The ATCA-SAMI Cluster Survey

P.I.: Julie Banfield (ANU; julie.banfield@anu.edu.au)

1. Science and Legacy Value

Scientific Aims: This ATCA legacy project tackles one of the outstanding puzzles of astrophysics today – *How do galaxies and black holes co-evolve?* Combining observations at multiple wavelengths is essential for understanding the physics of galaxy evolution. This project will quantitatively measure the quenching of galaxies and the effect of radio mode quenching of star-formation at the massive end of the galaxy scale through the effect of radio-loud active galactic nuclei (AGN) on their host galaxy and their environment. We will combine data from the ATCA at 1 – 10 GHz with the unprecedented dynamical and environmental data available as part of the SAMI (Sydney-AAO Multi-object Integral-field spectrograph; Bryant et al. 2015) survey. This combination of data provides the necessary information to trace the environmental impact of a black hole on its environment and to connect the black hole to the physical properties of galaxies. We will target 6 SAMI cluster fields (Table 1) to:

(1) determine the extent of the interaction between radio-loud AGN and the cluster environment through the mixing of thermal material with the relativistic AGN lobe plasma via Faraday rotation measurements (i.e., Bicknell et al. 1990);
(2) measure environment-driven star formation histories of cluster galaxy members surrounding the radio-loud AGN to quantify the "sphere-of-influence" of the AGN and how much radio-loud outflows affect the star formation history of neighbouring galaxies (Shabala et al. 2011);
(3) measure the quenching of galaxies as they enter cluster environments via the processes of stripping, starvation and strangulation;
(4) time-stamp AGN feedback through spectral aging of the radio sources across the ATCA broadband; and
(5) measure the intra-cluster magnetic field through measurement of the rotation measure of polarized radio sources as a function of distance from the cluster centre.

Our secondary science goals are to:

(1) measure the HI absorption (or obtain upper limits) against the brightest background continuum sources to determine the HI column density in the ICM across each galaxy cluster;
(2) trace the shocks driven into the intra-cluster medium (ICM) by cluster mergers, observable as diffuse relic sources in the radio continuum; and
(3) measure the variable properties of AGN and the surrounding ICM through comparing multiple epochs of observations of radio-loud AGN within each cluster and rotation measure variations in background radio sources caused by changing ICM properties.

Legacy Value: The SAMI Galaxy Survey is unique. No other program (in press or planned) provides the wealth of specific galaxy information delivered for sources in a cluster environment provided by the detailed dynamical analysis from SAMI. Our ATCA legacy project will augment this powerful visible wavelength data set and provide the astronomical community with the required radio frequency data spanning 1 – 10 GHz. In the context of the dense cluster environment, for the the first time with detailed galaxy kinematic analysis, these new data allow fundamental hypotheses underpinning galaxy and cluster evolution (e.g., AGN feedback in a variety of cluster environments, environment driven star formation histories) to finally be tested directly. Alongside data from the SDSS, SkyMapper, AAOmega, VST/ATLAS, *WISE*, *ROSAT*, *Chandra*, *XMM-Newton* and MWA archives, these data will provide the final panchromatic pieces of the data puzzle to stimulate new observational methods and theoretical modelling to constrain and guide the physics of galaxy evolution.

A key technical component of our proposed observations will be the characterization of the 16cm and 4cm feeds for accurate polarization measurements. This technical study, undertaken by the leading experts at the ATNF as part of a focused science analysis, will define the tools and procedures necessary for the wider astronomical community to utilize the ATCA to its full potential.

Table 1: Properties of the 6 SAMI cluster fields including redshift, virial mass, cluster radius, LST ranges, and total required observing time per cluster field.

Target	RA J2000 (deg)	DEC J2000 (deg)	z	Virial Mass ($\times 10^{14} M_{sun}$)	3 x R_{200} (deg)	LST Range	Obs. Time (hours)
EDCC0442	6.381	-33.047	0.0494	4.5 ± 0.9	1.15	18:00 – 07:00	96 (16cm), 316 (4cm)
Abell0085	10.460	-9.303	0.0556	15.4 ± 1.9	1.89	19:00 – 06:30	96 (16cm), 316 (4cm)
Abell2399	329.389	-7.894	0.0582	6.0 ± 0.8	1.21	16:15 – 03:30	96 (16cm), 316 (4cm)
Abell3880	336.977	-30.575	0.0579	2.8 ± 0.6	0.97	16:00 – 05:00	96 (16cm), 316 (4cm)
APMCC0917	355.398	-29.236	0.0509	2.0 ± 0.5	0.94	17:15 – 06:00	96 (16cm), 316 (4cm)
Abell4038	356.895	-28.125	0.0297	2.9 ± 0.6	2.30	17:15 – 06:00	96 (16cm), 316 (4cm)

2. Technical Requirements: The radio emission from clusters is not well understood, and consists of 3 elements: (i) the radio emission from constituent galaxies, including tailed galaxies that are interacting with the gas; (ii) relics, caused by shock-excited electrons; and (iii) the diffuse halo emission. We will measure all three, thereby making a major impact on our overall understanding of the kinematics and energetics of clusters. To do so means we require both compact ATCA configurations and extend configurations.

Observational Parameters	
Frequency	16cm and 4cm CABB bands (1 – 10 GHz).
CABB Modes	**16cm:** IF 1 with 2048 x 1 MHz channels for radio continuum and IF 2 with 32 x 64 MHz channels with one zoom band centered on the cluster velocities to measure HI absorption. **4cm:** IF 1 at 5.5 GHz and IF 2 at 9.5 GHz with 2048 x 1 MHz channels.
Array configurations	5 array configurations (6, 1.5, 750, 375, any hybrid) with each configuration observed each semester throughout the project.
Sensitivity	5 μJy beam^{-1}, total HI mass per beam = 1- 2 x 10^9 solar masses, and SFR density of approx. 2 x 10^{-4} M_{sun} yr^{-1} kpc^{-2}.
Observing time	**2550 hours (total)** with 465 hours in the first semester to include feed characterisation (48 hours) and 417 hours per semester thereafter.

3. Representative team members and skills available: This is an Australian wide and international team of experts covering every aspect of the proposal.

Wide-field and wide-band calibration & imaging/mosaic including polarimetry	**Cluster Physics**
Julie Banfield^ (ANU)	Scott Croom^ (USyd)
Miroslav Filipovic (UWS)	Alastair Edge^ (Durham)
Tom Franzen (ICRAR/Curtin)	Chiara Ferrari (OCA)
Minh Huynh (ICRAR/UWA)	Anush Gupta (ANU)
Shane O'Sullivan (UNAM)	Melanie Johnston-Hollitt (Wellington)
Ray Norris (CASS)	Matt Owers^ (MQ/AAO)
Russ Taylor (Cape Town/Calgary)	Kevin Pimbblet (Hull/Monash)
Jeroen Stil (Calgary)	**AGN**
ATCA Technical Systems	Julia Bryant^ (USyd/AAO)
Dave McConnell (CASS)	Brent Groves^ (ANU)
Jamie Stevens (CASS)	Andrew Hopkins^ (AAO)
Mark Wieringa (CASS)	Elaine Sadler^ (USyd)
HI	Nick Seymour (ICRAR/Curtin)
Barbara Catinella^ (ICRAR/UWA)	Rob Sharp^ (ANU)
Luca Cortese^ (ICRAR/UWA)	**Theoretical Modelling**
Helga Denes (ANU)	Darren Croton^ (Swin)
Naomi McClure-Griffiths (ANU)	Stas Shabala (UTas)
Ivy Wong^ (ICRAR/UWA)	

^ SAMI team member

Specific team expertise not yet identified or non-standard ATCA capability required: We require accurate feed characterization for wide-field wide-band imaging including polarization. We have included an estimate of 48 hours in our total observing time. These observations will need to be completed at the beginning of the project in order to maximize our science output from the start of the legacy project.

Selected key publications illustrating the depth of skills available within the team:

- **Banfield** et al. (inc. **Norris, Taylor, Stil**) 2014, MNRAS, 444, 700
- Brown et al. (inc. **Catinella, Cortese**) 2015, MNRAS, 452, 2479
- **Bryant** et al. (inc. **Owers, Croom, Cortese, Croton, Hopkins, Sharp**) 2015, MNRAS 447, 2857
- **Catinella & Cortese** 2015, MNRAS, 446, 3526
- **Croton** et al. 2006, MNRAS, 365, 11
- **Croton** et al. 2016, ApJS, 222, 22
- **Denes** et al (inc. **Wong**) 2016, MNRAS, 455, 1294
- Fogarty et al. (inc. **Owers, Croom, Bryant, Cortese, Sharp**), 2014, MNRAS, 485, 503
- **Franzen** et al. (inc. **Banfield, Norris, Hopkins, Huynh**) 2015, MNRAS, 453, 4020
- Ho et al. (inc. **Groves, Sharp, Bryant, Cortese, Croom, Owers**) 2016, MNRAS, 457, 1257
- Hogan et al. (inc. **Edge, Sadler**) 2014, MNRAS, 453, 1223
- **Huynh** et al. (inc. **Hopkins, Norris, Seymour**) 2015, MNRAS, 454, 942
- **Norris** et al. (inc. **Hopkins, Johnston-Hollitt, Seymour, Banfield, Edge, Huynh, Pimbblet, Sharp**) PASA, 2011, 28, 215
- **O'Sullivan** et al. (inc. **McClure-Griffiths & Taylor**) 2012, MNRAS, 421, 3300
- **O'Sullivan** et al. (inc. **McClure-Griffiths**) 2013, MNRAS, 435, 311
- **O'Sullivan** et al. (inc. **Banfield**) 2015, ApJ, 806, 83
- **Pimbblet** et al. (inc. **Shabala**) 2014, 429, 1827
- Pratley et al. (inc. **Johnston-Hollitt**) 2013, MNRAS, 432, 243
- **Shabala** et al. 2011, MNRAS, 413, 2815
- Vollmer et al. (inc. **Wong**) 2012, A&A, 543, 33
- **Wong** et al. 2014, ApJ, 783, 109
- **Wong** et al. 2015, MNRAS, 447 3311
- Yoon et al. (inc. **Wong**) 2015, PKAS, 30, 495