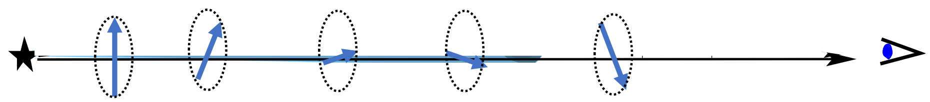
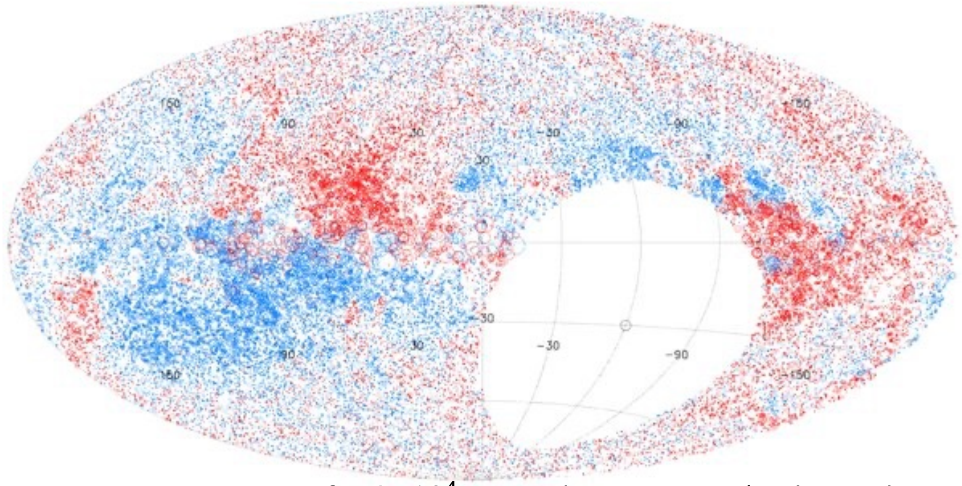
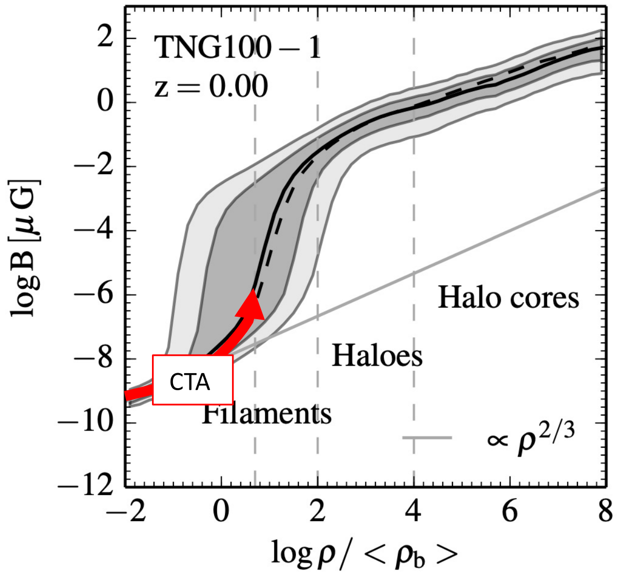




Rotation measure for 4×10^4 extragalactic sources (Taylor et al. 2009)

- $\simeq 1$ source per square degree.
- only about 10% of sources (mostly radio galaxies) have redshift measurements because of poor angular resolution ($45''$)
- the rotation measure is "noisy": estimated based on measurements on just two frequencies



SKA1 will provide a "rotation measure grid" with

- $\sim 10^2$ measurements per square degree.
- Large fraction of the sources will have redshift measurements, because the better angular resolution. Source sample will be dominated by star forming galaxies identifiable in optical surveys.
- Rotation measure will be derived from broad band (0.3-14 GHz) measurements.

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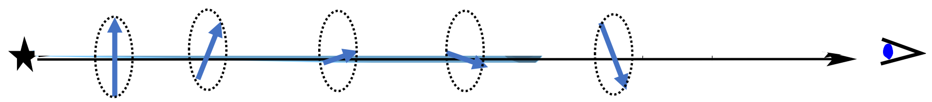

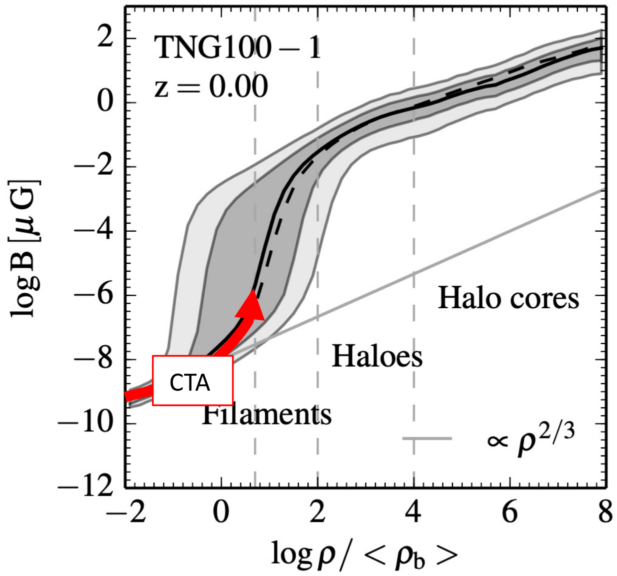

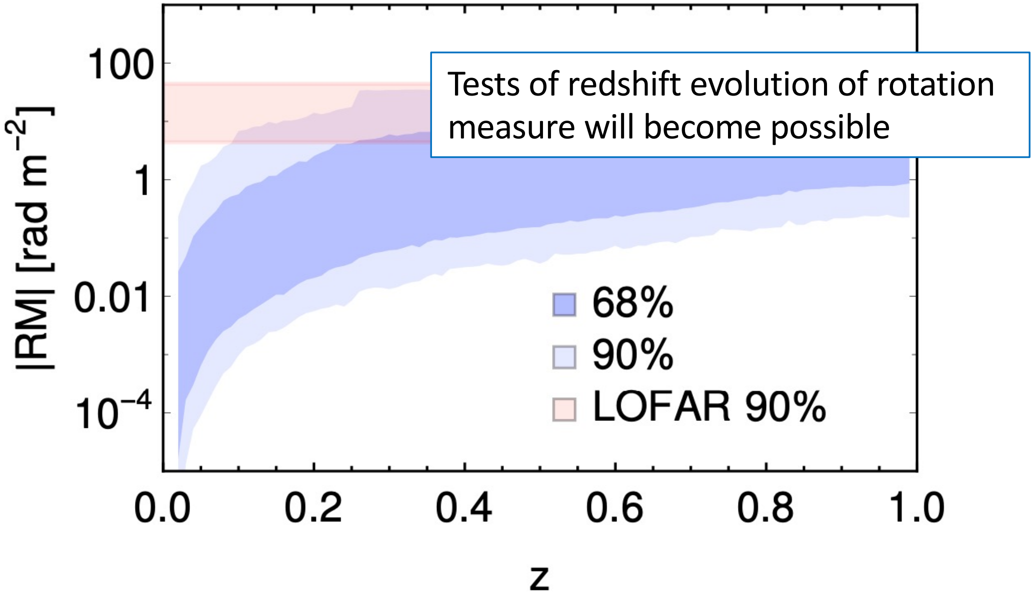

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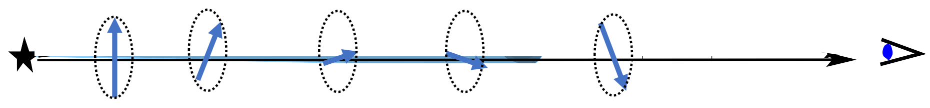
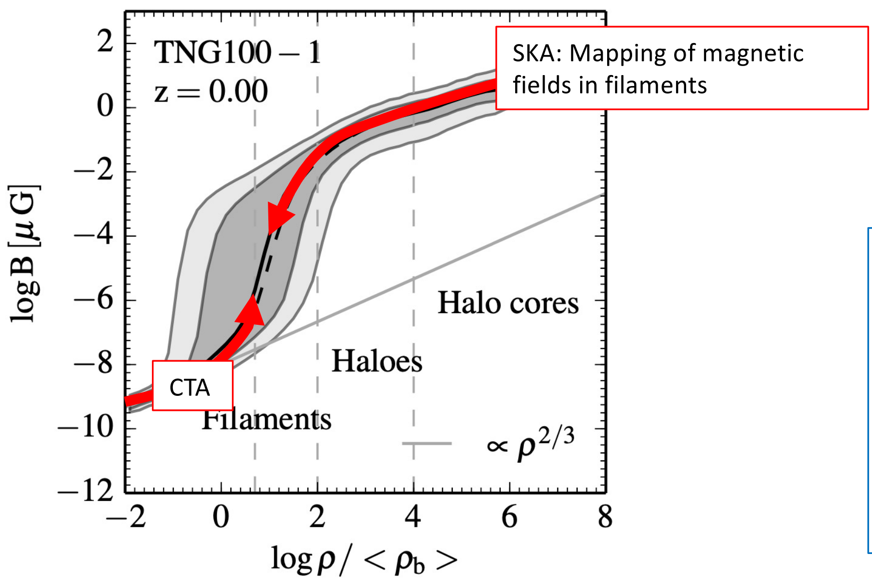
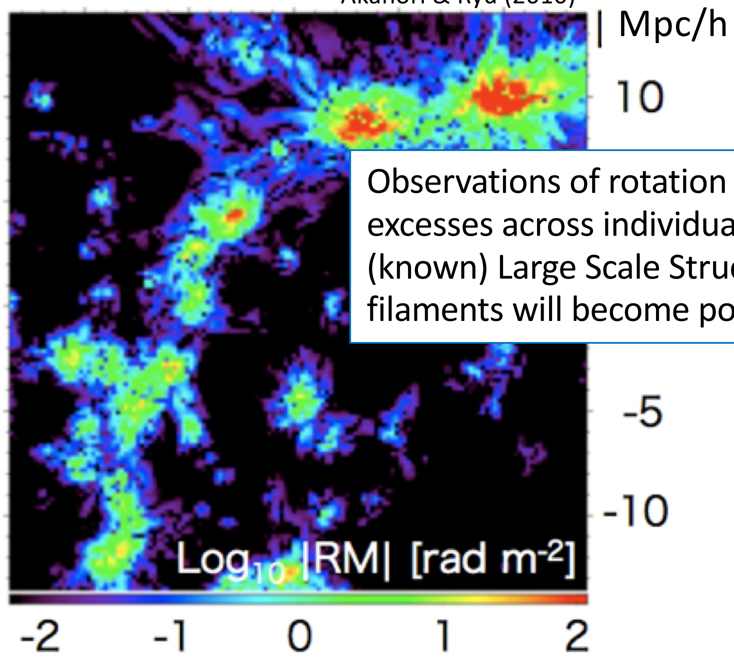




Akahori & Ryu (2010)



Observations of rotation measure excesses across individual nearby (known) Large Scale Structure filaments will become possible.

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SKA sensitivity reach: Galactic magnetic field foreground

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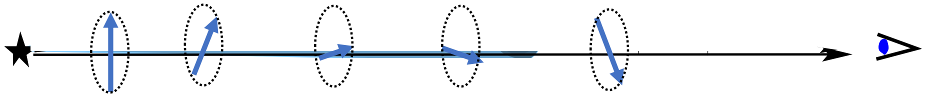
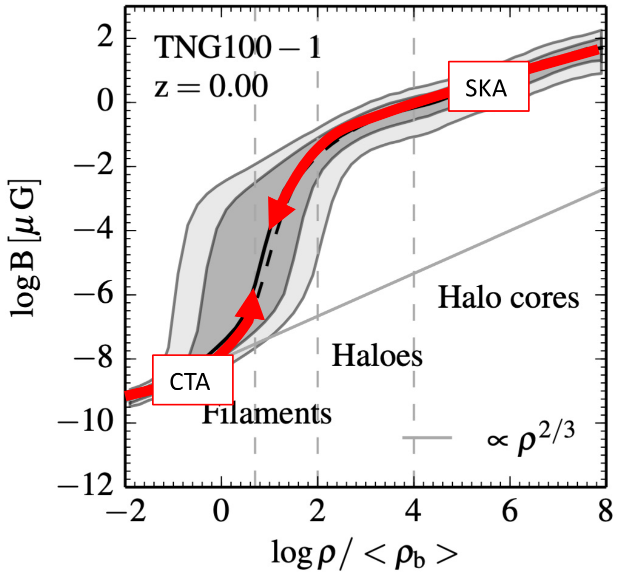
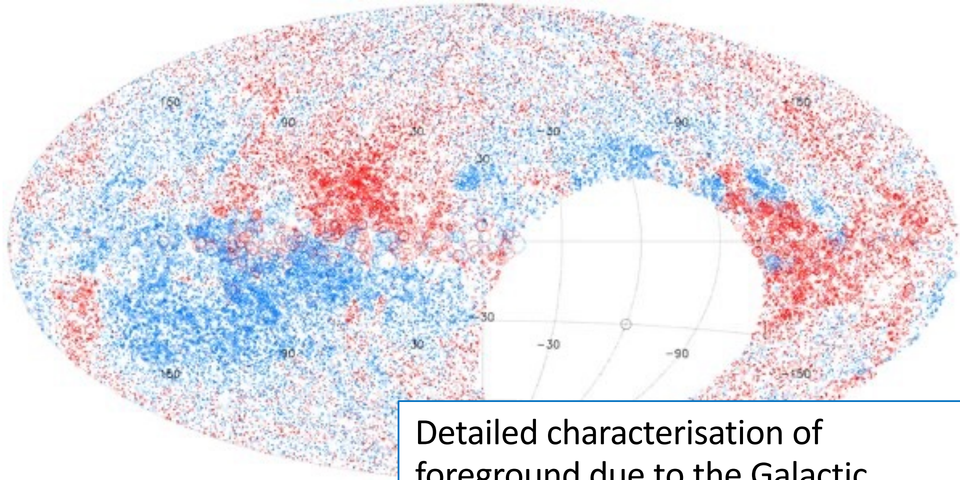
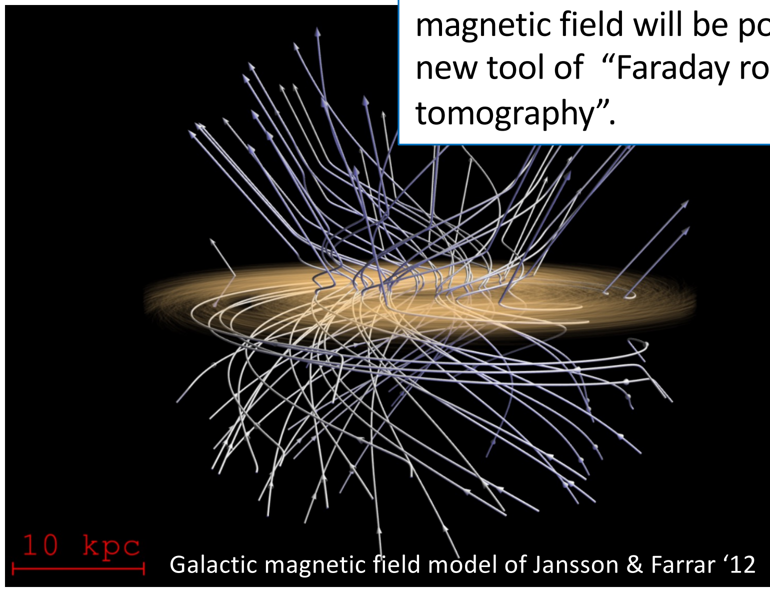




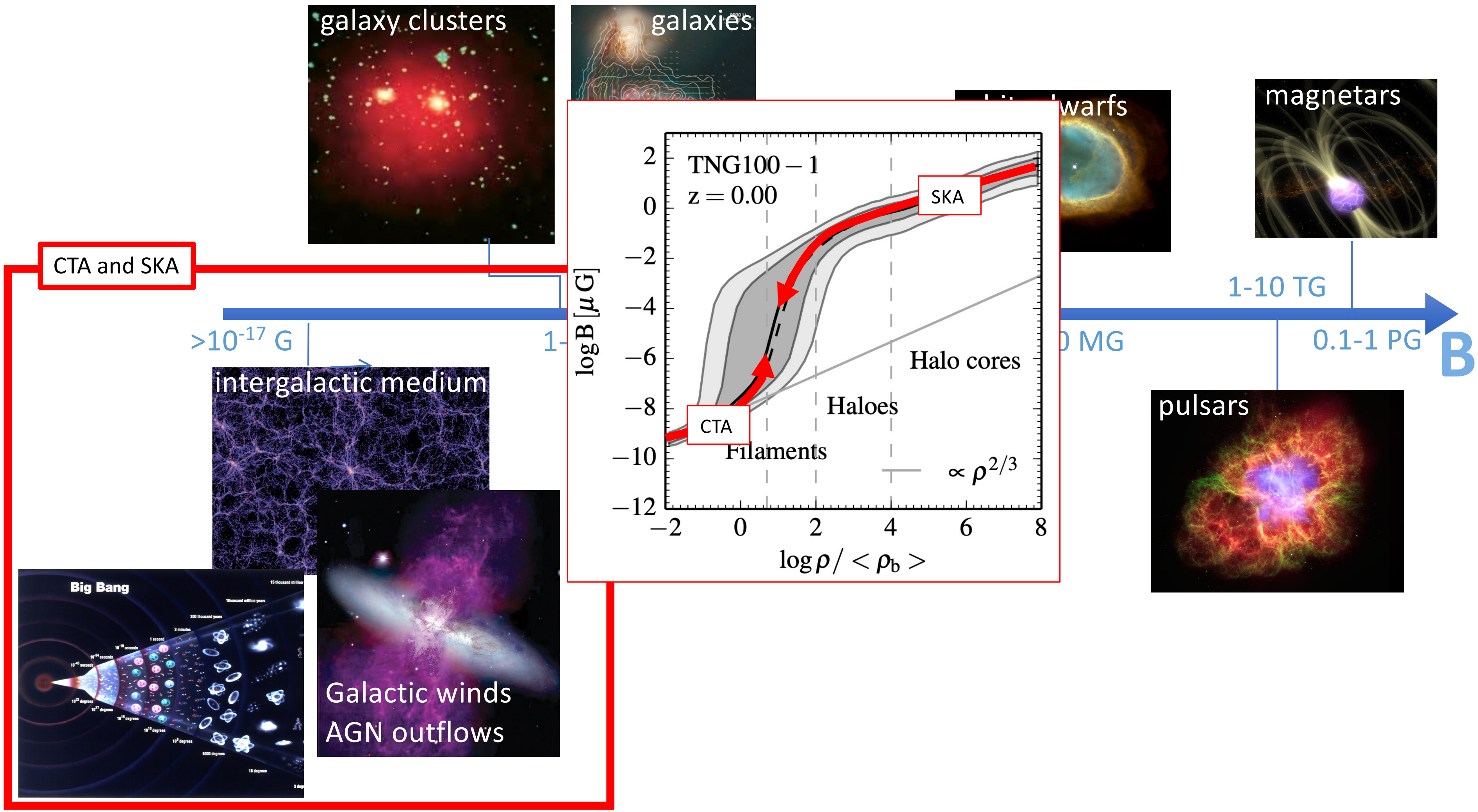


Detailed characterisation of foreground due to the Galactic magnetic field will be possible due to new tool of "Faraday rotation tomography".



Galactic magnetic field model of Jansson & Farrar '12

Summary



galaxy clusters
galaxies
magnetars
CTA and SKA
>10-17 G
1-10 TG
0.1-1 PG
B
intergalactic medium
pulsars
Big Bang
Galactic winds
AGN outflows
TNG100 – 1
z = 0.00
SKA
CTA
Halo cores
Haloes
Filaments
∝ ρ^2/3
log B [μG]
log ρ/ <ρ_b>