Galaxy And Mass Assembly (GAMA)

I. Baldry, S. Bamford, J. Bland-Hawthorn, M. Brown, M. Drinkwater, S. Driver (EU PI), A. Hopkins (AUS PI), J. Liske (Project Manager), J. Loveday, M. Meyer, P. Norberg, J. Peacock, S. Brough & A. Robotham (Science Coordinators), E. Andrae, A. Bauer, E. Cameron, J. Ching, M. Colless, C. Conselice, S. Croom, N. Cross, T. Davis, R. De Propris, J. Delhaize, E. Edmondson, S. Ellis, C. Foster, A. Graham, M. Grootes, M. Gunawardhana, D. Hill, H. Jones, E. van Kampen, L. Kelvin, M. Lara-Lopez, C. Maraston, R. Nichol, H. Parkinson, S. Phillipps, K. Pimbblet, C. Popescu, M. Prescott, R. Proctor, I. Roseboom, E. Sadler, A. Sansom, R. Sharp, M. Spolaor, L. Staveley-Smith, E. Taylor, D. Thomas, R. Tuffs, D. Wijesinghe, S. Wilkins
in collaboration with
ASKAP DINGO, Herschel ATLAS, VISTA VIKING, VST KIDS, GALEX, CFHTLenS, and Durham ICC

Executive Summary

We request continuation and expansion of the GAMA AAT Large Programme to achieve the following:
(1) New tests of fundamental cosmology, structure formation and the Cold Dark Matter (CDM) model.
(2) Comprehensive measurements of the fueling and cessation of star formation in galaxies since $z = 0.5$.
(3) Creation of a unique $0.15\,\mu$m-1 m galaxy database for $z < 0.1$ studies of stellar populations, gas, and dust.
(4) Acquisition of redshifts required to realise the science goals outlined in the ASKAP-DINGO proposal.
(5) To maximise the science return from the 3.5 year ESA Herschel mission.
(6) Cosmological tests from combining AAT redshifts with the CFHTLenS survey.

This expanded GAMA survey encompasses the spectroscopic aspirations of a number of programmes (original GAMA-I, ASKAP-DINGO, Herschel-ATLAS, CFHTLenS) and will provide a unique legacy database of ≈ 0.4 million objects over $\sim$360 deg^2 with supporting imaging coverage from GALEX, VST, VISTA, WISE, Herschel, ASKAP and GMRT – as well as a launch pad for major ESO VLT programmes. The labour, infrastructure, and external facilities necessary to conduct GAMA-II are secured and in place (15 research positions, reduction and quality control pipelines, internal and public database, and TAC approval on all facilities).

The following scientific justification showcases the headline science goals that motivate the survey design, along with the observing schedule, management, multi-wavelength and data release plans. We request 145 nights in addition to the 74 already invested, and following the time-limited call we request 28 dark/grey nights in Semester 11A, 27 in 12A, and 45 in each of 11B and 12B. If scheduling constraints limit the possible B-semester allocations, we are comfortable with the survey being distributed over a longer time-frame.

1 Scientific justification

1.1 New tests of fundamental cosmology and structure formation

1.1.1 Probing cosmic acceleration with the growth of structure

Large scale structure studies have been essential in establishing the CDM model of structure formation (e.g. Peacock et al., 2001; Cole et al., 2005). But this success is undeniably shadowed by the need to introduce Dark Energy, a new ingredient that accounts for $\sim$75% of the energy density of the Universe (e.g. Sanchez et al., 2006). A key task for cosmology is to discriminate between various explanations for this phenomenon: a cosmological constant, time varying scalar field, or a deficiency in our gravity model. This study is hence the focus of numerous large spectroscopic (e.g. WiggleZ, BOSS, VIPERS) and imaging (e.g. Pan-STARRS, DES, LSST) surveys (e.g. Peacock et al., 2006). The $\sim$360 deg^2 GAMA survey will play a unique and key part in testing the nature of the cosmic acceleration, distinguishing Dark Energy from modifications of gravity.

Figs. 1(a) & (b) show preliminary redshift-space clustering results from GAMA-I, with high stellar mass galaxies split into a red and a blue sample: the flattening of the clustering pattern on large scales is directly proportional to the growth rate of density fluctuations, $f_g(z) = d\ln\delta/d\ln(\mathrm{scalefactor})$, which in turn is directly sensitive to the theory of gravity. GAMA's comprehensive sampling of *all* galaxy types means that we are able to test whether consistent results on f_g arise from different types of galaxy. Once we have a consistent, tracer-independent means of measuring f_g, we can then expect to achieve a significantly more accurate overall measurement (via the multi-tracer approach of McDonald & Seljak, 2009).

In Fig. 1(c) we show as black open squares the predicted $f_g(z)$ measurements from the full expanded GAMA survey compared to various gravity models (lines), to existing measurements (solid symbols), preliminary GAMA-I results (shaded areas) and to projections for other forthcoming galaxy surveys (open symbols).

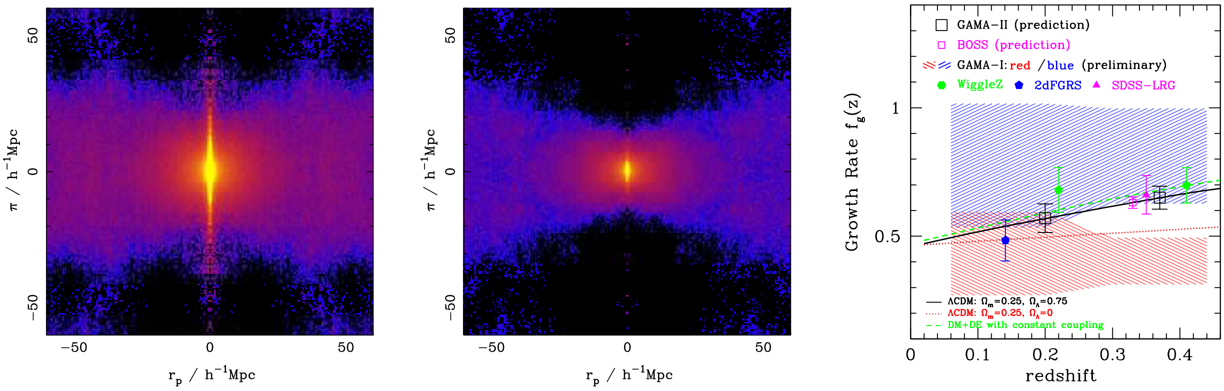

Figure 1: **Left (a) & Centre (b)**: Clustering signal in redshift space from red (left) and blue (centre) high stellar mass galaxies from GAMA-I data, as a function of line-of-sight (π) and projected (r_p) separations. This galaxy-dependent clustering pattern directly probes the nature of the underlying theory of gravity, as the flattening of the clustering pattern on large scales is proportional to the growth rate of structure. **Right (c):** growth rate of structure, $f_g(z)$, from different surveys (filled symbols), from preliminary redshift dependent GAMA-I estimates split by colour (shaded areas) and from future surveys (open symbols) compared to model predictions from various theories of gravity (lines). Preliminary GAMA-I results for $f_g(z)$ are marginally consistent for red and blue galaxies: the $\sim$360 deg^2 GAMA survey will provide the decisive test.

BOSS and WiggleZ, despite their large survey volumes, risk systematic limits in their $f_g(z)$ measurements by concentrating on single tracers of significantly lower number density: luminous red galaxies and star-forming galaxies respectively. GAMA will provide stronger constraints than VIPERS by virtue of our larger survey volume, its less biased galaxy samples and its lower median redshift (e.g. Simpson, 2010). Increasing the GAMA galaxy sample threefold has a major impact: preliminary GAMA-I measurements marginally detect a difference in the inferred $f_g(z)$ derived from red and blue high stellar mass galaxies using simple models for the redshift-space distortion signature (blue and red shaded areas in Fig. 1c). A $\sim$360 deg^2 GAMA survey allows us to probe empirically the enhancements of the redshift-space modelling that are needed in order to obtain a measure of $f_g(z)$ that is robustly independent of galaxy tracer, leading to the final statistically robust GAMA constraints (black open squares).

A precise and competitive measurement of the growth rate of structure at two cosmic epochs is a new GAMA scientific goal that is directly (and only) enabled by the increase in requested area coverage to $\sim$ 360 deg^2, in regions of each at least $\sim$70 deg^2. The extended GAMA will test the precise nature of the theory of gravity, and will be capable of setting the most robust constraints from this method: checking for consistency between different tracers will give an essential test that BOSS and WiggleZ lack.

1.1.2 Measuring the halo mass function, a fundamental prediction of CDM

The next challenge in validating the standard ΛCDM model is to move beyond small linear fluctuations. GAMA (Driver et al., 2009) has been engineered to conduct a direct test of the CDM model in the nonlinear regime, where a clear-cut prediction can be made. Fig. 2(a) shows the ΛCDM halo mass function (HMF), which is precisely predicted over seven orders of magnitude in halo mass (e.g. Springel et al., 2005). As this function depends solely on the cosmological parameters, the nature of gravity, and the dark matter particle mass, with negligible dependence on the baryons, it represents arguably the most testable prediction of the CDM model outside of particle physics.

Empirically the HMF is measurable via the construction of a galaxy group catalogue, where galaxies follow orbits dictated by the gravitational potential within the dark matter haloes. The velocity dispersion of identifiably bound groups can be inverted to provide a direct estimate of the halo mass (with a range of mock catalogues being used to test the estimator). Hence, by creating a sufficiently extensive galaxy catalogue, GAMA provides a direct HMF measurement to low halo masses for comparison with the predictions of the CDM model.

The 2dFGRS group catalogue (2PIGG; Eke et al., 2004a) delivered an accurate measurement of the HMF (open symbols in Fig. 2a), but only over one decade in mass and at one single epoch (Eke et al., 2006). GAMA-II samples galaxy number densities that are $\sim$3 times larger at $z \simeq 0.05$, and over $\sim$10 times higher at $z \simeq 0.25$, the GAMA median redshift. This will enable the detection of $\sim$7k groups in two distinct cosmic epochs, with group masses of a few $10^{12} M_\odot$ detected in the low redshift sample (shaded areas in Fig. 2a). This test provides

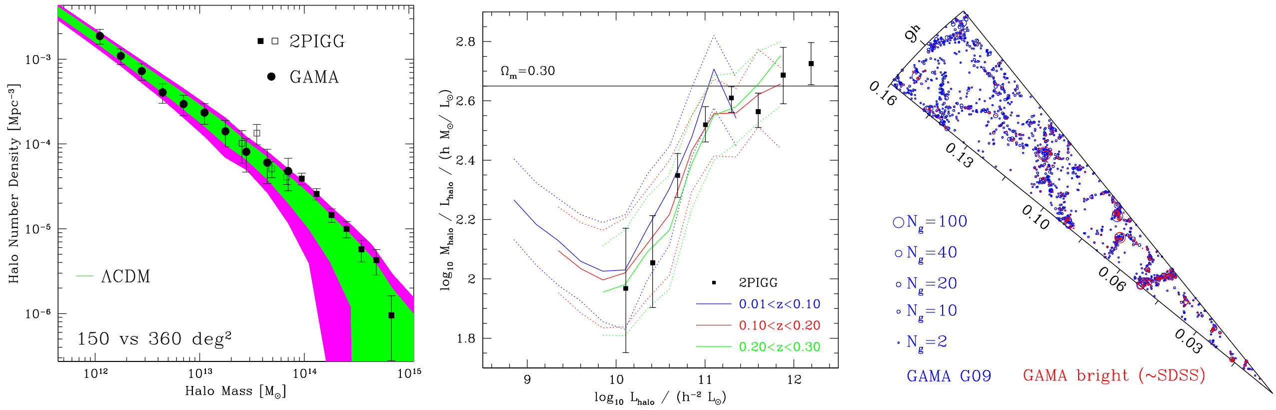

Figure 2: **Left (a):** Dark Matter halo mass function comparisons: simulated GAMA survey (filled circles), 2PIGG data (squares) and CDM theory (magenta: 144 deg^2; green 360 deg^2) for the low-z GAMA sample. **Centre (b):** Dynamical group mass-to-light ratio as a function of group luminosity: predictions from one set of GAMA lightcone mocks split in three redshift bins (median [solid lines] and scatter [dotted lines]) compared to 2PIGG of Eke et al (2004b) (squares). **Right (c):** Preliminary group catalogue in G09 (Robotham et al., 2010, in prep.). Blue shows GAMA groups (circle size proportional to number of group members), red shows the groups in G09 that can be identified using SDSS main galaxy survey selection.

a unique insight into the evolution of the HMF, probing a fundamental CDM model prediction.
GAMA will directly measure the precise shape of the HMF to a few x 10^{12}M$_\odot$ and its evolution over a 5 Gyr baseline; this constitutes standalone AAT science. The HMF is an independent diagnostic of the nonlinear evolution of the density field, and it gives further direct information on possible deviations from Einstein gravity, complementing the work on large-scale redshift-space distortions in Section 1.1.1.

1.1.3 The star-formation efficiency and properties of galaxy groups

Measuring the HMF requires only that galaxies fall freely in a gravitational potential and this is independent of their intrinsic properties. But the galaxy population within each halo depends critically on the interaction between the baryon processes (i.e., star formation rate and feedback efficiency) and the total halo mass. In fact most galaxy formation models predict that the ratio of DM halo to stellar mass is strongly dependent on halo mass, exhibiting a characteristic dip at Local Group masses (see Fig. 2b). The need for feedback mechanisms to suppress star formation in low mass (via supernovae) and high mass (via AGN) haloes is now part of standard galaxy formation prescriptions. With GAMA we can connect these theoretical ingredients systematically and directly with precise observational measurements.

Preliminary galaxy group studies with GAMA-I (Robotham et al., 2010, in prep.) have led to the discovery of ∼100 Local Group sized haloes (or smaller) with four or more members at $z < 0.1$, and a first sample of ∼30 groups as small as $10^{7.5}L_\odot$, for which there is no real comparable SDSS sample. Extending GAMA is key to obtaining the statistics for studying these low-mass groups as a function of large-scale environment. With theory suggesting that their formation history is dependent on environment (e.g. Gao et al., 2005), such environmental studies offer a new powerful galaxy formation test.
If the observed dynamical mass-to-light ratio of groups do not follow the trend shown on Fig. 2(b) for Local Group sized and smaller haloes, a radical re-think of feedback processes in the Dark Matter baryon interface will be required.

1.1.4 Lensing masses for ∼20% of GAMA groups via CFHTLenS

The Canada-France Hawaii Lensing Survey (CFHTLenS) provides accurate weak gravitational lensing measurements for the CFHTLenS-W1 field. Access to these proprietary data opens a new dimension for GAMA by providing a direct and complementary measurement of Dark Matter haloes on cluster, group and galaxy scales.

Within the CFHTLenS-W1 field the aim is to measure the ensemble-average masses of robustly identified galaxy groups via weak lensing, as a function of richness, morphological content and redshift. This will provide a powerful independent measurement of the group masses, allowing for a completely separate calibration of dynamical group mass estimates. Weak lensing also probes the Dark Matter sub-haloes around individual

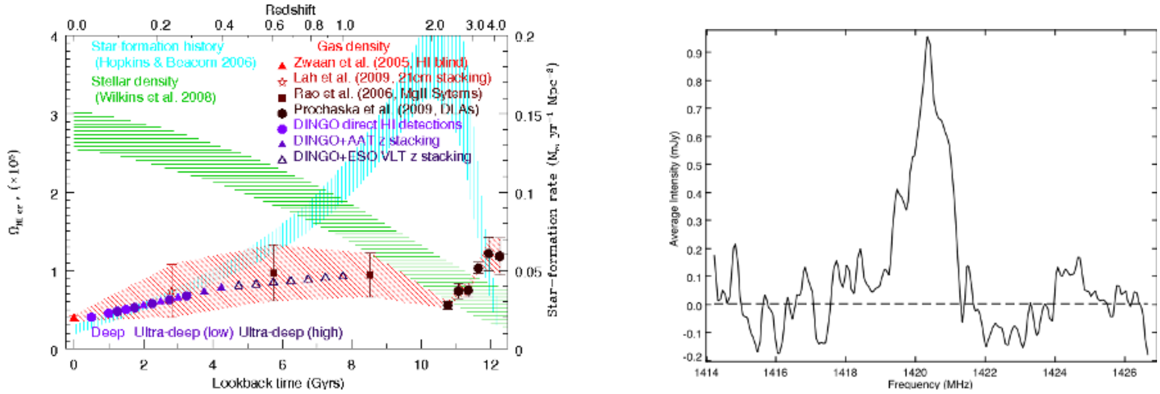

Figure 3: **Left:** Evolution of star formation rate (SFR) density, stellar mass density and HI mass density. From $z \approx 1$ to the present the global SFR density is seen to decline by an order of magnitude, while the neutral gas density changes by at most a factor of two. The DINGO datapoints are predictions, all other data and regions are existing measurements. **Right:** $10\,\sigma$ detection of HI at $z \approx 0.1$ after stacking data from 5374 GAMA redshift positions (Delhaize et al., 2010, in prep). This is the technique we will use to map the cosmic HI density from $z = 0.5$ to $z = 0.1$.

galaxies. As groups form, haloes of individual galaxies are expected to merge into a common halo. The weak lensing data from CFHTLenS will allow us to measure the average halo properties of galaxy members within groups, as a function of galaxy mass and distance from the group centre. This will directly reveal the importance of physical processes such as tidal stripping, the first time this can been studied below scales of rich clusters.

1.2 Understanding the fueling and cessation of star formation in galaxies since z $= 0.5$.

1.2.1 A comprehensive study of the HI and stellar properties of galaxies

The previous section outlines how GAMA will advance global studies of the cosmological density field; but a full understanding of structure in the visible universe requires us to confront key puzzles regarding the assembly of individual galaxies. Over the past decade, observations have produced robust measurements of the growth of stellar mass up to redshift $z \simeq 6$ (Fig. 3(left), Hopkins & Beacom, 2006). This growth follows a puzzling pattern termed 'downsizing', in that the most massive galaxies finish assembly and turn off their star formation at the highest redshifts (e.g. Cowie et al., 1996; Juneau et al., 2005; Perez-Gonzalez et al., 2008). This pattern contradicts most models of galaxy formation, which predict continuing strong star formation in the most massive galaxies, and have difficulty in generating a passive red sequence at all (e.g. Benson et al., 2003). The origin of the apparent paradox is traced to the rapid cooling of ionized gas into the neutral gas from which stars form, and the general assumption is that energy input ('feedback') from AGN is required to counteract this cooling. An understanding of the fueling and cessation of star formation is therefore bound up with the history of the gas: observations of the neutral hydrogen (HI) content in galaxies, its relationship to ongoing star formation, and its evolution (e.g. Hopkins et al., 2008) is necessary to understand the downsizing puzzle. The key questions currently limiting our understanding of galaxy evolution are thus: (1) What regulates the fueling of star formation in galaxies? (2) What causes the cessation of star formation in galaxies?

Using 90k GAMA-I spectra, we have laid the groundwork to address these questions. We have measured the star formation rates for 40k galaxies from GAMA via UV, Hα and [OII] line measurements and established self-consistency between these three methods with accurate aperture and dust attenuation corrections (Wijesinghe et al., 2010). We have also obtained the first direct measurement of the cosmic HI density at $z \approx 0.1$ (Fig. 3(right); Delhaize et al., 2010, in prep.). The HI measurements with ASKAP-DINGO in the new GAMA-II survey regions will expand this test sample to $\sim$100k galaxies, for which we have both the stellar and gas properties. **GAMA is positioned to resolve how galaxies are fueled, and their star formation activity moderated, by combining star formation rate measurements based on AAOmega spectra with HI measurements from DINGO and WALLABY. GAMA will be the first and only survey able to directly measure which systems, in which environments and of what masses, dominate the neutral gas distribution in the universe, and how this has evolved over the past 5 Gyr.**

1.2.2 The role of mergers in galaxy evolution

The role of mergers in triggering or truncating star formation or AGN processes will also be quantified with GAMA. We will measure the merger rate in two independent ways, using the frequency of close pairs (e.g.

Patton et al., 2000, 2002; De Propris et al., 2005, 2007), and through structural parameters, such as CAS and Gini/M_{20}, using galaxy imaging. The best recent merger-rate estimates include at most three redshift bins up to $z < 0.5$, with no sampling at all between $0.05 < z < 0.2$ (Lotz et al., 2008; Conselice et al., 2009). GAMA prioritises close pairs in the observing strategy to ensure the fibre collision bias present in SDSS and 2dFGRS data is overcome (Robotham et al., 2010). With up to $\approx 10\,000$ merging systems expected, we will quantify the major (1:3) and minor (1:10) merger rates in ten redshift bins (improving by a factor of three over existing measurements) to accuracies of $< 10\%$. In this way, GAMA will measure both the internal star/gas properties of galaxies and the environmental factors which may influence these – both small-scale (mergers) and larger-scale (host haloes).

1.3 A unique legacy for extragalactic research

We believe that the targeted science goals articulated above provide a strong justification for this requested expansion of the GAMA survey. But we emphasize that these represent the highest priority items out of a much broader range of science that will be enabled by the GAMA database. This will constitute a unique legacy, by virtue of its panchromatic grasp: $\sim$0.4 million galaxy spectra plus photometric measurements at 26 wavelengths (FUV-Opt-IR-Radio) plus 21cm velocity profiles, drawing in data from world-leading facilities such as VISTA (VIKING), GALEX (MIS), Herschel (ATLAS), WISE, GMRT, and ASKAP. The key role of GAMA spectroscopy is clearly understood by these surveys, which in several cases have adapted their strategy to make sure they will be consistent with the possibility of GAMA coverage. These data will yield detailed internal knowledge of each GAMA galaxy (stellar, dust, HI and dynamical mass measurements), enabling a wide range of further science goals. We briefly describe here, by way of illustration, a selection of projects that the GAMA team is pursuing in addition to our principal science goals. As with other legacy surveys we expect that the broader community will also produce valuable research using these resources.

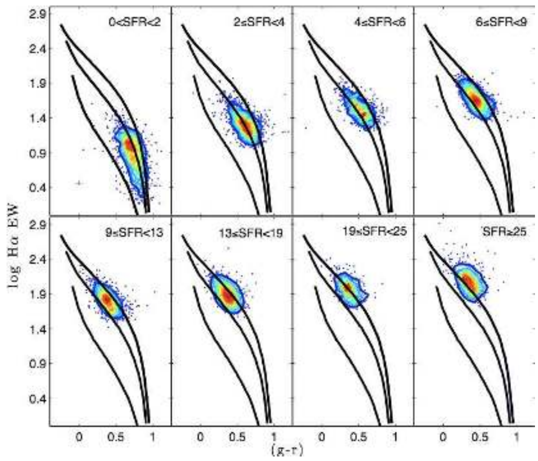

Figure 4: Hα equivalent width vs optical $(g - r)$ colour, used as a diagnostic of the slope of the massive end of the IMF in galaxies (Hoversten & Glazebrook, 2008). Data from an $M_r = -21$ volume-limited sub-sample of GAMA galaxies. Panels are split by SFR. Solid tracks are predictions from PEGASE for different IMF slopes ($\alpha = -2, -2.35, -3$ from top to bottom). The implication is that high-SFR galaxies have flatter IMF slopes (Gunawardhana et al., 2010).

Is the Initial Mass Function Universal? Whether the stellar initial mass function (IMF) is universal or not is a much debated issue, with strong arguments both for universality (Bastian et al., 2010; Gilmore, 2001) and against (Hoversten & Glazebrook, 2008; Meurer et al., 2009). GAMA is positioned to lead this debate by measuring the SFR, stellar masses and colours for a large and diverse set of galaxies. Preliminary GAMA results (Fig. 4, Gunawardhana et al., 2010) indicate that the IMF depends strongly on SFR, potentially allowing the cosmic star formation history to integrate to the correct stellar mass density today (Wilkins et al., 2008). The proposed observations will allow measurements for sufficient numbers of galaxies to identify the underlying dependencies (mass, SFR, metallicity, environment) that could drive variation of the IMF.

The mass-metallicity relation. Galaxy mass and metallicity correlate tightly over a factor of 100 in mass (Tremonti et al., 2004), but several factors may contribute to this: (i) the gas-to-stellar mass fraction; (ii) the expulsion of supernova ejecta; and (iii) the stellar IMF. GAMA will detect galaxies to $M_r = -11$ mag, enabling for the first time the detailed measurement of the mass-metallicity relation into the dwarf galaxy regime outside the local volume. In addition to measuring the metallicity of the faintest sources, GAMA will for the first time measure the evolution of the mass-metallicity relation over $0 < z < 0.5$. Preliminary GAMA analyses (Foster et al., 2010, in prep.) have identified a SFR-metallicity relationship, similar to that recently identified for the SDSS by Lara-Lopez et al. (2010), suggesting that this does not evolve with redshift to $z \sim 0.3$. HI masses from ASKAP will be critical for interpreting these variations and determining the main causes of the relation.

Faintest stellar, HI and baryonic mass functions at z < 0.1. Current indications in all measured optical/NIR filters are that the space density of galaxies exhibits a sharp upturn at the dwarf-giant boundary ($\lesssim 10^9\,M_\odot$;

Baldry et al., 2008; Driver et al., 2010, in prep.). This upturn is predicted by many galaxy formation models (e.g. Benson et al., 2002), but current measurements are tentative owing to sample variance. The increased area, improved photometry and high spectroscopic completeness of GAMA are crucial to a credible measurement of the faint end of the galaxy luminosity function. Initial investigations of the star forming dwarf galaxy population in GAMA already probe to systems of $10^6\,\mathrm{M}_\odot$ with SFRs as low as $10^{-3}\,\mathrm{M}_\odot\mathrm{yr}^{-1}$ (Brough et al., 2010). Even more fundamental is the measurement of the stellar mass, HI and baryonic mass functions, with the latter two only obtainable from the unique combination of the GAMA and ASKAP DINGO surveys. The power of the new GAMA-II sample in this regime will be greatly enhanced by covering the $\sim$70 deg^2 CFHTLenS W1 field; the significant depth of the optical data tells us much more about low surface brightness galaxies, as well as helping diagnose any possible incompleteness in the SDSS imaging for targets of this type.

AGN Feedback. Feedback mechanisms in AGNs will be tested by exploring their HI content, environments and masses, in comparison with the properties of the actively star forming galaxies. AGNs comprise about $2-3\%$ of the total GAMA sample, but about $20-30\%$ of the $M_* > 10^{11}\,M_\odot$ galaxies. Accordingly, $\approx 7000-10\,000$ AGNs will be identified from (1) broad emission lines; (2) spectral diagnostics of narrow emission line systems; (3) radio continuum luminosity and spectral index from the ASKAP all-sky radio continuum survey called EMU (for which Hopkins is Project Scientist). This will be more than an order of magnitude larger than the current largest sample of AGNs with HI measurements (Ho et al., 2008).

2 GAMA area and depth justification

The increase in area is largely motivated by the ASKAP DINGO survey for which extensive *a priori* redshifts are vital for the high precision measurement of the global HI mass density since $z = 0.5$ (Fig. 3 left). This measurement requires stacking of tens of thousands of HI spectra for galaxies with known redshifts (Fig. 3 right). To reduce sample variance to $< 20\%$ (Driver & Robotham, 2010), DINGO requires an absolute minimum of 5 deep and 2 ultra-deep 6×6 deg^2 pointings. Two of these can be located in G09 by broadening this region from 4×12 to 6×12 deg^2. The G12 & G15 regions are unsuitable for ASKAP follow-up, due to known bright radio continuum sources. Because of the unique Herschel-ATLAS coverage, however, extending beyond the observed GAMA regions, we request an increase of G12 & G15 from 4×12 to 5.5×13.1 deg^2. Satisfying DINGOs requirements therefore requires five further high fidelity redshift fields in the more suitable (for ASKAP) SGP region. The GAMA and DINGO Executives have agreed on three of these fields (G23(G/H) and X(W1)) (see Fig. 5 right), for which suitable input catalogue data exists from CFHT or VISTA, and are continuing to negotiate the locations of the two additional fields to be covered in a future proposal beyond Semester 12B.

The increase in area is also critical in order to meet the requirements for the cosmology goals of § 1.1, and the galaxy evolution goals of § 1.2. The present GAMA-I dataset marginally detects a difference in the inferred growth rate of structure derived from red and blue galaxies. The greater precision from the full survey will allow us to obtain a measure of the growth rate that is robustly independent of galaxy type. GAMA-I identifies ≈ 100 groups comparable in size to the Local Group. This sample is too small to be subdivided by the main parameters of interest (environment and redshift): GAMA-II allows 3 bins in each while retaining over 30 groups per subsample, allowing detailed exploration of halo formation and the evolution of peak-background effects. In order to disentangle the complexity of galaxy evolution we must be able to bin data in the primary parameters of stellar mass, environment, metallicity, star-formation rate, galaxy type and redshift. Even allowing 5 bins of resolution with only ~ 50 galaxies in each bin (±15 % random error) requires a sample size of ~ 375k.

The depth requirements of GAMA are supported by the success of GAMA-I, with $r < 19.8$ being the sweet spot. SDSS selection is reliable at this depth (but cannot be pushed much deeper); AAOmega spectroscopy to this limit yields high redshift completeness and quality spectra. The 2 mag. improvement with respect to the SDSS main galaxy survey is effective in identifying a new regime of low mass galaxy groups. Finally, the space density of galaxies at this limit forms a natural match to the HI ASKAP-DINGO survey. In combination, this confluence of motivations provide a compelling case for expanding GAMA to cover a total of 360 deg^2.

3 Observing Plan

The GAMA survey consists of four $\sim 6 \times 12$ deg^2 blocks and one 8×9 deg^2 block covering a total area of 360 deg^2 with ~ 375k targets for which 157k redshifts are already known (mainly through GAMA-I). The block sizes are selected to provide a manageable window function for our cosmology goals as well as to pre-survey

Table 1: Complete GAMA footprint

GAMA Region	RA range (deg.)	Dec range (deg.)	Targ. ('000)	GAMA z's ('000)	Other z's ('000)	Remaining (000')	Prog. (%)
G09	129.0—141.0	-3 to +3	73	36	8	**29**	60%
G12	173.3—186.4	-3.25 to +2.25	76	42	13	**21**	72%
G15	210.8—223.9	-2.25 to +3.25	77	32	12	**33**	57%
G23	338.1—351.9	-30 to -36	75	0	5	**69**	7%
X(W1)	30.0—39.0	-3 to -11	74	9†	0	**65**	12%
Semester A (G09+G12+G15)			226	110	33	**83**	63%
Semester B (X(W1)+G23)			149	9	5 †	**135**	9%
Total (All)			375	119	38	**218**	42 %

† forecast of forthcoming nights in November.

the 5 deep and 2 ultra-deep fields of the ASKAP DINGO survey. Four blocks will enjoy uniform coverage with GALEX, VST, VISTA and Herschel as part of the MIS, KIDS, VIKING and ATLAS surveys. This will provide near-uniform sensitivity in 26 passbands from $0.15\,\mu$m-1 m for all objects (see Fig. 5 left). The fifth field now lies on the CFHTLenS-W1 region following earlier feedback from ATAC and positive discussions with the CFHTLenS team. This switch strengthens GAMA science by providing independent corroboration of GAMA group masses via weak lensing as well as strenghtening our investigations of the dwarf regime by utilising the very deep high-resolution CFHTLenS imaging data. Note that while this region will have only patchy multi-wavelength coverage outside the optical regime, the optical data are already in place, are significantly deeper and of higher resolution than SDSS and SkyMapper, and are deeper than the proposed PanSTARRS, VST KIDS, DES, and LSST surveys. The GAMA team has therefore formed a collaboration with the CFHTLenS team represented by C. Heymans, L. Van Waerbeke and M. Hudson, and we have agreed to prioritise the X(W1) region within our survey programme to ensure completion by the end of Semester 12B.

The RA distribution of the five fields is suitable for study from equatorial and southern observatories from late-Sept until late-April. Fig. 5(right) shows the survey regions (black rectangles) and the survey footprints of other notable surveys (as indicated, note that the ASKAP-DINGO pointings will be fields A,B,E,F,**G**,H,& **X**, with the ultra-deep DINGO fields in bold). The G12 region is unsuitable for ASKAP follow-up because of the proximity of bright radio continuum sources (filled blue circles).

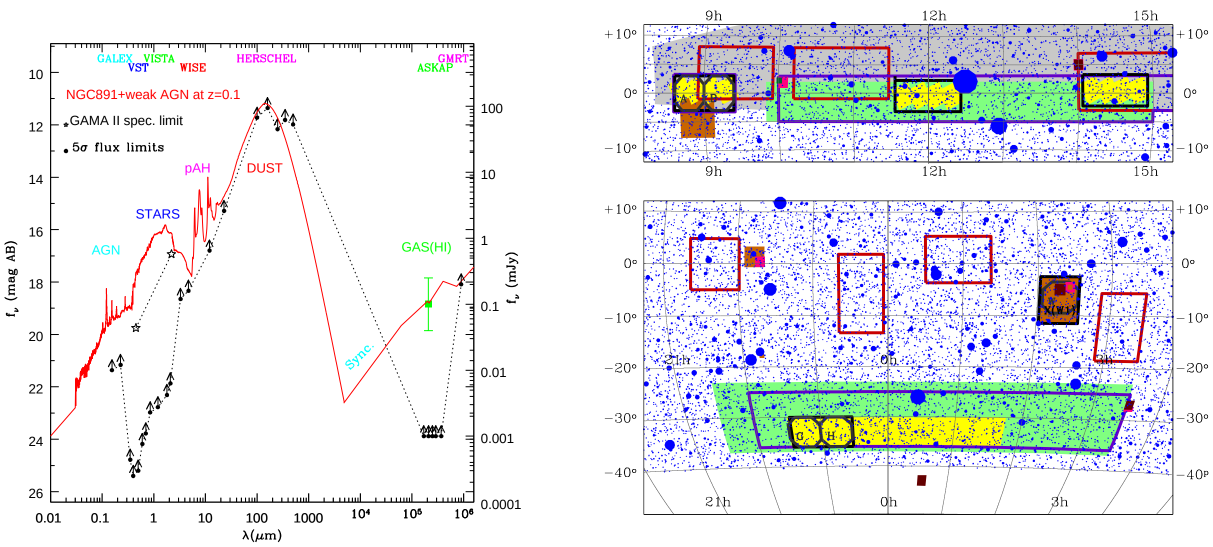

Figure 5: Left: The spectroscopic and photometric limits of the final GAMA database compared to the SED of NGC891 relocated to $z = 0.1$ and with a weak AGN added. Right: The GAMA footprint (black rectangles) and complementary surveys including the proposed ASKAP DINGO fields (hexagons) and the Herschel-ATLAS (solid yellow regions). The solid black blocks show the current VISTA coverage already in hand.

The depth for all regions is identical to that in the G12 field of the current GAMA survey in which the 1 hr integrations are well matched to the configuration time and provide a yield of 90% redshift success in normal and good weather conditions. Repeat observations allow the final redshift completeness to be greater than 98%. The GAMA survey speed at this source density (to $r < 19.8$), accounting for multiple passes per 2dF pointing, averages to 1.5k redshifts per night (including weather allowance). Therefore to complete the full survey requires 145 nights, or 55 nights in Semester A and 90 nights in Semester B.

We therefore request 28 nights in semester 11A and 27 in 12A, and 45 nights in each of 11B and 12B, but note that the survey can progress at a more sedate pace over a longer timeline if required.

Input catalogues: The input catalogues in the equatorial fields are based on reprocessed SDSS+UKIDSS data and are in place and well tested (Baldry et al., 2010; Hill et al., 2010). In due course the data will be superseded by higher quality data delivered by VISTA and VST (VISTA is now surveying the GAMA fields at a rate of 1.5 $\deg^2$ per night and VST is scheduled for operations from April 2011). The input catalogues for the SGP fields are now complete and scheduled for observations during November and are based on z-band data from VISTA for G23 (currently in progress) and on CFHTLenS data for X(W1). For the second year of the campaign we expect to have our VST KIDS catalogues in place.

Tiling algorithm: The tiling algorithm adopted by GAMA is a GREEDY algorithm (Robotham et al., 2010), which selects the next region for observation on the basis of its relative completeness (defined within a 0.14 $\deg^2$ boxcar filter). The algorithm has been extensively tested and proven to provide optimal spatial completeness if the precise number of tiles to be observed is not known (because of the weather).

Observing process: Observing will be the joint responsibility of the two PIs who will select team members to assist in observations. There will be equal participation in observing and redshifting from both Australian and European members. All data will be reduced and redshifted at the telescope, followed by ingestion into the ESO and ANU-SF databases. The timeline for the observations, including key milestones, is shown in Fig. 6.

4 Management Plan

GAMA-II is a joint European-Australian project with the Australian team (25 members) contributing access to the AAT and ASKAP and the European team (30 members) contributing data-flows from VISTA, VST, Herschel, GALEX and VLT. The GAMA structure consist of an Executive Board, two PIs (Driver and Hopkins), a Project Manager (Liske), two Science Coordinators (Robotham and Brough), and a number of working group heads (Baldry, Brough, Brown, Driver, Hopkins, Liske, Norberg, Robotham) responsible for day-to-day aspects of the survey. The GAMA Executive Board has been selected by the two PIs to provide guidance and oversight to the PIs. The Executive will meet quarterly to review the progress of the survey, the science outputs, the database development, and the interface with external science teams. The day-to-day running of the survey will be managed by the PIs, the Project Manager, the Science Coordinators, and the working group heads via regular fortnightly telecons (Executive members are welcome but not expected to attend these meetings). The purpose of these meetings is to ensure the smooth running of AAT observations and the flow of data management units into the database. The role of the Project Manager is to advance all logistical aspects of the programme and ensure appropriate quality controls with the assistance of the two Science Coordinators to provide science effort as and where required. In addition the GAMA project has commenced annual team meetings to showcase science results, alternating between the UK and Australia, with the first meeting held in Edinburgh over 13-14 September 2010 (see GAMA wiki for talk PDFs, details below).

The GAMA team currently receives funding from the ERC (2 PDRAs), the UK RS (1 URF), SUPA (1 SAF), STFC (1 AF, 1 PDRA), and the ARC (1 QEII fellow, 2 Discovery PDRAs, 4 Super Science Fellows), and the AAO (AAO Fellow). Further funds are being sought through both the European Research Council (Advanced Investigators Grant), the Leverhulme Trust (Large Project Grant) and to the ARC (Laureate Fellowship). At the present time there are over 20 PhD students currently utilising GAMA data (11 named on this proposal).

5 The broader GAMA multi-wavelength programme

The unique and unassailable aspect of GAMA will be its multi-wavelength coverage. Surveys such as SDSS, SDSS II, BOSS, BigBOSS and others exceed or will exceed GAMA in terms of total number of objects. None, however, will have complete and uniform wavelength coverage from FUV to radio wavelengths and in particular HI datacubes from ASKAP. This is due to extensive coordination between the GAMA Exec. and a number of external surveys, in particular GALEX MIS, VISTA VIKING, Herschel-ATLAS, and ASKAP-DINGO. This multi-wavelength aspect is absolutely vital for studying the underlying physics of galaxy formation. Furthermore, sub-regions of GAMA are now being proposed by the GAMA Exec. (and others) for deep spectroscopic study by the VLT following an ESO call for Public Spectroscopic Surveys. The details of these surveys and how they interface with GAMA are summarised below.

1. VST KIDS. An ESO Public Survey due to commence operations in April 2011, which will survey all five GAMA fields to (10σ,AB) u=24.8, g=25.4, r=25.2, i=24.2). GAMA has Exec. membership of VST KIDS through J. Peacock, and agreement in principle to share data through VST KIDS PI (K. Kuijken).

2. VISTA VIKING. An ESO Public Survey now in progress covering all five GAMA fields to (5σ,AB) z=23.1, Y=22.3, J=22.1, H=21.5, K=21.2. GAMA has immediate access to all data through S. Driver as a member of the VIKING Exec.

3. Herschel-ATLAS. The widest area Herschel programme which has now surveyed three of the GAMA regions and will survey the remaining two over the next two years to (5σ,AB) 100μm=11.8, 160μm=11.5, 250μm=12.3, 350μm=12.0, 500μm=12.1. An MoU has been agreed between the GAMA and Herschel-ATLAS teams regards data sharing and a cross-team group formed to facilitate this. Joint catalogues should be available for use by both teams by January 2011.

4. GALEX MIS. Following a successful bid for GALEX time by GAMA team members the MIS team have now adopted the GAMA regions for complete FUV and NUV observations to (5σ,AB) FUV =21.5 NUV=21.2. Unfortunately the FUV channel is now looking defunct, however full coverage of the three equatorial blocks have been obtained and partial coverage of the southern fields. In due course all GAMA regions will have uniform NUV coverage and partial FUV coverage.

5. WISE. WISE data are scheduled for public release in April 2011 and will provide Mid-IR coverage to (5σ, AB) 3.4μm=19.1, 4.6μm=18.8, 12.0μm=16.4, 23.0μm=14.5.

6. ASKAP-DINGO. DINGO will survey five deep fields and two ultra-deep fields at frequencies suitable for detecting 21cm to $z = 0.5$ (5σ,AB) of 23.9 (1 μJy). The DINGO and GAMA PIs consult regularly over developments and optimal design, operating as a full partnership with cross-membership of respective Executives.

7. ESO-GAMAdeep. A Letter of Intent will be submitted by the 15 October 2010 ESO deadline for a $\sim$200 night programme to extend the GAMA depth in survey fields G and X(W1) to $r < 22$ mag. As well as extending GAMA science to $z \sim 1$ this programme will pre-survey the two ultra-deep DINGO regions and add approximately 400k faint redshifts to the $\sim$ 375k objects obtained by the AAT.

In addition, we have begun discussions with the DES team (Peacock and Nichol are members of both GAMA and DES), regarding a future extension of the GAMA AAT spectroscopy to cover fainter DES targets. The conjunction of the complementary VISTA, VST, ASKAP, GALEX and Herschel surveys to this AAT programme is by design and driven by the fundamental need these legacy programmes have for deep wide area spectroscopic coverage (GAMA has more than ten times the redshift density of SDSS). A general understanding is now in place to produce a new galaxy database which will remain the benchmark for the foreseeable future. We expect the resulting dataset to impact on all extra-galactic galaxy studies by superseding most previous measurements in the $z < 0.5$ domain, through detailed comparisons to numerical models attempting to encode the baryon physics, as a reference sample for all high-z surveys at wavelengths longwards of 0.2μm, and as a starting point for the definition of well defined samples for higher-fidelity studies. The requested sky coverage is based on the subset of sky covered by the ASKAP-DINGO and Herschel-ATLAS surveys, and the flux limits set to minimise the time request (i.e., exposure time matched to the configuration times). The studies possible from such a dataset are extensive. The SDSS project has now amassed 6000+ papers and 50 000+ citations and we believe GAMA's impact will be comparable.

6 Publications and the GAMA database

The GAMA team has seven papers submitted or in press, and a further six submitted or in press in collaboration with the Herschel-ATLAS team along with 20+ conference articles, 1 Astronomy & Geophysics article, and 2 AAO Newsletter articles on GAMA. The GAMA team has over 40 papers currently declared and a further 20 declared by the Herschel-ATLAS team. Details of these papers are available at either the public database **http://www.gama-survey.org/pubs/** for papers in press or via the internal GAMA wiki **http://star-www.st-and.ac.uk/gamawiki/** for proposed papers. Access to the wiki has been arranged for ATAC and referees with **username: ATAC**, **password: gama-atac**. As part of the June 2010 AAO celebrations, the GAMA team released 50k redshifts via our public portal **http://www.gama-survey.org/** . This release includes:

- the full GAMA target catalogue
- 30k new redshifts and spectra

- 20k pre-existing redshifts and spectra
- entire region ugrizYJHK native and seeing convolved SWARP images (27×20 Gb)
- reprocessed ugrizYJHK photometry for all GAMA targets
- Sersic profiles via GALFIT3 for all 50k objects
- data inspection tools including a MySQL database and near-object search
- all known redshifts in the Herschel-ATLAS Science Verification region (1.2k) along with H-ATLAS IDs.

The TAC and referees are invited to view both the public and private pages using the links and username/password combination given above. Future releases will occur on a roughly annual cycle and will include data analysis and multiwavelength products as these become available. In general we aim to operate under the principle that the team should have privileged access to all data products for no more than 2 years. In due course the GAMA database will include all measurements of spectral line diagnostics, environmental markers (including group catalogues), mass estimates (group masses, stellar masses, baryonic masses, dynamical masses), bulge-bar-disc decompositions, and imaging with matched photometric catalogues from FUV to radio wavelengths for ~0.8 million galaxies (if both AAT and ESO programmes are approved). This database will take approximately 5 years to construct and will constitute a comprehensive galaxy resource which will remain unique for the foreseeable future.

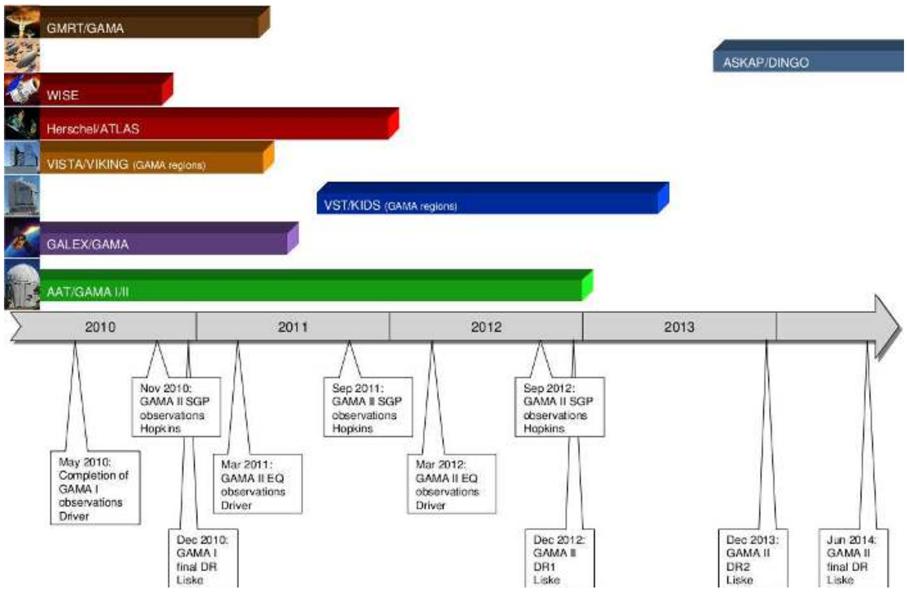

Figure 6: The proposed GAMA timeline showing key milestones, including team data releases (DR), public data releases follow within 18 months.

References

Baldry, I. K., et al., 2008, MNRAS, 388, 945
Baldry, I. K., et al., 2010, MNRAS, 404, 86
Bastian, N., et al., 2010, ARAA, (in press; arXiv:1001.2965)
Benson, A.J., et al., 2002, MNRAS, 336, 564
Benson, A.J., et al., 2003, ApJ, 599, 38
Bower R. G. et al., 2006, MNRAS, 370, 645
Boylan-Kolchin M. et al., 2009, MNRAS, 398, 1150
Brough S. et al., 2010, MNRAS, (submitted)
Cole S. et al., 2005, MNRAS, 362, 505
Conselice C., et al., 2009, MNRAS, 394, 1956
Cook, M., et al., 2010, MNRAS, 402, 941
Croton D. J. et al., 2006, MNRAS, 365, 11
Cowie, L. L., et al., 1996, AJ, 112, 839
De Lucia G. et al., 2006, MNRAS, 366, 499
De Propris R., et al., 2005, AJ, 130, 1516
De Propris R., et al., 2007, ApJ, 2007, 666, 212
Driver S. P., et al., 2006, MNRAS, 368, 414
Driver S. P. et al., 2009, A&G, 50, 12
Driver S. P. et al., 2010, MNRAS, (submitted; arXiv:1009.0614)
Driver S. P., Robotham, A. S. G., 2010, MNRAS, (in press; arXiv:1005.2538)
Eke V. R. et al., 2004a, MNRAS, 348, 866
Eke V. R. et al., 2004b, MNRAS, 355, 769
Eke V. R. et al., 2006, MNRAS, 370, 1147
Gao L., et al., 2005, MNRAS, 363L, 66
Gilmore, G., 2001 (astro-ph/0102189)
Gunawardhana, M., et al., 2010, MNRAS, (submitted)
Hill, D., et al., 2010, MNRAS, (submitted; arXiv:1009.0615)
Ho, L., et al., 2008, ApJ, 681, 128
Hopkins, A. M., Beacom, J. F. 2006, ApJ, 651, 142
Hopkins, A. M., McClure-Griffiths, N. M., Gaensler, B. M. 2008, ApJ, 682, L13
Hoversten, E. A., Glazebrook, K. 2008, ApJ, 675, 163
Juneau, S., et al.2005, ApJ, 619, L135
Lah, P., et al., 2007, MNRAS, 376, 1357
Lara-Lopez, M., et al., 2010, A&A, (in press; arXiv:1005.0509)
Lotz, J., et al., 2008, ApJ, 672, 177
McDonald, P., Seljak, U., 2009, JCAP, 10, 7
Meurer, G., et al., 2009, ApJ, 695, 765
Mobasher, B., et al., 2009, ApJ, 690, 1074
Patton D., et al., 2000, ApJ, 536, 153
Patton D., et al., 2002, ApJ, 565, 208
Peacock J. A., et al., 2001, Nature, 410, 169
Peacock J. A. et al., 2006, astro-ph/0610906
Perez-Gonzalez P.G. et al., 2008, ApJ 657, 234
Robotham, A. S. G., et al., 2010, PASA, 27, 76
Sanchez A. G. et al., 2006, MNRAS, 366, 189
Schawinski, K., et al., 2007, MNRAS, 382, 1415
Seymour, N., et al., 2008, MNRAS, 386, 1695
Simpson F. R. G., 2010, Phys. Rev. accepted (arXiv:0910.3836)
Springel V. et al., 2005, Nature, 435, 629
Tremonti, C., et al., 2004, ApJ, 613, 898
Wilkins, S., et al., 2008, MNRAS, 385, 687
Wijesinghe, D., et al., 2010, MNRAS, (in press; arXiv:1009.0616)