Anglo-Australian Time Assignment Committee

Semester: 2008A

Anglo–Australian Observatory, PO Box 296 Epping NSW 1710
AATAC Reference:
Contact: Helen Woods, hmw@aao.gov.au, +61 (02) 9372 4812
Date Stamp:

1. Names and Institutions of Applicants

Names and Institutions of Applicants	**Possible Observer?**
PIs: S.Driver (St Andrews), I.Baldry (LJMU), A.Hopkins (USyd), J.Liske (ESO), B.Nichol (Ports)	yes
P.Norberg (IfA), J.Peacock (IfA), **UK**: Bamford (Ports), Cameron (St And), Conselice (Nott)	yes
Cross (IfA), Edmondson (Ports), Lahav (ICL), Loveday (Sussex), Oliver (Sussex), Phillipps (Bristol)	yes
AUS: Forbes, Graham, Proctor (all Swin), **AAO**: Ellis, Jones, Sharp, **EU**: van Kampen (Innsbr)	yes
GROUPS: UKIDSS (Warren), KIDS (Kuijken), VIKING (Sutherland), ICC (Frenk)	no

Principal Contact: Simon Driver
Telephone: +44-1334-461680
Email: spd3@st-and.ac.uk

Postal Address:
School of Physics and Astronomy, North Haugh,
St Andrews, Fife, KY16 9SS, UK

Are the observations required for the completion of a student's thesis? no
Name of Student(s):
Name of Supervisor(s):

2. Project Title: Galaxy And Mass Assembly (GAMA)

Summary of Scientific Objectives:

We request time with AAΩ to assemble a comprehensive galaxy database that bridges a crucial gap between the SDSS and VVDS surveys. The science focus is to study structure and the relationship between matter and light on 1 kpc – 1 Mpc scales. The final sample will comprise 250k galaxies over 200 deg^2, in two 100 deg^2 segments. In this instance we request 75 nights to complete the first segment. The range of scales probed will enable direct constraints of the standard Cold Dark Matter (CDM) model by: (1) directly measuring the CDM **halo mass function** to very low halo masses ($M_h \simeq 10^{12}h^{-1}M_\odot$), and its evolution to $z \simeq 0.4$; (2) directly measuring the galaxy **stellar mass function** to very low mass limits ($M_{\rm star} \simeq 10^7 M_\odot$), constraining baryonic feedback processes; and, (3) quantifying the environment-dependent **halo merger rate** since $z \simeq 0.4$. The final legacy database (to IVO standard) will include $ugrizYJHK$ imaging with sub-arcsec spatial resolution, spectroscopy, bulge-disc decompositions, and HI observations. GAMA will also augment the science goals of the VST/KIDS and VISTA/VIKING ESO Public Surveys.

3. AAT Focal station, Instrument and Detector

Focal station:	Instrument(s):	Detector(s):	Gratings/Filters:
Prime	AAOmega	EEV	580V, 385R

All users must also fill out the AAT Instrument Request Form on the WWW. If you have any special instrumentation requirements please describe them in that form *and* in the technical case of this application.

4. AAT Scheduling Information

Proposers must ensure that all AAT time requests include a 33% allowance for weather.

Number of nights requested *this semester*	Dark:	10	Grey:	5	Bright:	0		
Minimum useful allocation *this semester*	Dark:	5	Grey:	3	Bright:	0		
Additional nights required to complete project in future	Dark:	40	Grey:	20	Bright:	0	Long term status requested	☒

Preferred dates:	Mar – Apr
Impossible dates: *(NB: astronomical reasons will have scheduling priority)*	Jun – Jul (wrong RA range)
Special scheduling constraints *(e.g. clashes with other applications, lunar position or quarter, daytime observing, requirements for multiple instruments)*	

5. Observations requested in Service?

yes: ☐ no: ☒ maybe: ☐

Under a special arranagement with PPARC, UK AAOmega MOS proposals will be performed in service as standard. Otherwise, justify service mode in proposal text.

Will real-time analysis by a Service Observer, or real-time interaction of proposers with a Service Observer be required?

yes: ☒ no: ☐ maybe: ☐

If so a member of the proposing team may be required to attend observing at the AAT.

6. **Observing Requirements**

Average signal-to-noise ratio required:	5
Any seeing limitations:	Median seeing acceptable
Required spectral resolution (if applicable):	1000-1600

7. **Support Astronomer Required** no: ☐ first night only: ☐ (Night assistant & technical backup provided at all times.)

8. **List of Principal Targets** *(add pages if more than twelve targets need to be listed)*

Source	RA	Dec	mag limits	Exposure	Priority
GAMA galaxy targets	12h 20m to 14h	-2 to $+2$ deg	$r_{\rm AB} < 19.8$ mag	1–2 hrs	1
GAMA galaxy targets	12h 20m to 14h	-2 to $+2$ deg	$K_{\rm AB} < 18.9$ mag & $r_{\rm AB} < 20.5$ mag	1–2 hrs	2

9. **Other applications for this (and related) projects in this semester**

Telescope/satellite	Title of programme
VST	The VST Kilo-Degree Survey (KIDS; approved, Peacock Co-I)
VISTA	The VISTA Kilo-Degree IR Survey (VIKING; approved, Driver, Liske, Peacock Co-Is)
Spitzer	The Spitzer-Millennium Galaxy Catalogue Survey (Pending, Driver, Liske Co-Is)

10. **Report on previous applications for time for this (and related) projects**
Show all requests for AAT time, as well as time on other ATAC/PATT telescopes, in the past 4 semesters.

Ref.No.(if known)	**Allocation**	**% useful**	**Comments (Data OK?, publications? etc.)**
G/2006A/21	11 hrs	100%	GMOS follow-up of eLSBGs for MGCz
ATAC/04A/27	4	45%	2dF for MGCz (MGC catalogue released online; overall 12 refereed papers, 3 submitted, 7+ in prep., 2 IAU press releases)
MSO/1040079	8	75%	2.3-m DBS for MGCz
PATT/04A/25	4	42%	2dF for MGCz

11. **Complete if the observations are associated with a current PPARC grant** *(UK only)*

Grant title:

Grant number: **Principal investigator:**

12. **Non-standard Travel & Subsistence** *(UK only. Justify T&S for more than one person, and/or other unusual costs)*

13. **Scientific & Technical Justification:** Attach a case (including technical information, figures and references) of no more than 3 pages, with font no smaller than 11pt. An extended 5 page case may be submitted for long-term programs, providing permission has been requested and granted from the AATAC Secretary (hmw@aao.gov.au).

Galaxy And Mass Assembly (GAMA)

PIs: S. Driver, I. Baldry, A. Hopkins, J. Liske , B. Nichol, P. Norberg, J. Peacock

Executive Summary

International surveys, such as the Two-Degree Field Galaxy Redshift Survey (2dFGRS; Colless et al. 2001) and the Sloan Digital Sky Survey (SDSS; York et al. 2000) have transformed our view of large scale structure and have contributed directly towards the emergence of a concordance cosmology (e.g., Spergel et al. 2003; Cole et al. 2005). These surveys have also provided a confirmation of the basic Cold Dark Matter (CDM) paradigm for the growth of structure through the comparison of robust model predictions with empirical clustering measurements on 1 Mpc – 1 Gpc scales (Peacock et al. 2001). On smaller, sub-Mpc scales (i.e., on the scales of clusters, groups and galaxies) our theoretical understanding of the growth of structure is less well-founded and at kpc scales it breaks down almost entirely. It is on these scales (1 kpc – 1 Mpc) where dark matter haloes virialize and merge, and where baryons decouple, collapse and eventually form complex structures such as galaxies. The 1 kpc to 1 Mpc range is therefore *the* key scale over which the baryons and baryon physics become critical to our understanding of the structures we see. The models which endeavour to describe the lower end of this regime (1 kpc – 100 kpc) are based on semi-analytic extensions to the larger scale numerical simulations. In addition to these semi-analytical models (SAMs), the halo model formalism has also attracted much recent attention (Cooray & Sheth 2002) and provides equally powerful options for understanding the properties of galaxies (satellite or central) and their relationship with the underlying dark matter. However both SAMs and the halo model require high quality datasets which are sufficiently extensive to overcome selection bias and cosmic variance.

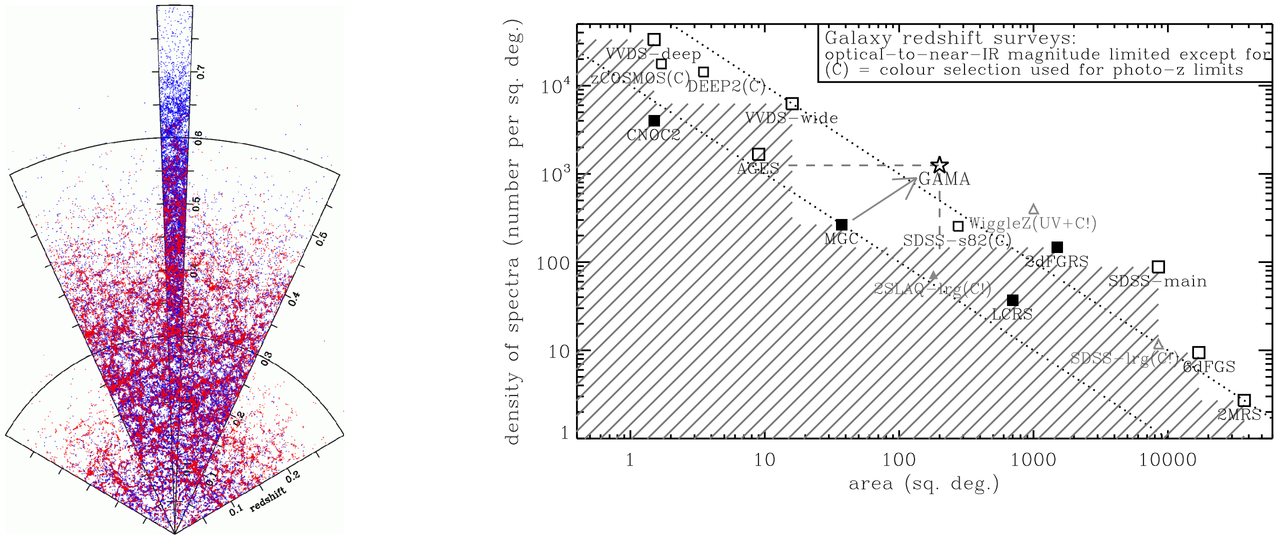

Figure 1: (*left*) Simulations of a 2 deg thick survey section for 3% of SDSS, 50% of GAMA and 50% of VVDS-wide. While SDSS samples giant galaxies locally and VVDS giant galaxies at $z \approx 1$, GAMA will sample giants over the range $z = 0$ to 0.4 and provide the first *comprehensive* study into the realm of field dwarf galaxies. (*right*) A comparison of the source density and area covered for a number of completed (filled symbols) and ongoing (open symbols) surveys. GAMA fills an obvious gap between the shallow large-area surveys and the deep 8m surveys. This region can only be probed efficiently with AAΩ. The dotted lines correspond to surveys of 10^4 and 10^5 galaxies.

AAΩ, with its unique wide area field-of-view and multiplexing capability, represents the only facility capable of surveying these critical scales in a comprehensive and efficient manner (see Fig. 1, right). In addition, we have now secured access to the highest quality wide-field imaging data from ESO's VST and VISTA facilities in order to maximise the science return and legacy value of this project. The database that will be produced from the combination of these cutting-edge facilities will be on a scale comparable to the SDSS and 2MASS surveys but specifically geared to comprehensively study structure in an unbiased manner on 1 kpc – 1 Mpc scales. Herein we describe three key scientific goals that will be addressed by our survey, followed by an incomplete list of complementary projects:

1) A robust test of the Cold Dark Matter paradigm by measuring the precisely predicted halo mass function from cluster to individual galaxy halo masses over a 4 Gyr baseline.
2) A comprehensive determination of the galaxy stellar mass function to Magellanic Cloud masses to fully define baryonic feedback processes.
3) A direct measurement of the recent major and minor galaxy merger rates across all environments and for all galaxy types.

1) The halo mass function and galaxy formation efficiency

At any redshift, the halo mass function, dN/dM, is well established via detailed numerical simulations, requiring no knowledge of the baryonic physics, and is precisely *predicted* over more than 5 orders of magnitude in halo mass (e.g. Springel et al. 2005). With the cosmological parameters now specified to high accuracy in the post-WMAP era (Spergel et al. 2003; Sanchez et al. 2006), this theoretical prediction of the CDM paradigm is one of the most robust predictions available (Jenkins et al. 2001; Warren et al. 2006).

Observationally, the halo masses can be obtained through dynamical mass estimates of galaxy groups. For example, through the assumption of equilibrium conditions, a velocity dispersion estimate for bound galaxies directly constrains the halo mass. An attempt at this was made with the 2dFGRS dataset and the 2PIGG group catalogue (Eke et al. 2004). While 2PIGG is able to probe the mass function down to a few$\times 10^{13}$ $h^{-1}M_{\odot}$ (Eke et al. 2006), the catalogue is incomplete below 10^{14} $h^{-1}M_{\odot}$, implying that the best observations currently available only test the theoretical predictions for dN/dM over less than one order of magnitude in mass (see Fig. 2, left). The main reason behind this limitation is that the 2dFGRS was not deep enough to probe low-mass haloes over a sufficiently representative volume: the 2PIGG mass estimates are typically measured from a small number of relatively luminous galaxies – thus limiting the comparison range and the accuracy of the individual halo mass estimates. In addition, the 2dFGRS spectral resolution corresponds to an r.m.s. velocity uncertainty of $85\,\mathrm{km\,s^{-1}}$ per galaxy, indirectly implying a lower halo mass limit of a few$\times 10^{12}$ $h^{-1}M_{\odot}$.

By going ∼10 times deeper and doubling the spectral resolution w.r.t. the 2dFGRS, the above limitations are overcome. The extra depth increases the number of galaxy group members by a factor of 2 to 3 and, together with the increased spectral resolution, enables the detection of significantly lower mass groups: GAMA will provide robust halo mass measurements down to 10^{12} $h^{-1}M_{\odot}$ – an improvement of two orders of magnitude over 2PIGG. A detailed prediction of the errors inherent in this measurement is complex as the semi-analytic galaxy formation models vary significantly in their predictions at these low masses (by a factor of 5). Hence, not only will GAMA constrain the CDM halo mass function over three orders of magnitude but, in combination with 2PIGG, it will also provide the first indication as to the true halo occupancy numbers from rich cluster to local group scale masses.

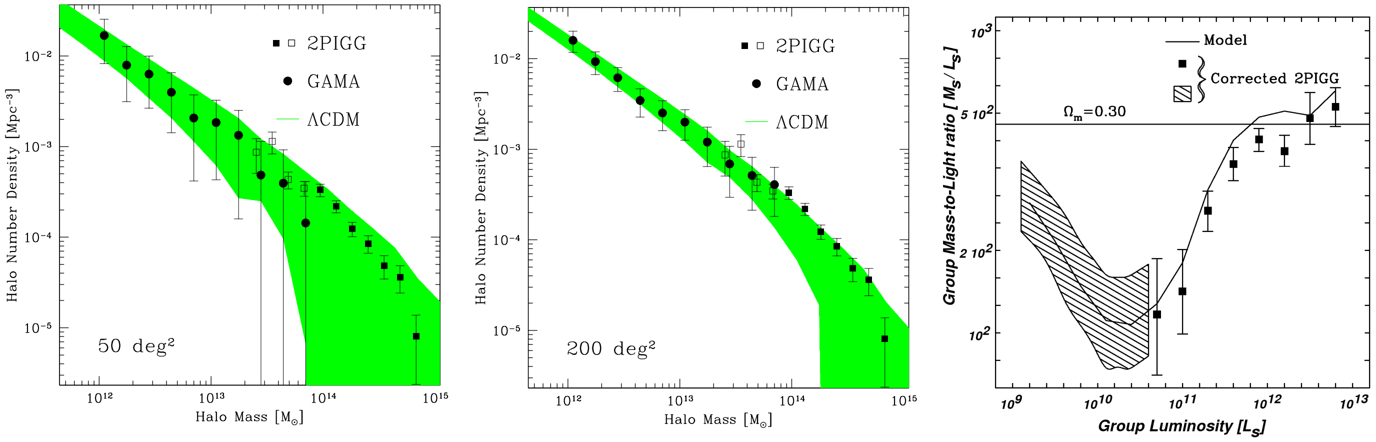

Figure 2: In the left and middle panels we compare a simulated GAMA group mass function (circles) to the 2PIGG mass function data (squares) and a ΛCDM halo mass function (shaded area), assuming an area of 50 and 200 deg^2 for GAMA, respectively. In each panel the uncertainty of the halo mass function is representative of the scatter in the underlying theoretical mass function for a GAMA sized survey, whereas the errors on the simulated GAMA data also include limitations in detecting real groups. (*right*) The 2PIGG group mass-to-light ratio as function of the group $\mathrm{b_J}$-band luminosity (squares with errorbars). This group $\mathrm{M}_h/\mathrm{L}_{\mathrm{b_J}}$ is a tracer of the galaxy formation efficiency, which has a maximum for Local Group sized systems. The shaded area is obtained by assuming the group mass function is identical to the Jenkins et al. (2001) dark matter halo mass function. It is precisely this shaded regime we will probe with GAMA. (Figure adapted from Eke et al. 2006.)

With this new group catalogue, we will be able to address predictions from current galaxy formation models for their feedback mechanisms and their star formation efficiency. The latter is predicted to increase with declining group mass down to Local Group sized haloes, below which the efficiency is predicted to decrease. Due to the previously mentioned limitations of 2PIGG, this regime of maximum efficiency and what happens within the smaller haloes is unknown (see Fig. 2, right). With GAMA, that regime will be accurately tested; we will probe statistically feedback mechanisms in low mass haloes for the first time, and will be able to use a single experiment to cover the range from cluster sized haloes down to 10^{12} $h^{-1}M_{\odot}$ groups – a two orders of magnitude improvement compared to 2PIGG.

2) The galaxy stellar mass function vs. dark matter mass function

The total M/L ratio for groups is an important measure, but cannot probe to individual galaxy masses. On these scales the CDM model predicts that the mass function of the sub-haloes that each host a single galaxy should be a steeply rising power law, such that the low mass population contributes a significant fraction to the total mass density (Gao et al. 2004). This is at odds with observations of the galaxy luminosity function (e.g. Norberg et al. 2002; Driver et al. 2005) which find a relatively flat luminosity distribution down to 0.01 L^* (i.e. negligible contribution from low-flux systems).

The favoured explanation requires the star-formation efficiency to vary as a function of halo mass, such that low mass haloes are extremely inefficient in converting baryons to stars. The proposed physical mechanism for curtailing star-formation is star-formation itself (e.g. supernova winds heating or even expelling the remaining gas from low mass haloes). This requires that *all* dark matter haloes have a non-zero and therefore detectable stellar luminosity. Put simply, the halo mass function and galaxy stellar mass function must be related by a mass dependent star-formation efficiency function. With the halo mass function a parameter-free prediction, then an empirical measurement of the stellar mass function yields not only a precise measurement of this feedback prescription but also the dark-matter to stellar-mass ratio as a function of stellar mass.

The present compendium of data (see Fig. 3) probes to $10^{8.5}M_\odot$. GAMA will extend this by over an order of magnitude down to $10^7 M_\odot$. Moreover, the depth and resolution of the imaging data, the red and near-IR selection, and the broad wavelength coverage will enable us to overcome complex practical issues such as dust attenuation (Driver et al. 2007), and both high and low surface brightness selection biases (Driver et al. 2005; Liske et al. 2006). Moreover, the scale of GAMA (200 deg^2) will enable a detailed study of the stellar mass function, star-formation efficiency, and the dark matter to stellar mass ratios as a function of environment and redshift. Dividing the survey into 5 environment bins and 5 redshift bins will result in each sample containing ∼10 000 galaxies. This is comparable to the full MGC sample and what we consider the minimum sample size for robust mass function estimates (see Driver et al. 2005).

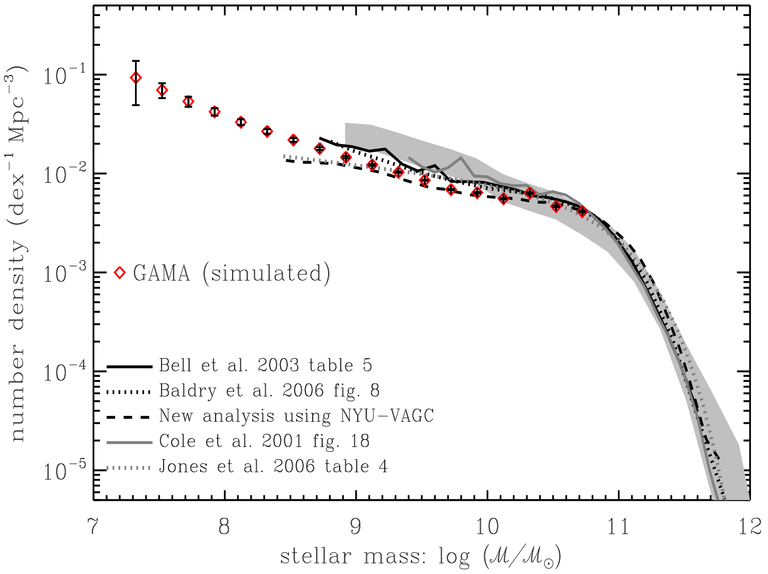

Figure 3: Galaxy stellar mass functions from SDSS, 2MASS+2dFGRS and 6dFGS (various lines), compared to the prediction of a recent semi-analytic galaxy formation model (shaded region; De Lucia et al. 2006), and a simulation of the numbers expected for GAMA (open diamonds with errorbars). Note that detailed model predictions cannot be made below $\sim 10^9 M_\odot$, as the Millennium simulation, on which the semi-analytic catalogues are based, becomes incomplete. We expect GAMA to be able to probe the stellar mass function down to $\sim 10^7 M_\odot$, where the precise limit depends on the assumed baryonic feedback description. The prediction shown is based on galaxies with $0.008 < z < 0.1$ and errors are purely Poisson. We intend to derive the stellar mass function for five environment bins and over five redshift intervals.

Together with the determination of the halo mass function, the measurement of the galaxy stellar mass function to Magellanic Cloud stellar masses is key to effectively constraining galaxy formation models and providing a major test of CDM theory on these hitherto unexplored scales. Note that our observations will probe mass scales beyond the current state-of-the art numerical simulations (i.e., the Millennium simulation) and the Virgo Consortium (which includes the IfA and the Durham ICC) will be initiating new numerical simulations for comparison with GAMA.

3) Galaxy merger rates vs. dark matter merger trees

The hierarchical assembly of galaxies is a keystone of all CDM models of galaxy formation (White & Frenk 1991; Coles 2005). The build-up of both dark matter haloes and the baryonic mass of galaxies through repeated mergers of smaller units is one of the principal modes of growth in these models. For example, De Lucia et al. (2006) recently predicted that as much as 50% of halo mass has been accreted since $z = 0.8$. Observationally this process is constrained by measuring the galaxy merger rate and comparing the predicted galaxy merger rate and its redshift evolution (e.g. Khochfar & Burkert 2001) with observations provides a fundamental test of the CDM paradigm. In recent years there have been a number of attempts to measure the galaxy merger rate both locally (e.g. Patton et al. 2000, 2002; De Propris et al. 2005) and at high z (e.g. Conselice et al. 2003; Lin et al. 2004). However, no clear picture has yet emerged from these studies. While Lin et al. (2004) find that the galaxy major merger rate evolves less rapidly than predicted by CDM models, Bell et al. (2006) find the right amount of evolution. Conselice (2006), on the other hand, observes *more* evolution than predicted. GAMA will improve on previous low-z studies in several ways:

(i) High-resolution imaging and complete spectroscopy: The galaxy merger rate is measured either by finding galaxies in pairs that are close enough (on the sky and in redshift space) so that they will merge in the near future, or by identifying recent merger remnants through their asymmetric light distribution. These methods require spectroscopy that is highly complete for close pairs (which is difficult because of fibre placement restrictions) and high-resolution imaging, respectively. Existing large-scale surveys, such as the 2dFGRS and SDSS) essentially fail on both accounts. In contrast, the high target density of GAMA will require 10–11 configurations per AAΩ pointing which will entirely eliminate any close pair bias in the spectroscopy. Hence, together with the high-resolution KIDS and VIKING imaging, GAMA will be ideally suited for studies of the galaxy merger rate.

(ii) Statistics: The MGC (Liske et al. 2003) represents the largest local study to date with the best combination of high-resolution imaging and spectroscopic close pair completeness. However, it is severely limited by its size since it only contains 112 dynamically close pairs and 53 highly asymmetric systems. While the merger rate and timescales have been constrained (see De Propris et al. 2005; 2007) the errors remain large due to small number statistics. GAMA will probe a volume that is 15 times larger (for 100 deg^2) than the MGC's, so that we can expect a sample of $\sim$ 1700 close pairs and $\sim$ 800 merger remnants. Not only will this result in an order of magnitude refinement over previous measurements but it will also allow us to split the sample into several environment, redshift and galaxy type bins, and thus measure the merger rate as a function of local galaxy density and galaxy type ('wet' vs. 'dry' mergers) as well as its recent evolution.

(iii) Large mass range: Observationally, the dependence of the major merger rate on mass, and the contribution of *minor* mergers to the growth of galaxies is entirely unconstrained. The reason is that existing surveys lack the size and dynamic range in luminosity to probe these questions. For example, the MGC can probe a mass ratio of at most 1:16 (De Propris et al. 2007). GAMA will go 1.5–2 mag deeper, and cover a 2.7 times larger area (for 100 deg^2) than the MGC so that it will be able to measure the merger rate down to a mass ratio of 1:100.

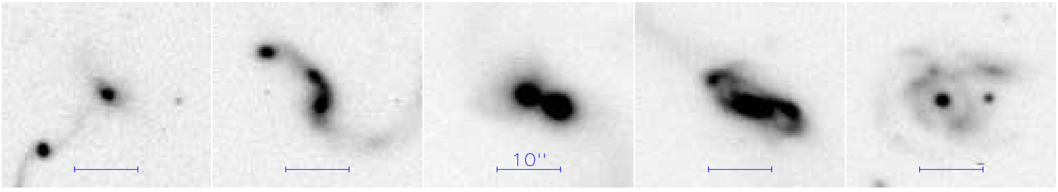

Figure 4: Examples of dynamically close pairs and highly asymmetric galaxies representing the pre- to post-merger phases from the MGC.

We have recently calibrated the close pair and the asymmetry methods for the first time on a single dataset (De Propris et al. 2007). Reconciling the measured merger rates with the predictions of hierarchical CDM models requires a merger time-scale of < 0.3 Gyr, with high asymmetry persisting for 0.2 Gyr after the merger event. This is just at the limit of what is considered realistic. To increase the accuracy of these constraints and to quantify the dependence of the merger rate on environment, mass and galaxy type now requires a large, fully sampled survey to faint flux limits. In addition, we will be able to study star-formation rates and sizes for the various merger stages from the combination of our spectra and multi-wavelength imaging data in order to better understand the role of merger events in triggering star formation.

4) A legacy database for galaxy studies

GAMA builds a vital bridge between the shallow but large SDSS, and the deep but narrow VVDS-type surveys and is expected to have an impact comparable to the SDSS and 2MASS surveys, each of which has produced over 300 refereed publications. Below we highlight a few of the science topics in which the proposing team is specifically interested, but this list is by no means exhaustive.

1. the super-massive black hole mass function for late and early types
2. galaxy colour-concentration bimodality versus environment and redshift
3. the stellar-mass–size relation for ellipticals, bulges and discs versus environment
4. a study of dust attenuation versus wavelength for bulges and discs
5. a study of outer disc (anti-)truncation
6. incidence of nucleation in dwarf systems
7. a study of low-luminosity blue spheroids
8. calibration of morphology indicators (B/D decomposition, CAS, Gini, etc.)
9. dwarf taxonomy and density relations
10. global age and metallicity measurements using Lick indices
11. global star-formation rate versus stellar mass using OII and Hα
12. correlations between star-formation and structural properties
13. colour bimodality of giant galaxies since $z = 0.4$
14. the star-formation rate and build-up of stellar mass since $z = 0.4$
15. stellar, dust, gas and dynamical mass estimates
16. stellar, baryonic and dynamical mass-to-light ratios versus mass, structure, environment and redshift
17. σ_8 and associated intermediate scale clustering statistics
18. calibration of 250k photo-z's for VST KIDS/VISTA VIKING to assist weak lensing studies
19. deep Galactic structure studies

5) Synergy with the SKA Extended New Technology Demonstrator (xNTD)

The xNTD, a Square Kilometre Array (SKA) pathfinder facility, is the Extended version of the New Technology Demonstrator also known as MIRA. The xNTD is designed to be a front-line scientific instrument in its own right, capable of sampling a field-of-view of 40 deg^2 at $\sim 1\,\mathrm{GHz}$, and it will be located in Boolardy, Western Australia, the proposed Australian site for the SKA. A shallow all-sky survey will probe neutral hydrogen in galaxies to $z \approx 0.18$, *a deep survey spanning about 120 deg*^{2} *will cover* $0.14 < z < 0.42$, and an ultra-deep survey of 30 deg^2 will probe up to $z \approx 1.1$ (Johnston 2006). The deep survey region, anticipated to require about 100 days of xNTD observing time, is ideally matched in both size and sensitivity to a GAMA Segment (see below) and we are engaged in discussions to coordinate the survey areas. Given xNTD's resolution of 15–30 arcsec it will not be possible to unambiguously identify optical counterparts to its detections from imaging alone. This will only be made possible by the inclusion of spectroscopic data. Hence GAMA will enable us to connect the deep xNTD survey with optical–near-IR surveys and allow the construction of a catalogue including optical, near-IR, spectroscopic, and HI mass and dynamical mass estimates within a single survey (as well as radio continuum measurements). The combination of HI and optical data on such a grand scale will enable detailed studies of the relationship between light, stellar mass, gas mass, and dynamical mass on an unprecedented scale. Moreover, the polarisation information obtained naturally as part of any xNTD survey will provide rotation measures and position angles of polarised emission from strong sources, perhaps up to several thousand galaxies. This will allow the first detailed investigation into the evolution of magnetic field properties of galaxies.

The final GAMA database will combine data from the latest world-class survey facilities (AAΩ, VST and VISTA) and may also include xNTD, SCUBA-II as well as limited GALEX, Spitzer and eventually JWST data. It will comprise $\sim$250k galaxies, each with deep, sub-arcsec resolution, UV – near-IR imaging, well-sampled spectra, line indices, bulge-disc decompositions and stellar masses. A subset may also have far-IR dust estimates, as well as HI gas and dynamical mass estimates. Constructing this database will take 5 years but it will comprehensively supersede all previous databases over these scales, provide the definitive zero-redshift benchmark for the JWST and SKA, and remain as one of the principal galaxy resources for the foreseeable future.

Survey design

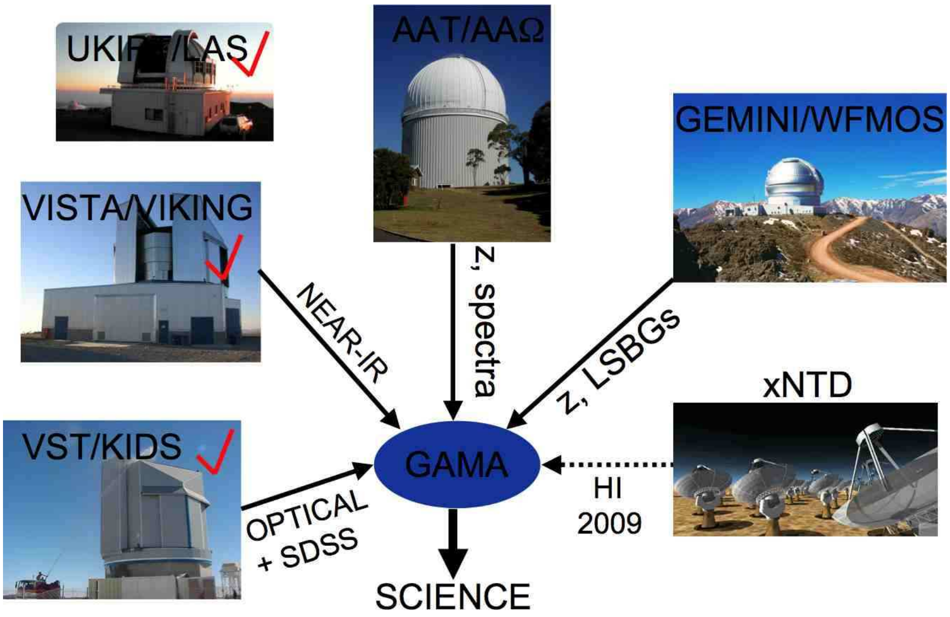

Figure 5: Summary of contributing facilities.

Depth Accurate measurements of the halo mass function and the stellar mass function to the lowest possible masses requires deep observations. This is because redshifts below $z \approx 0.008$ are severely affected by peculiar velocities introducing significant magnitude errors ($\Delta M \sim 0.5$). At this redshift the distance modulus is $32 - 5 \log h$ mag. While ideally one wishes to probe to the lowest luminosities known ($M_r \approx -7$ mag) one is realistically limited by current technology. In 1–2 hr integrations AAΩ should reach to $r_{\rm AB} = 20.5$ mag with S/N = 5, which probes to $M_r = -11.5$ mag. Our aim would be to obtain redshifts for a complete sample to $r_{\rm AB} = 19.8$ mag, with additional selection to $r_{\rm AB} = 20.5$ mag, including a near-IR constraint of $K_{\rm AB} < 18.9$ mag (or $K_{\rm Vega} < 17.0$). We are aware that in reality some systems at these faint absolute magnitudes will be of extremely low surface brightness and beyond the capability of AAΩ. This constitutes a small number of systems for which we intend to augment our AAΩ programme with additional observations using Gemini, Salt and VLT, to which we have ready access. To date we have used Gemini to pursue extreme low surface brightness galaxies with a 100% success rate and have significant expertise in the management of galaxy selection bias (e.g., Driver et al. 2005; Liske et al. 2006).

Wavelength of target selection Our main (initial) selection is done in the SDSS r and UKIDSS K bands. The r-band selection maximises redshift success rate, while the additional K-band selection is closer to a direct stellar mass limit. The primary sample will be $r_{\rm AB} < 19.8$ mag (≈ 1050 targets deg^{-2}). The aim here is for very high completeness (important for measurements of the merger rate and group masses). The secondary sample will consist of galaxies with $19.8 < r_{\rm AB} < 20.5$ mag and $K_{\rm AB} < 18.9$ mag (≈ 400 deg^{-2} with ∼75% sampling for 300 targets deg^{-2}). The K-band limit will leverage the stellar mass function as well as contributing to halo masses. Note that for low redshift galaxies, $z < 0.1$, the sample will be highly complete to $K_{\rm AB} = 18.9$ mag because galaxies with $(r - K)_{\rm AB} > 1.6$ will mostly be at $z > 0.3$. Allowing for some redshift failures and stellar contamination, the aim is to obtain **1250 galaxy redshifts per deg^2**: 14 times the target density of the SDSS main galaxy sample and 9 times that of the 2dFGRS.

Area The area requirement for this survey is mainly based on the minimal number of low luminosity groups needed to perform a sound statistical analysis. With the assumption that the smaller the galaxy group is, the fainter we need to reach in order to recover enough of its members (a requirement for reliable mass estimates), then using the Jenkins et al. (2001) CDM halo mass function together with the local galaxy luminosity function (e.g. Norberg et al. 2002), we estimate the number of 10^{12} (3×10^{12}; 10^{13}) $h^{-1} M_\odot$ groups with $z < 0.04$ (< 0.06; < 0.09) to be ~ 0.5 (0.5; 0.6) per deg^2 respectively. Hence, a survey area of 200 deg^2 is required in order to detect a sufficiently large number (~ 100) of low mass groups (see Fig. 2 middle versus left). An additional justification is the requirement to explore redshift and environment. By subdividing into 5 environment and 5 redshift bins each subsample comprises around 10,000 galaxies (i.e., comparable to the full MGC and what we consider a minimum sample size for robust mass function measurements).

Geometry Clusters and groups typically exist up to 2 h^{-1} Mpc in diameter. To avoid severe boundary problems the survey should not be narrower than 5 cluster diameters, i.e. 10 h^{-1} Mpc. At low redshifts, $z \approx 0.05$, this corresponds to 4 deg. A single long strip in RA or several shorter, separate strips can be used to maximise observational efficiency. Possible geometries range from one 4×50 deg^2 strip to four 5×10 deg^2 strips. Our proposal is for one 4×25 deg^2 strip in the NGP near the celestial equator (Segment 1) and two 5×10 deg^2 strips in the SGP (Segment 2, Dec ≈ -30 where two strips should enable a more accelerated observing schedule). However, two 5×10 deg^2 strips would also be acceptable for Segment 1 if required by the scheduler. Our initial request is to obtain spectroscopy for the 100 deg^2 of Segment 1 in the NGP, where an appropriate and reliable input catalogue already exists (see below). A larger request is not viable at this time because of the ongoing WiggleZ programme. Hence we anticipate requesting time for Segment 2 in 2009/2010 to coincide with the conclusion of the WiggleZ survey.

Location For GAMA Segment 1 we select a survey area in the high Galactic latitude, equatorial region of the NGP: $-2 <$ Dec $< +2$ deg and 12h20m $<$ RA $<$ 14h. However, we stress our flexibility with regard to the exact location in RA to ease scheduling. The selected area has already been the target of several (mostly shallower) redshift surveys, including the SDSS, 2dFGRS, MGCz and 2SLAQ. Within our limits, these surveys will already provide us with $\sim 30\,000$ redshifts. Further advantages of the equatorial region are: (i) it is accessible to all telescopes world-wide; (ii) it has been selected as the target region of the upcoming deep GALEX survey; (iii) it has been declared a priority region within the UKIDSS, VST KIDS and VISTA VIKING surveys; (iv) it forms the basis for a major Spitzer legacy proposal.

Spectral resolution Our main aim is to maximise redshift success over a fairly broad redshift range (0–0.5). To this end, we will use the lowest resolution setup, namely the 580V and 385R gratings, which give a resolution of $R \sim 1000$–1600 and a wavelength coverage of 370–880 nm. This represents a 2-fold increase in the number of spectral resolution elements w.r.t. the 2dFGRS.

Input catalogue

We have divided our survey into two segments of 100 deg^2 each. Segment 1 will build upon the 2dFGRS NGP/SDSS/MGC/UKIDSS LAS region where sufficient data already exist to define the input catalogue. Segment 2 will lie in the south and will be based on an input catalogue built from the VST KIDS and VISTA VIKING surveys. Here we are proposing to commence with Segment 1, and we foreshadow a request in 2009/10 to continue with Segment 2 in 2010B (i.e., post-WiggleZ).

In detail, the Segment 1 (NGP) input catalogue is currently based on SDSS Stripes 9–11 and the UKIDSS Large Area Survey. Both datasets currently exist, are well understood and are sufficiently deep to perform target selection and to define the initial input catalogue. The PIs of the relevant teams are all GAMA team members, ensuring good communication between these key surveys. Observing for KIDS and/or VIKING will commence as soon as VST and/or VISTA are commissioned, which is currently expected for the first half of 2008. We stress that the final database will be based on the VST and VISTA imaging data *for both segments*. However, the *initial* input catalogue for the NGP segment is based on the existing SDSS and UKIDSS data and is already in place.

Table 1: 5-σ point-source detection limits (AB mag) and typical resolution of existing and near-future imaging surveys in the GAMA region. The last line lists the proposed GAMA spectroscopic limits.

Survey limits	**u**	**g,B**	**r**	**i**	**z**	**Y**	**J**	**H**	**K**	Seeing
MGC	—	24.0	—	—	—	—	—	—	—	1.25″
SDSS	22.0	22.2	22.2	21.3	20.5	—	—	—	—	1.5″
2MASS	—	—	—	—	—	—	16.7	16.5	16.2	3.0″
VST KIDS	24.8	25.4	25.2	25.2	—	—	—	—	—	0.7″
UKIDSS LAS	—	—	—	—	—	20.8	20.5	20.1	20.1	0.9″
VISTA VIKING	—	—	—	—	23.1	22.3	22.1	21.5	21.2	0.7″
Proposed GAMA limits	—	—	**20.5**	—	—	—	—	—	**18.9**	N/A

Comparison to other galaxy redshift surveys

GAMA represents a germane connection between the shallow, wide (6dFGS, SDSS, 2dFGRS) and the deep, narrow (VVDS, DEEP2) redshift surveys that have recently been completed or are currently underway (see Fig. 1, right). The broad science goal, to study CDM structure predictions on 1 kpc – 1 Mpc scales at $z < 0.1$ and on 10 kpc – 1 Mpc scales at $z < 0.4$, is unique and cannot reasonably be achieved by any facility other than AAΩ. The sub-Mpc scale has not been adequately probed by either the 2dFGRS or SDSS surveys primarily because of the lack of depth, single pass mode and fibre collision constraints. GAMA will survey sufficiently deep ($r_{\rm AB} = 20.5$ mag) to identify low stellar mass systems, low halo mass groups, and span a 4 Gyr lookback-time baseline for the giant galaxy population. It will cover a sufficiently extensive area (200 $\deg^2$) to provide robust statistics, enabling environmental studies. The necessity for numerous repeat visits to each field will naturally overcome close pairs, group and cluster biases. The spectral resolution will be sufficient ($1000 - 1600$) to enable the use of spectral diagnostics and crude kinematics. Other redshift surveys cannot probe GAMA science for varying reasons. The area of the VVDS-wide consists of four disjoint 2×2 deg fields which is not suitable for group detection at low redshift, its spectral resolution of 250 limits velocity accuracy, and its targeting completeness is low. The DEEP2 survey uses a colour cut to pre-select galaxies at $z > 0.7$. The SDSS-LRG and 2SLAQ surveys only probe the most luminous red galaxies and the WiggleZ survey targets only UV luminous galaxies at high redshift. In fact, our sample is entirely non-overlapping with WiggleZ: $20.5 < r < 22.5$ and UV selected compared to $r < 20.5$ and near-IR selected.

Execution

The survey will target extended objects with $r_{\rm AB} < 20.5$ mag and $K_{\rm AB} < 18.9$ mag within the survey regions with the 580V/385R gratings. Redshifts for the $\sim 30\,000$ brightest objects already exist (from SDSS, 2dFGRS, MGCz, 2SLAQ and NED). Table 2 shows target numbers and estimates of observing time to obtain redshifts (for an example strategy). The spectral resolving power of 1000–1600 for the AAΩ setup will increase the S/N of typical galaxy emission lines compared to the 2dFGRS setup (400–900), in addition to improved throughput. Since we have multiple visits to each field, any targets that we do not obtain redshifts for can be re-observed.

Table 2: Target list details (for 100 $\deg^2$)

$r_{\rm AB}$ range	other limit	galaxies	pointings[a]	S/N est.[b]	exp. time (hrs)	total time[c]
< 18		mostly obtained				
18.0–18.6		14000	40	7–20	0.8	40
18.6–19.2		26000	74	7–20	1.0	86
19.2–19.8		46000	131	5–13	1.0	153
19.8–20.5	$K_{\rm AB} < 18.9$	15000	43	5–10	1.0	50
fibre faint[b]		17000	49	4–8	2.0	106

[a] The pointings assume an allocation of 350 fibres per configuration.
[b] The S/N per Å is about the same for the blue and red arms ($V - r \approx 0.2$, $R - r \approx -0.3$). From existing SDSS data we find that it is the r-band S/N which most closely correlates with the redshift success rate. The ranges of S/N shown reflect the variation in SDSS fibre magnitudes over the middle 90% of each sample. Galaxies with fibre-aperture magnitudes of $r > 21$ mag are allocated to the 'fibre faint' sample.
[c] Includes 10 min setup time per configuration.

Each GAMA segment will be covered by 3 or 4 overlapping strips in declination but with adaptive centres in RA. Due to the high density of objects any given field will be re-observed many times resulting in around 340 (680) pointings in total for 100 (200) $\deg^2$, where we have assumed 350 fibre allocations per pointing (allowing for sky fibres, re-observations of some galaxies, quality control, etc.). Our strategy will be to observe according to conditions, pursuing the brighter fields in moderate conditions and the fainter fields in pristine conditions. Initially, most pointings will be observed for 1 hour. Galaxies requiring re-observation will then be allocated to future tiles and we will develop software for co-adding spectra from multiple pointings. We estimate that this will require a total of 440 (880) hours (including overheads). Adding the weather allowance results in a request of 75 (150) nights, to be spread over 5 years. The data will be reduced and redshifted on-the-fly so that the input file can be updated at the end of each night and fresh configurations can be prepared for each night's observations (as was routinely done for the MGCz and 2SLAQ surveys). Our multiple-observation strategy with dynamically chosen tile centres is aimed at making the best use of AAΩ's 2-deg field of view and multiplexing capabilities and significantly increases the survey efficiency. We stress that our team has extensive experience with all the steps involved in this procedure (from 2dFGRS, 2SLAQ, MGCz and SDSS).

Management Plan

GAMA will be led by Driver (St Andrews) with Baldry (LJMU), Liske (ESO), Hopkins (USyd), Nichol (Portsmouth), Norberg (IfA) and Peacock (IfA) as co-PIs. Each are taking full responsibility for one key aspect of the survey (management/execution, input catalogues, database, observing/radio, spectra, mocks and science). The management of the data flow is shown schematically in Fig. 6. Decisions and planning will be made through regular telecons between the seven PIs with other team members brought in as necessary. This corporate style is much more efficient and flexible than regular all-team meetings which will be reserved purely for science and will occur on an ad hoc basis as opportunities arise (e.g., NAM, AAS, ASA, etc). Driver will be devoting 100% of his research time to this project as well as seeking PPARC, ARC and EU support. A key feature of the data flow is that it operates on an annual cycle with the observing in Feb–Apr, quality control May–Oct, database update during Nov–Dec and Jan for input catalogue preparation. This essentially requires Driver, Baldry, Liske to commit an intensive 3 month period each year to each segment which fits in well with the usual academic cycle and their respective teaching responsibilities. The observing will be carried out primarily by team members based in Australia which includes a number of expert 2dF observers. However Driver, Liske, Baldry and Nichol will each commit to one week observing per year and all team members will be encouraged to participate. We are willing and able to commit to any observing procedure implemented by the AAO.

Reduction and Database The Observing Team is expected to contribute towards data reduction and redshift classification software in co-ordination with the AAO, building upon the existing 2dfdr and run*z* codes. Data will be reduced and processed on-the-fly as for the 2dFGRS, 2SLAQ and MGCz. Quality control will be implemented by Liske prior to assimilation into the GAMA database. Liske will take ultimate responsibility for the management of the GAMA database, which currently consists of the available imaging data ($ugriz$ from SDSS, B for MGC sub-region, JHK from 2MASS and $YJHK$ from UKIDSS LAS) and spectra for $\sim 30\,000$ objects. This dataset forms the starting point of our survey to the limits specified in Table 1. It will be augmented with VST and VISTA imaging data as they become available. These will also be used to obtain multi-wavelength bulge-disc decompositions for each galaxy (with GIM2D; Simard et al. 2002), which will also be included in the database. As GAMA progresses, the database will be updated annually during semester B and made accessible online or on request on DVD (see the 2dFGRS, MGC and 2SLAQ web sites, e.g. www.eso.org/~jliske/mgc). Mirror sites will be set up at each major contributing institution (i.e., St Andrews, LJMU, IfA and AAO). The final database will be prepared to IVO standards and also published through AstroGrid.

Students Students will be encouraged onto the project and allowed to fence off a topic on which to work, having demonstrated suitable expertise and supervisory support. The PIs will keep track of the fenced-off areas and, if progress is stalled for more than a year, re-open these areas to others. It therefore falls on the supervisors to ensure the viability of the project, as well as the capability and productivity of the student.

Publications All papers will include the core team which consists of the seven PIs (who are each committing 1/3 of their time to the project), all observers/software developers and those who have contributed directly to the paper in question. Papers will be published in available journals. Page charges will be the responsibility of the lead author.

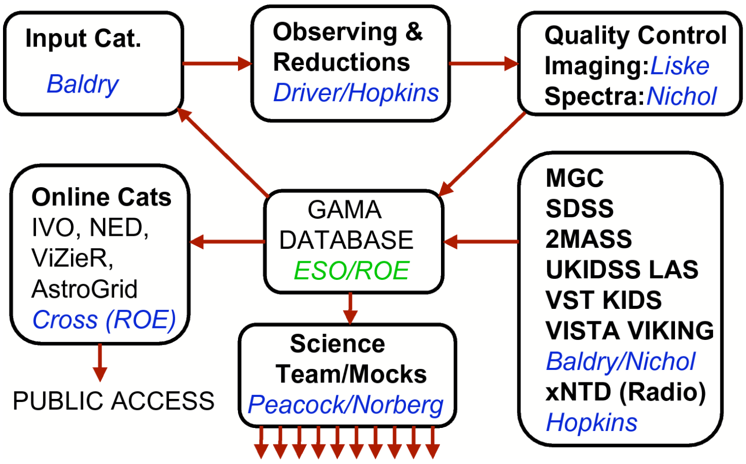

Figure 6: Schematic of GAMA data flow.

Timeline

Our timeline is shown below. The obvious AATAC review points are at the time of submission for GAMA-Segment 2 and directly after each data release.

Table 3: Timeline for the GAMA project

Milestone	Time	Key people
Construct optical input catalogue for GAMA-S1	Dec 2006	Baldry, Nichol **DONE**
Construct mock catalogues for GAMA-S1&S2	Feb 2007	Norberg, Peacock **DONE**
Submit to AATAC to commence GAMA-S1	Mar 2007	Driver et al. **DONE**
Complete UKIRT observations of GAMA-S1	Jun 2007	Warren, Driver **APPROVED**
Construct near-IR input catalogue for GAMA-S1	Dec 2007	Baldry, Cross
Commence AAΩ observations of GAMA-S1	Feb 2008	Driver, Hopkins
Commence VST observations of GAMA-S1&2	Feb 2008	Kuijken, Peacock **APPROVED**
Commence VISTA observations of GAMA-S1&2	Feb 2008	Sutherland, Driver **APPROVED**
Commence spectral line diagnostic analyses	Oct 2008	Nichol, Forbes
Public release of GAMA-S1 Year 1 data	Dec 2008	Liske, Baldry
Commence GEMINI/VLT studies of eLSBGs	Feb 2009	Driver, Liske
Complete VST observations of GAMA-S1&2	Jun 2009	Kuijken, Peacock
Complete VISTA observations of GAMA-S1&2	Jun 2009	Sutherland, Driver
Assimilate VST/VISTA data into GAMA database	Oct 2009	Baldry, Liske
Commence bulge-disc decompositions	Oct 2009	Nichol, Driver
Construct full input catalogue for GAMA-S2	Oct 2009	Baldry, Nichol
Public release of GAMA-S1 Year 2 data	Dec 2009	Liske, Baldry
Commence xNTD 21cm observations of GAMA-S1	Jan 2010	Hopkins, Driver
Public release of GAMA-S1 Year 3 data	Dec 2010	Liske, Baldry
Submit to AATAC to commence GAMA-S2	Feb 2010	Driver et al.
Commence AAΩ observations of GAMA-S2	Oct 2010	Driver, Hopkins
Public release of GAMA-S1 Year 4 data	Dec 2011	Liske, Baldry
Complete AAΩ observations of GAMA-S1	Jun 2012	Driver, Hopkins
Public release of GAMA-S1 Year 5 data	Dec 2012	Liske, Baldry
Construct final selection masks for GAMA-S1	Dec 2012	Norberg, Peacock
Complete AAΩ observations of GAMA-S2	Dec 2012	Driver, Hopkins
Complete xNTD 21cm observations of GAMA-S1	Dec 2012	Hopkins, Driver
Public release of GAMA-S2 Year 1,2,3 data	Jun 2013	Liske, Baldry
Construct final selection masks for GAMA-S2	Dec 2013	Norberg, Peacock
Complete bulge-disc decompositions	Dec 2013	Nichol, Driver
Complete spectral line diagnostic analysis	Dec 2013	Nichol, Forbes
Complete HI baryonic/dynamical mass estimates	Dec 2013	Hopkins, Driver
Final release of GAMA and analysis products	Jun 2014	Liske, Baldry

Note: GAMA-S1 = GAMA Segment 1.

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