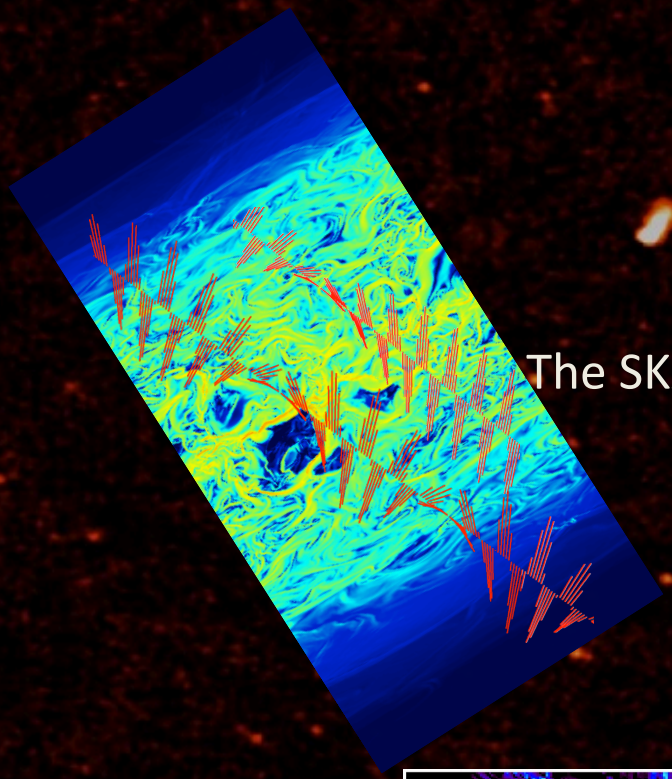
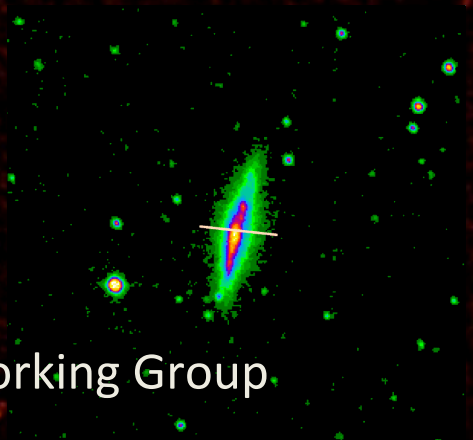
SKA1 Cosmic Magnetism Science

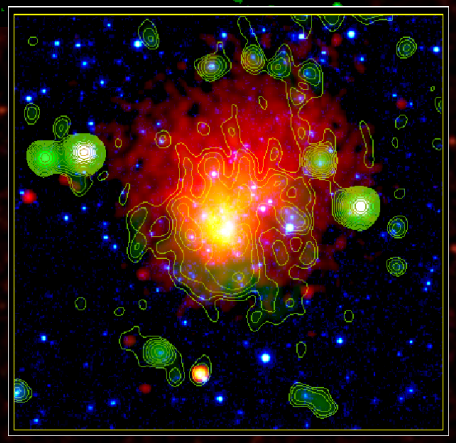


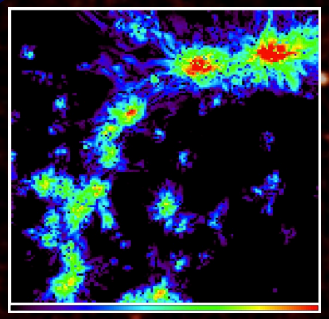
Russ Taylor

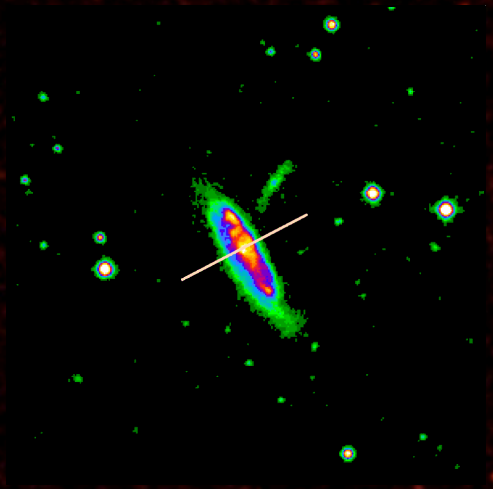
on behalf of

The SKA Cosmic Magnetism Working Group









Cosmic Magnetism SWG
Core Members

Melanie Johnston-Hollitt (co-chair)
Federica Govoni
Takuya Akahori
Annalisa Bonafede
Bryan Gaensler
George Heald
Tim Robishaw
Anna Scaife
Joeren Still
James Green

Russ Taylor (co-chair)
Ivan Agudo
Rainer Beck
Luigina Feretti
Marijke Haverkorn
Sui Ann Mao
Larry Rudnick
Dominic Schnitzeler
Xiaohui Sun
Tyler Bourke

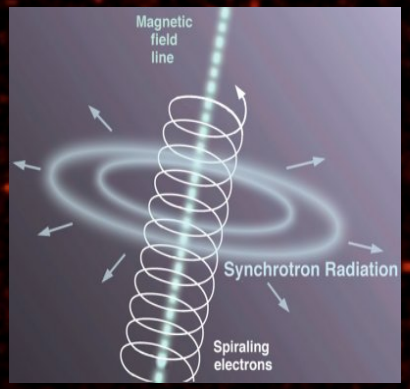
+ many associated members
involved in survey planning for CM precursor and pathfinder pr

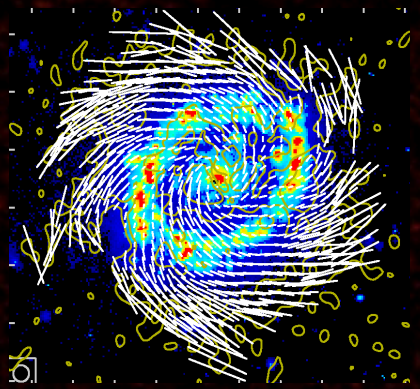
Cosmic Magnetism

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





PROCEEDINGS OF SCIENCE

Advancing Astrophysics with the Square Kilometre Array

19 papers out of 135

9 -13 June, 2014
Giardini Naxos, Italy

Session 6: Magnetism

Using SKA Rotation Measures to Reveal the Mysteries of the Magnetised Universe
PoS(AASKA14)092 pdf *M. Johnston-Hollitt, F. Govoni, R. Beck, S. Dehghan, L. Pratley, T. Akahori, G. Heald, I. Agudo, A. Bonafede, E. Carretti, T. Clarke, S. Colafrancesco, T.A. Ensslin, L. Feretti, B. Gaensler, M. Haverkorn, S.A. Mao, N. Oppermann, L. Rudnick, A. Scaife, D. Schnitzeler, J. Stil, A.R. Taylor and V. Vacca*

Studies of Relativistic Jets in Active Galactic Nuclei with SKA
PoS(AASKA14)093 pdf *I. Agudo, M. Boettcher, H.D.E. Falcke, M. Georganopoulos, G. Ghisellini, G. Giovannini, M. Giroletti, L. Gurvits, J.L. Gómez, R Laing, M. Lister, J.M. Martí, E. Meyer, Y. Mizuno, S. O'Sullivan, P. Padovani, Z. Paragi, M. Perucho, D. Schleicher, L. Stawarz, N. Vlahakis and J. Wardle*

Structure, dynamical impact and origin of magnetic fields in nearby galaxies in the SKA era
PoS(AASKA14)094 pdf *R. Beck, D. Bomans, S. Colafrancesco, R.J. Dettmar, K. Ferrière, A. Fletcher, G. Heald, V. Heesen, C. Horellou, M. Krause, Y. Lou, S.A. Mao, R. Paladino, E. Schinnerer, D. Sokoloff, J. Stil and F. Tabatabaei*

Unravelling the origin of large-scale magnetic fields in galaxy clusters and beyond through Faraday Rotation Measures with the SKA
PoS(AASKA14)095 pdf *A. Bonafede, F. Vazza, M. Brüggen, T. Akahori, E. Carretti, S. Colafrancesco, L. Feretti, C. Ferrari, G. Giovannini, F. Govoni, M Johnston-Hollitt, M. Murgia, A. Scaife, V. Vacca, F. Govoni, L. Rudnick and A. Scaife*

Measuring magnetism in the Milky Way with the Square Kilometre Array
PoS(AASKA14)096 pdf *M. Haverkorn, T. Akahori, E. Carretti, K. Ferrière, P. Frick, B. Gaensler, G. Heald, M. Johnston-Hollitt, D. Jones, T. Landecker, S.A. Mao, A. Noutsos, N. Oppermann, W. Reich, T. Robishaw, A. Scaife, D. Schnitzeler, R. Stepanov, X. Sun and R. Taylor*

Filaments of the radio cosmic web: opportunities and challenges for SKA
PoS(AASKA14)097 pdf *F. Vazza, C. Ferrari, A. Bonafede, M. Brüggen, C. Gheller, R. Braun and S. Brown*

Probing the nature of Dark Matter with the SKA
PoS(AASKA14)100 pdf *S. Colafrancesco, M. Regis, P. Marchegiani, G. Beck, R. Beck, H. Zechlin, A. Lobanov and D. Horns*

Using Tailed Radio Galaxies to Probe the Environment and Magnetic Field of Galaxy Clusters in the SKA Era
PoS(AASKA14)101 pdf *M. Johnston-Hollitt, S. Dehghan and L. Pratley*

SKA studies of in situ synchrotron radiation from molecular clouds
PoS(AASKA14)102 pdf *C. Dickinson, R. Beck, R. Crocker, R.M Crutcher, R.D. Davies, K. Ferrière, G. Fuller, T.R. Jaffe, D. Jones, P. Leahy, E. Murphy, M.W Peel, E. Orlando, T. Porter, R.J Protheroe, A. Strong, T. Robishaw, R.A. Watson and F. Yusef-Zadeh*

Broadband Polarimetry with the Square Kilometre Array: A Unique Astrophysical Probe
PoS(AASKA14)103 pdf *B. Gaensler, I. Agudo, T. Akahori, J. Banfield, R. Beck, E. Carretti, J. Farnes, M. Haverkorn, G. Heald, D. Jones, T. Landecker, S.A. Mao, R. Norris, S. O'Sullivan, L. Rudnick, D. Schnitzeler, N. Seymour and X. Sun*

Mega-parsec scale magnetic fields in low density regions in the SKA era: filaments connecting galaxy clusters and groups
PoS(AASKA14)104 pdf *G. Giovannini, A. Bonafede, S. Brown, L. Feretti, C. Ferrari, M. Gitti, F. Govoni, M. Murgia and V. Vacca*

Cluster magnetic fields through the study of polarized radio halos in the SKA era
PoS(AASKA14)105 pdf *F. Govoni, M. Murgia, H. Xu, H. Li, M. Norman, L. Feretti, G. Giovannini, V. Vacca, G. Bernardi, A. Bonafede, G. Brunetti, E. Carretti, S. Colafrancesco, J. Donnert, C. Ferrari, M. Gitti, L. Iapichino, M. Johnston-Hollitt, R. Pizzo and L. Rudnick*

Magnetic Field Tomography in Nearby Galaxies with the Square Kilometre Array
PoS(AASKA14)106 pdf *G. Heald, R. Beck, W.J.G. de Blok, R.J. Dettmar, A. Fletcher, B. Gaensler, M. Haverkorn, V. Heesen, C. Horellou, M. Krause, S.A. Mao, N. Oppermann, A. Scaife, D. Sokoloff, J. Stil, F. Tabatabaei, K. Takahashi, A.R. Taylor and A. Williams*

Kinematics and Dynamics of kiloparsec-scale Jets in Radio Galaxies with SKA
PoS(AASKA14)107 pdf *R. Laing*

Giant radio galaxies as probes of the ambient WHIM in the era of the SKA
PoS(AASKA14)109 pdf *B. Peng, R.R. Chen and R. Strom*

Measuring Magnetic Fields Near and Far with the SKA via the Zeeman Effect
PoS(AASKA14)110 pdf *T. Robishaw, J. Green, G. Surcis, W.H.T. Vlemmings, A.M.S. Richards, S. Etoka, T.L Bourke, V. Fish, M.D Gray, H. Imai, B. Kramer, J. McBride, E. Momjian, A.P. Sarma and A.A Zijlstra*

Stacking for Cosmic Magnetism with SKA Surveys
PoS(AASKA14)112 pdf *J. Stil and B. Keller*

SKA Deep Polarization and Cosmic Magnetism
PoS(AASKA14)113 pdf *R. Taylor, I. Agudo, T. Akahori, R. Beck, B. Gaensler, G. Heald, M. Johnston-Hollitt, M. Langer, L. Rudnick, A. Scaife, D. Schleicher, J. Stil and D. Ryu*

Statistical methods for the analysis of rotation measure grids in large scale structures in the SKA era
PoS(AASKA14)114 pdf *V. Vacca, N. Oppermann, T.A. Ensslin, M. Selig, H. Junklewitz, M. Greiner, J. Jasche, C.A Hales, M. Reneicke, E. Carretti, L. Feretti, C. Ferrari, G. Giovannini, F. Govoni, C. Horellou, S. Ideguchi, M. Johnston-Hollitt, M. Murgia, R. Paladino, R. Pizzo and A. Scaife*

Origin and Evolution of cosmic magnetism

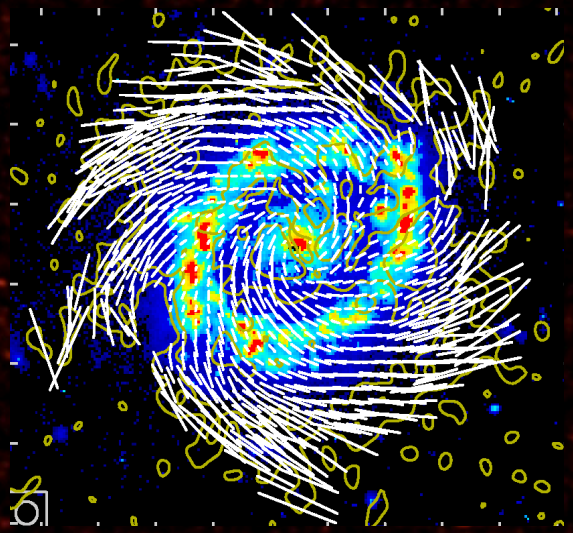
Core questions:

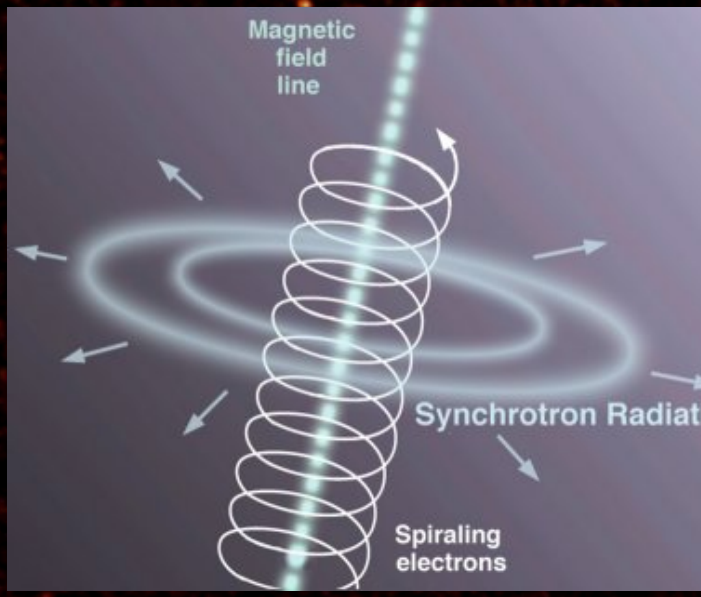
- Is there a magnetic counterpart to the large scale structure of the universe?
- What is the role magnetic fields in galaxy cluster formation and evolution
- How do magnetic fields emergence and grow in galaxies and what is their role in galaxy formation and evolution (star formation, AGN,…)?
- What is the structure of the Galactic magnetic field from sub-parsec to kiloparses 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

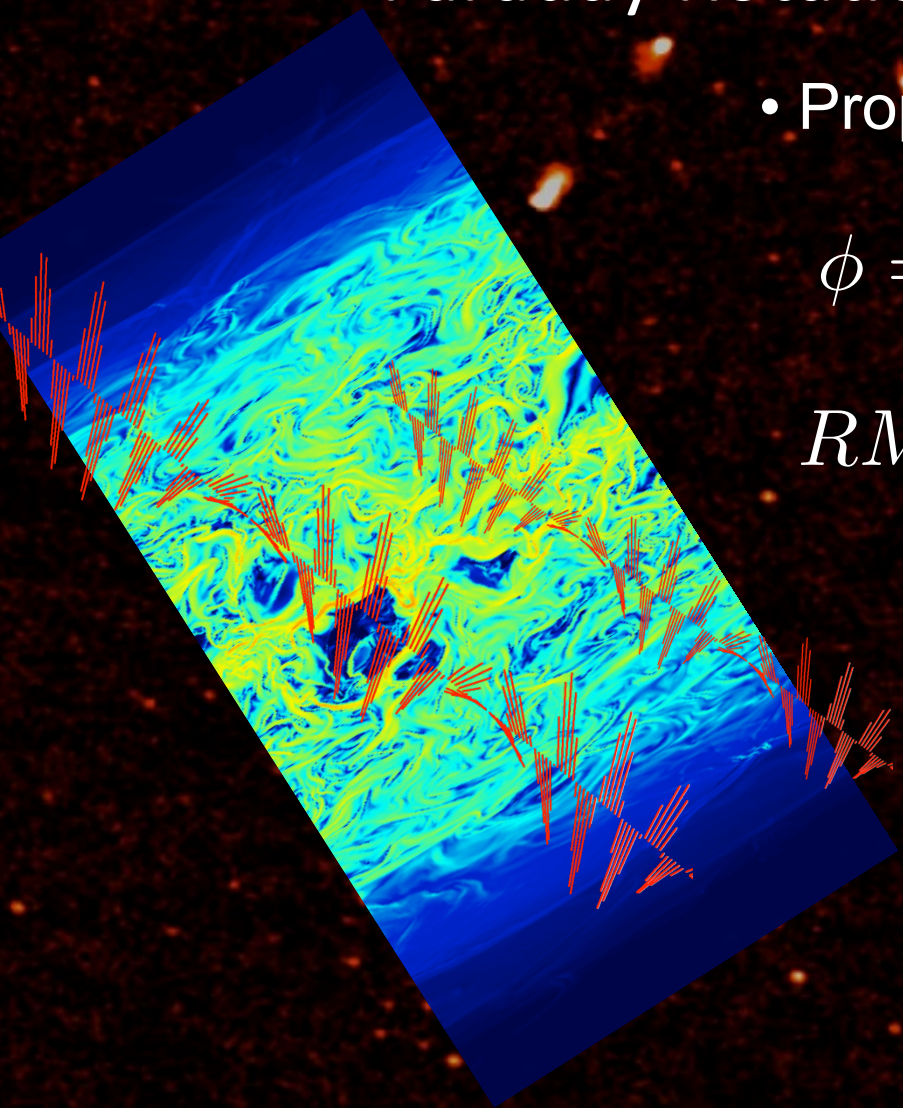




AstronomyOnline.org

Radio Polarization probes magnetic fields

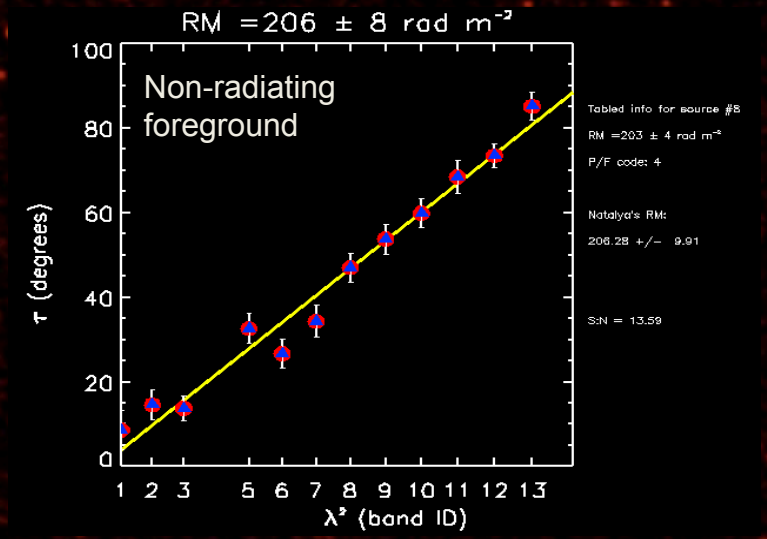
Faraday Rotation



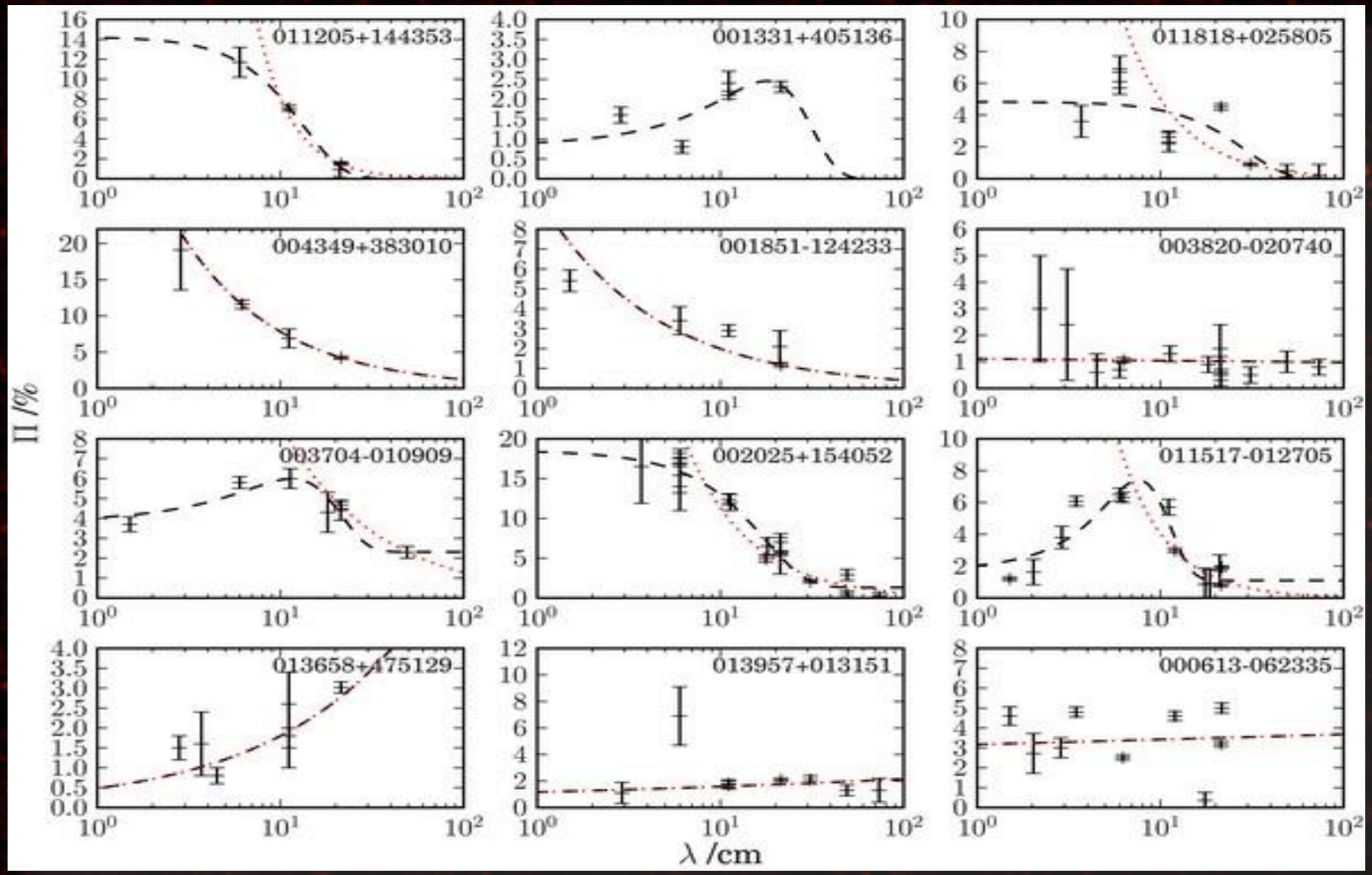
- Propagation through diffuse plasma

$$\phi = \phi_o + RM \times \lambda^2$$

$$RM = 0.81 \int n_e \bar{B} \cdot \overline{dl} \quad \mathrm{rad\,m^{-1}}$$

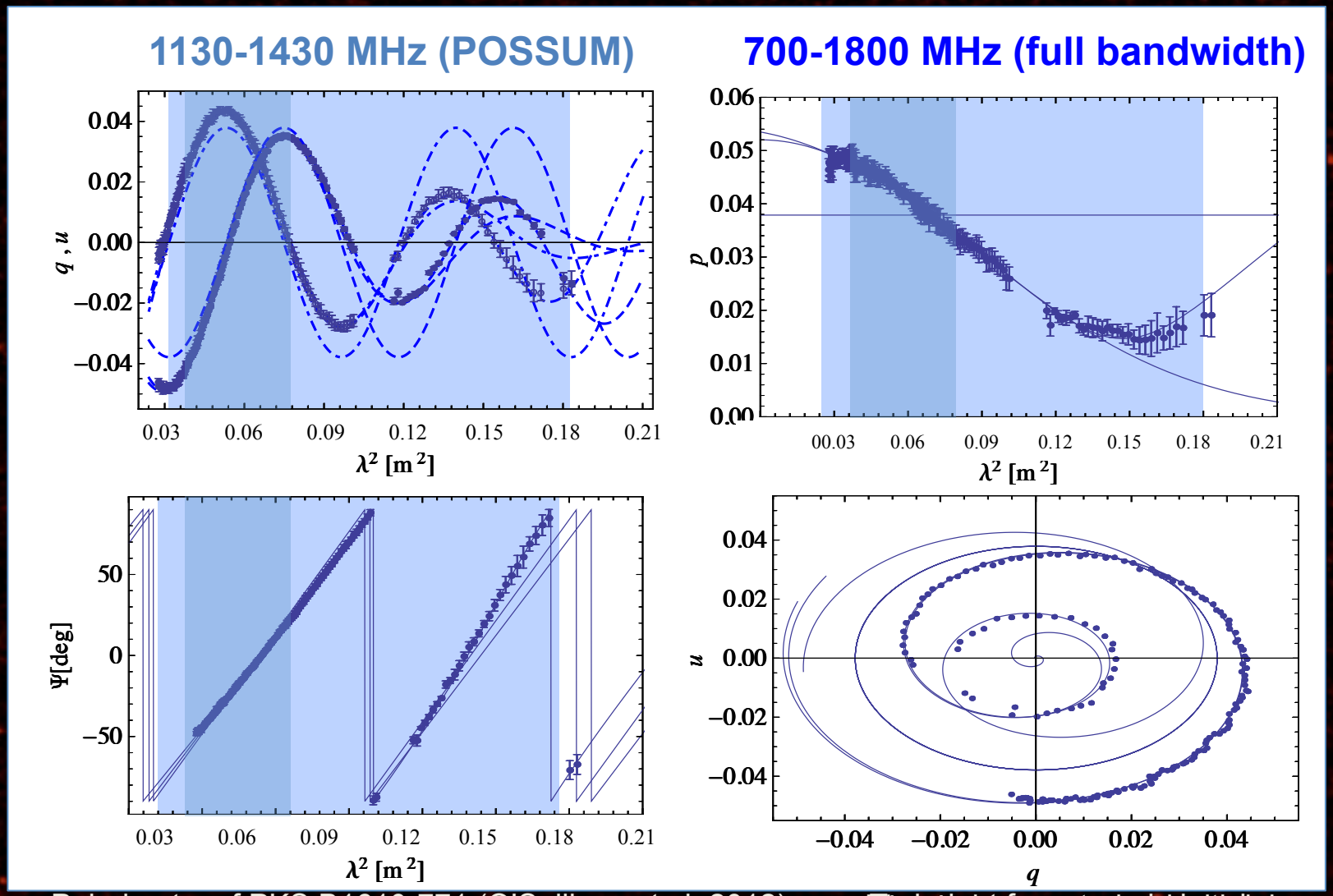


Broadband Polarimetry: Internal Faraday Complexity



Farnes et al. 2014

Broadband Polarimetry: A Unique Physical Probe



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

: Simple sources can be contained within beams

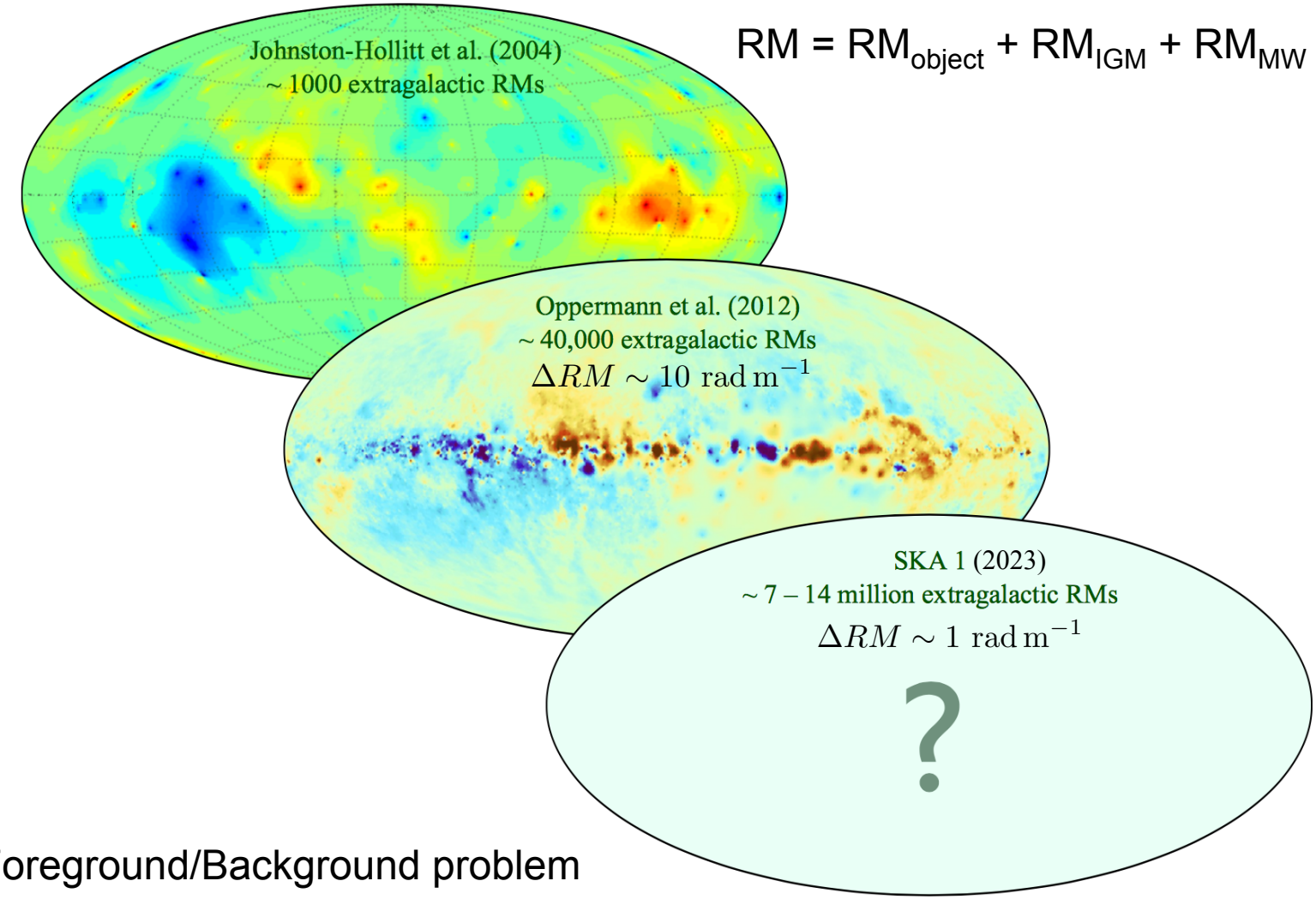
: The least fore-contained sources

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

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



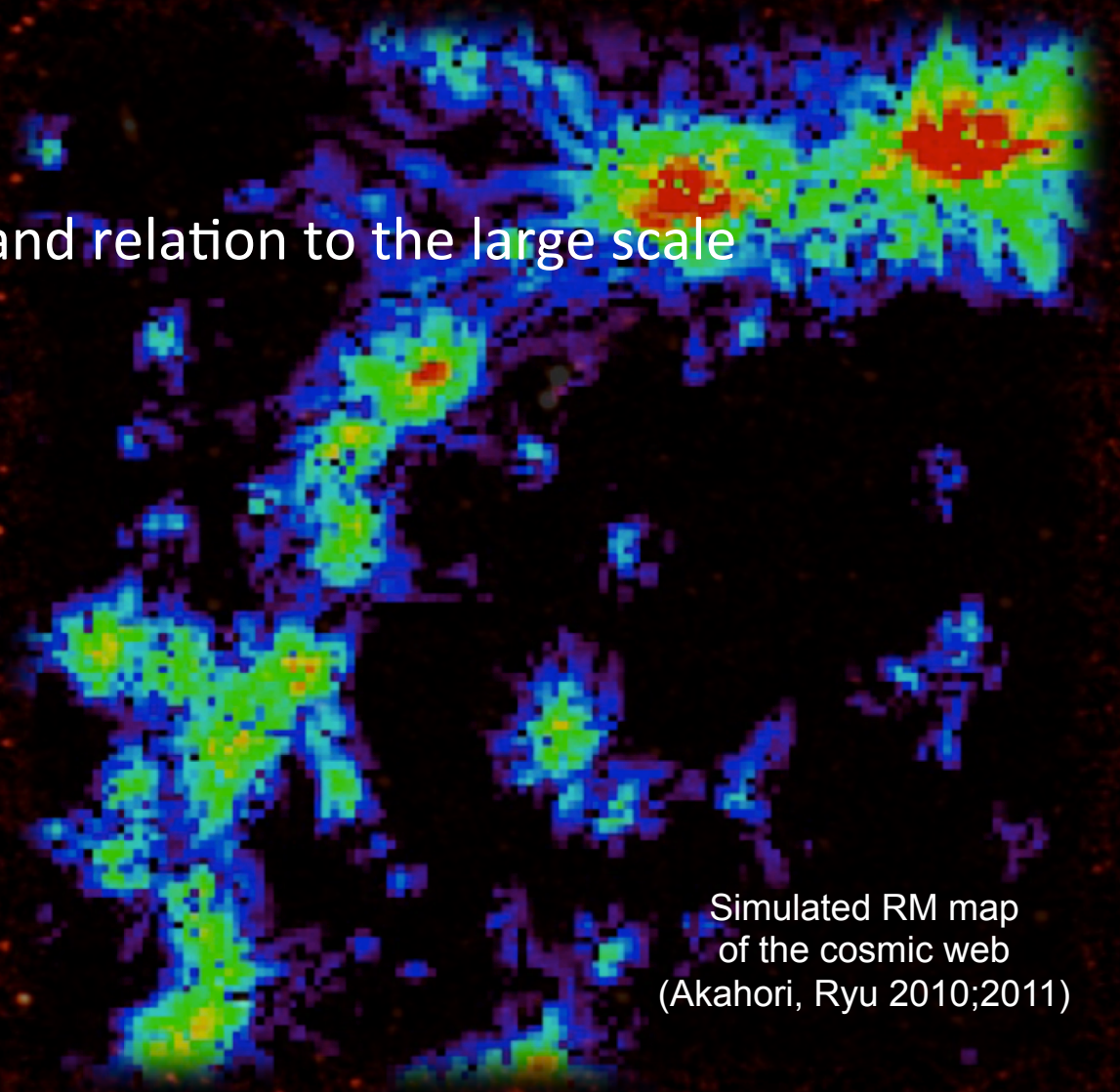
Foreground/Background problem

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 Phys
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

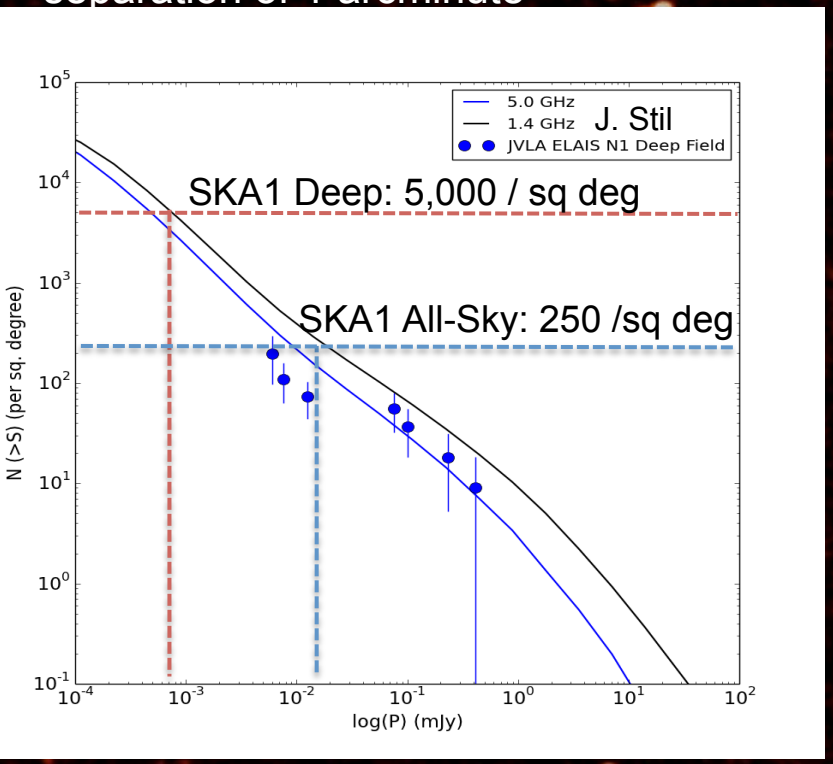
- Can it be detected?
- How did it arise?
- What are its properties and relation to the large scale structure of matter?



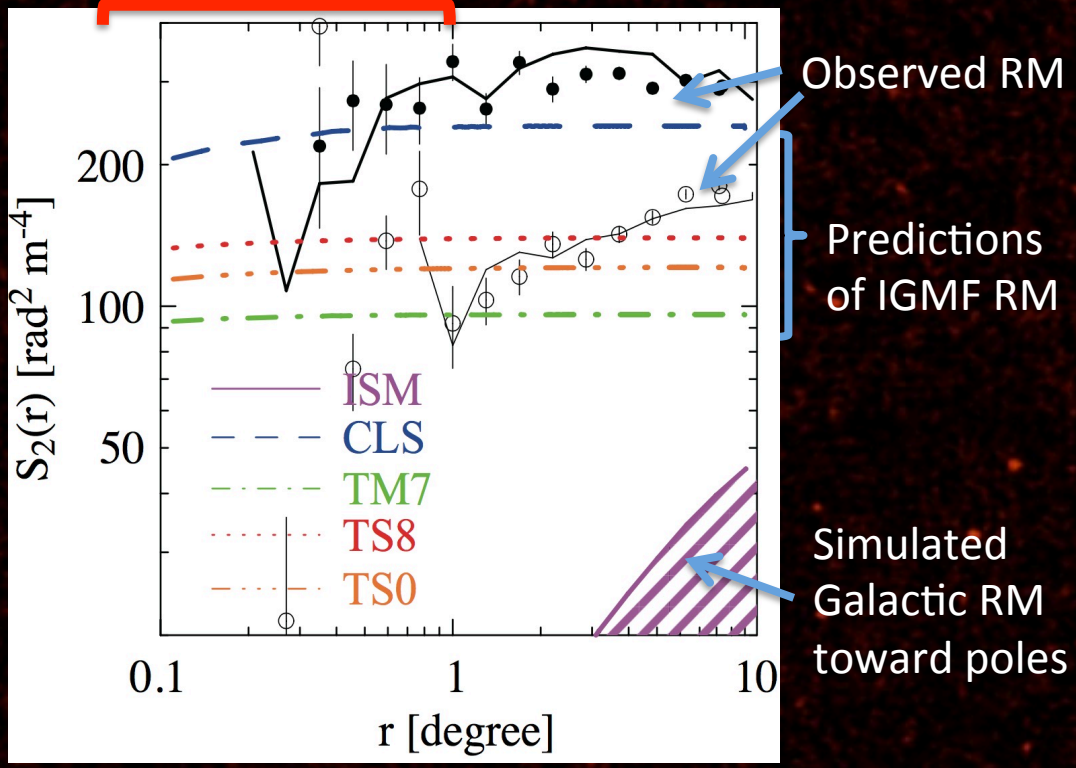
Simulated RM map of the cosmic web (Akahori, Ryu 2010;2011)

Magnetic Cosmic Web

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



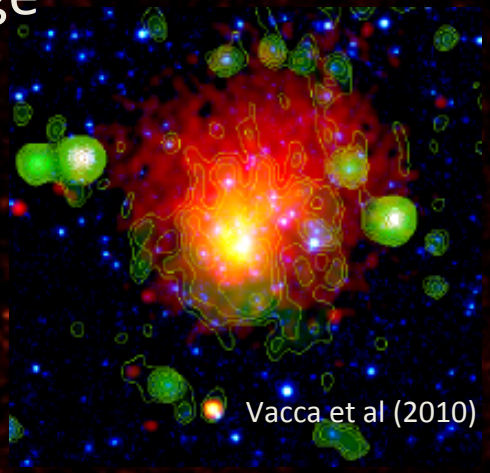
VLA Data – Taylor et al. 2015,
Simulations courtesy of J. Stil.



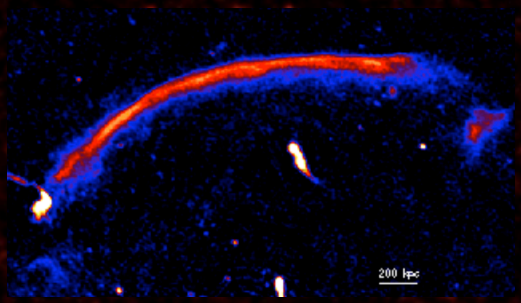
2nd order structure function of RM toward Galactic poles
(Mao et al. 2010; Stil et al. 2011; Akahori et al. 2013; 2014)

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



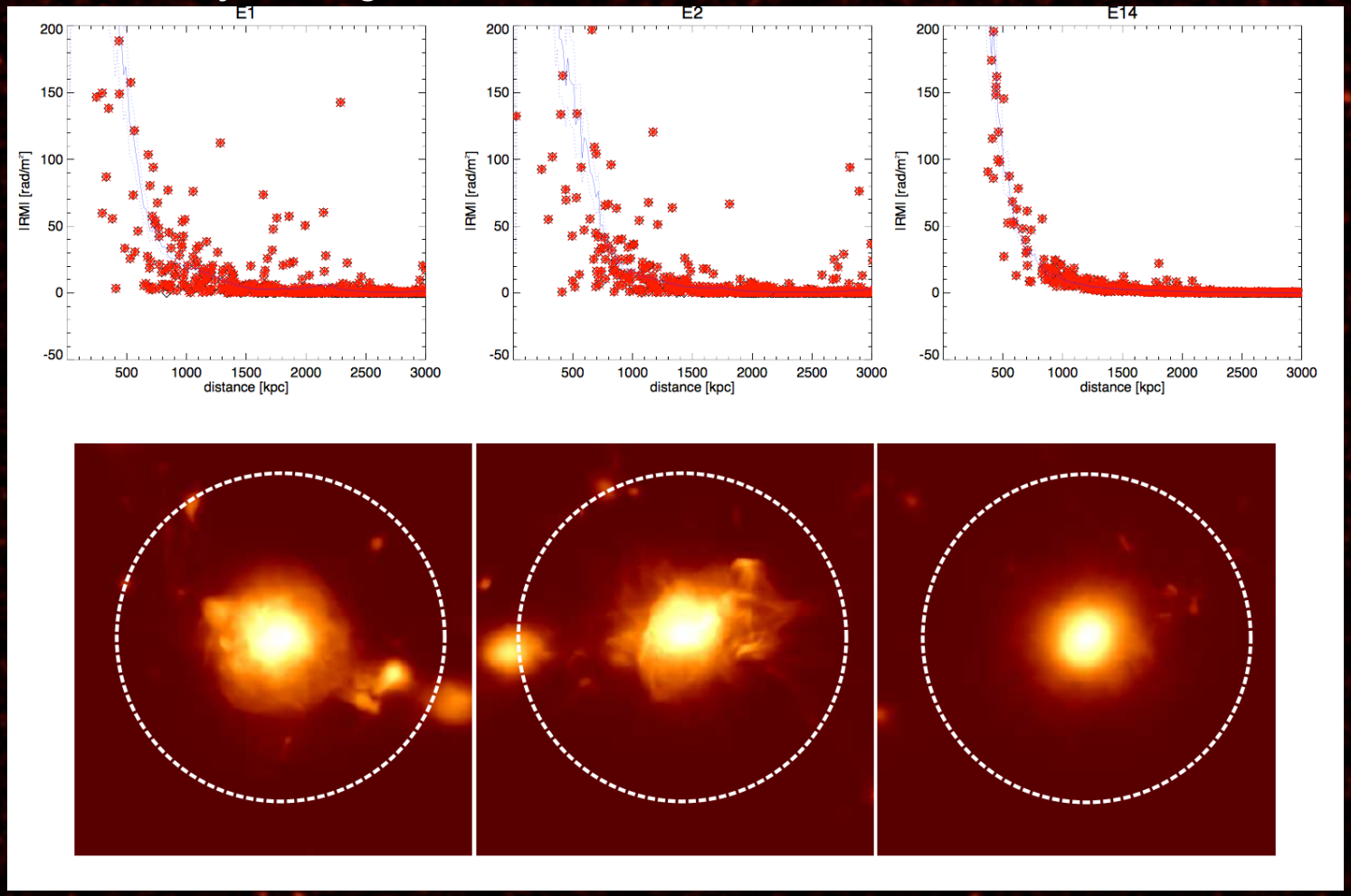
Vacca et al (2010)



van Weeren et al. (2010)

RM Profiles and Cluster Evolution

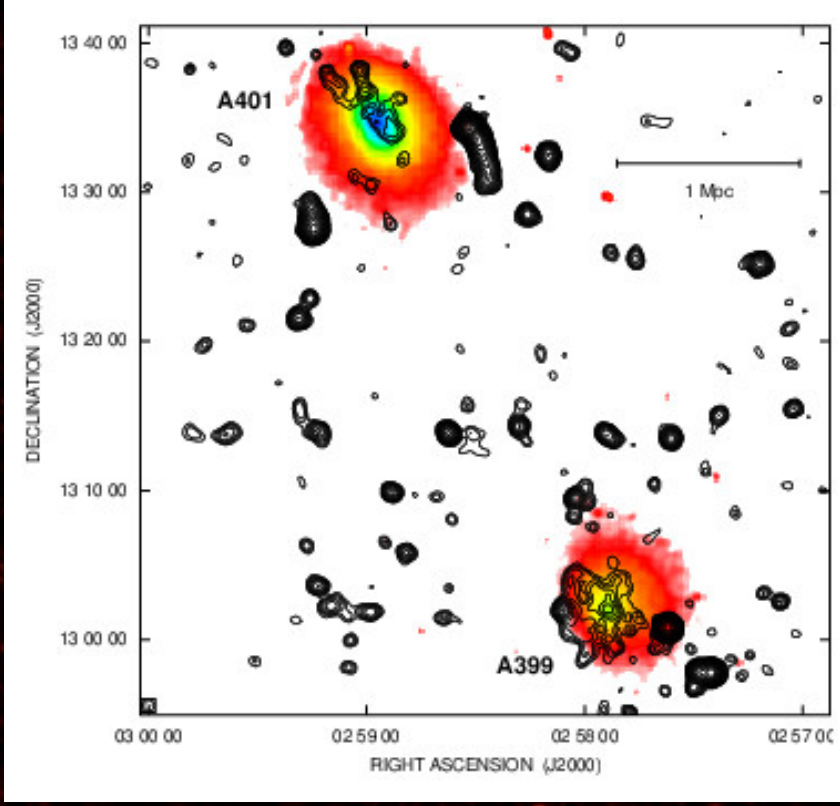
Post Major Merger | Merging | Relaxed



SKA1 Simulations Vazza et al. (2010)

Emission from Magnetic Cosmic Web?

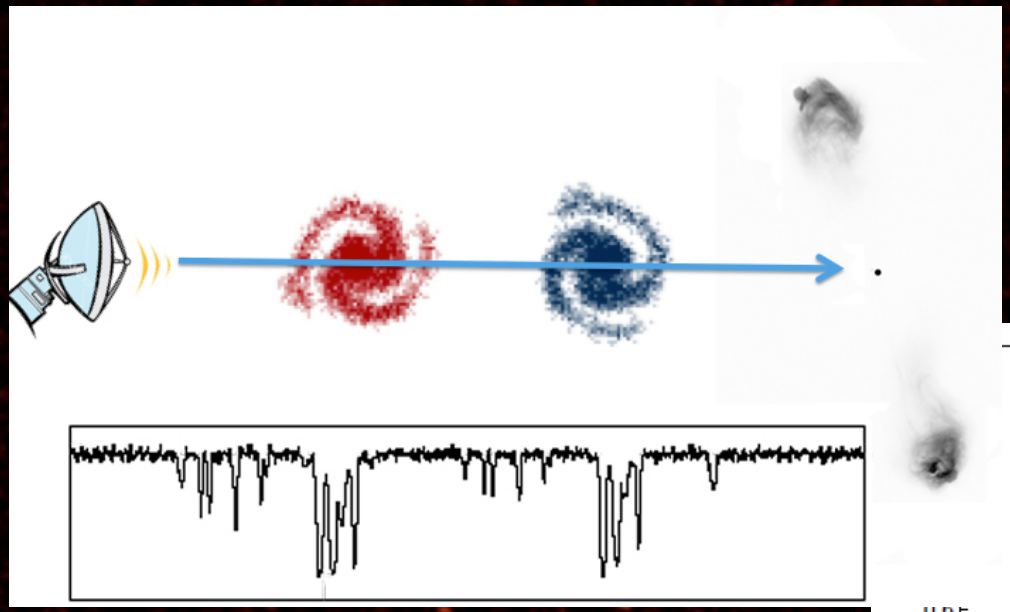
1.4 GHz (contours) on x-ray



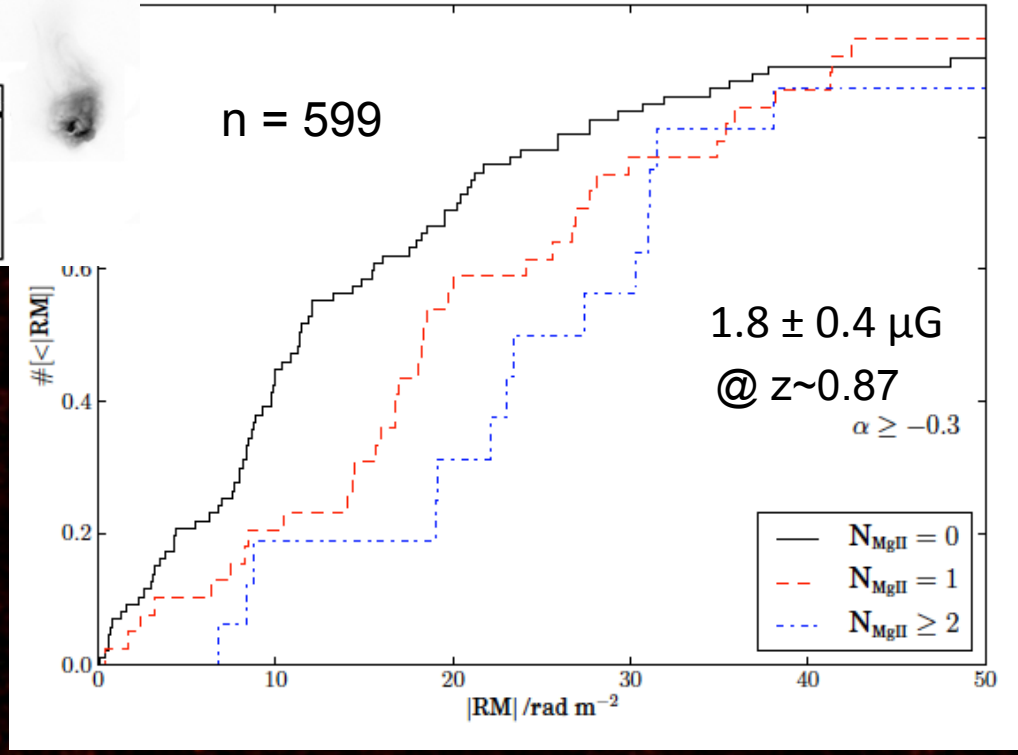
Planck S-Z emission

Murgia et al. 2010

Line of sight probes of Evolution of Fields



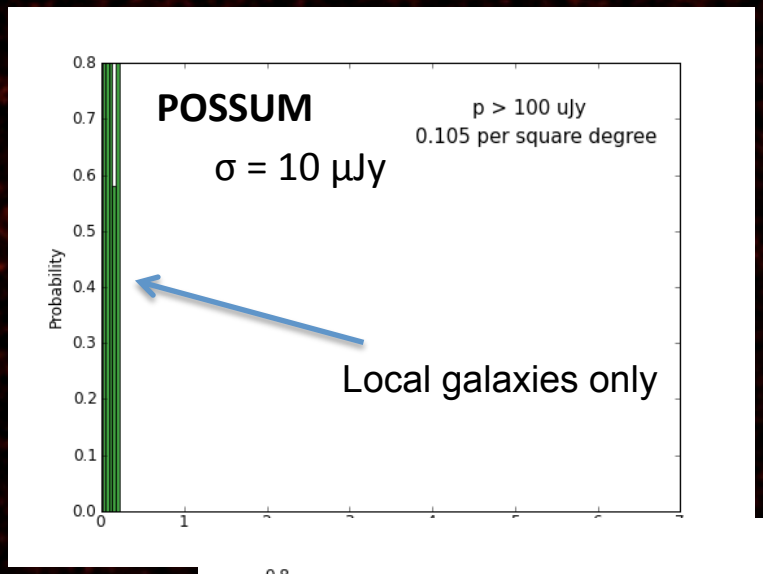
Cumulative distribution of RM versus Number of absorbers
Farnes et al 2014

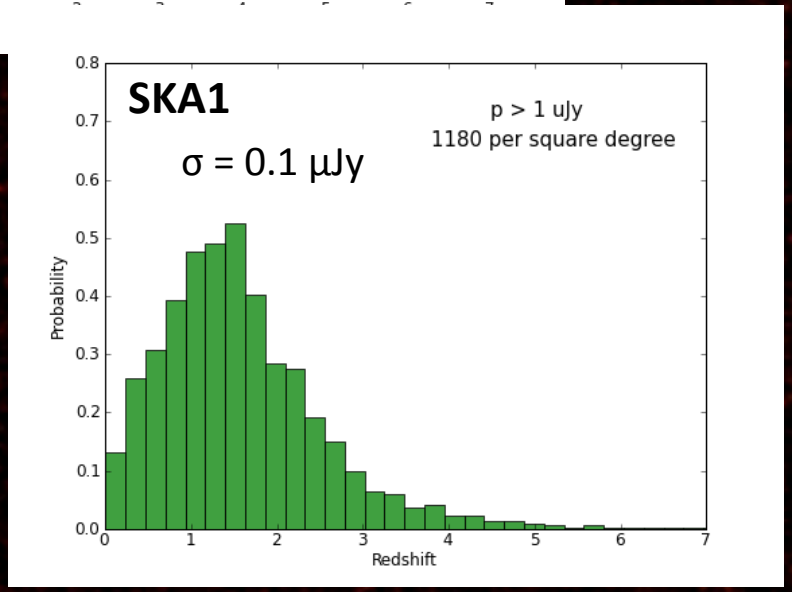


SKA1 will provide 4 million sources with intervening MgII and Faraday rotation.

Magnetism and Galaxy Evolution

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

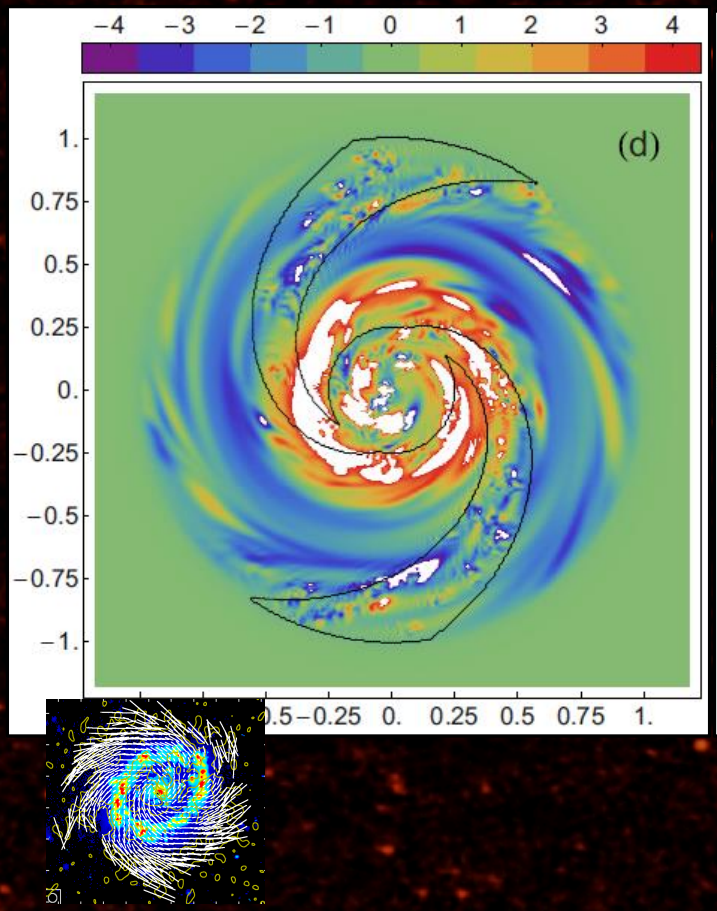




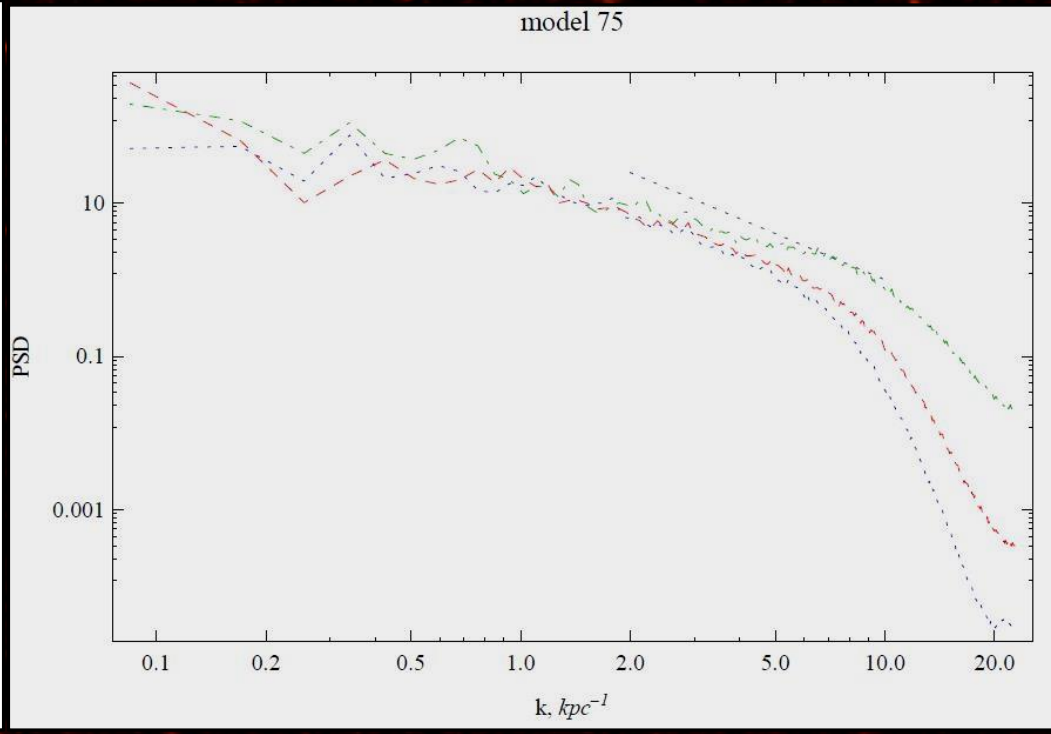
SKA1 Deep fields will detect thousands of galaxies in polarization out to redshifts beyond 4.

Dynamos and magnetic field structure

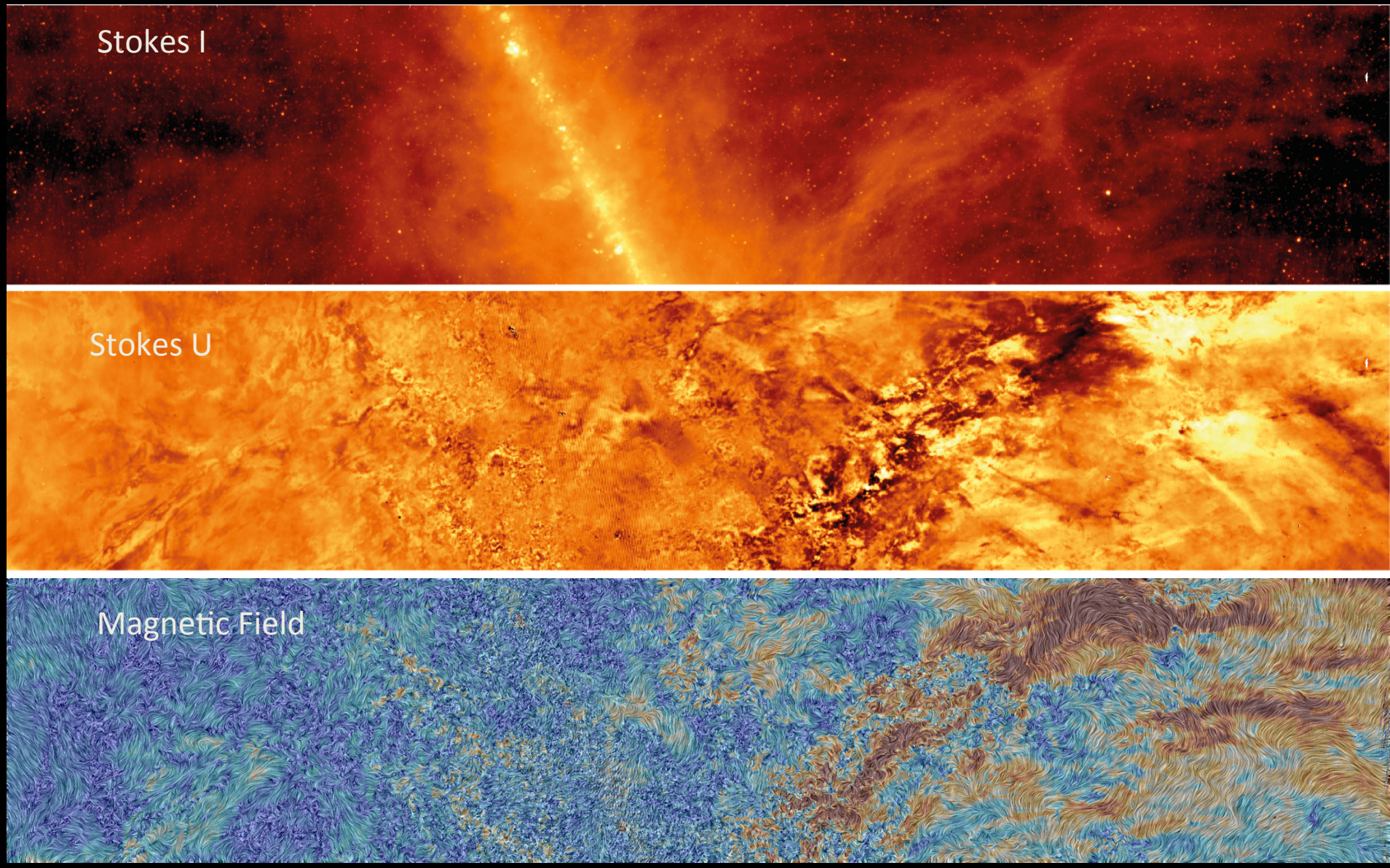
Large-scale dynamo in the disk and turbulent dynamo in the spiral arms



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