POSSUM Newsletter 1

March 2012

From the PIs

Welcome to the long-awaited first edition of the POSSUM newsletter!

POSSUM is an ambitious project that aims to dramatically improve our understanding of cosmic magnetism. Motivated by ASKAP's unique wide-field survey capabilities, we aim to make detailed measurements of polarisation and Faraday rotation over 30,000 square degrees of the sky, the data from which will provide (amongst other things) the rotation measures (RMs) for more than 3 million extragalactic sources. With the resulting data, we aim to revolutionise our understanding of the ordered and turbulent components of the Milky Way's magnetic field, to test dynamo and other models for magnetic field generation in galaxies and clusters, and to carry out a comprehensive census of magnetic fields as a function of redshift in galaxies, active galactic nuclei, galaxy clusters and the overall intergalactic medium.

POSSUM is a complex project that will require several years of preparation, execution and analysis. The POSSUM team made enormous progress in 2011, with the completion of more than 20 memos and reports submitted to CSIRO, along with five refereed papers on associated techniques, simulations and pilot studies. At the annual internal review of ASKAP survey science projects conducted in November 2011, the review committee reported that they were extremely impressed by the extensive technical work that POSSUM had performed in many areas of relevance to the POSSUM design study. This work included simulations of the ASKAP primary beam over 500-MHz bandwidth, development of metrics for source-finding in Faraday depth space, modelling of ionospheric Faraday rotation, and detailed planning of initial commissioning observations of the ASKAP system. CSIRO's review committee especially highlighted the work led by Shane O'Sullivan on ASKAP polarisation calibrators, which they praised for its high quality, timeliness and utility.

Even bigger things are expected in 2012, with the addition of many new staff and students to the POSSUM team, plus the anticipated arrival of the first data from BETA later in the year. Some of the major milestones anticipated for the year ahead include the first version of an integrated polarisation pipeline, initial tests of correction for ionospheric Faraday rotation, identification of the optimum specifications for RM synthesis and RM clean, and of course initial commissioning of polarisation data for BETA. Some of the stories you can read about in this newsletter include: complex Faraday depth structure of polarised sources, sparse Faraday RM synthesis, Faraday synthesis and profiles of two new members of the POSSUM team, Cormac Purcell and Xiaohui Sun.

We will be holding a POSSUM workshop at CSIRO in Sydney over 7-11 May 2012, which we hope many of you will be able to attend – see http://askap.org/possum/Meetings/SydneyPossumWorkshop2012 for details. This meeting will have a strong science focus, with dedicated sessions each day to cover recent developments on polarisation and magnetic fields. In addition, we will assess and plan for all aspects of POSSUM, and will also get updates on related activities in other ASKAP surveys and in other polarisation projects.

We thank all of you who have so generously and enthusiastically contributed your ideas and energy to POSSUM so far, and look forward to working with you all again in 2012. We encourage you to submit reports on your activities and recent papers to future editions of this newsletter, so that our large and widely distributed team (70 researchers in 15 countries!) gets a feel for everything going on across the project.

Bryan Gaensler, Tom Landecker and Russ Taylor

POSSUM Activities

Complex Faraday depth structure of Active Galactic Nuclei as revealed by broadband radio polarimetry

Shane O'Sullivan, Shea Brown, Tim Robishaw, Dominic Schnitzeler, Naomi McClure-Griffiths, Ilana Feain, Russ Taylor, Bryan Gaensler, Tom Landecker, Lisa Harvey-Smith and Ettore Carretti

We present a detailed study of the polarisation and RM properties of four bright, unresolved and strongly polarised quasars. These sources were observed by the Australia Telescope Compact Array (ATCA) with the Compact Array Broadband Backend (CABB) 16-cm system in the 6A array configuration as part of a larger project to find suitable polarisation calibrators for ASKAP (see POSSUM Report #13 for details). By fitting various Faraday rotation models to the data, we conclusively demonstrate that two sources (PKS B1610-771 and PKS B1039-47) cannot be described by a simple RM component modified by depolarisation from a foreground Faraday screen. For PKS B1610-771, two RM components are required to describe the Faraday structure as shown in Figure 1.

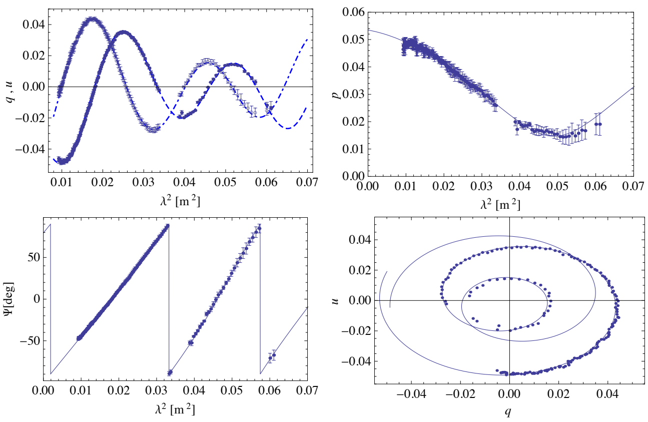

Figure 1: Polarisation data for PKS B1610-771 (points) and the corresponding best-fit two-component model (lines).

Our results have two important implications: (1) RM synthesis and RM clean do not recover the correct RMs for sources with multiple RM components within the FWHM of the rotation measure spread function (RMSF). Modelling of both the polarisation angle and degree of polarisation dependences with wavelength squared is essential in determining the true Faraday depth structure. (2) RM estimations from narrow-band observations, which is the case for most of the currently available database, can give erroneous results in the presence of multiple interfering Faraday components.

Follow-up, high spatial resolution observations will directly probe the origin of the multiple RM components.

O'Sullivan et al. 2012, MNRAS, in press

Sparse Faraday RM Synthesis

Mircea Andrecut, Jeroen Stil and Russ Taylor

The RM synthesis can give erroneous results in the presence of complex Faraday structures. It is therefore crucial to develop robust deconvolution methods for the recovery of the Faraday dispersion function.

We propose a greedy algorithm to solve the deconvolution problem. We assume that the complex Faraday dispersion function can be approximated by a small number of discrete components from an overcomplete dictionary. The deconvolution now turns out to be a sparse optimisation problem, which we employ the Matching Pursuit (MP) algorithm to solve. The RM-MP method can be efficiently used in a multi-scaling context, and it can easily include different types of analysis functions.

Figure 2 shows one of the complex Faraday depth spectra in our simulations, with one Faraday thin component and two Faraday thick components. RM clean does not recover the structure in such case. Our approach recovers the input model with component dictionaries for which the multi-scale analysis (top panel) has converged.

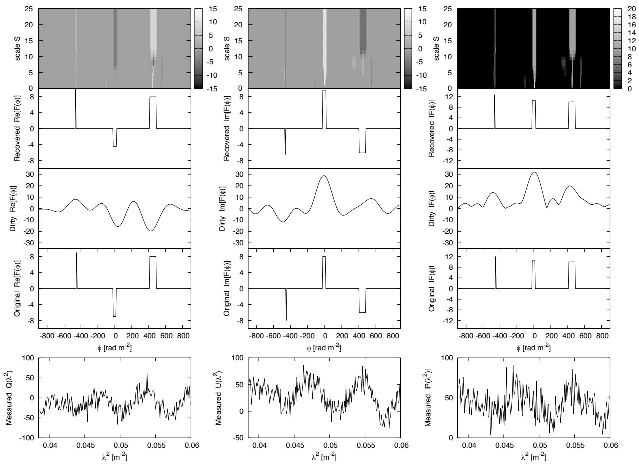

Figure 2: From the bottom to the top: measured data; input Faraday dispersion function $F(\varphi)$; dirty $F(\varphi)$ calculated from RM synthesis; RM-MP algorithm recovered $F(\varphi)$; multi-scale representation of the solution.

If the separation of two components is smaller than the half-maximum of the main peak of the RMSF, the RM-MP algorithm cannot resolve the components correctly, but returns a boxcar function with a width equal to the separation between the two components.

This method will soon be tested for POSSUM.

Andrecut et al. 2012, ApJ, 143, 33

Faraday synthesis: The synergy of aperture and rotation measure synthesis

Michael Bell and Torsten Enßlin

We introduce a new technique for imaging the polarised radio sky using interferometric data. The new approach, which we call Faraday synthesis, combines aperture and rotation measure synthesis imaging and deconvolution into a single algorithm. This has several inherent advantages over the traditional two-step technique, including improved sky plane resolution, fidelity, and dynamic range. In addition, the direct visibility- to Faraday-space imaging approach is a more sound foundation on which to build more sophisticated deconvolution or inference algorithms. For testing purposes, we have implemented a basic Faraday synthesis imaging software package including a three-dimensional clean deconvolution algorithm. We compare the results of this new technique to those of the traditional approach using mock data (Figure 3).

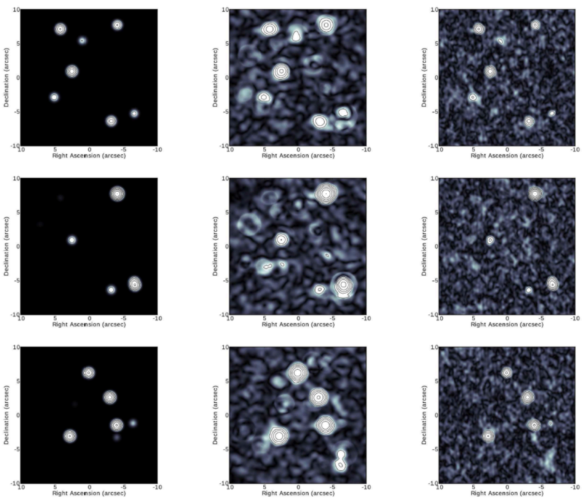

Figure 3: Left: the model image convolved with a Gaussian. Middle: the traditional 2+1D reconstruction. Right: the Faraday synthesis reconstruction. From top to bottom, the Faraday depth is: -205, -160 and 200 rad m^{-2}.

We find many artefacts in the images made using the traditional approach that are not present in the Faraday synthesis results. In all, we achieve a higher spatial resolution, an improvement in dynamic range of about 20%, and a more accurate reconstruction of low signal to noise source fluxes when using the Faraday synthesis technique.

The feasibility of applying the method to POSSM is to be tested.

Bell & Enßlin 2011, A&A submitted (arxiv:1112.4175).

Characterising polarisation of the BETA test fields

Craig Anderson, a PhD student at The University of Sydney, is leading the analysis of polarisation data from the ATCA observations of the two BETA test fields: one is toward the Circinus Galaxy and part of the Galactic plane, while the other is an extragalactic field toward the Fornax cluster. The CABB 16-cm system was used, with a frequency range 1.1-3.1GHz that fully encompassed the planned POSSUM bandpass.

Initial focus has been on the pointing toward Fornax. Multi-frequency images of the entire field have been made in all four Stokes parameters, at 8-MHz increments. Over 1200 sources have been detected in Stokes I (to 10-sigma), of which ~15% show significant linear polarisation. We are in the process of applying RM synthesis and RM clean to all 1200 sources (regardless of whether they appear polarised), to assess the thresholds for polarisation detection, and to build up a large database of Faraday depth spectra showing both simple and complex behaviour. An example of the high-quality Faraday depth spectra resulting from this data set is shown in Figure 4.

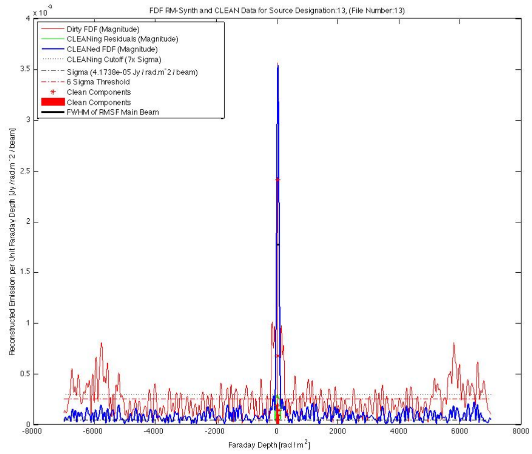

Figure 4: Faraday depth spectrum of a polarised source over the 2-GHz CABB bandwidth.

We can further assess the extent to which complex Faraday depth structure will be recovered over the POSSUM bandpass.

Profile – Cormac Purcell & Xiaohui Sun

Cormac and Xiaohui are two new postdocs at the University of Sydney working for POSSUM. Cormac received his PhD from UNSW in 2007, and has been involved in two large surveys: CORNISH and HOPS. Xiaohui received his PhD from NAOC in 2006, and has been involved in the Sino-German 6cm polarisation survey of the Galactic plane.

What are your main research interests?

C: All aspects of high-mass star-formation.
X: Magnetic fields and radio polarimetry.

What excites you about POSSUM?

C: It will provide the first dataset capable of examining magnetic structure in the Galaxy on scales spanning the whole Galaxy down to individual HII regions. The combination of new telescopes and

advances in computing, and modelling herald a paradigm shift magnetic field research.
X: The potential that it can significantly advance our understanding of cosmic magnetism, and the opportunity to work with most of the big figures in this field.

What tasks are you undertaking for POSSUM?

C: Integrating the various modules of the POSSUM pipeline into a cohesive whole.
X: Optimum RM synthesis specification and extraction of parameters from Faraday depth spectra.

What are the main challenges for your current tasks?

C: The pipeline modules have been written by individuals in a variety of language, or simply written up as descriptions of algorithms. I need to efficiently implement them into a prototype pipeline.
X: Some Faraday spectra are very complex, which we are struggling to understand. New approaches such as compressive sampling have to be developed.

What other papers are you working on?

C: A key S-PASS paper on the magnetic field of the Gum nebula, the nearest and largest magnetic bubble to the Sun.
X: Combining the polarisation data from SPASS, the Sino-German 6cm and the Effelsberg 11cm surveys to study a region near in the inner Galaxy.

What do you enjoy outside work?

C: Nothing better than to head off into the wild: camping, bushwalking, canyoning, kayacking and climbing.
X: Watching soccer and basketball matches. Playing with my daughter.

Other Related Science Results

RM due to the intergalactic magnetic field

Takuya Akahori and Dongsu Ryu

We recently published two ApJ papers about RM due to the intergalactic magnetic field (IGMF) in filaments of galaxies (Figure 5).

We found that the rms value of the RMs is ~1-10 rad m^{-2}, and the structure function (SF) of the RMs has a flat profile with an amplitude of 100-200 rad m^{-2} in angular separations of >0.2°, suggesting that the IGMF significantly contributes to the RMs toward lsGalactic poles particularly at small angular scales. We are now estimating Galactic foreground of RMs, by incorporating results of 3D MHD turbulence simulations.

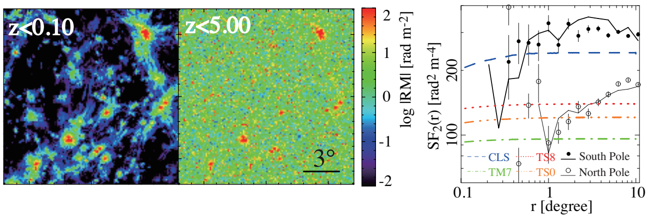

Figure 5: Left and middle: RM maps due to the IGMF integrated up to the shown redshifts. Right: Second-order SFs of RMs.

Akahori & Ryu 2010, ApJ, 723, 476
Akahori & Ryu 2011, ApJ, 738, 134

An improved map of the Galactic Faraday sky

N. Oppermann, H. Junklewitz, G. Robbers, M. R. Bell, T. A. Enßlin, A. Bonafede, R. Braun, J. C. Brown, T. E. Clarke, I. J. Feain, B. M. Gaensler, A. Hammond, L. Harvey-Smith, G. Held, M. Johston-Hollitt, U. Klein, P. P. Kronberg, S. A. Mao, N. M. McClure-Griffiths, S. P. O'Sullivan, L. Pratley, T. Robishaw, S. Roy, D. H. F. M. Schnitzeler, C. Sotomayor-Beltran, J. Stevens, J. M. Stil, C. Sunstrum, A. Tanna, A. R. Taylor, C. L. Van Eck

We have assembled the most extensive catalogue of Faraday rotation data of compact extragalactic polarised radio sources to date. We use a recently developed algorithm that reconstructs the map and the power spectrum of a statistically isotropic and homogeneous field while taking into account uncertainties in the noise statistics. The resulting map (Figure 6) can be seen as an improved version of earlier such maps and is made publicly available, along with a map of its uncertainty.

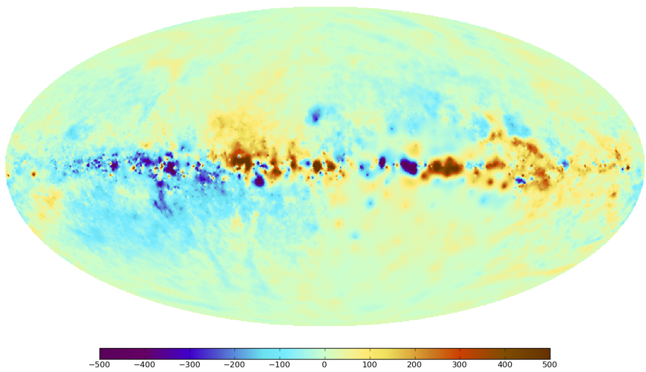

Figure 6: All-sky map of the Galactic Faraday depth.

Oppermann et al. 2011, A&A submitted (arxiv: 1111.6186)

Upcoming meetings

POSSUM workshop

CASS, Sydney, May 7-11, 2012

http://askap.org/possum/Meetings/SydneyPossumWorkshop2012