SKA1 Cosmic Magnetism Science

Russ Taylor

on behalf of

The SKA Cosmic Magnetism Working Group
Cosmic Magnetism SWG

Core Members

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James Green  Tyler Bourke

+ many associated members
involved in survey planning for CM precursor and pathfinder proj.
Cosmic Magnetism

One of the fundamental forces of Nature

Magnetism is central to astrophysics:

- pulsars and collapsed stellar objects
- Jovian planets
- cloud collapse & star formation
- stellar activity & outflows
- ISM turbulence
- stability of galactic disks
- acceleration, propagation & confinement of cosmic rays
- heat transport in galaxy clusters
- AGN and IGM feedback
## Session 6: Magnetism

### Using SKA Rotation Measures to Reveal the Mysteries of the Magnetised Universe
- **PoS(AASKA14)092**

### Studies of Relativistic Jets in Active Galactic Nuclei with SKA
- **PoS(AASKA14)093**

### Structure, dynamical impact and origin of magnetic fields in nearby galaxies in the SKA era
- **PoS(AASKA14)094**

### Unravelling the origin of large-scale magnetic fields in galaxy clusters and beyond through Faraday Rotation Measures with the SKA
- **PoS(AASKA14)095**

### Measuring magnetism in the Milky Way with the Square Kilometre Array
- **PoS(AASKA14)096**

### Filaments of the radio cosmic web: opportunities and challenges for SKA
- **PoS(AASKA14)097**
- Authors: F. Vazza, C. Ferrari, A. Bonafede, M. Brüggen, C. Gheller, R. Braun and S. Brown
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<td>Using Tailed Radio Galaxies to Probe the Environment and Magnetic Field of Galaxy Clusters in the SKA Era</td>
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<td>Mega-parsec scale magnetic fields in low density regions in the SKA era: filaments connecting galaxy clusters and groups</td>
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Origin and Evolution of cosmic magnetism

Core questions:

• Is there a magnetic counterpart to the large scale structure of the universe?
• What is the role magnetic fields in galaxy cluster formation and evolution
• How do magnetic fields emergence and grow in galaxies and what is their role in galaxy formation and evolution (star formation, AGN,...)?
• What is the structure of the Galactic magnetic field from sub-parsecc to kiloparsec scales, and its role in to Galactic ecosystem.
Radio Polarization probes magnetic fields

Polarization of Synchrotron Radiation

• presence of field
• direction of field
• strength of field
• spatial scales of field
Radio Polarization probes magnetic fields

Faraday Rotation

- Propagation through diffuse plasma

\[
\phi = \phi_o + RM \times \lambda^2
\]

\[
RM = 0.81 \int n_e \bar{B} \cdot d\bar{l} \quad \text{rad m}^{-1}
\]

Non-radiating foreground
Broadband Polarimetry: Internal Faraday Complexity

Farnes et al. 2014
Broadband Polarimetry: A Unique Physical Probe

Polarimetry of PKS B1610-771 (O'Sullivan et al. 2012)

Thermal gas entrained with lobes
Simple source constrained absorber
Turbulent foreground absorber
SKA1 Cosmic Magnetism Key Observations

1. All-sky high precision Rotation Measure grid
   • SKA-MID band 2, rms 2 μJy, resolution 2”

2. Deep polarization field and grid high-z magnetic universe
   • 10 sq deg. SKA-MID band 2, rms 0.1 μJy, resolution 0.5” – 1”
   • 3 sq deg. SKA-MID Band 3, rms 0.1 μJy, resolution 0.5” – 1”

3. High brightness sensitivity imaging between galaxy clusters
   • SKA1-MID band 1, rms 0.2 μJy, resolution 5”
   • SKA-LOW, rms 10 μJy, resolution 5”

4. Targeted imaging of nearby galaxies and AGN
   • SKA-MID Band 5 and/or Band 4, 0.2 μJy, 1”
   • SKA-MID band 4, VLBI mode
The All-Sky Precision Polarimetry Rotation Measure Grid

RM = RM_{object} + RM_{IGM} + RM_{MW}

Johnston-Hollitt et al. (2004)
\sim 1000 extragalactic RM

Oppermann et al. (2012)
\sim 40,000 extragalactic RM
\Delta RM \sim 10 \text{ rad m}^{-1}

SKA 1 (2023)
\sim 7 - 14 million extragalactic RM
\Delta RM \sim 1 \text{ rad m}^{-1}

Foreground/Background problem
Initial KSP Concepts from CM SWG

1. Line of sight probes of Evolution of Cosmic Magnetism
2. The Magnetic cosmic web
3. Broad-band polarimetry as a probe of AGN and Galaxy Physics
4. Magnetic fields in AGN at all redshifts and luminosities
5. The magnetic field in the clusters and filaments
6. Magnetic field in nearby galaxies
7. Magnetic fields in the heart of the Milky Way
8. Multi-scale magnetism in the Milky Way
9. Emergence and Evolution of magnetic fields in galaxy disks.
10. Imaging of Diffuse Polarization Features in the Milky Way
11. Probing the nature of Dark Matter
Magnetic Cosmic Web

- Can it be detected?
- How did it arise?
- What are its properties and relation to the large scale structure of matter?

Simulated RM map of the cosmic web (Akahori, Ryu 2010;2011)
Magnetic Cosmic Web

RM with 1 rad m\(^{-1}\) precision with average separation of 1 arcminute

VLA Data – Taylor et al. 2015, Simulations courtesy of J. Stil.

2\(^{nd}\) order structure function of RM toward Galactic poles (Mao et al. 2010; Stil et al. 2011; Akahori et al. 2013; 2014)
Formation and Evolution of Clusters

• Assembly, merger, accretion and relation to large scale structure

• AGN outflows and dynamics of the intracluster medium

• Origin of cluster fields, seeds, amplification and relation to cluster assembly


van Weeren et al. (2010)
RM Profiles and Cluster Evolution

Post Major Merger | Merging | Relaxed

SKA1 Simulations Vazza et al. (2010)
Emission from Magnetic Cosmic Web?

1.4 GHz (contours) on x-ray

Planck S-Z emission

Murgia et al. 2010
Line of sight probes of Evolution of Fields

Cumulative distribution of RM versus Number of absorbers
Farnes et al 2014

SKA1 will provide 4 million sources with intervening MgII and Faraday rotation.

$1.8 \pm 0.4 \, \mu G$
@ $z \sim 0.87$

$n = 599$
Magnetism and Galaxy Evolution

Effelsberg imaging of integrated polarization reveals presence of global fields in disk galaxies (Stil et al. 2009)

SKA1 Deep fields will detect thousands of galaxies in polarization out to redshifts beyond 4.
Dynamos and magnetic field structure

Large-scale dynamo in the disk and turbulent dynamo in the spiral arms

Power spectrum of dynamo-generated magnetic fields (Moss et al. 2013)
Magnetic Fields in the Milky Way

Arecibo: 4.5’ GALFACTS (Taylor and Salter 2010 ) SKA -> several arc seconds.

Drapery image courtesy of J. Fairnes.
Key SKA1 observations for cosmic magnetism

- SKA-MID “all-sky” survey for Rotation Measure grid and high precision Faraday synthesis (2 μJy, 2”)
  - AGN environments over cosmic history
  - Cluster formation and evolution
  - Galactic magnetic field via high spatial density RM synthesis map
  - Detection of large scale magnetic web
  - Cosmic Evolution of magnetic fields in galaxies via intervenors

- SKA-MID broad-band deep surveys (several 10’s of degrees, <0.1 μJy, 0.5”)
  - Emergence and evolution of magnetic fields in galaxy disks
  - Cosmic web and primordial magnetic fields
  - AGN over all redshift and luminosity

- SKA-MID, SKA-LOW high surface brightness sensitivity imaging with spatial dynamic range up to several 10s of arc-minute scales
  - Cluster evolution via relics and haloes
  - Emission from the cosmic web
  - Magnetized ISM of the Milky Way and foreground emission
  - Dark matter annihilations
Cosmic Magnetism SWG Next Steps

- Further elaboration of Key Science Project concepts and CM Key Survey Observations
- Commensality and Scientific Overlap (magnetism is not a universe of its own)
  - Continuum, Pulsars, Milky Way, HI (Ω), VLBI, EOR,…
- Evolve use cases
- Role of pathfinder and precursor projects
- Technical challenges and solutions
- Organization, teams, data plans and resource implication, relationship to the SKA Observatory
- SWG and Pathway to KSP proposals