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The SAMI Galaxy Survey: early data release and first science

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Abstract. The Sydney–AAO Multi-object Integral field spectrograph (SAMI) Galaxy Survey is an ongoing project to obtain spatially resolved spectroscopic observations of ∼3400 galaxies by mid-2016. To date, a total of ∼1000 galaxies have been observed, making the SAMI Galaxy Survey the largest integral field survey in existence. In July 2014 the early data release for the SAMI galaxy Survey occurred, with over 100 galaxies available to the community. The richness of the SAMI dataset allows a vast array of science. We highlight some of the early science results from the project, including the discovery and analysis of galactic winds, the distribution of fast and slow rotating early type galaxies, and the unification of galaxy scaling relations.

Keywords. galaxies: evolution – galaxies: kinematics and dynamics – galaxies: structure – techniques: imaging spectroscopy

1. Introduction

Highly multiplexed spectroscopic galaxy surveys, such as the 2dF Galaxy Survey (Colless *et al.* 2001), the Sloan Digital Sky Survey (SDSS; York *et al.* 2000) and the Galaxy And Mass Assembly (GAMA; Driver *et al.* 2011) survey, are powerful tools for investigating galaxy evolution. However, they are limited by only observing a single aperture in the centre of each galaxy, so are inherently unable to investigate the spatially distributed properties of galaxies. Integral field spectrographs (IFSs) provide this missing information. The spatially resolved spectroscopic data produced by an IFS can be used to measure an enormous range of quantities, including the kinematics of gas and stars, spatially varying ionization states, stellar age and metallicity distributions, the location of current star formation and much more. Until recently, technical limitations made IFS observations of large samples time-consuming, as each object was targeted one at a time. Despite this, spectacular scientific progress has been made with samples such as ATLAS-3D (Cappellari *et al.* 2011) and CALIFA (Sánchez *et al.* 2012).

A major leap forward is now possible due to instruments that can make IFS observations of multiple objects at once. The Sydney–AAO Multi-object Integral field spectrograph (SAMI) is one of the first instruments in this class, with thirteen 15″diameter integral field units (IFUs) deployed across a 1-degree field (Croom *et al.* 2012). Each IFU consists of a bundle of 61 optical fibres lightly fused to have a high (∼75%) filling factor (Bryant *et al.* 2014a). SAMI is installed on the 3.9-m Anglo-Australian Telescope, feeding the existing AAOmega spectrograph (Sharp *et al.* 2006).

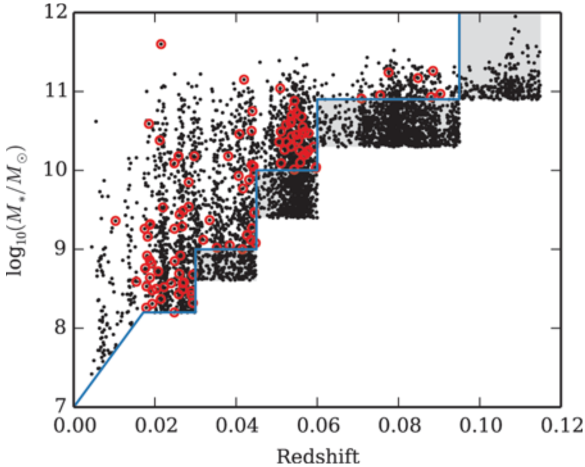

Figure 1. Stellar mass and redshift for all galaxies in the GAMA regions of the SAMI Galaxy Survey (black points) and those in the EDR sample (red circles). The area above the blue boundary indicates the primary sample, while the shaded regions indicate lower-priority targets.

2. The SAMI Galaxy Survey

The SAMI Galaxy Survey will obtain integral field spectroscopic data for ∼3400 galaxies, with an expected completion date of mid-2016. At the time of writing, ∼1000 galaxies have been observed, including the pilot survey of ∼100 galaxies. The overarching science questions for the project are:

• What are the primary physical mechanisms causing environmental suppression of star formation and morphological changes in galaxies?

• How common are inflows and outflows of gas and how do they influence galaxy properties?

• How is angular momentum distributed in the galaxy population and how is mass built up?

AAOmega is a double-beam spectrograph, and for our project we use a 580V grating in the blue arm, giving a resolution $R \sim 1700$ over 3700–5700Å, while the 1000R grating in the red arm results in $R \sim 4500$ over 6300–7400Å. This setup provides an excellent balance, accessing the many emission and absorption features in the blue, but also providing enhanced resolution around the Hα and [N II] emission lines in the red.

The target galaxies for the SAMI Galaxy Survey are split into two samples: a volume-limited field and group sample from the Galaxy And Mass Assembly (GAMA; Driver *et al.* 2011) survey G09, G12 and G15 fields (see Fig. 1), and a cluster sample from a set of eight galaxy clusters. The inclusion of a dedicated cluster sample extends the range of environmental densities to higher values than a simple mass- or luminosity-selected sample of galaxies would provide. Full details of the target selection are provided by Bryant *et al.* (2014b).

The details of SAMI data reduction is described by Sharp *et al.* (2015). This is based on the AAO's 2DFDR† package, together with a dedicated pipeline which handles flux calibration and combining dithered observations into cubes. Fig. 2 illustrates the finished product for a single galaxy, showing the nature and quality of the data obtained.

We have recently made available a set of fully calibrated datacubes for 107 galaxies, forming the SAMI Galaxy Survey Early Data Release (EDR; Allen *et al.* 2015). The

† `http://www.aao.gov.au/science/software/2dfdr`

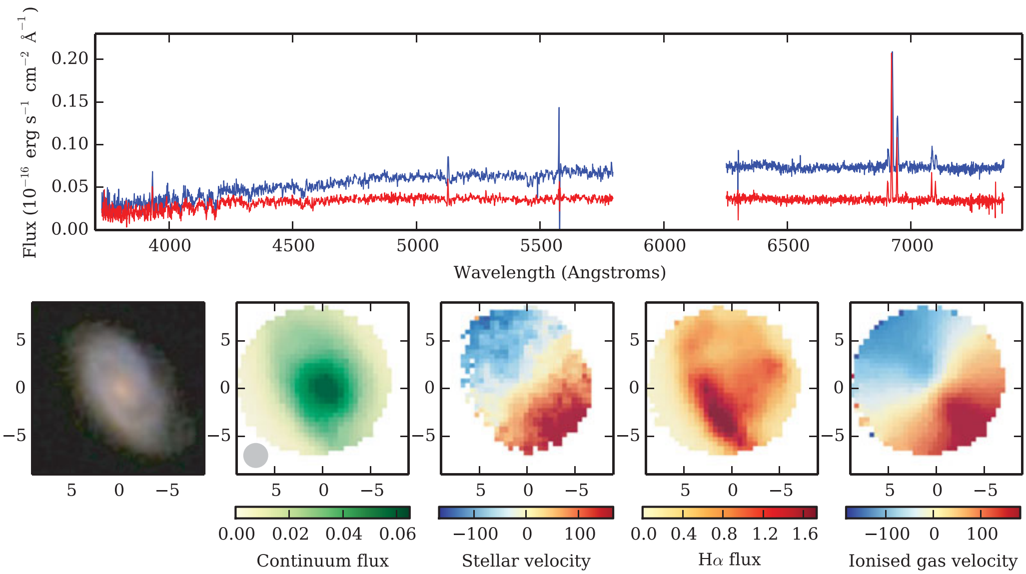

Figure 2. Example SAMI data for the galaxy 511867, with $z = 0.05523$ and $M_* = 10^{10.68}\mathrm{M}_\odot$. Upper panel: flux for a central spaxel (blue) and one 4" to the North (red). Lower panels, from left to right: SDSS *gri* image; continuum flux map ($10^{-16}\,\mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}$); stellar velocity field ($\mathrm{km\,s^{-1}}$); Hα flux map ($10^{-16}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$); H$\alpha$ velocity field ($\mathrm{km\,s^{-1}}$). The two velocity fields are each scaled individually. Each panel is 18″ square, with North up and East to the left. The grey circle in the second panel shows the FWHM of the PSF.

galaxies were selected from the GAMA regions of the survey. Also available are the datacubes of the corresponding secondary standard stars and a table of ancillary data including quantities such as stellar mass, effective radius and surface brightness. All data can be downloaded from the SAMI Galaxy Survey EDR website‡.

3. First Science

Early science investigations have included studies such as detailed diagnostics of galactic winds (Fogarty *et al.* 2012; Ho *et al.* 2014), study of the kinematic morphology–density relation in clusters (Fogarty *et al.* 2014), star formation in dwarf galaxies (Richards *et al.* 2014) and new analysis of galaxy scaling relations (Cortese *et al.* 2014). Other ongoing work includes studies of spatially resolved star formation and how it is modulated with environment, dynamical mass estimates and the fundamental plane, radial age gradients and much more. Here we highlight just a few of the recent results.

3.1. *Decomposing a star-burst driven wind*

The high spectral resolution of SAMI data in the red arm of AAOmega makes it an excellent probe of complex kinematic structure. Recently Ho *et al.* (2014) demonstrated this, using SAMI to discover and analyse a star-burst driven wind in an isolated disk galaxy. There are multiple kinematics components within this galaxy, which shows (1) a narrow kinematic component consistent with HII regions, (2) a broad kinematic component consistent with shock excitation, and (3) an intermediate component consistent with shock and photoionisation mixing. The three kinematic components have distinct velocity fields, velocity dispersions, line ratios, and electron densities (see Fig. 3). The bipolar galactic winds introduce shock excitation and cause the elevated line ratios and

‡ `http://sami-survey.org/edr`

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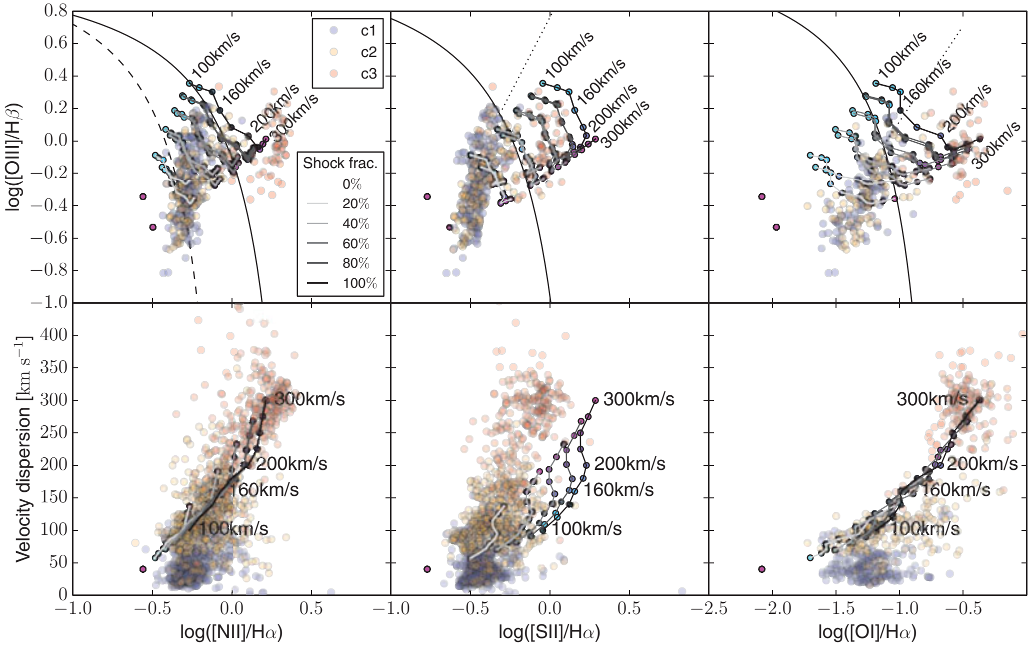

Figure 3. *Top:* The three standard BPT (Baldwin, Phillips & Terlevich 1981) diagrams for a single galaxy from Ho *et al.* (2014) *Bottom:* The three line ratios vs. velocity dispersion. The blue, orange, and red points denote the three distinct kinematic components fit. The points connected by lines are shock/photoionization model grids from MAPPINGS (Dopita *et al.* 2013). The lines connect models of a given shock fraction with changing shock velocities. The pure photoionization (zero shock fraction) is at the bottom left.

velocity dispersion in the broad kinematic component. Building on this analysis we are now assessing the frequency of winds and outflows throughout the full SAMI sample.

3.2. *Kinematic morphology in clusters*

Understanding how the distribution of stellar angular momentum is built up is a key focus of the SAMI Galaxy Survey. To do this we are measuring the specific stellar angular momentum (quantified using the λ_r parameter, where $\lambda_r = \langle R|V_{rot}|\rangle / \langle R\sqrt{V_{rot}^2 + \sigma^2}\rangle$; Emsellem *et al.* 2011) and identifying rotation supported galaxies and dispersion supported galaxies. With the large sample size of SAMI we are then able to study how trends in angular momentum vary with galaxy environment, mass and other characteristics. Fogarty *et al.* (2014) find that slow rotators are distributed across a range of environments within clusters, and also find evidence that groups in-falling into clusters contain slow rotators.

3.3. *Galaxy scaling relations*

Galaxy scaling relations such as the Tully-Fisher (1977) relation for spirals, or the Faber-Jackson (1976) relation for early types provide fundamental insights into galaxy structure. Until now, such relations have always been formed from a subset of galaxies, selected on morphology, inclination and other properties. We have taken advantage of the data from the SAMI Galaxy Survey to investigate the relation between the kinematics of gas and stars, and stellar mass in a comprehensive sample of nearby galaxies, regardless of morphology (Cortese *et al.* 2014). We find that regardless of their morphology, all galaxies lie on a tight relation linking stellar mass (M_*) to internal velocity quantified

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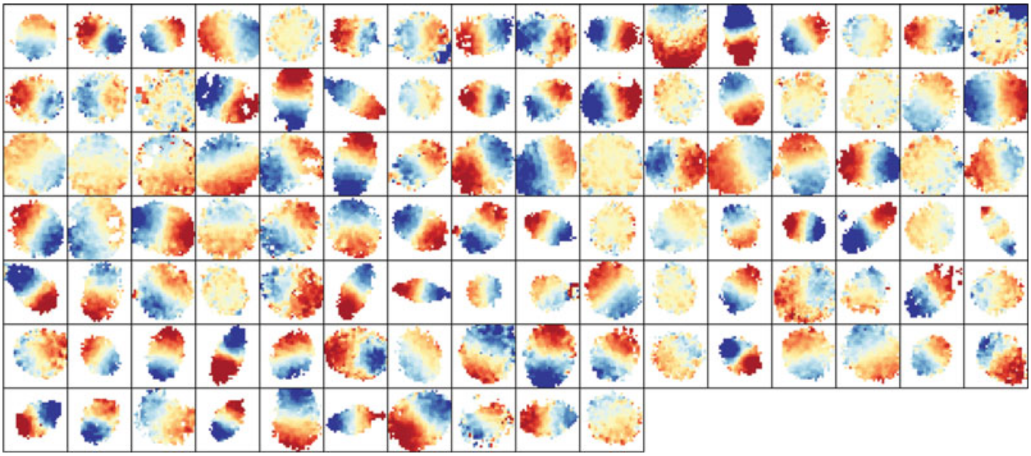

Figure 4. Stellar velocity maps for the 106 galaxies from the SAMI Pilot Survey in three galaxy clusters used by Fogarty *et al.* (2014). The velocity range is $\pm150 \mathrm{km\,s^{-1}}$

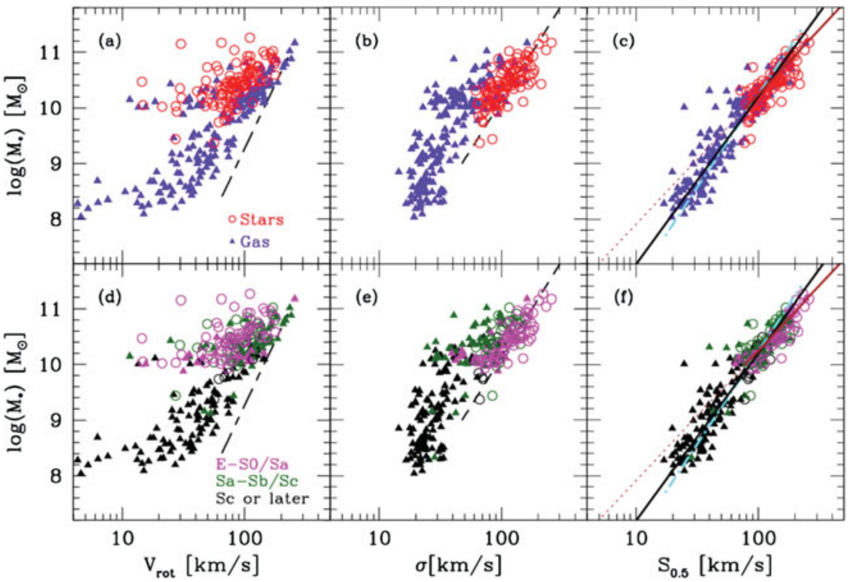

Figure 5. The M vs. V_{rot} (left), σ (center) and $S_{0.5}$ (right) relations for SAMI galaxies from Cortese *et al.* (2014). Circles and triangles indicate stellar and gas kinematics, respectively. In the bottom row, symbols are colour-coded according to morphological type: E-S0/Sa (magenta), Sa-Sb/Sc (dark green), Sc or later types (black). The stellar mass Tully-Fisher (long-short dashed line; Bell & de Jong 2001) and Faber-Jackson (dashed line; Gallazzi *et al.* 2006) relations for nearby galaxies are shown in the left and central panel for comparison. In the right panels, the best inverse linear fit for the whole sample (black line), and for $M > 10^{10}$ M$_\odot$ (brown line) are shown. The dashed-dotted line shows the M vs. $S_{0:5}$ relation obtained by Kassin *et al.* (2007).

by the $S_{0.5}$ parameter (Kassin *et al.* 2007), which combines both the dispersion (σ) and rotational velocity (V_{rot}) contributions to the dynamical support of a galaxy, such that $S_{0.5} = \sqrt{0.5V_{rot}^2 + \sigma^2}$ (see Fig. 5). Galaxies lie on the same relation regardless of whether we use kinematics measured from stars or gas. This relation appears to be more general and at least as tight as any other dynamical scaling relation, representing a unique tool for investigating the link between galaxy kinematics and baryonic content, and a less biased comparison with theoretical models.

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4. Conclusions

By completion in 2016 the SAMI Galaxy Survey will have collected integral field data for ~ 3400 galaxies in the local Universe, enabling a vast array of science. We are truly entering an era when integral field observations will be central to our understanding of galaxies. Major new projects are now starting, including MaNGA (see Bundy *et al.* in this proceedings) to extend sample sizes to $\sim 10,000$ in the local Universe. At high redshift KMOS (see Davies *et al.*, in this proceedings) will drive our understanding of galaxy evolution with thousands of galaxies at $z \simeq 1-2$. Next generation facilities, such as Hector (Bland-Hawthorn 2014), will push our understanding in new directions by building samples of $\sim 100,000$ galaxies.

Acknowledgements

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