GAMA Legacy ATCA Southern Survey (GLASS): A Legacy 4cm Survey of the GAMA G23 Field

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1. Abstract

The new 4cm receivers and CABB backend on ATCA represent an unprecedented opportunity to explore star formation and active galactic nuclei (AGN) at 4.5 to 10.5 GHz. We propose a deep (30 μJy rms) and wide (60 sq deg) 4cm (5.5 and 9.5 GHz) survey of the GAMA G23 field to complement the existing and forthcoming multi-wavelength data in this field. These observations will enable a wide range of galaxy evolution science but in particular we will study the evolution of radio-loud AGN using spectral aging and radio morphologies, and calibrate thermal and non-thermal radio measures of star formation.

2. Scientific Aims

This legacy survey will study AGN and SF activity using sensitive radio data of the well-studied GAMA G23 field. The main science focus is as follows.

2.1 Evolution of Radio-Loud AGN: Spectral Energy Distributions and Morphology

Radio-loud AGN can be classified into well-defined groups separated by radio morphology, radio luminosity and physical size. The latter is generally assumed to be proportional to age. The smallest radio galaxies are Compact Steep Spectrum (CSS) and Gigahertz Peaked Spectrum (GPS) sources, which are small (< 10 kpc) radio sources embedded in their host galaxies. CSS and GPS sources are thought to be young radio galaxies just starting to emit powerful radio jets. As the radio galaxy evolves, its relativistic jets extend into the inter-galactic (IGM) and intra-cluster (ICM) medium, forming two distinct morphological classes, FRI and FRII radio galaxies (Fanaroff & Riley 1974; Carvalho 1985; Snellen 1999, 2000). However, many questions remain, such as, why don't all radio galaxies reach the FRI-FRII stage, and indeed, why don't all galaxies become giant radio galaxies ($\gtrsim$ Mpc)? The age of radio galaxy jets/lobes can be estimated from its spectral energy distribution. The GAMA G23 field has radio measurements from GLEAM/MWA (70-230 MHz), SUMSS (845 MHz), NVSS (1.4 GHz), and (in the near future) EMU/ASKAP (1.4 GHz). Combined with these proposed observations at 5.5 and 9.5 GHz, almost 2 decades in frequency is covered, and this enables detailed spectral energy distribution analysis to i) select CSS and GPS sources, and ii) determine the spectral ages of the radio lobes. The detailed morphological (FRI vs FRII) and size information from arcsec resolution achieved by ATCA will allow detailed constraints on AGN jet models, and population counts (i.e. $N(z)$) will allow an investigation of AGN duty cycles. Furthermore, the GAMA team have detailed clustering analysis to allow for the study of radio AGN populations with host environment.

2.2 Tracing Star Formation With Thermal Radio Emission

Radio emission from galaxies is a powerful tracer of star formation (SF) as it is not attenuated by dust. Deep radio surveys from the Square Kilometre Array (SKA) and its pathfinders will be dominated by star forming galaxies and hence will provide the most detailed measurements of the star formation history of the Universe yet. Radio continuum measures of SF rely on the conversion of monochromatic 1.4 GHz flux density to star formation rate (SFR) (e.g. Condon 1992, Kennicutt & Evans 2012). At 1.4 GHz the radio continuum is dominated by non-thermal synchrotron radiation from electrons accelerated by supernovae. This non-thermal radio emission is a non-instantaneous tracer of star formation, and in many cases the conversion relies on FIR-radio correlation, which is only well determined locally. While some work has been done on the FIR-radio correlation at high redshift (e.g. Ivison et al. 2010, Mao et al. 2011) there is a large amount of scatter. Furthermore, at high redshift non-thermal radio emission can be suppressed by inverse-Compton losses against the CMB which scale as $(1+z)^4$.

Thermal free-free emission in HII regions also contributes to radio continuum emission. At 1.4 GHz thermal emission only makes up $\sim$10% of the total radio emission, but at 10 GHz the fraction is about 1/3 for a typical star forming galaxy, and thermal emission dominates at >30 GHz. For high redshift ($z > 2$) sources the rest-frame frequency probed by 9.5 GHz observations is therefore in the thermal regime. Despite being a more direct tracer of star formation than non-thermal radio emission, few studies have looked in detail at thermal radio emission. We will use the 5.5 and 9.5 GHz observations to decompose the radio continuum emission into thermal and non-thermal components. We will use all the various measures of SFR from the GAMA multiwavelength data (Davies et al. MNRAS submitted), from UV to Hα to FIR, to calibrate the thermal and non-thermal radio continuum SFRs. With a 5σ limit of 250 μJy, thermal emission could be detected from ultra-luminous infrared galaxies (ULIRGs) to $z \sim 0.5$, and luminous infrared galaxies (LIRGs) to $z \sim 0.2$ (Murphy 2009).

3. Legacy Value

The GAMA survey is a unique multi- wavelength survey including optical spectroscopy of ∼240,000 galaxies complete to a limiting apparent magnitude of r $<$ 19.8 and median redshift of z $\sim$ 0.3. Our target field is the southern GAMA field observable by ATCA, G23. GAMA has 60,000 spectra in G23, with supporting multi-wavelength imaging in the UV to infrared bands from GALEX (UV), KiDS- VST (ugri), VIKING-VISTA (ZYJHKs), WISE (mid-infrared), and Herschel (far-infrared). It will also be observed by ASKAP as part of the EMU and DINGO Survey Science Projects. EMU Early Science is expected to begin in 2016 and the full survey in 2018. By adding 5.5 and 9.5 GHz data to this field, we will enhance the scientific return of the GAMA and EMU Surveys. While EMU is more sensitive, even in the early science phase, the proposed ATCA observations have greater resolution, allowing for more reliable counterpart identification and testing of matching algorithms used by the EMU team. The future WAVES survey also plans to target the GAMA G23 region, going to fainter magnitudes and with GAMA-like completeness to $z \sim 0.8$, with ∼0.5M redshifts expected.

4. Proposed Observations and Technical Considerations

We have extensive experience in wide-field mosaicing at 4cm from ATCA project C2028 (Huynh et al.). We will use a similar observing strategy for this legacy project. Using an efficient hexagonal mosaicing pattern, 1.2 sq deg can be covered by ∼210 pointings separated by 5 arcmin for Nyquist sampling at 5.5 GHz. In 5 × 12 (60) hour run, the 210 pointings will have approximately 25 × 30 sec cuts, leading to ∼44 μJy/beam rms sensitivity (robust=0 weighting), and ∼30 μJy/beam rms sensitivity after combining the overlapping pointings. The 25 cuts per pointing ensures good *uv* coverage for imaging. The full G23 field, 60 sq deg in size, will require 50 × 210 pointings, or 50 × 60 (3000) hours.

The second IF will take simultaneous data centered at 9.5 GHz. The estimated 9.5 GHz sensitivity for a single pointing, at the primary beam centre, is 50 μJy/beam. While the pointings will be optimised for 5.5 GHz our experience with C2028 is this will lead to only ∼25% increase in the rms for regions of the mosaic that are furthest from pointing centres. Hence the 9.5 GHz mosaic will have sensitivities of 50 – 65 μJy/beam rms.

Our total time request is therefore 3000 hours. This is 500 hours in each of 6 semesters, and the observations could be completed by Oct 2019. This would be timely as the EMU full survey is expected to begin in 2018.

Table 1: Observing Summary

RA (J2000)	Dec (J2000)	Frequency	Configuration	CABB Mode	Sensitivity
22:36:00 to 23:24:00	−30 to −35	5.5 & 9.5 GHz	6km (∼75%?) 1.5km (∼25%?)	CFB 1M (no zooms)	30 μJy/beam at 5.5 GHz 50 μJy/beam at 9.5 GHz

5. Representative Team Members and Resources

Minh Huynh (ICRAR/UWA, co-chair SKA Continuum Science Working Group and EMU core team member) • Nick Seymour (ICRAR/Curtin University, EMU co-Project Scientist, MWA GEG convenor) • Luke Davies, (ICRAR/UWA, GAMA team member, WAVES-Deep Project Scientist) • Aaron Robotham (ICRAR/UWA, GAMA Science Co-ordinator, WAVES-Wide Project Scientist) • Martin Meyer (ICRAR/UWA, co-chair SKA HI Science Working Group, DINGO PI and GAMA team member) • Stas Shabala (UTas, EMU team member) • Ray Norris (CSIRO, EMU PI) • Andrew Hopkins (AAO, EMU co-Project scientist, GAMA PI) • Anna Kapinska (ICRAR/UWA, MWA/GLEAM core team member, EMU project manager) • Ross Turner (UTas, EMU team member, PhD student) • Andrew Butler (ICRAR/UWA, PhD student) • Julie Banfield (ANU, EMU team member) • Elaine Sadler (USyd, GAMA team member) • Leith Godfrey (ASTRON, EMU team member) • Tim Galvin (WSU, PhD student) • Jordan Collier (WSU, EMU team member, PhD student) • Andrew O'Brien (WSU, EMU team member, PhD student)

The team members already identified comprise AGN and SF galaxy evolution experts. We have considerable ATCA expertise (Huynh, Seymour, Norris, Butler), especially Huynh who has made the largest 5.5 and 9.0 GHz mosaics at 10 μJy depths. The team includes key EMU, MWA, GAMA and WAVES members to maximise collaboration and science return. We also have theory expertise to derive radio galaxy duty cycles from the multi-frequency radio observations and GAMA clustering data (e.g. Turner & Shabala 2015).

ICRAR/UWA has a dedicated remote observing station which can be used by all WA team members to carry out the large amount of observing required for this project. ICRAR also has high performance computing facilities to store and process the ATCA data. The images and catalogues will be made public via the GAMA server.

ICRAR/UWA will offer PhD scholarships to work specifically on this project and we expect to have at least one HDR student whose research project is based on this data.