SKA AND
THE COSMOLOGICAL EVOLUTION
OF CLUSTER MAGNETIC FIELDS

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ELECTRON DENSITY

- Density of electrons well known:
  - Cosmological parameters, e.g. baryon fraction
  - Cosmological evolution / simulations
  - Observations, e.g. X-ray measurements

COSMOLOGICAL SIMULATION, CREDITS: DONGSU RYU
MAGNETIC FIELD

- Magnetic fields poorly known
- Observations (synchrotron, inverse Compton, Faraday rotation): few microgauss
- In voids: very small fields, produced in early universe, unknown
- In clusters: enhanced by turbulent dynamo to equipartition, problem: turbulent energy unknown

COSMOLOGICAL SIMULATION, CREDITS: DONGSU RYU

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REVISION – FARADAY ROTATION

- Measure magnetic fields through Faraday rotation of plane of polarisation of light from background source. Rotation dependent on wavelength - measure rotation in several channels.

- Only gives line integral - $B$ parallel to LOS.

- Requires electron density to be known (X-ray).

\[
RM = 812 \int n_e B_{LOS} dl \quad \text{Radians m}^{-2}
\]

\[
\Delta \theta = \frac{RM \times \lambda^2}{(1 + z)^2}
\]
FARADAY ROTATION: MEASUREMENT

☐ MEASURE RM AND NE

☐ INFER B

☐ CAVEAT: FIELD STRUCTURE/REVERSALS - LATER

COSMOLOGICAL SIMULATION, CREDITS: DONGSU RYU
OVERVIEW

☐ MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION

☐ CURRENT FARADAY ROTATION STUDIES

☐ THE FUTURE: TOWARDS THE SKA, SOURCE STATISTICS

☐ SYNERGIES: ELECTRON DENSITIES AT HIGH REDSHIFT
MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION

- **SEED FIELDS:**
  - **BIERMANN BATTERY:** \( \mathbf{E} = \nabla \times \mathbf{B} \)\( \Rightarrow \) \( \mathbf{E}_{\text{BIERM}} = -\frac{\nabla \rho}{\mathbf{E}} \times \mathbf{B} \)\( \Rightarrow \) INDUCTION SOURCE \( \Rightarrow \) \( B \) OF ORDER \( 10^{-20} \) GAUSS

- **THOMSON CROSS SECTION** \( \propto \frac{1}{m} \Rightarrow \) PHOTON/ \( e^-p \) SCATTERING
  ASSYMETRY/ RECOMBINATION ERA \( \Rightarrow \) \( 10^{-30} - 10^{-21} \) GAUSS

- **SEEDED IN STARS (SIM.: AGN) AND EJECTION** \( \Rightarrow \) \( < 10^{-9} \) GAUSS

- **VACUUM FLUCTUATIONS / INFLATION** \( \Rightarrow \) UP TO \( 10^{-9} \) GAUSS, NOW
MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION

- AMPLIFICATION

- HELICAL/MEAN FIELD DYNAMOS: GALAXIES

- RELEVANT IN CLUSTERS: TURBULENT DYNAMO - FIELD LINE STRETCHING $\Rightarrow B \propto L \Rightarrow L$ GROWS (RANDOM WALK) $\Rightarrow$ EXPONENTIAL GROWTH ON EDDY TURNOVER TIMESCALE, SATURATION AT EQUIPARTITION
CONCLUSION:

MAGNETIC FIELDS NEED A SPECIFIC SEED MECHANISM, DYNAMOES FOR AMPLIFICATION AND SUSTAINING

MF MEASUREMENTS PROMISE UNDERSTANDING OF:

- SEED MECHANISM
- AMPLIFICATION/CLUSTER DYNAMICS
- PLASMA PHYSICS/TRANSPORT COEFFICIENTS
MAGNETIC FIELDS: ORIGIN AND AMPLIFICATION

- How may we measure this?
- \( \text{DIV}(B) = 0 \)
- Ampl. early universe fields, coherent Mpc scales: \( <RM> \neq 0 \)
- Locally dynamo amplified fields, coherent on cluster scales: \( <RM^2> \neq 0 \)
CURRENT
FARADAY ROTATION STUDIES

A2255 - GOVONI ET AL.

☐ FEW SOURCES/CLUSTER

☐ <RM> = 0

☐ <RM^2> = 100 RAD/M^2

☐ KOLMOGOROV TURBULENCE?
THE FUTURE: TOWARDS THE SKA

- HOW MAY WE IMPROVE?

- NEED MORE INDEPENDENT SIGHTLINES

  >> MORE SOURCES: $\Delta <RM> \propto 1/\sqrt{N}$,

  CURRENTLY: $\Delta <RM> \sim 10\text{rad/m}^2$

- ALSO FOREGROUND SOURCES (GALACTIC CONTR.)

- HOW MUCH WILL WE IMPROVE? SIMULATIONS!

1. CLUSTERS AND RADIO SOURCES FROM COSMOLOGICAL CALCULATION (POPULATION OF DENSITY FIELD EVOLVED ACCORDING TO LINEAR THEORY)
**EXPECTED RM’S STATISTICS**

<table>
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<th>SKA full</th>
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<td>7</td>
<td>0.1</td>
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<td>field of view / deg</td>
<td>.6/f^2</td>
<td>200</td>
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- Still few BG sources
- First high z measurements

**Phase 1 SKA, 1h pointing**

**Radio sources / cluster**

**Clusters / pointing**

**Martin Krause: SKA and the Cosmological Evolution of Cluster Magnetic Fields**
**EXPECTED RM’S STATISTICS**

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- **Better than present day statistics at z > 1**
- **Good statistics, 1000s of clusters will have measured RMS**

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**Phase 1 SKA, 100h pointing**

- **Radio sources / cluster**

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**Martin Krause: SKA and the Cosmological Evolution of Cluster Magnetic Fields**

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**SKADS**
> 100 CLUSTERS WITH 100S OF BG SOURCES EVEN SOME AT Z > 1
Expected RM’s Statistics

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Some clusters will have RMS from > 10,000 sources

\[ \Delta <RM> \sim 0.1 \text{rad/m}^2 \]
SYNERGIES

- ESP. FOR HIGH REDSHIFT: ELECTRON DENSITIES
- SUNYAEV-ZELDOVICH EFFECT / HIGH FREQUENCY RADIO TELESCOPES
- THERMAL EMISSION / X-RAY
MARTIN KRAUSE: SKA AND THE COSMOLOGICAL EVOLUTION OF CLUSTER MAGNETIC FIELDS

CONCLUSIONS

- Magnetic fields in clusters of galaxies may have a component correlated on super-cluster scale, producing a small $<\langle R M \rangle > \neq 0$

- Overlaid is a turbulence related cluster scale field, producing $<\langle R M^2 \rangle > \neq 0$

- Today: $<\langle R M^2 \rangle > = 100 \text{rad/m}^2 > <\langle R M \rangle$, Kolmogorov?

- Full SKA: $>1000$ sources even at high $z$, impacting on:
  - Turbulence / Cluster Dynamics
  - Plasma Physics / Transport Coefficients
  - Large scale field detection possible