Polarisation Possibilities from the POSSUM Posse

Bryan Gaensler, Tom Landecker, Russ Taylor, Naomi McClure-Griffiths and the POSSUM team

askap.org/possum
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), Bruce Slee (CSIRO), 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), Tony Willis (NRC), Maik Wolleben (Skaha Ltd)

69 people, 37 institutions, 18 countries
Magnetism Matters!

- **Origin of magnetic fields is a fundamental & unsolved cosmological problem**
  - exotic processes (phase transitions, string cosmology)
    ... or standard plasma physics? (battery, turbulence, instabilities)
  - top-down or bottom-up process?
  - moderates structure formation?
  - role in formation of the first galaxies and stars?

- **Key to long-standing problems in plasma physics & astrophysics**
  - $B$ in galaxies & clusters test extremes of dynamo theory & turbulence
  - acceleration & propagation of cosmic rays
  - radio / far-infrared correlation
  - physics, geometry, evolution of AGN
  - star formation, thermal conduction, diffusion, accretion, ...
Mapping Magnetic Fields

- **Faraday rotation** & **rotation measure** (RM) are powerful probes of $B_{||}$

$$\Theta = \Theta_0 + \text{RM} \lambda^2$$

$$\text{RM} = K \int_L^0 n_e \vec{B} \cdot d\vec{l}$$

- provides *direction* of $B$
- radio wavelengths:
  - no attenuation of radiation

- The RM grid:

\[ \text{RM} \approx 220 \text{ rad m}^{-2} \left( \frac{n_e}{0.03 \text{ cm}^{-3}} \right) \left( \frac{B_{||}}{3 \mu \text{G}} \right) \left( \frac{L}{3 \text{ kpc}} \right) \]
The (Q, U) Plane and RM Synthesis

“Faraday Thin”
The (Q, U) Plane and RM Synthesis
The (Q, U) Plane and RM Synthesis

“Faraday thick”
ASKAP POSSUM

- Polarisation Sky Survey of the Universe’s Magnetism
  - PIs Gaensler, Landecker, Taylor, McClure-Griffiths
    [http://askap.org/possum](http://askap.org/possum)

- All-sky ($\delta < +30^\circ$) ASKAP survey of polarised continuum, 1130-1430 MHz to 10 $\mu$Jy/beam rms at 10" resolution
  - commensal with 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
› 37,543 RMs to background AGN
(NVSS; Taylor, Stil & Sunstrum 2009)

- sampling ~1 RM per deg²:
  → insufficient to study most structures

- determined from 2 channels!
  → individual RMs not always reliable
focus on the NPS and so constrain its distance. The Galactic Magnetic Field Survey (GMIMS) was conducted with the Dominion Radio Astrophysical Observatory 26 m Telescope covering the frequency range from 1280 to 1750 MHz split into 2048 channels. The observations were made in long scans along the meridian with a spacing of 12°. A detailed description of the GMIMS data and the RM map is presented in Section 2.

In Section 3, we discuss the relationship between the GMIMS and other radio sources. We also present the GMIMS data and the RM map in Figure 1. The resulting images are shown in stereographic projection with the projection center at the Galactic center. There have also been suggestions that the NPS may be associated with the Aquila Rift. Sofue (2000) found the soft X-ray horizon of the NPS to be about 2 kpc, while Kataoka et al. (2013) showed that the lower part of the NPS is strongly depolarized at 2.3 GHz and thus beyond the polarization horizon. We also find that the NPS emission from the lower part follows the extinction law caused by the ISM in the Galactic scale feature. Sofue (2000) also demonstrated that the NPS can be explained by a bipolar wind originating from a starburst in the Aquila Rift and derived a lower limit of about 1 kpc for the kinematic distance to the Aquila Rift.

The magnetic field in the Galaxy is an important factor in the study of the NPS. The Galactic Magnetic Field model (Jansson & Farrar 2012) was used to determine the total intensity and RM of the NPS. The resulting images are shown in stereographic projection with the projection center at the Galactic center. We also show the Galactic Faraday depth map constructed by Oppermann et al. (2015) and the linear polarization angle image where \( \chi \) is a constant. The map of RMs is shown in Figure 2. Although the linear polarization angle is known, the outer boundary of Loop I is much brighter than the outer edge, which is consistent with previous findings. We also show the Galactic Faraday depth map constructed by Oppermann et al. (2015). We mark a contour denoting the outer boundary of Loop I. The resolution is 40° for the total intensity and 3° for the RM image where \( \chi = 0.1 \). The map of RMs is shown in Figure 2 as a position marked as a blue dot in each panel. The contour marks the map of RMs from RMs of extragalactic sources in the GMIMS; Wolleben et al. (2015, in preparation).

Global magnetic field model (Jansson & Farrar 2012)
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 $\rightarrow$ increased depolarisation

Simulations of intergalactic magnetic field: $B \sim 10 \text{nG}$, $\text{RM} \sim 7 \text{rad m}^{-2}$
(Akahori & Ryu 2010, 2011; Akahori, BMG et al. 2014a, 2014b)

- simulate intrinsic, IGM, intervenors, ISM, measurement error
- potential detection & reconstruction of IGM magnetic field with ASKAP RM density
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. 2014)

Foreground model, measurement errors, high-z sample size all major limitations
POSSUM Structure & Activities

- Four principal investigators (Australia, Canada x 2, South Africa)
- Monthly POSSUM-wide meetings
- Four core working groups for early science (monthly meetings)
  - SG2: Polarisation Source Finding
  - SG4: Polarisation Commissioning
  - SG5: POSSUM Pipeline
  - SG8: RM determination
- Heavily-used wiki and mailing list
- 33 memos and reports
- 3 core catalogs: PBCat (broadband), PPCat (polarisation), PVACat (value-added)
- Face-to-face meetings
  - Sydney, Nov 2009
  - Sydney, Feb 2010
  - Calgary, Aug 2010
  - Calgary, Jul 2011
  - Sydney, May 2012
  - Beijing, Aug 2012
  - Penticton, May 2013
  - Sydney, Dec 2014
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 et al. 2013; Sun et al. 2015)
- POSSUM pipeline and data products specification (POSSUM memos #22, #23, #62)
  → next talk by Cormac Purcell
- 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)
Current Investigations: Source Counts

- We know: sky density of polarised sources at $L > 100 \, \mu$Jy will be $\sim 25 \, \text{deg}^{-2}$
- 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)

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)
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) - Symbols are contained within boxes.
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

› Excellent synergies w 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!