The Polarisation Sky Survey of the Universe's Magnetism: Revealing the Magnetised Cosmos

Bryan Gaensler (University of Toronto)

with Jane Kaczmarek, Craig Anderson, Xiaohui Sun, Cormac Purcell, Jamie Farnes, Takuya Akahori, Shane O'Sullivan, Sui Ann Mao, and the POSSUM team

Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

askap.org/possum

Exploring the Universe with the world's largest radio telescope

Fundamental Physics with the Square Kilometre Array

- May 1st-5th, 2017, in Flic-en-Flac, Mauritius
- Topics
  - Cosmology & Dark Energy
  - Cosmic Dawn & Reionisation
  - Dark Matter & Astroparticle Physics
  - Gravity & Gravitational Waves
- Invited speakers include:
  - R. Barkana
  - C. Boehm
  - P. Bull
  - T. Davis
  - S. Nissanke
  - F. Pretorius
  - J. Pritchard
  - J. Silk

www.skatelescope.ca/physics

La Pirogue

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The POSSUM Team

José Afonso (Lisboa), Takuya Akahori (Kagoshima), Craig Anderson (Sydney), Balwinder Arora (Curtin), Julie Banfield (ANU), Rainer Beck (MPIfR), Douglas Bock (CSIRO), Jo-Anne Brown (Calgary), Shea Brown (Iowa), Ettore Carretti (INAF), Tracy Clarke (NRL), Dan Clemens (Boston), Salvador Curiel (UNAM), Avinash Deshpande (RRI), Klaus Dolag (MPA), Torsten Enßlin (MPA), John Dickey (Tasmania), Jamie Farnes (Radboud), Glennys Farrar (NYU), Ilana Feain (Sydney), Peter Frick (Perm), **Bryan Gaensler (Toronto)**, Steve Gibson (Western Kentucky), Anne Green (Sydney), Jin-Lin Han (BAO), Lisa Harvey-Smith (CSIRO), Marijke Haverkorn (Radboud), Stuart Hay (CSIRO), **George Heald (CSIRO)**, George Hobbs (CSIRO), Andrew Hopkins (AAO), Shinsuke Ideguchi (Kumamoto), Tess Jaffe (CESR), Melanie Johnston-Hollitt (VUW), Jane Kaczmarek (Sydney), Roland Kothes (NRC), Philipp Kronberg (Toronto), Tom Landecker (NRC), Paddy Leahy (Manchester), Emil Lenc (Sydney), **Naomi McClure-Griffiths (ANU)**, Greg Madsen (Cambridge), Antonio Mario Magalhães (São Paulo), Sui Ann Mao (MPIfR), Josh Marvil (CSIRO), Tara Murphy (Sydney), Ray Norris (CSIRO), Shane O'Sullivan (UNAM), Cormac Purcell (Sydney), Wasim Raja (CSIRO), Wolfgang Reich (MPIfR), Larry Rudnick (Minnesota), Dongsu Ryu (UNIST), Anna Scaife (Manchester), Dominic Schnitzeler (MPIfR), Dmitry Sokoloff (Moscow State), Rodion Stepanov (Perm), Jeroen Stil (Calgary), Xiaohui Sun (Sydney), Keitaro Takahashi (Kumamoto), **Russ Taylor (Cape Town)**, Grazia Umana (INAF), Willem van Straten (AUT), Tessa Vernstrom (Toronto), Jennifer West (Toronto), Tony Willis (NRC), Maik Wolleben (Skaha Ltd)

69 people, 37 institutions, 18 countries

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ASKAP POSSUM

› ***Polarisation Sky Survey of the Universe's Magnetism***
- PIs Gaensler, McClure-Griffiths, Heald, Taylor

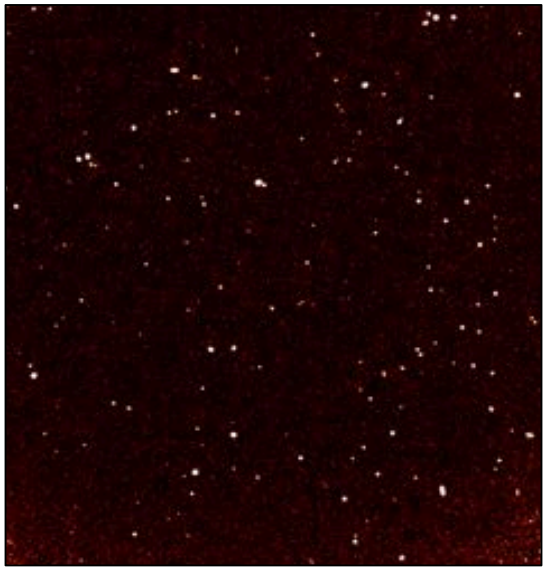
http://askap.org/possum

› All-sky (δ < +30°) ASKAP survey of polarised continuum, 1130-1430 MHz to 10 μJy/beam rms at 10" resolution
- commensal with all-sky continuum survey (EMU)
- "Faraday grid" at density of ~25 RMs/deg^2 (~10^6 RMs)

› Four science goals:
- magneto-ionic properties of ISM and its components
- structure and geometry of large-scale *B* of Milky Way
- magnetic properties of galaxies, clusters & IGM
- evolution of magnetic fields with cosmic time

› POSSUM Early Science program
- broadband survey of 700-1800 MHz polarisation
- focus on intrinsic magnetic properties of polarised sources, cf. foreground magnetism for full ASKAP

CSIRO / Swinburne



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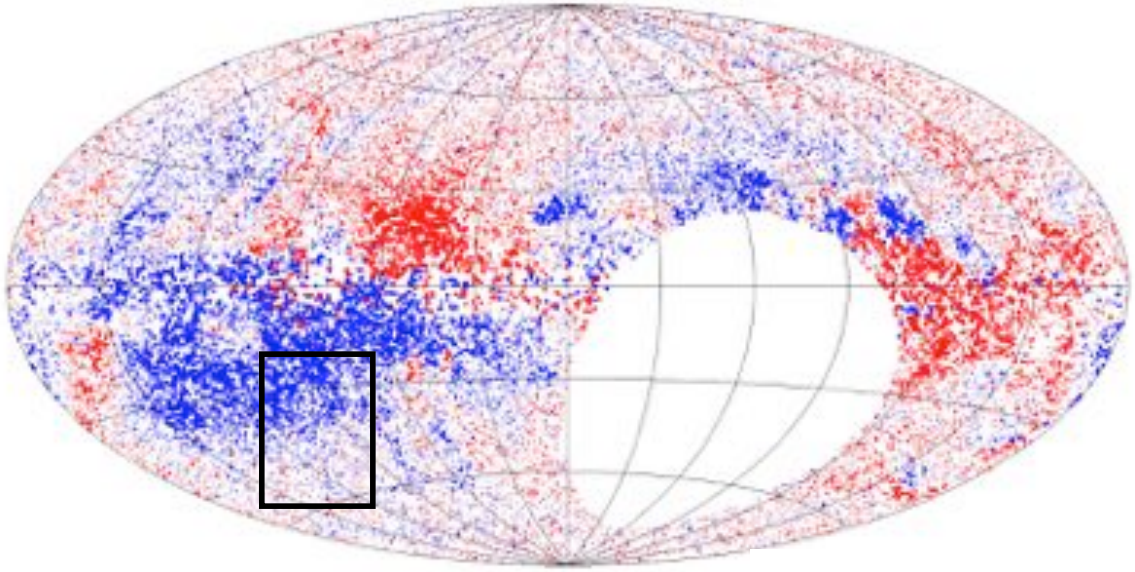
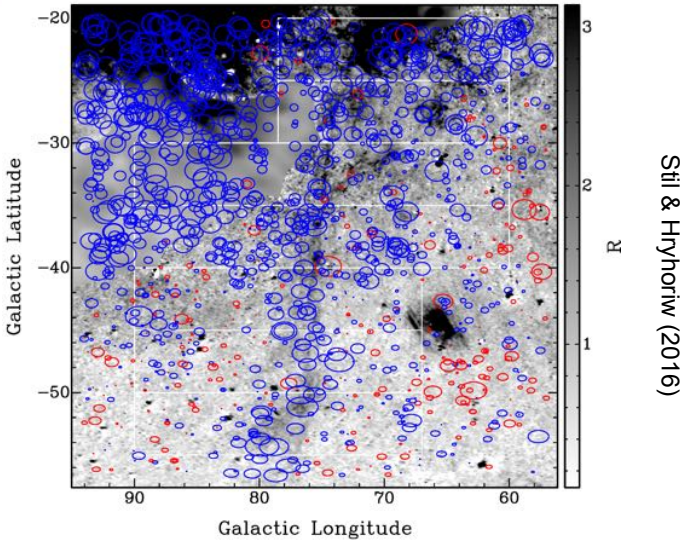
ISM and its Components (I)



- 37,543 RMs to background AGN (NVSS; Taylor, Stil & Sunstrum 2009)
  - sampling ~1 RM per deg^2 :
  → insufficient to study most structures
  - determined from 2 channels!
  → individual RMs not always reliable



Stil & Hryhoriw (2016)

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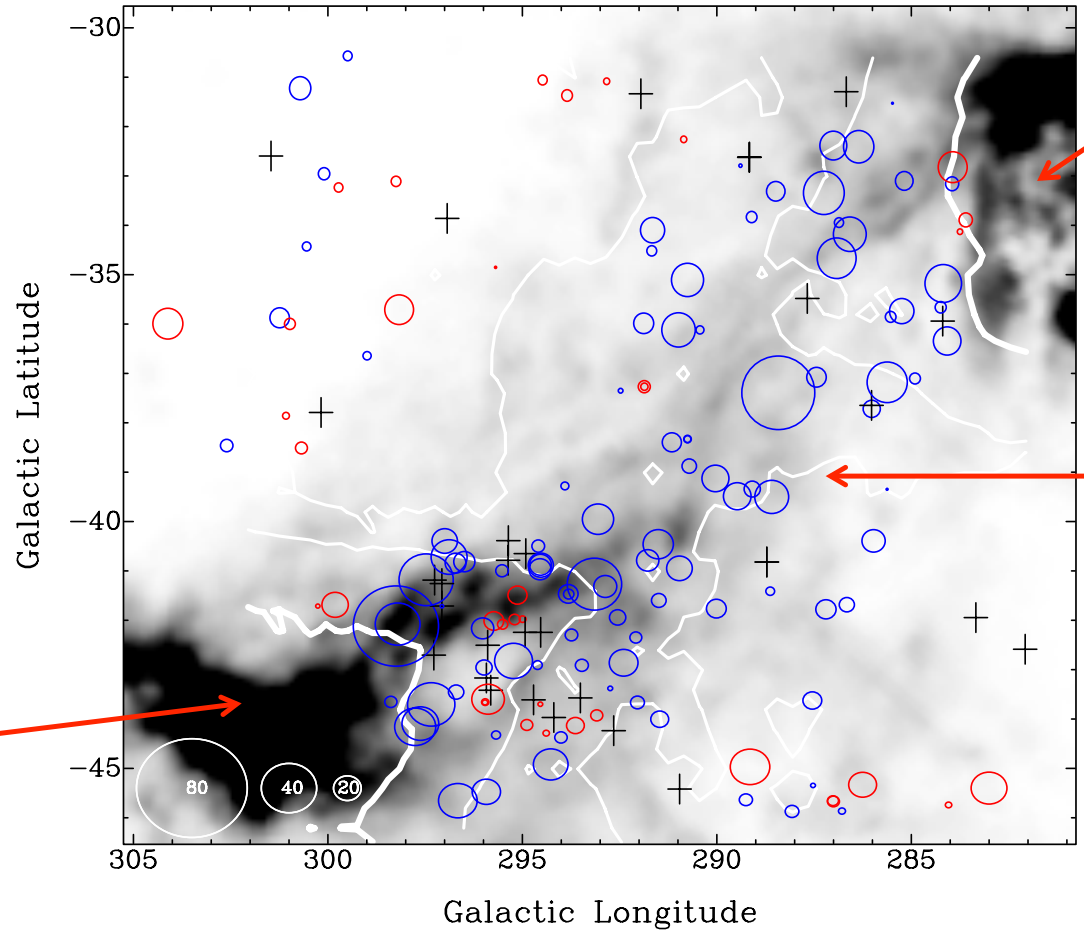
ISM and its Components (II)

› Detection of coherent magnetic field in the Magellanic Bridge
(Kaczmarek, BMG et al. 2016)



LMC

Bridge

SMC

Kaczmarek, BMG et al (2016)

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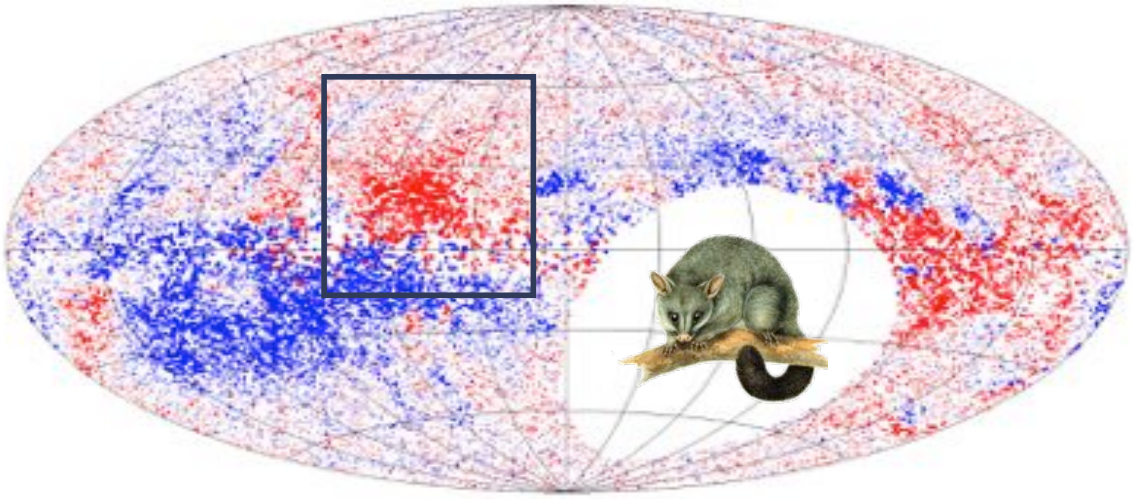
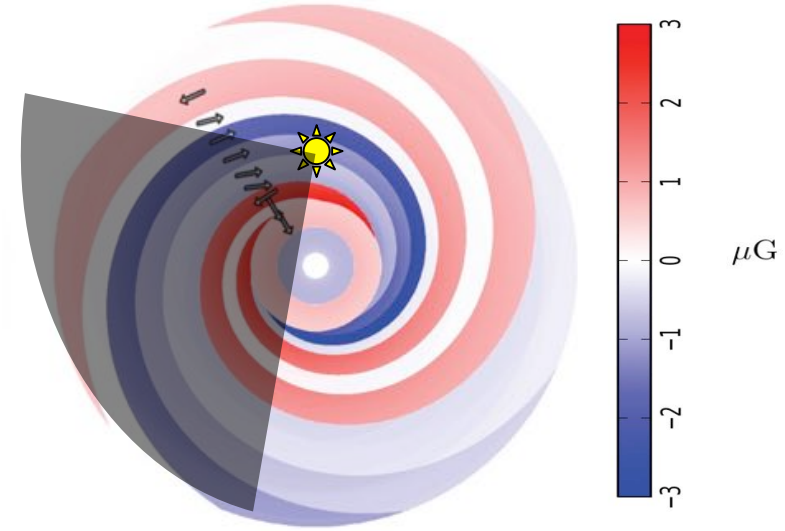
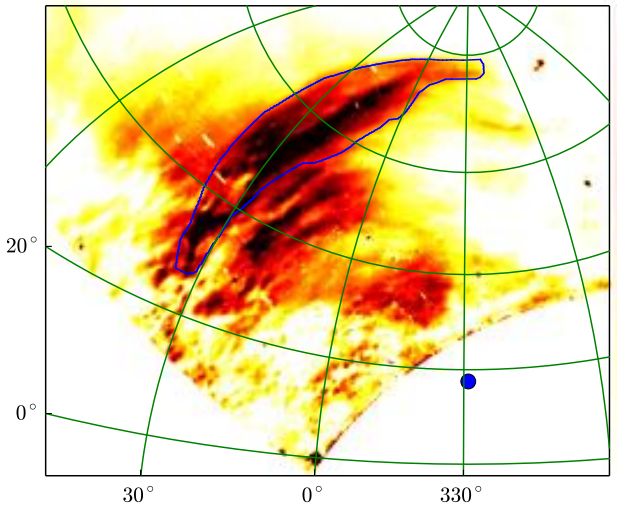
Galactic Magnetic Field



37,543 RMs (NVSS; Taylor, Stil & Sunstrum 2009)



Global magnetic field model (Jansson & Farrar 2012)



Polarised intensity from North Polar Spur (Sun, BMG et al. 2015)

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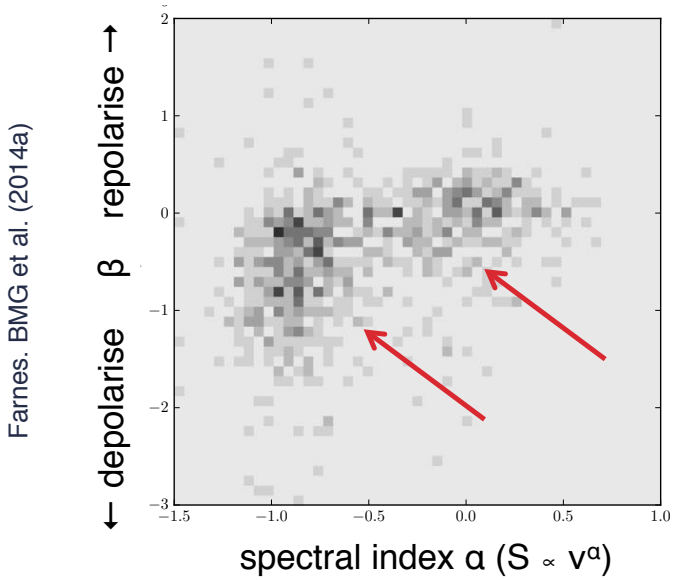
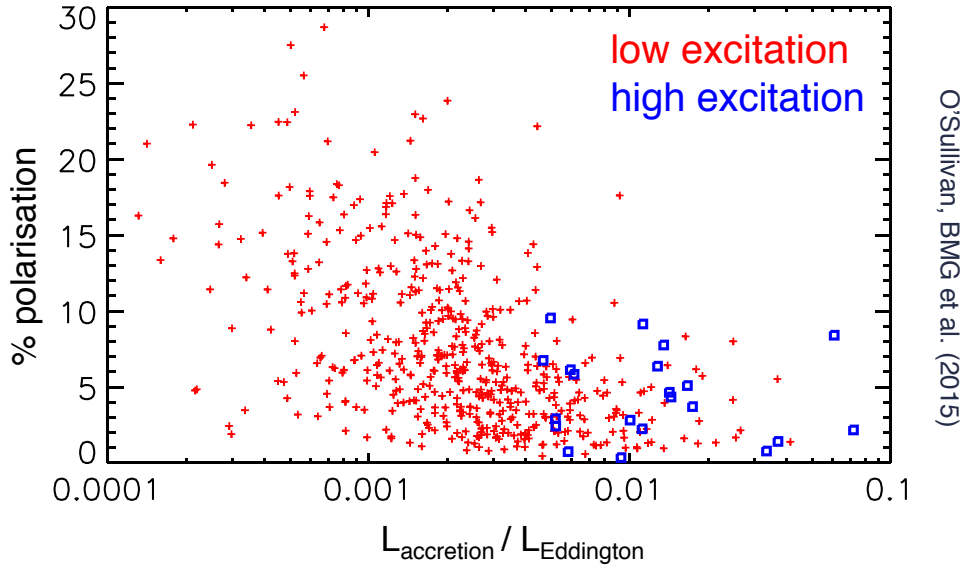
Magnetism in Galaxies (I)

- New catalogue of 951 sources with polarisation spectral indices ($p \propto \lambda^{\beta}$) (Farnes, BMG et al. 2014a)
  - steep and flat spectrum sources have different distributions in β
  - β must be intrinsic to the source, not due to foreground effects
- Catalogue of 796 radio galaxies with optical spectra at $z < 0.7$ (Best & Heckman 2012; O'Sullivan, BMG et al. 2015)
  - low excitation: polarisation tied to accretion rate; both trace environment?
  - high excitation: increased ionisation → increased depolarisation





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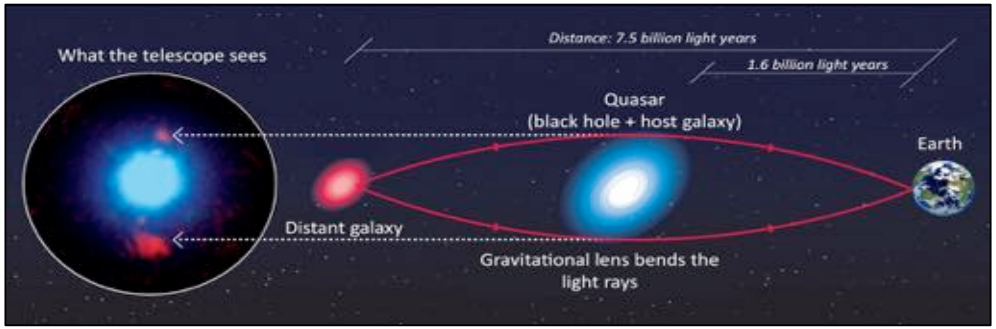
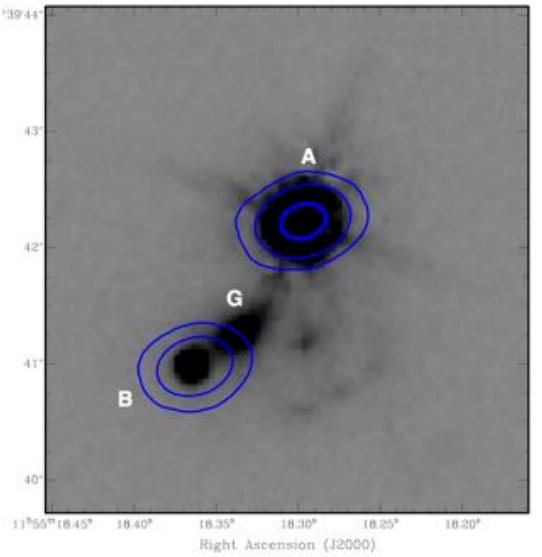
Magnetism in Galaxies (II)

- Small population of lensed, polarised, sources
  - identical sightlines, except for the lensed component
  - direct measure of magnetism in a distant object

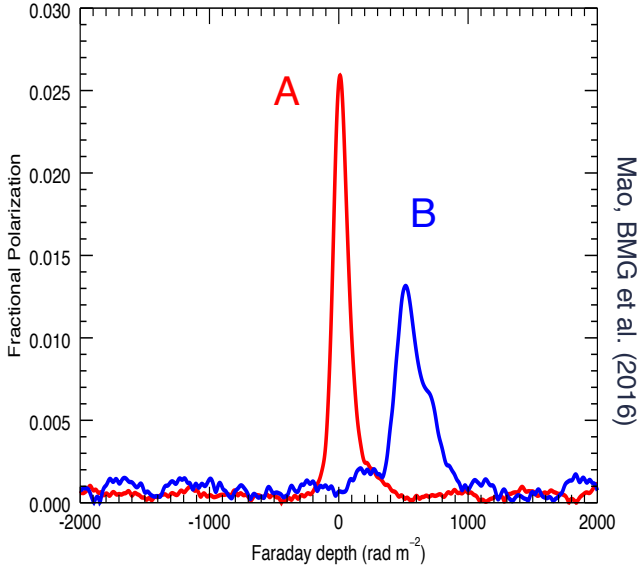
F. Courbin et al. / Caltech / EPFL / WMKO





Mao, BMG al. (2016)

- Polarised lens with two components, A & B (Mao, BMG et al. 2016)
- Observations with Jansky Very Large Array
  - component A: outskirts of galaxy, low RM
  - component B: disk of galaxy, high RM
- Coherent field, $B \sim 8 - 11$ μG at location B ($R \approx 5 - 20$ kpc)
- Random field, $B \sim 15$ μG at location B
- Strong galactic magnetism at $z = 0.439$
- Rapid dynamo action!



Mao, BMG et al. (2016)

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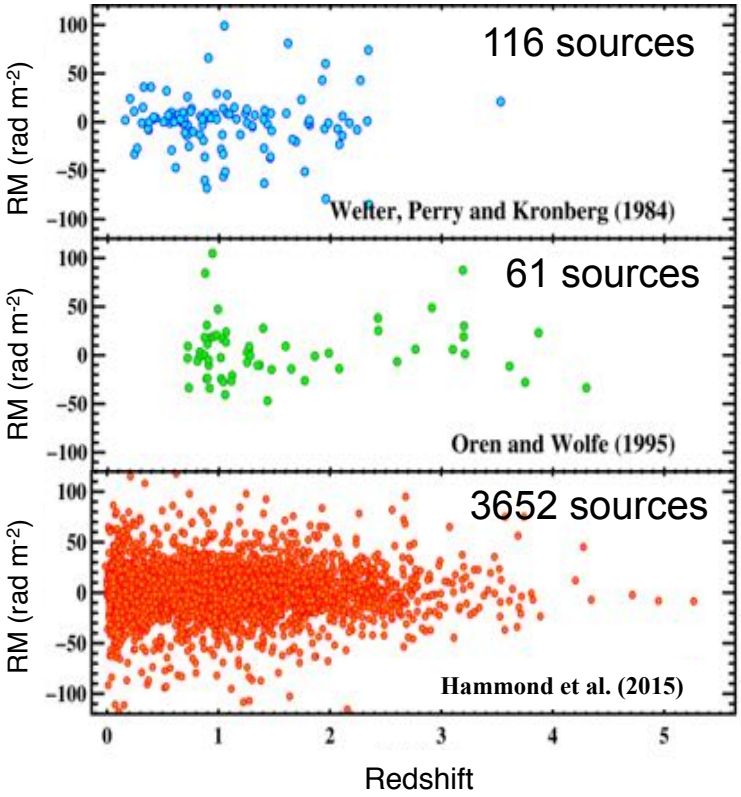
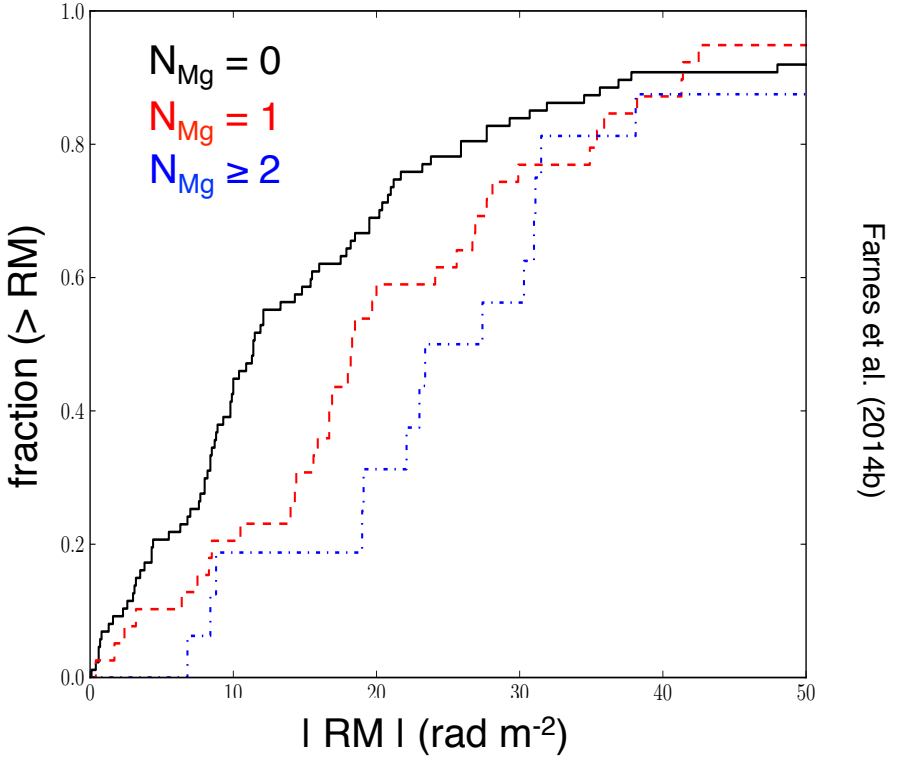
Magnetism Over Cosmic Time (I)

› Cross-match of NVSS RMs with optical redshifts & spectra
  - 3652 RM - *z* pairs to *z* > 5 : no apparent evolution in *z* (Hammond, BMG et al. 2015)
  - 201 RM – Mg II pairs : 3.5 σ difference in RM over no Mg II (Farnes, BMG et al. 2014b)

› Highly magnetised outflows at *z* ~ 0.9 : rapid field growth?





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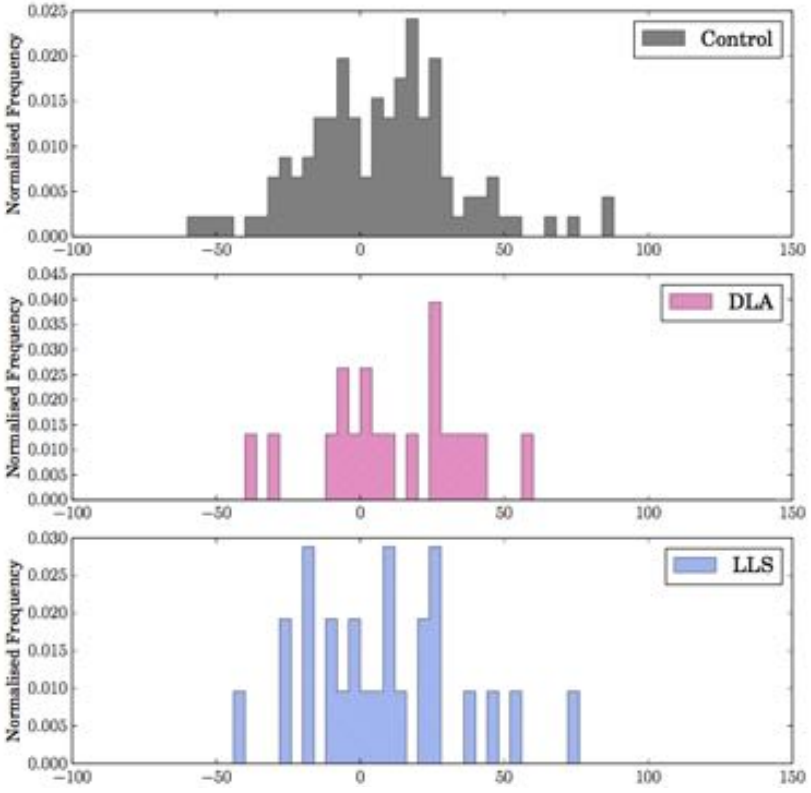
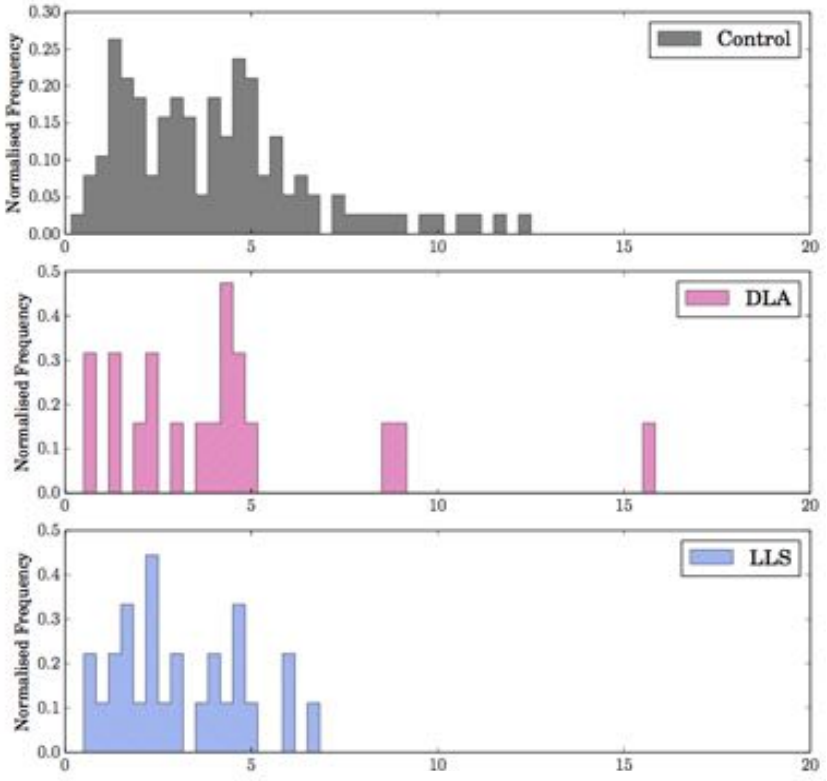
Magnetism Over Cosmic Time (II)

› Match RMs with optical spectra for damped Ly-α absorbers, Lyman-limit systems
  - 19 RM – DLA pairs, 27 RM – LLS pairs (Farnes, BMG et al. 2016)
  - LLS sample: slightly higher RMs, lower fractional polarisation, than control sample
  - coherent and random magnetic field components emerging in proto-galaxies?





Farnes, BMG et al. (2016)

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Major Technical Achievements

- Source finding and handling of extended sources (POSSUM memos #2, #11, #14)
- Complexity flags for rotation measure (POSSUM memo #9; Anderson et al. 2015)
- *Ionospheric correction software* (POSSUM memos #15, #25; Willis et al. 2016)
- Simulations of polarisation errors in ASKAP beam (POSSUM memo #19)
- *Polarisation calibration tests and commissioning plan* (POSSUM memos #44, #66)
- Rotation measure data challenge (POSSUM memo #52; O'Sullivan+ 2013; Sun+ 2015)
- *POSSUM pipeline and data products specification* (POSSUM memos #22, #23, #62)
- Effect of frequency sampling on RM transfer function (POSSUM memo #67)
- Parkes single-dish all-sky polarisation survey, 1300-1800 MHz (Sun et al., in prep)

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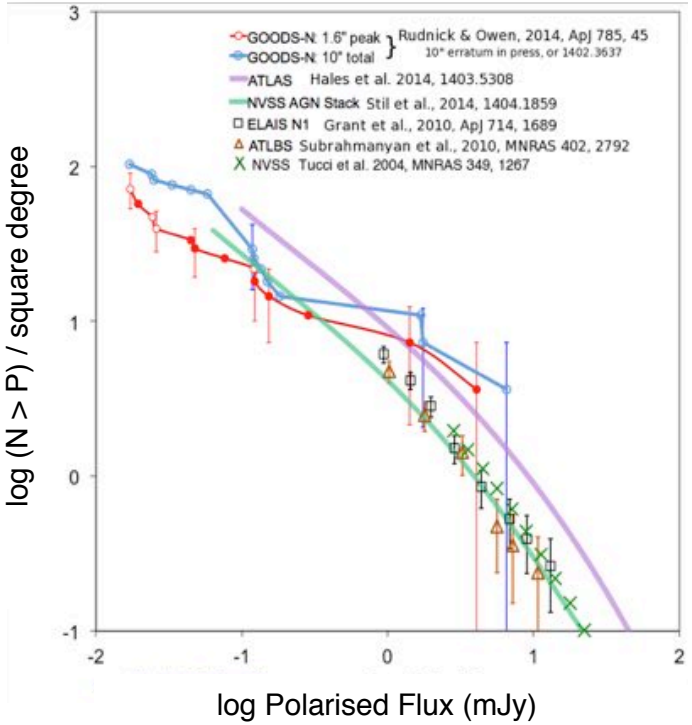
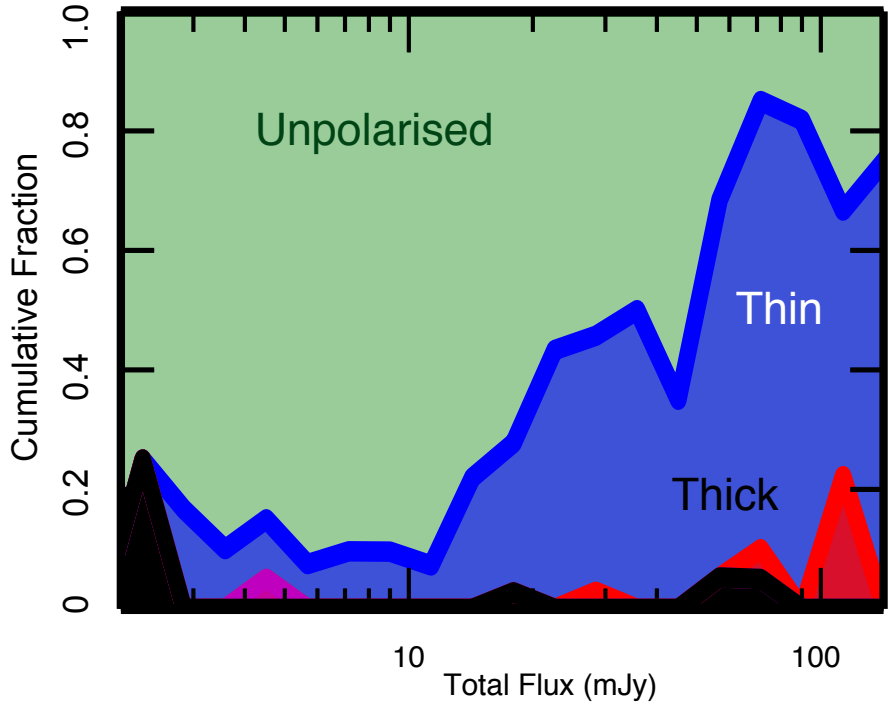
Current Investigations: Source Counts

- We know: sky density of polarised sources at L > 100 μJy will be ~25 deg^{-2}
- We don't know: what fraction of sources will be Faraday thin (i.e., good for foreground RM grid experiments) vs Faraday thick (intrinsic effects)?





Larry Rudnick (after Rudnick & Owen 2014)

Anderson, BMG, Feain & Franzen (2015)

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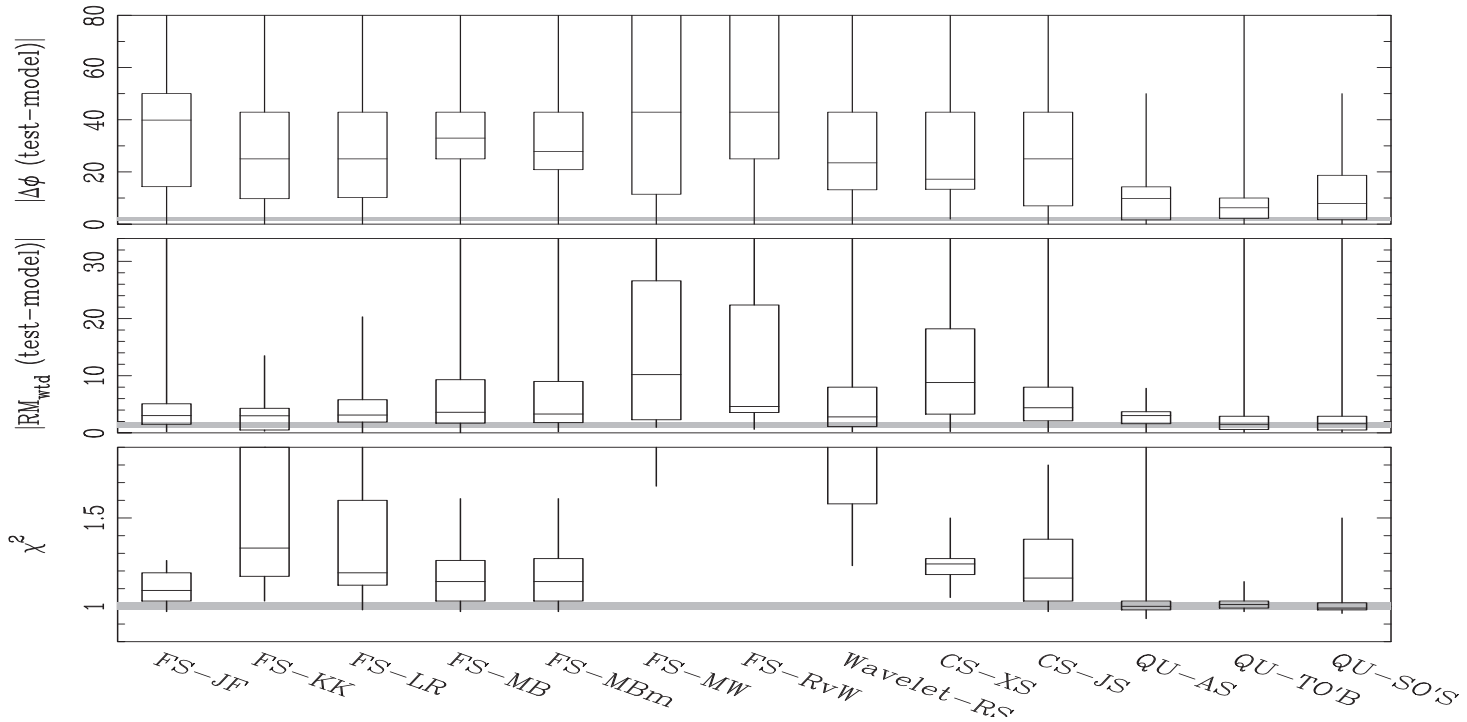
Current Investigations: Faraday Thick Sources

- Data challenge: 4 distinct algorithms, 13 implementations (Sun et al. 2015)
- "Q-U" fitting does best, but none correctly recover sources over 1130-1430 MHz
- Next step: repeat challenge for early science frequencies (700-1800 MHz)



Sun et al. (2015)

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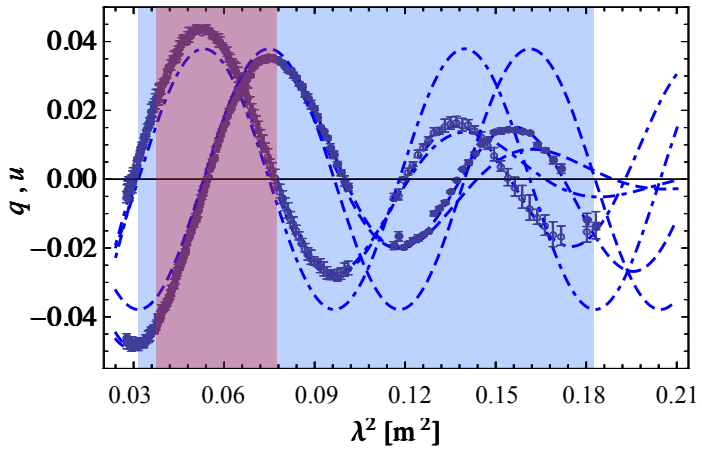
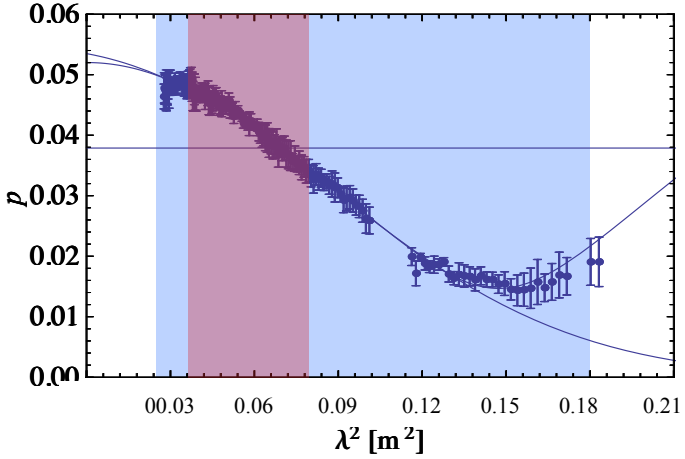
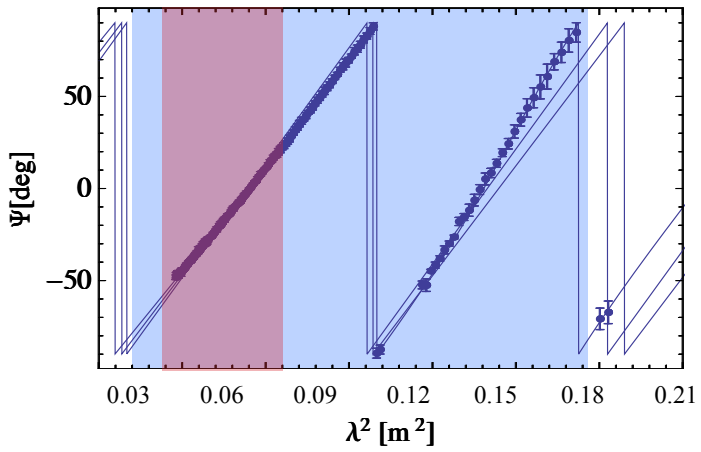
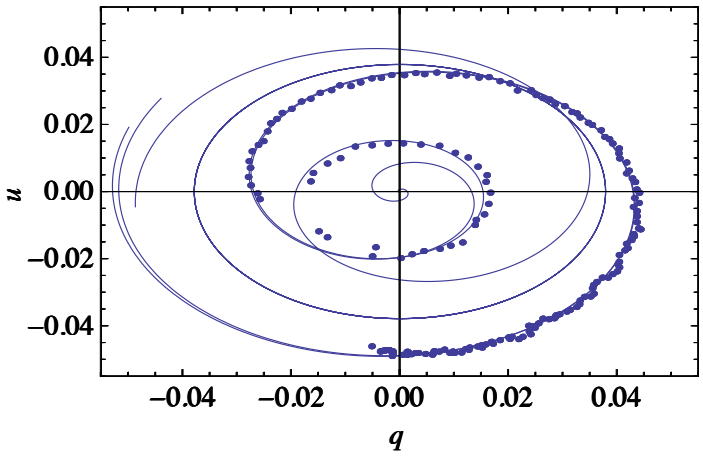
New Discovery Space with ASKAP Early Science

1130-1430 MHz (POSSUM) **700-1800 MHz (Early Science)**









Polarimetry of PKS B1610-771 (O'Sullivan et al. 2012) : Simple lobes contained within

The POSSUM Pitch

- Cosmic magnetism is key to understanding a wide range of topics across astrophysics
- Polarised radio sky is (still!) relatively unexplored
- POSSUM will provide an order of magnitude leap forward over all previous work
- ASKAP synergies: EMU, FLASH, VAST, WALLABY
- Numerous technical questions being asked, and answered, for the first time
- Early Science: unique broadband polarimetry (+ vital for understanding reduced bandwidth of full POSSUM)
- We're ready to do some POSSUM Magic!

Beck et al. / Hubble Heritage

CSIRO / Swinburne

Mihos / Huey / Science