Polarisation Possibilities from the POSSUM Posse

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

Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

askap.org/possum

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69 people, 37 institutions, 18 countries

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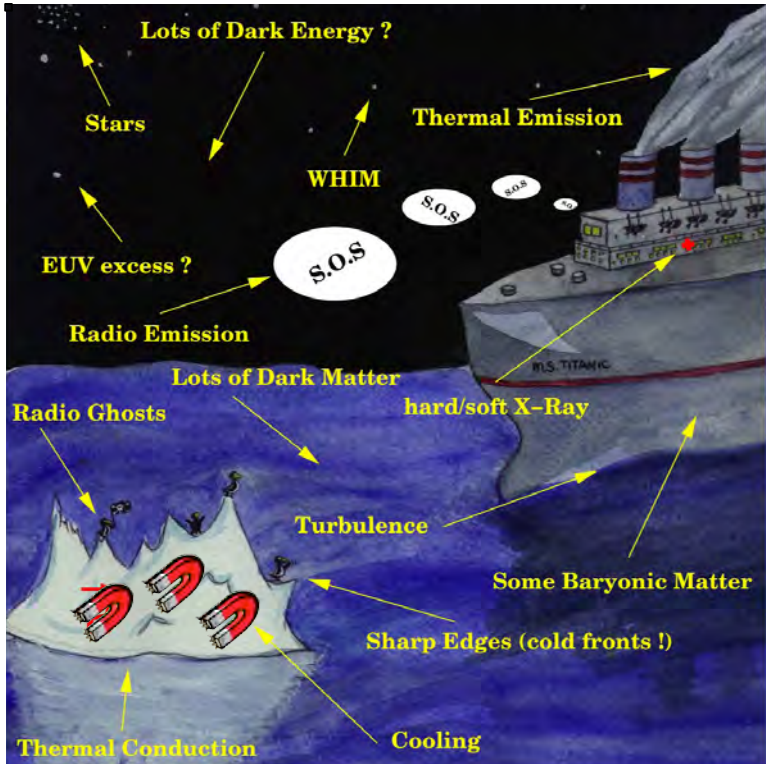
Magnetism Matters!

› ***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, …



Do we want to understand our Universe?

Klaus Dolag

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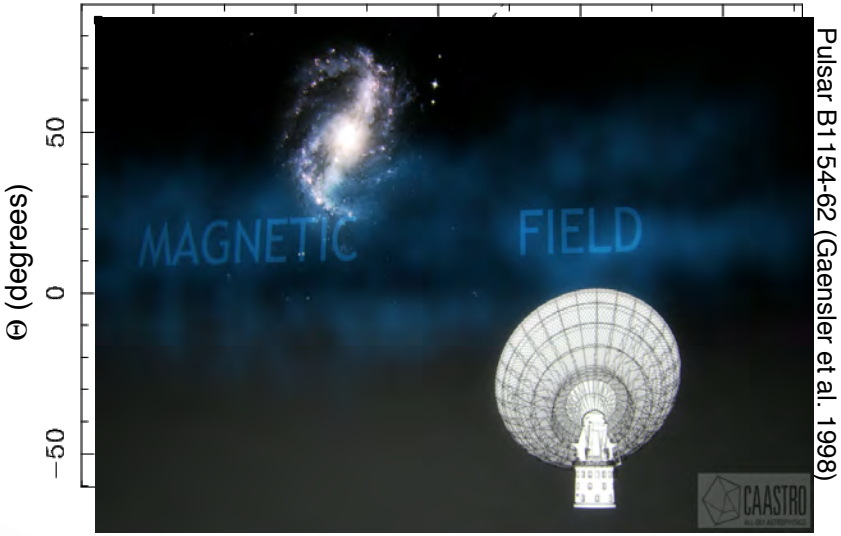
Mapping Magnetic Fields

› ***Faraday rotation*** & ***rotation measure*** (RM) are powerful probes of $B_{\parallel}$

$$\Theta = \Theta_0 + \mathrm{RM}\,\lambda^2 \qquad \mathrm{RM} = K\int_L^0 n_e \vec{B}\cdot d\vec{l}$$

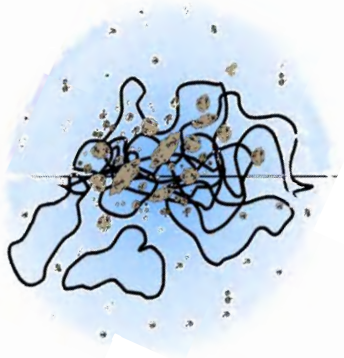
$$\mathrm{RM} \approx 220\ \mathrm{rad\ m^{-2}} \left(\frac{n_e}{0.03\ \mathrm{cm^{-3}}}\right)\left(\frac{B_{\parallel}}{3\ \mu\mathrm{G}}\right)\left(\frac{L}{3\ \mathrm{kpc}}\right)$$

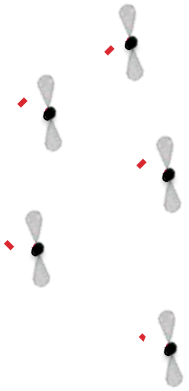
- provides *direction* of *B*
- radio wavelengths:
  no attenuation of radiation



Pulsar B1154-62 (Gaensler et al. 1998)
Swinburne Astronomy Productions / CAASTRO

› The RM grid:





Philipp Kronberg / Physics Today

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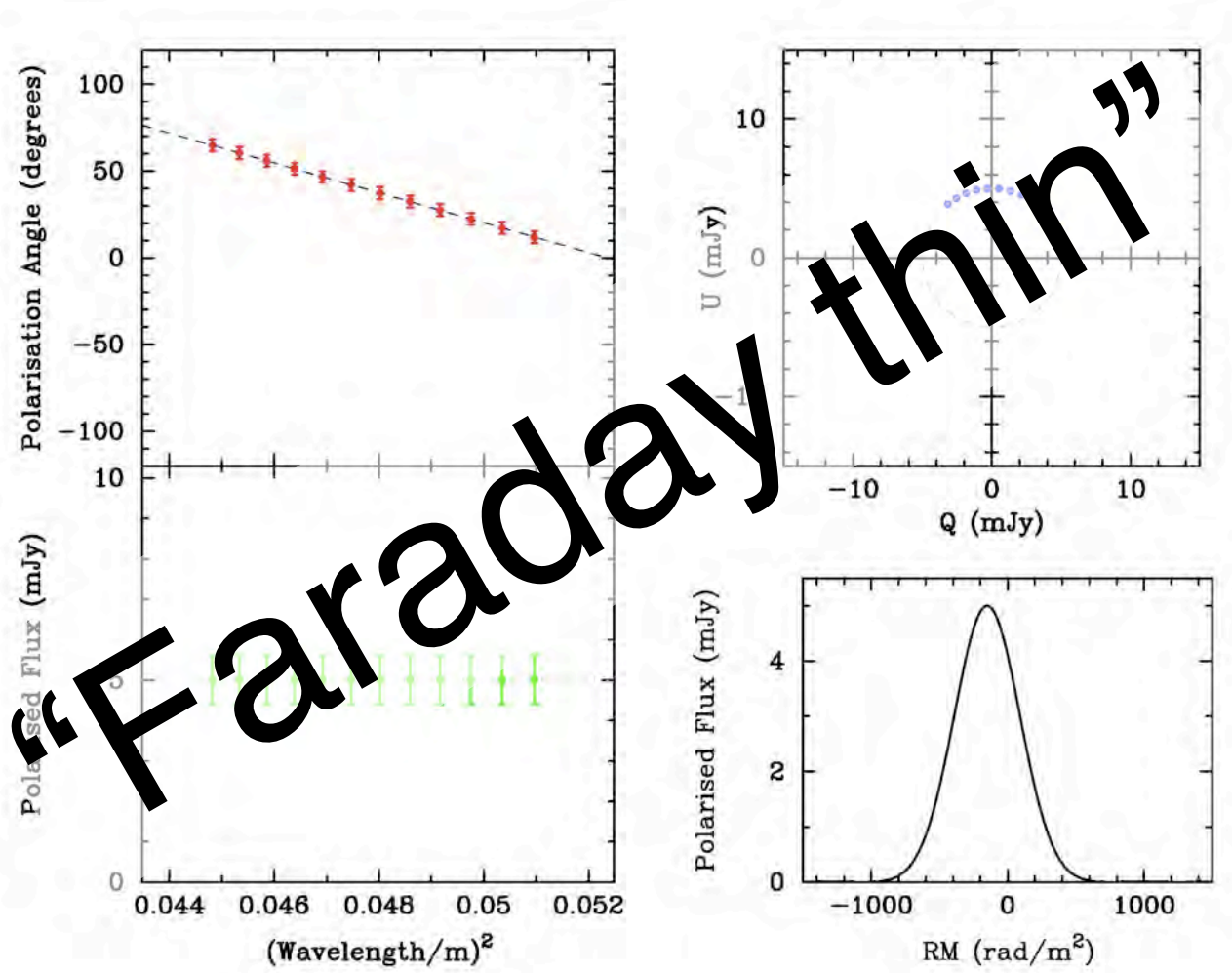
The (Q, U) Plane and RM Synthesis



"Faraday thin"

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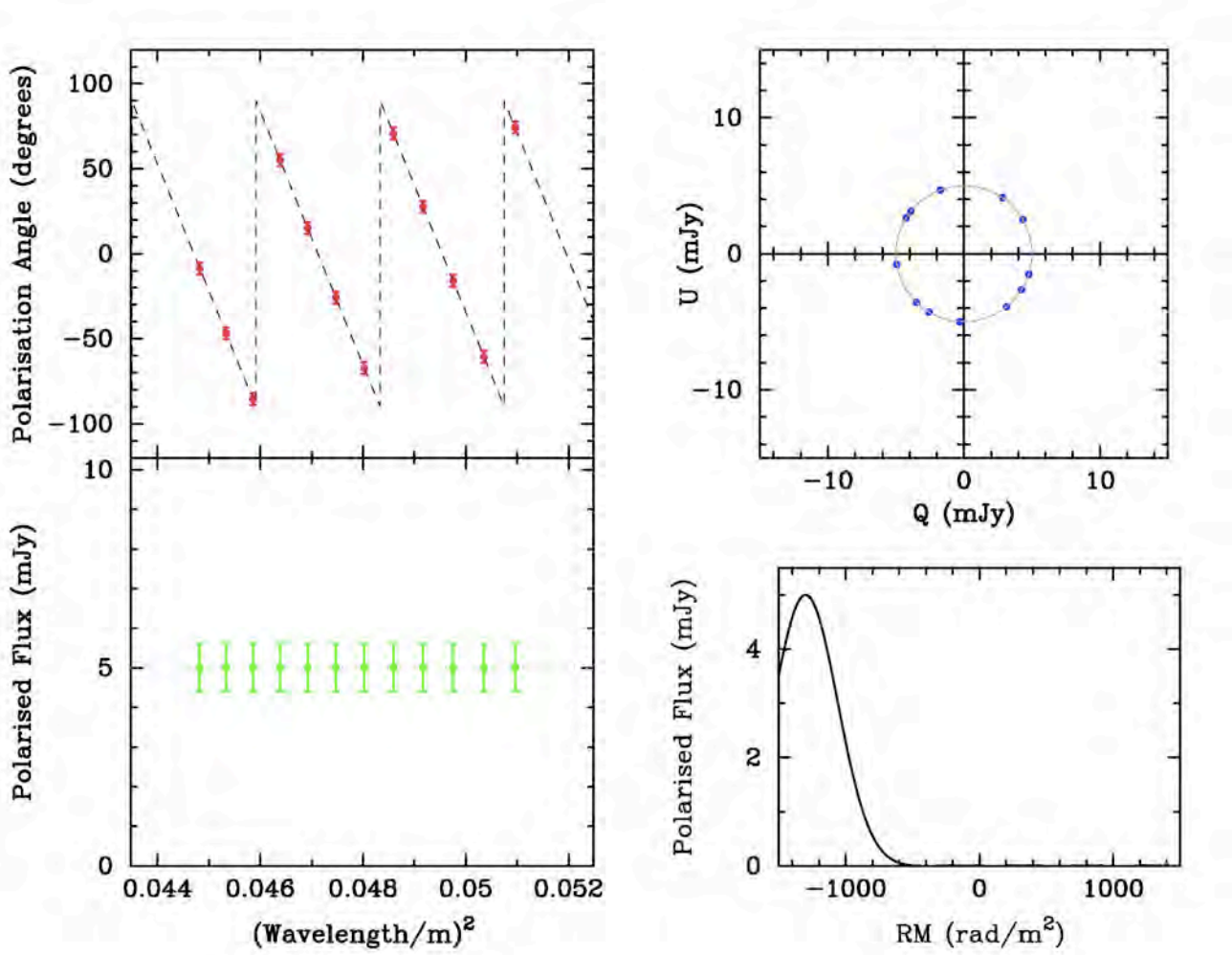
The (Q, U) Plane and RM Synthesis



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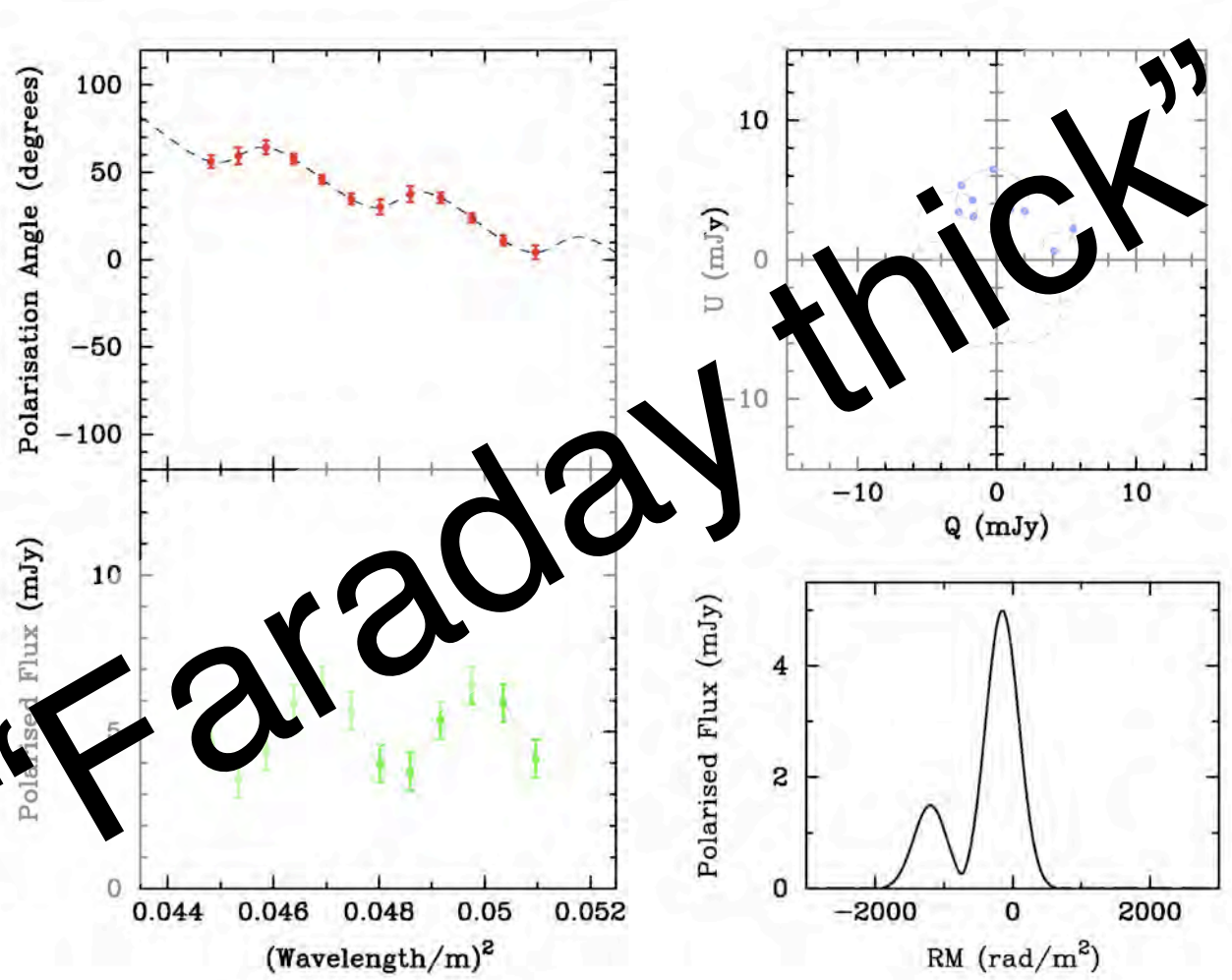
The (Q, U) Plane and RM Synthesis



"Faraday thick"

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ASKAP POSSUM

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

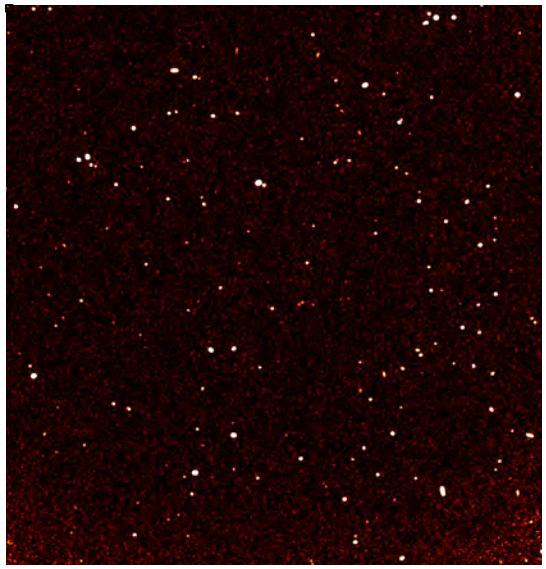
    http://askap.org/possum

- All-sky ($\delta < +30^{o}$) ASKAP survey of polarised continuum, 1130-1430 MHz to 10 μJy/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

CSIRO / Swinburne



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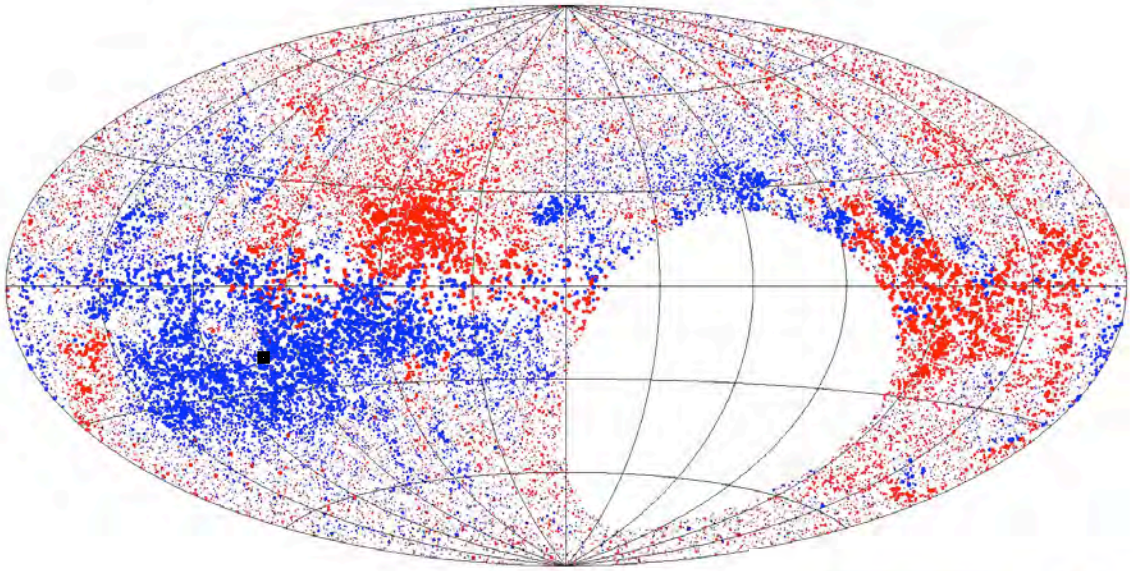
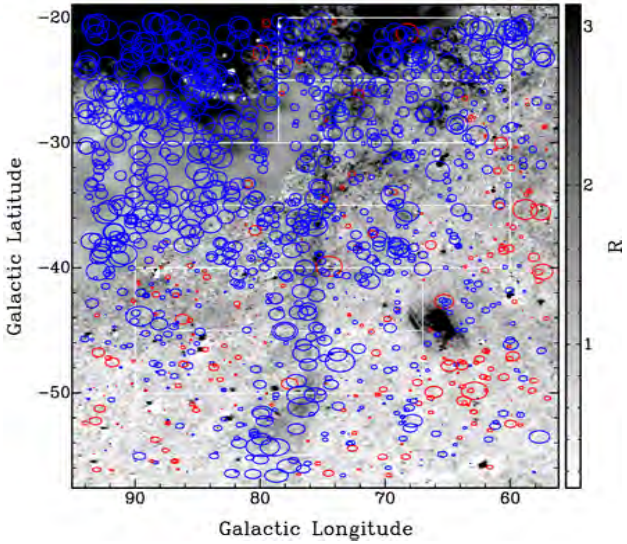
ISM and its Components



- 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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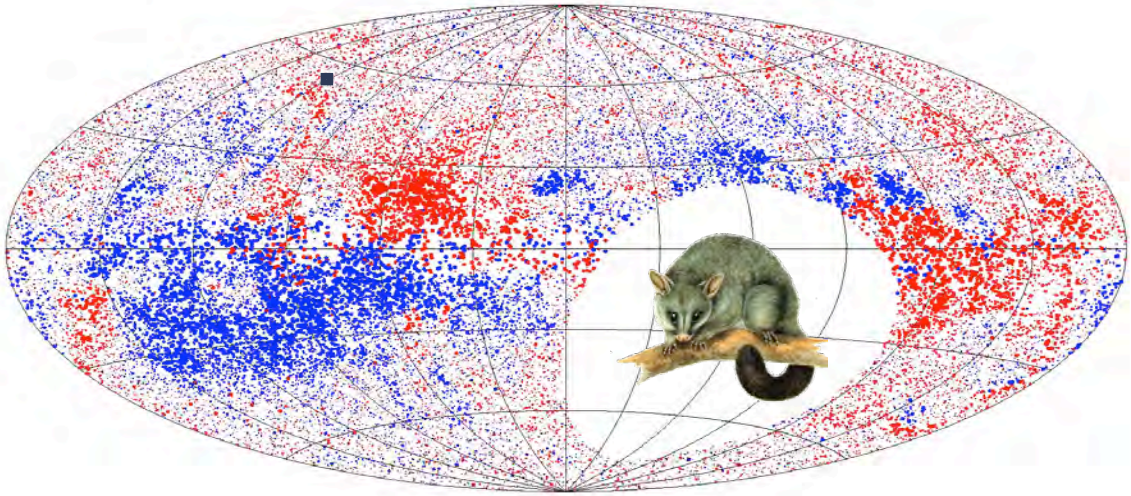
Galactic Magnetic Field



37,543 RMs (NVSS;
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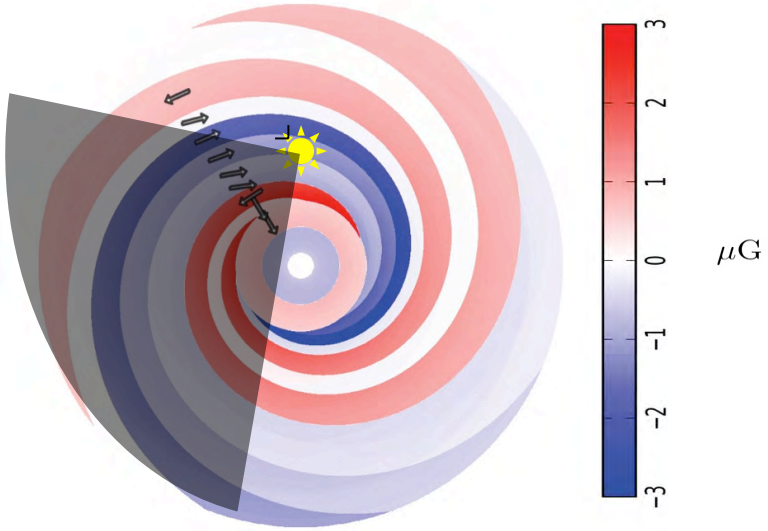
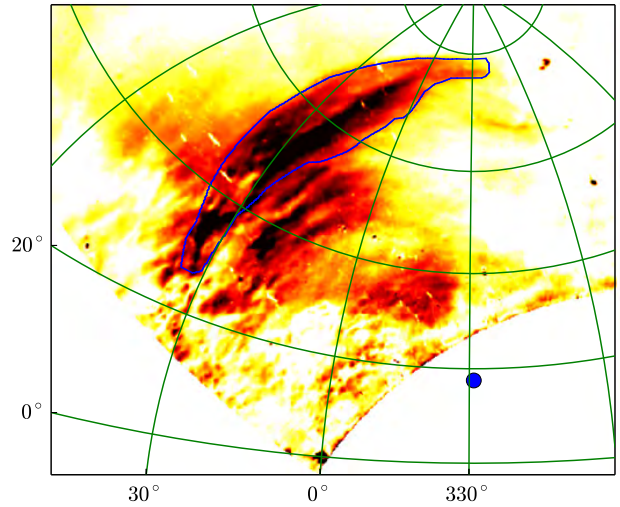


Global magnetic field model (Jansson & Farrar 2012)



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

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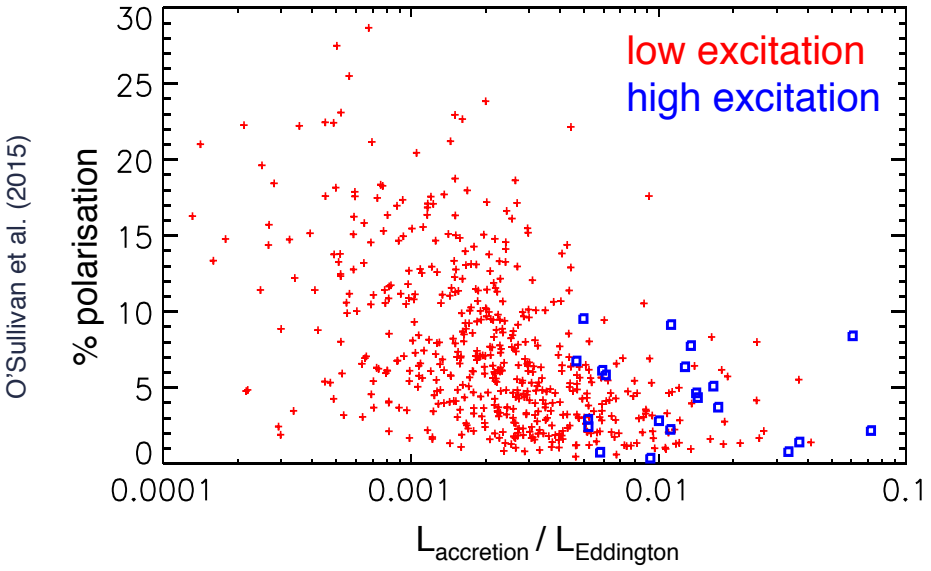
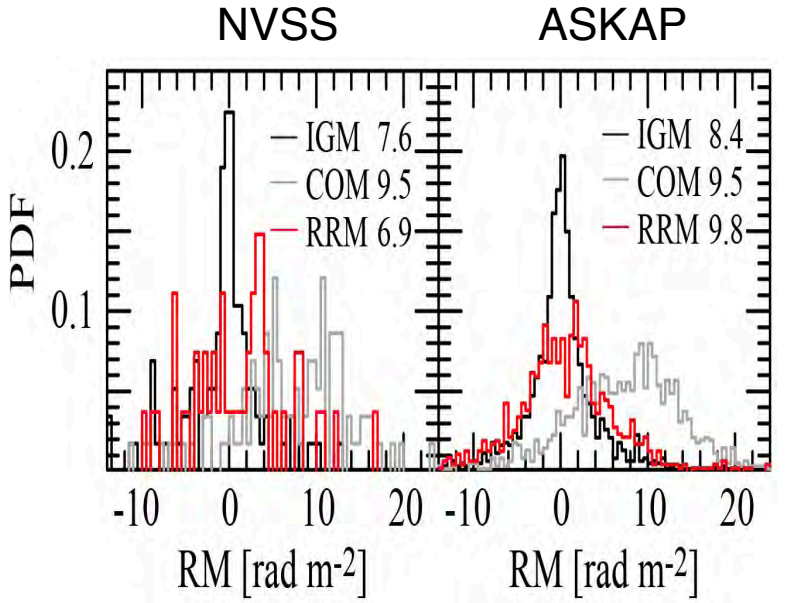
Magnetism in Galaxies & IGM

- 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
- Simulations of intergalactic magnetic field: $B \sim 10$ nG , RM ~ 7 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



O'Sullivan et al. (2015)



Akahori et al. (2014)

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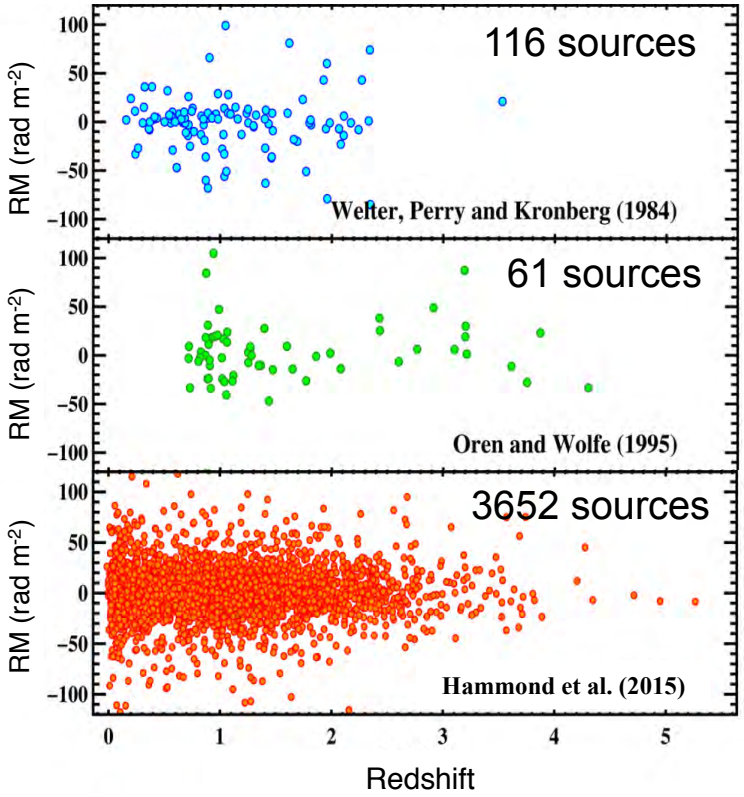
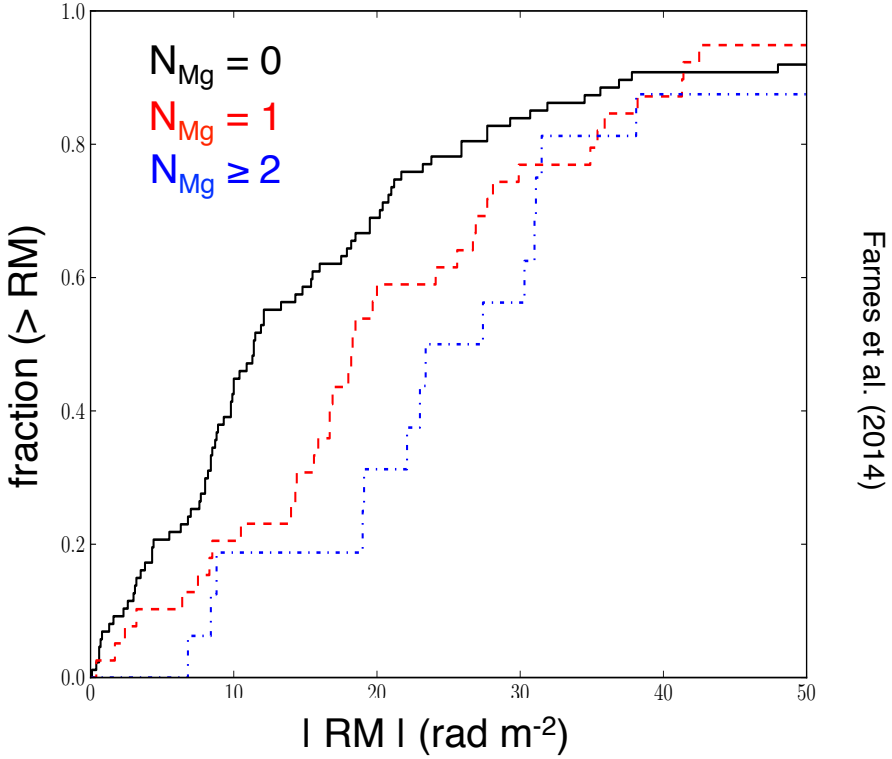
Magnetism Over Cosmic Time

- 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





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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

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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 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)

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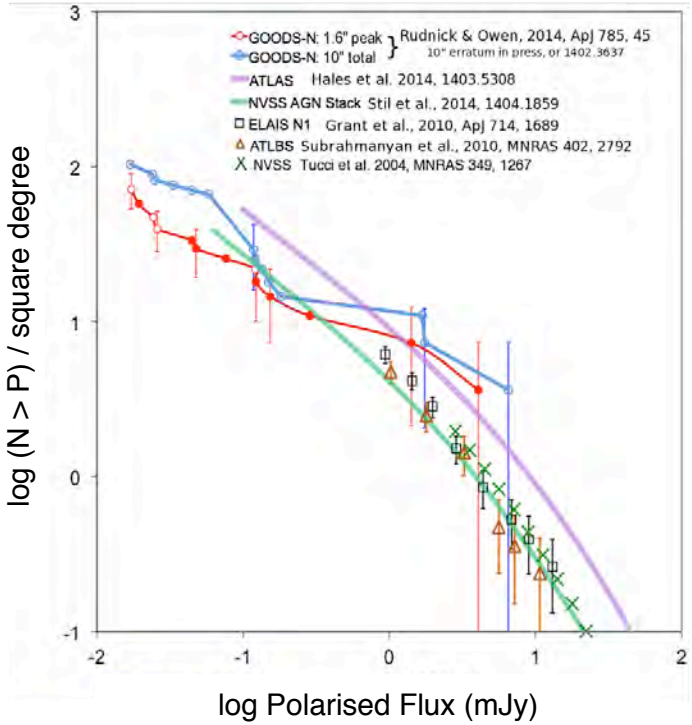
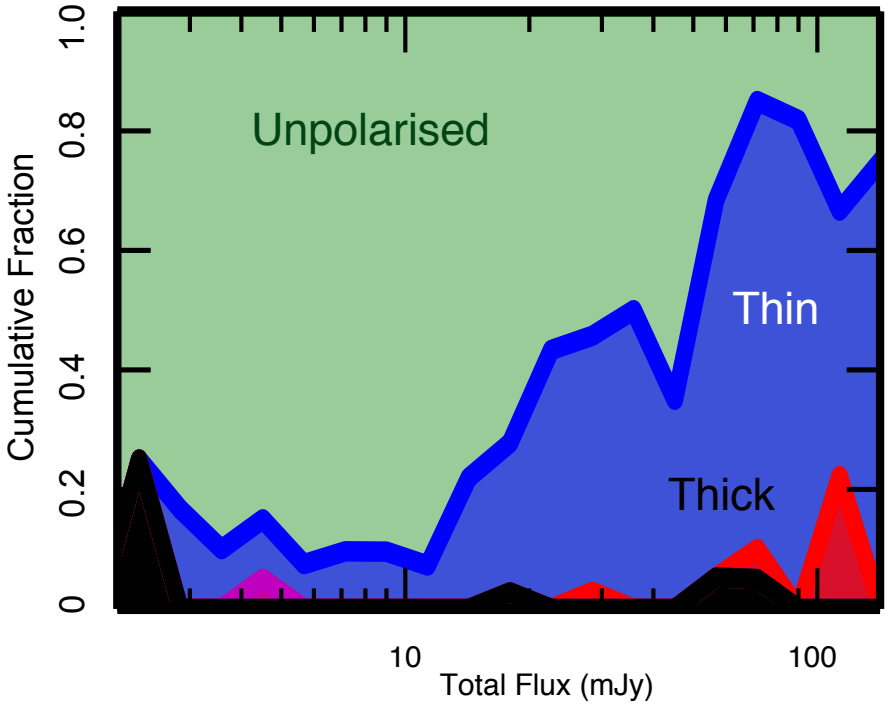
Current Investigations: Source Counts

- 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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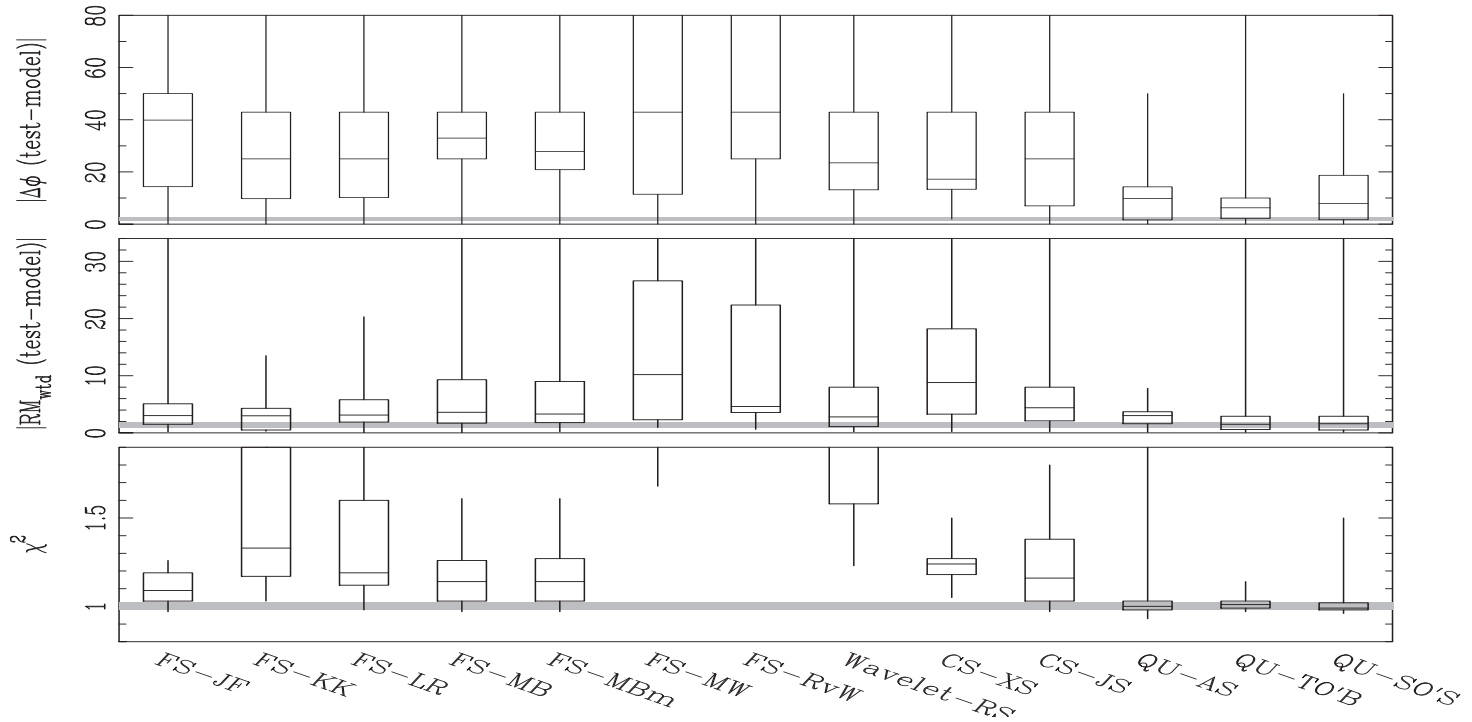
Current Investigations: Faraday Thick Sources

- 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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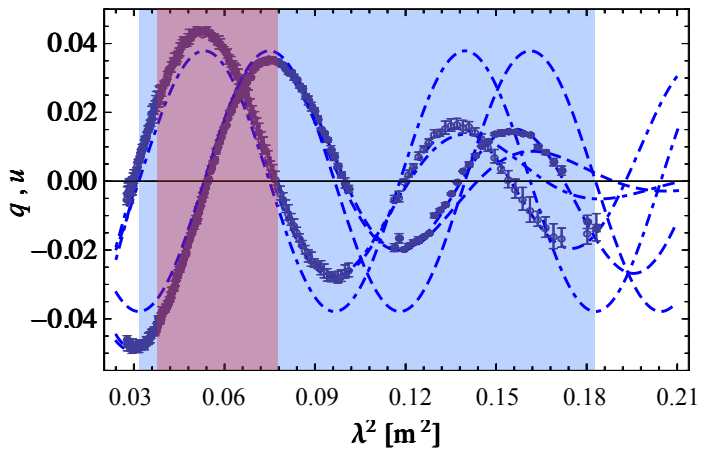
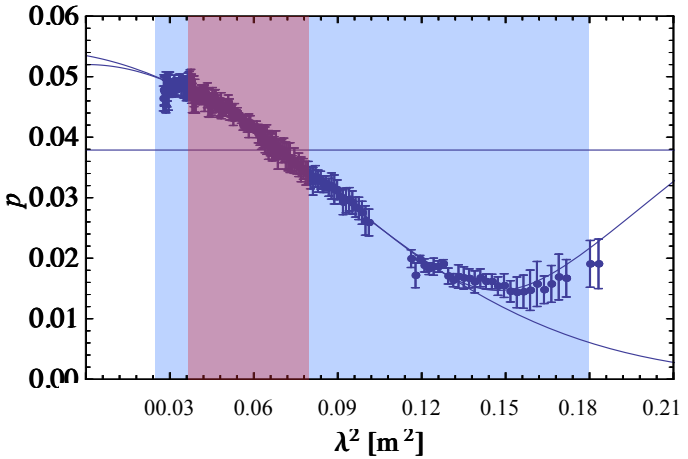
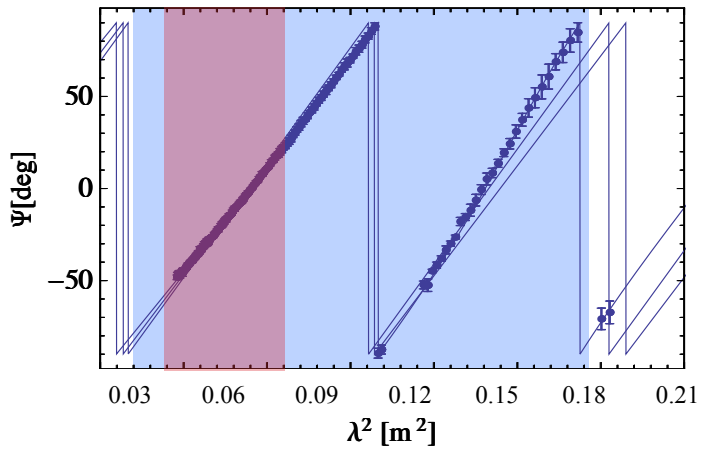
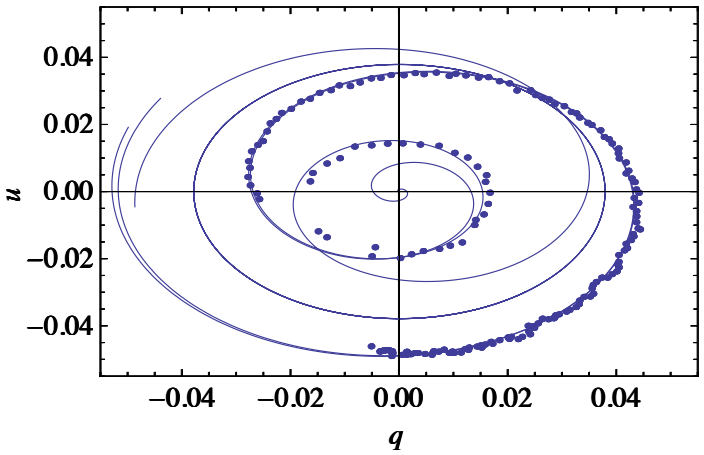
New Discovery Space with ASKAP Early Science

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









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

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!

Beck et al. / Hubble Heritage

CSIRO / Swinburne

Mihos / Huey / Science