Faraday Rotation Observations Mapping Group Evolution (FROMaGE)

Contacts: Jane Kaczmarek & Eric Wilcots
jane@physics.usyd.edu.au – ewilcots@astro.wisc.edu

Scientific Aims:

The Universe is magnetised on all scales – from the interior of stars to the diffuse intracluster medium. While we now have a deeper understanding of how large-scale fields in individual galaxies grow, our knowledge of the origin and evolution of Mpc-scale magnetic fields in the large scale structure of the Universe is extremely limited. This legacy project aims to make significant progress towards answering this overarching question by investigating the polarised nature of the building blocks from which galaxy clusters are built: galaxy groups. This research will answer fundamental questions about magnetism in galaxy groups:

- What is the strength and morphology of intragroup medium magnetic fields?
- What role do magnetic fields play in the evolution of the group environment?

Galaxy groups are a unique class of cosmic environment: they host up to 60% of the galaxies in the Universe and halo masses span the range between that of the largest galaxies ($10^{12}\,M_{\odot}$) and that of galaxy clusters ($10^{15}\,M_{\odot}$). As a consequence, interactions give rise to increased star formation rates and a smattering of tidal debris diffused throughout the intragroup medium (IGrM) (Donahue et al. 1995). These phenomena, along with galactic winds and active galactic nuclei, have been suggested as mechanisms by which magnetic fields can be expelled from a galaxy into their surrounding medium (Menon 1995; Chyzy & Beck 2004; Kronberg et al. 1999; Bertone et al. 2006). Observing them conveniently offers astronomers insight as to how magnetic fields can affect, and be affected by, galaxy evolution.

However, magnetism of the intragroup medium remains as one of the least studied aspects of galaxy groups. Until recently, there lacked a large sample of galaxy groups with spectroscopic redshifts that could be targeted for a dedicated survey, especially in the southern hemisphere. There has been some evidence of diffuse synchrotron emission originating in the IGrM of poor clusters (Brown & Rudnick 2009; Giovannini et al. 2011). Yet detailed investigations have been hindered due to the relatively low thermal electron density comprising the diffuse IGrM, making it difficult for past telescopes to confidently detect any existing field. To date, observations of magnetic fields in galaxy groups have been limited to the observations of tidal bridges at discrete and/or narrow bandwidths (Nikiel-Wroczynski et al. 2013a,b; Xu et al. 2003; Condon et al. 1993). With the advent of broad bandwidth observations, such as those offered with the ATCA and CABB, astronomers are entering a new scientific era making it possible to carry out an in-depth investigation of magnetism in galaxy groups for the first time.

The FROMaGE legacy survey will use the broad bandwidth of the ATCA to map polarisation and Faraday rotation across a large number of galaxy groups below $\delta = -20^{\circ}$. By observing polarised background sources that shine through the intervening intragroup medium, in addition to mapping continuum emission of the groups members, we will gain valuable insight into the growth of magnetism on cosmic scales. The FROMaGE dataset will be complimentary to those generated by SKA precursors as we will increase the frequency coverage from ASKAP's 700 - 1800 MHz and MeerKAT's 1000 - 1750 MHz to 1100 - 8100 MHz. Broad frequency coverage is of vital importance for any polarisation research, as the signal depends on λ^2. Additionally, by increasing the central frequency of our observations, we will be avoiding strong depolarisation in our signal that tends to occur at the lowest frequencies. The FROMaGE survey aims to carry out SKA-era science before the SKA and will result in a unique dataset that will remain unrivalled for years to come.

Observing Strategy:

We propose to observe a diverse sample of southern hemisphere galaxy groups to measure the strength and morphology of synchrotron emission within the group and the intragroup medium. We will aim to investigate the magnetic field across a range of dark matter halo masses, therefore probing the polarisation across groups as they grow and accrete more galaxies, which in turn leads to the growth of large scale structure.

We have constructed a preliminary target list by cross-matching the uniform, all sky group catalogue of Tully (2015) with the ROSAT All-Sky Survey for groups $\delta \leq -20^{\circ}$ with 5 or more group members. Of the 362 groups that met this initial criteria, 62 contain diffuse X-ray emission projected in the area of the known groups location. Each of these 62 galaxy groups have an angular scale of 30 arcminutes or more on the sky. By choosing to target only galaxy groups with X-ray emission, it guarantees the existence of a magnetic field in the intervening medium between the group member galaxies. Additionally, the X-ray data will provide a thermal electron density for each group, which is otherwise left as a free parameter for estimates of the intervening magnetic field strength. A subset of this target list is shown in Table 1.

Observations and analyses of Faraday Rotation rely critically on λ^2 coverage, therefore ATCA in conjunction with CABB is an ideal telescope to recover the true polarised nature of the diffuse IGrM. Using the continuous bandwidth offered with

Target Group	RA (J2000)	Dec (J2000)	N	Extent (arcmin)	R_X (arcmin)	Pointings (16 cm)	$\tau_{2100MHz}$ (hours)
IC 1860	02:49:33.4	-31:11:27.1	28	30	18	30	70
NGC 3923	11:50:29.7	-28:39:20.5	30	200	8	600	1400
HCG 90	22:01:59.5	-31:57:50.4	16	100	10	150	350
IC 1459	22:57:7.15	-36:31:11.5	5	70	12	70	160

Table 1: A small sample of proposed legacy targets. The columns indicate the following. (1) Group name. (2) Right Ascension and (3) Declination. (4) Number of group members (see Mulchaey et al. 2003 and references therein for membership justification). (5) Projected radial extent considering average redshift (see Brough et al. 2006 for radial extent justification). (6) Outer radius of detected X-ray emission from ROSAT (Mulchaey et al. 2003). (7) Estimated number of mosaic pointings for observations centered at 16 cm with a total observing area equivalent to a radius equal to the extent of the group (column 5). (8) Estimated total number of observing time required at the 2100 MHz band, in hours, assuming a rms sensitivity of 50μJy b^{-1}. See text for justification of observing area. Note that times are considered an upper limit.

CABB, we will observe each of the galaxy groups from 1100 - 3100 MHz and 4100 - 8100 MHz. Observing over this large frequency range will make it possible to decouple the various Faraday depth contributions from the integrated polarised signal along the line of sight.

Our scientific goals require the observation of both point-like background sources in addition to diffuse radio structures within each group; therefore, we will request that time be allocated in the 1.5km and 750m array configurations. Majority of the targeted groups have declinations below $\delta < -24°$; therefore, full (u,v)-coverage will be attainable for nearly all targets. Considering the large projected sizes of the groups, we will propose to Nyquist sample each galaxy group spanning 1100 - 3100 MHz in order to achieve complete coverage of the diffuse intragroup medium. From these initial observations, we will generate a list of point-like and diffuse structures associated with each group and follow these up with targeted observations at 4100 - 8100 MHz. This approach significantly reduces the observational overhead while still covering all of the interesting sources in the field.

In order to adequately probe the IGrM of a group, we will need to observe multiple polarised background sources for each galaxy group. In order to observe $\sim$1 background source per square arcminute, we will need to observe to a flux density of 10 mJy b^{-1}. We will conservatively assume that the average flux density of the background emission translates to a 15% polarisation level of the source (Beck & Gaensler 2004). In order to definitively reconstruct the Faraday depth, polarisation needs to be detected to at least 15σ and we therefore aim to achieve an rms noise level of $\sim 50\mu$Jy b^{-1}. This sensitivity requires 140 and 60 minutes of total integration, per pointing for the 2100 and 5500 MHz bands, respectively.

We intend to update and refine our observing estimates for future proposals through detailed modelling of the expected signal to confirm our sensitivity limits and refine our detection techniques. Furthermore, mosaics will be built to cover the minimum enclosed area of each group, significantly reducing the number of pointings required.

We aim to create science-ready datasets as quickly as possible. We will achieve this by combining our science with some of the results from POSSUM. In doing so, we are able to avoid the requirement of observing additional off-source targets for a foreground correction to our groups Faraday depth values. Our observing approach will be to target a small sample of galaxy groups as a proof-of-concept in the early semesters of the legacy program and we will adapt and modify our future targets to maximise our science goals.

Team members:

Jane Kaczmarek, Eric Wilcots, Kelley Hess, John Mulchaey, Cormac Purcell, Jamie Stevens, Anna Williams, Ellen Zweibel

Resources:

FROMaGE survey members consists of a core team of experienced ATCA observers (Kaczmarek, Stevens, Purcell, Wilcots, Hess, Williams), the foremost experts on modelling Faraday active media (Kaczmarek, Purcell, Williams), and a core group with expertise in magnetic fields (Zweibel) and galaxy groups (Mulchaey, Hess, Wilcots). In addition to those resources available at the ATNF, the team will have access to the Advanced Computing Initiative at the University of Wisconsin-Madison for data storage and processing. If the results of FROMaGE require complementary optical observations, the team also has access to the Carnegie Observatories (Mulchaey) and the Southern African Large Telescope (Wilcots, Zweibel). We anticipate having at least one graduate student, in addition to Williams, from the University of Wisconsin involved in this project.

References: Beck, R. & Gaensler, B. M., 2004 NAR, **48**, 1289 • Bertone, S., et al. 2006, MNRAS, **370**, 319 • Brough, S. et al. 2006, MNRAS, **370**, 1223 • Brown, S. & Rudnick, L. 2009, AJ, **137**, 3158 • Chyzy, K. T., & Beck, R. 2004, A&A, **417**, 541 • Condon J. J., et al. AJ, **105**, 1730 • Donahue, M. et al. 1995, ApJ, 450, 45 • Giovannini, G. et al. 2011, A&A, **530**, 5 • Kronberg, P. P., et al. 1999, ApJ, **511**, 56 • Menon, T. K. 1995a, MNRAS, **274**, 845 • Mulchaey J. S., et al. 2003, ApJS, **145**, 39 • Nikiel-Wroczynski B., et al. 2013, MNRAS, **435**, 149 • Nikiel-Wroczynski B., et al. 2013, A&A, **553**, A4 • Tully, R. B. 2015, AJ, **149**, 171 • Xu, C. K., et al. 2003, ApJ, **595**, 665