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Galaxy And Mass Assembly (GAMA): The input catalogue and star-galaxy separation

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ABSTRACT

We describe the spectroscopic target selection for the Galaxy And Mass Assembly (GAMA) survey. The input catalogue is drawn from the Sloan Digital Sky Survey (SDSS) and UKIRT Infrared Deep Sky Survey (UKIDSS). The aim is to measure redshifts for galaxies in three 4×12 degree regions at 9 h, 12 h and 14.5 h, on the celestial equator, with magnitude selections $r < 19.4$, $z < 18.2$ and $K_{\rm AB} < 17.6$ over all three regions, and $r < 19.8$ in the 12-h region. The target density is $1080\,{\rm deg}^{-2}$ in the 12-h region and $720\,{\rm deg}^{-2}$ in the other regions. The average GAMA target density and area are compared with completed and ongoing galaxy redshift surveys. The GAMA survey implements a highly complete star-galaxy separation that jointly uses an intensity-profile separator ($\Delta_{\rm sg} = r_{\rm psf} - r_{\rm model}$ as per the SDSS) and a colour separator. The colour separator is defined as $\Delta_{\rm sg,jk} = J - K - f(g-i)$, where $f(g-i)$ is a quadratic fit to the $J-K$ colour of the stellar locus over the range $0.3 < g-i < 2.3$. All galaxy populations investigated are well separated with $\Delta_{\rm sg,jk} > 0.2$. From two years out of a three-year AAOmega program on the Anglo-Australian Telescope, we have obtained 79 599 unique galaxy redshifts. Previously known redshifts in the GAMA region bring the total up to 98 497. The median galaxy redshift is 0.2 with 99% at $z < 0.5$. We present some of the global statistical properties of the survey, including colour-redshift relations and preliminary $n(z)$.

Key words: catalogues — surveys — galaxies: redshifts — galaxies: photometry

1 INTRODUCTION

Galaxy redshift surveys provide a fundamental resource for studies of galaxy evolution. The redshift of a galaxy can be used to obtain a distance assuming a set of cosmological parameters, modulo peculiar velocities, and a well-defined selection function enables the comoving number density of galaxies to be estimated as a function of various properties, e.g., galaxy luminosity functions (Schechter 1976; Binggeli et al. 1988; Norberg et al. 2002a; Blanton et al. 2003). In addition, using the combined sky distribution and distance information, the clustering properties of galaxies can be determined (Davis et al. 1978; de Lapparent et al.

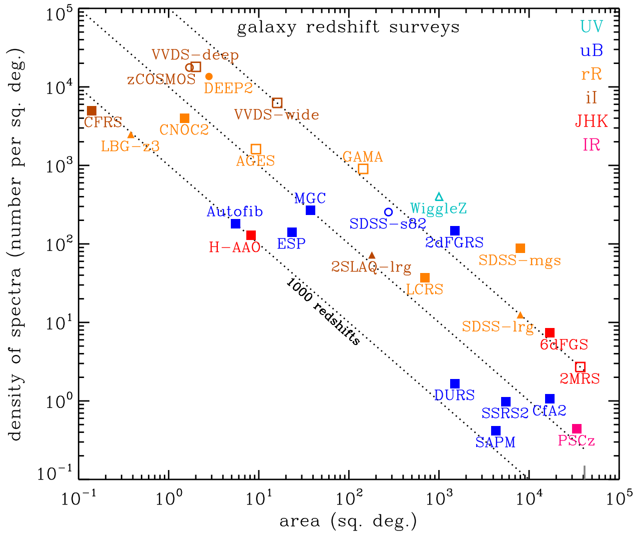

Figure 1. Comparison between field galaxy surveys with spectroscopic redshifts: *squares* represent predominantly magnitude-limited surveys; *circles* represent surveys involving colour cuts for photometric redshift selection; while *triangles* represent highly targeted surveys. The colours represent different principal wavelength selections as in the legend. Filled symbols represent completed surveys. See Table 1 for survey names and references.

1988; Norberg et al. 2002b; Zehavi et al. 2005) and the velocity dispersion of galaxies in groups and clusters can be used to infer dark-matter halo masses (Zwicky 1937; Huchra & Geller 1982; Moore et al. 1993; Carlberg et al. 1996; Eke et al. 2004; Berlind et al. 2006).

The target selection algorithm and area covered by a redshift survey relate to the redshift range and volume surveyed. The industry of these surveys started in the 1980's with surveys of ~ 2500 galaxies over large sky areas (Davis et al. 1982; Saunders et al. 1990) and a deeper survey of 330 galaxies over $70\,\mathrm{deg}^2$ (Peterson et al. 1986). It expanded and diversified in the 1990's with surveys such as the wide-but-shallow CfA2 redshift survey, Las Campanas Redshift Survey, ESO Slice Project, and the deep-but-narrow Canada-France Redshift Survey. Figure 1 shows the surface density of galaxy spectra versus area for these and other surveys, and Table 1 gives selections and references. The target density is a wavelength-independent metric for depth, at least for high-completeness magnitude-limited surveys. The advent of multi-object spectrographs such as the Two-Degree Field (2dF; Lewis et al. 2002) and Sloan Digital Sky Survey (SDSS; York et al. 2000) telescope have enabled redshift surveys of $> 10^5$ galaxies: the 2dF Galaxy Redshift Survey (2dFGRS) and SDSS Main Galaxy Sample (MGS).

The Galaxy And Mass Assembly (GAMA) project has at its core a galaxy redshift survey using the upgraded 2dF instrument AAOmega on the Anglo-Australian Telescope (AAT). GAMA will eventually incorporate a range of new surveys from UV, visible, IR and radio wavelengths (Driver et al. 2009). The redshift survey uses for its input catalogue data from the Sloan Digital Sky Survey and United Kingdom InfraRed Telescope (UKIRT). The primary goals of the redshift survey are measurement of the halo mass function (Eke et al. 2006), galaxy stellar mass function (Cole et al. 2001), and the merger rates of galaxies (De Propris et al. 2005): for systems of the lowest possible masses (at low redshift $z < 0.05$) and for their evolution out to $z \sim 0.5$. In terms of depth and area of magnitude-limited surveys (squares in Fig. 1), GAMA bridges the gap between the wide but shallower surveys like 2dFGRS and SDSS MGS, and the deep but narrower surveys such as those using the VIsible MultiObject Spectrograph (VIMOS) on the Very Large Telescope (VLT).

The outline of the paper is as follows. The imaging data, magnitude measurements and initial catalogues are described in § 2. The target selection is described in § 3: star-galaxy separation, magnitude limits, and other quality checks. The pre-existing and GAMA spectroscopic data sets are outlined in § 4. An analysis of results as pertaining to the star-galaxy separation and other selection criteria is presented in § 5. In other survey papers, the scientific and multi-wavelength database aims are described in Driver et al. 2009, and tiling strategy is described in Robotham et al. 2009.

Magnitudes are corrected for Milky-Way extinction using the dust maps of Schlegel et al. (1998) except for fibre magnitudes. Extinction in the bands u, g, i, z, J, K are obtained from SDSS r-band extinction using fixed ratios (1.873864, 1.378771, 0.758270, 0.537623, 0.323, 0.131).[1] The UKIRT magnitudes are converted to the AB system using $J_{\rm AB} = J + 0.94$ and $K_{\rm AB} = K + 1.90$ (Hewett et al. 2006). The contours used to represent bivariate distributions (Figs. 4–7, 9–12, 14) are logarithmically spaced in number density, with four levels per factor of ten.

2 IMAGING

2.1 Sloan Digital Sky Survey and GAMA regions

The SDSS project (York et al. 2000; Stoughton et al. 2002) has used a dedicated 2.5-m telescope to image $\sim 10^4\,\mathrm{deg}^2$ and to obtain spectra of $\sim 10^6$ objects (Adelman-McCarthy et al. 2008). The imaging was obtained through five broadband filters, *ugriz* with effective wavelengths of 355, 470, 620, 750 and 895 nm, using a mosaic CCD camera consisting of 5 rows and 6 columns (Gunn et al. 1998). Observations with a 0.5-m photometric telescope (Hogg et al. 2001) are used to calibrate the 2.5-m telescope images using the $u'g'r'i'z'$ standard star system (Fukugita et al. 1996; Smith et al. 2002). The GAMA survey targets were selected using DR6 imaging.[2]

The imaging was obtained by drift scanning along a strip defined in an SDSS coordinate system. Two strips, designated N and S, are interleaved to fill in the gaps between the camera columns and are combined to make one stripe. The choice for the GAMA survey consisted of the Southern-most stripes (DEC $< 3^\circ$) for good access from Southern observatories. The contiguous SDSS coverage of Stripes 9–12 was chosen to allow GAMA regions that are four-degrees wide: an estimated requirement for group finding and measurement of the halo mass function at $z < 0.1$ (Driver et al. 2009). Figure 2 shows these regions in relation to the SDSS stripes and Milky-Way extinction. They each cover 4×12 degrees and are centred on 9 h, 12 h and 14.5 h. The RA and DEC ranges are given in Table 2.

[1] The SDSS extinction ratios are given in table 22 of Stoughton et al. (2002). The ratios for J- and K-band extinctions were obtained from UKIRT WFCAM science archive (Hambly et al. 2008) data matched to SDSS r-band extinction.

[2] We are aware that a new photometric calibration was implemented for the DR7 release (Padmanabhan et al. 2008; Abazajian et al. 2009). However, the magnitude changes are typically less than 0.02 mag and therefore, for consistency, we have not used the DR7 magnitudes because we started spectroscopic observations prior to this release.

Table 1. List of field galaxy redshift surveys. The surveys shown in Fig. 1 are listed in order of increasing area. They are mostly magnitude limited galaxy samples except for some with colour selection (CS). The information was obtained from the references and the survey websites.

abbrev.	survey name	selection(s)	area/deg^2	reference
CFRS	Canada-France Redshift Survey	$I_{AB} < 22.5$	0.14	Lilly et al. 1995
LBG-z3	Lyman Break Galaxies at $z \sim 3$ Survey	$R_{AB} < 25.5$ with CS[a]	0.38	Steidel et al. 2003
CNOC2	Canadian Network for Obs. Cosmology 2 ...	$R < 21.5$	1.5	Yee et al. 2000
zCOSMOS	Redshifts for the Cosmic Evolution Survey	$I_{AB} < 22.5$, $I_{AB} \lesssim 24$ with CS[b]	1.7	Lilly et al. 2007
VVDS-deep	VIMOS VLT Deep Survey deep sample	$I_{AB} < 24.0$	2.0	Le Fèvre et al. 2005
DEEP2	Deep Evolutionary Exploratory Probe 2 ...	$R_{AB} < 24.1$ with CS[c]	2.8	Davis et al. 2003
Autofib	Autofib Redshift Survey	$b_J < 22.0$	5.5	Ellis et al. 1996
H-AAO	Hawaii+AAO K-band Redshift Survey	$K < 15.0$	8.2	Huang et al. 2003
AGES	AGN and Galaxy Evolution Survey	incl. $R < 20.0$, $B_W < 20.5$	9.3	Watson et al. 2009
VVDS-wide	VIMOS VLT Deep Survey wide sample	$I_{AB} < 22.5$	16.0	Le Fèvre et al. 2005
ESP	ESO Slice Project	$b_J < 19.4$	23.3	Vettolani et al. 1997
MGC	Millennium Galaxy Catalogue	$B < 20.0$	37.5	Liske et al. 2003
GAMA	Galaxy And Mass Assembly Survey	$r < 19.8$, $z < 18.2$, $K_{AB} < 17.6$	144	— this paper —
2SLAQ-lrg	2SLAQ Luminous Red Galaxy Survey	$i < 19.8$ with CS[d]	180	Cannon et al. 2006
SDSS-s82	SDSS Stripe 82 surveys	incl. $u \lesssim 20$, $r < 19.5$ with CS[e]	275	Adelman-McCarthy et al. 2006
LCRS	Las Campanas Redshift Survey	$R < 17.5$	700	Shectman et al. 1996
WiggleZ	WiggleZ Dark Energy Survey	NUV < 22.8 with CS[f]	1000	Blake et al. 2008
2dFGRS	2dF Galaxy Redshift Survey	$b_J < 19.4$	1500	Colless et al. 2001
DURS	Durham-UKST Redshift Survey	$b_J < 17.0$	1500	Ratcliffe et al. 1996
SAPM	Stromlo-APM Redshift Survey	$b_J < 17.1$ (1 in 20 sampling)	4300	Loveday et al. 1992
SSRS2	Southern Sky Redshift Survey 2	$B < 15.5$	5500	da Costa et al. 1998
SDSS-mgs	SDSS Main Galaxy Sample	$r < 17.8$	8000	Strauss et al. 2002
SDSS-lrg	SDSS Luminous Red Galaxy Survey	$r < 19.5$ with CS[g]	8000	Eisenstein et al. 2001
6dFGS	6dF Galaxy Survey	$K < 12.7$, b_J, r_F, J, H limits	17000	Jones et al. 2009
CfA2	Center for Astrophysics 2 Redshift Survey	$B < 15.5$	17000	Falco et al. 1999[h]
PSCz	IRAS Point Source Catalog Redshift Survey	$60\mu m_{AB} < 9.5$	34000	Saunders et al. 2000
2MRS	2MASS Redshift Survey	$K < 12.2$	37000	Erdoğdu et al. 2006

Notes: [a]CS by U-band 'dropouts' for photometric redshifts (z_{ph}) $\sim$ 2.5–3.5; [b]CS for $z_{ph} \sim 1.4$–3.0, deeper limit over 1 deg^2; [c]CS for $z_{ph} \gtrsim 0.7$; [d]CS for $z_{ph} \sim 0.45$–0.8; [e]CS for $z_{ph} \lesssim 0.15$; [f]CS by FUV $-$ NUV > 1.5 (GALEX bands) and $20.5 < r < 22.5$ for $z_{ph} \sim 0.5$–1.0; [g]CS for $z_{ph} \sim 0.2$–0.5; [h]Reference is for the Updated Zwicky Catalog that includes CfA2 redshifts.

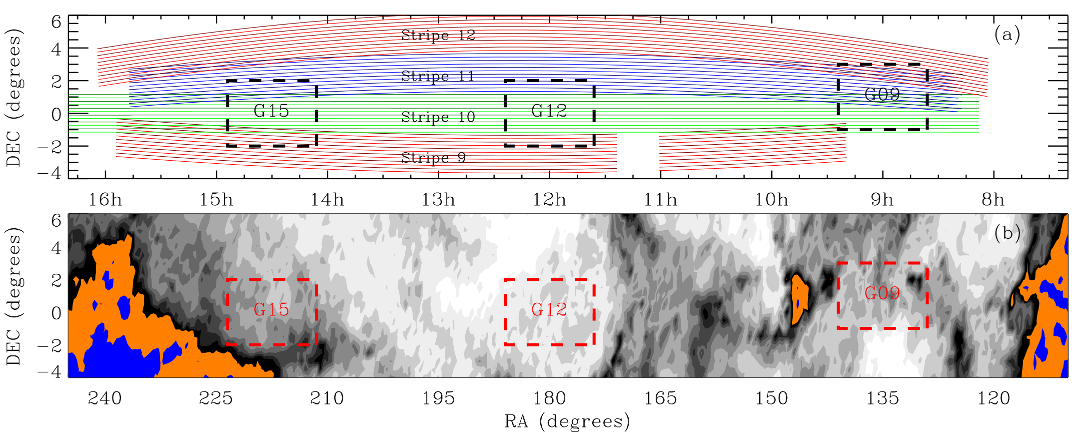

Figure 2. (a): Scan-line positions for SDSS Stripes 9–12. The GAMA regions are outlined using dashed lines. The twelve scan-lines for each stripe are the result of interleaving North and South strips each with six camera columns. **(b):** GAMA regions in relation to the dust map of Schlegel et al. (1998). The colours represent SDSS r-band extinction in magnitude ranges: < 0.06 white; 0.06-0.20 grey scale; 0.20-0.25 black; 0.25–0.5 orange; and > 0.5 blue.

The SDSS produces various magnitude measurements (Stoughton et al. 2002). These include:

• Petrosian magnitudes are measured using a circular aperture that is twice the Petrosian radius. The radius is determined using the surface brightness profile of the object in the r-band.

• Model magnitudes are determined from the best fit of an exponential or de Vaucouleurs profile. The shape parameters (major-minor axes ratio, position angle, scale radius) are determined from the r-band image, while only the amplitude is fitted in the other bands.

• PSF magnitudes are determined from a fit using the point spread function in each band.

• Fibre magnitudes are measured using a circular aperture that is $3''$ in diameter. For these magnitudes, no attempt is made to de-

Table 2. The GAMA regions defined in J2000 coordinates

G09	$129°.0 < \mathrm{RA} < 141°.0$	$-1°.0 < \mathrm{DEC} < 3°.0$
G12	$174°.0 < \mathrm{RA} < 186°.0$	$-2°.0 < \mathrm{DEC} < 2°.0$
G15	$211°.5 < \mathrm{RA} < 223°.5$	$-2°.0 < \mathrm{DEC} < 2°.0$

blend overlapping objects. Their purpose is to provide an estimate of signal in the spectrographs.

These magnitude types are all used in our selection for various reasons. Note we make no adjustment from the SDSS 3″ fibre magnitudes to AAOmega 2″ apertures. An average correction is 0.35 mag, with the 95% range from 0.15–0.6 mag (for galaxies with $18 < r < 20$).

The SDSS pipeline PHOTO also gives a number of flags for each measured source (table 9 of Stoughton et al. 2002). The most important for target selection is SATUR, which is set if any pixel in a source or its 'parent' is saturated. This can be used to effectively exclude deblends of bright stars. We also consider the PARENTID of sources, which can be used to group together objects that may be significantly overlapping. This is used in the visual classification process (§ 3.5) to identify deblended parts of galaxies.

The initial input catalogue was selected from the DR6.PHOTOOBJ table with, in addition to magnitude limits and area restrictions, the following criteria (in SQL):

```
(mode = 1)  or
(mode = 2 and ra < 139.939 and dec < -0.5 and
  (status & dbo.fphotostatus('OK_SCANLINE')) > 0)
```

The MODE column is set to 1 for primary objects and 2 for secondary objects, which are in areas where stripes and/or scan-lines overlap. However, Stripe 9 is mostly incomplete for G09 and thus secondary objects need to be selected from some Stripe 10 scan-lines in this region because the code assumes Stripe 9 is complete when determining the MODE values [see Fig. 2(a), consider the extension of Stripe 9 to 8 h]. The RA and DEC limits above select the appropriate part of Stripe 10, and the OK_SCANLINE flag ensures that selected objects are not in the overlap edge areas of the scan-lines.

While data from Stripes 9–12 were used for GAMA target selection, data from from Stripe 82 were used for early testing of our star-galaxy separation method. This was because of the available UKIRT J and K band coverage at the time and because of significant additional SDSS redshifts beyond the main SDSS surveys. The additional targets included selections for both resolved and unresolved sources (Adelman-McCarthy et al. 2006).

2.2 UKIRT Infrared Deep Sky Survey

The UKIRT Infrared Deep Sky Survey (UKIDSS; Dye et al. 2006; Lawrence et al. 2007) is a project using the Wide-Field Camera (WFCAM; Casali et al. 2007) on the 3.8-m UKIRT. The WFCAM instrument consists of four $2k \times 2k$ HgCdTe detectors in a two-by-two pattern. Each detector covers $13.7' \times 13.7'$ and is separated from neighbouring detectors by $12.9'$ (94% of each detector's active length). Thus, four observations can be interleaved to form a contiguous $0.9° \times 0.9°$ tile. The available filters are *ZYJHK* with effective wavelengths of 0.88, 1.03, 1.25, 1.63 and $2.20\,\mu m$ (Hewett et al. 2006). The UKIDSS consists of a number of different sub-surveys, including the Large Area Survey (LAS) obtaining imaging in *YJHK* over $> 2000\,\mathrm{deg}^2$ within the SDSS main survey regions.

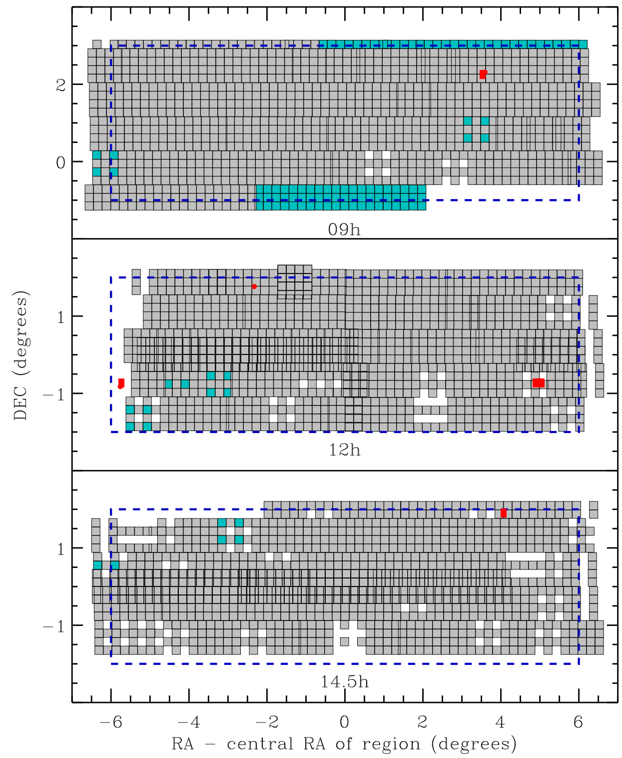

Figure 3. UKIDSS J and K-band coverage for AAT observations in 2009. The squares represent the WFCAM frames: filled grey if J and K-bands were available, and cyan if only the K-band was available. The red areas show the largest areas missing from the SDSS coverage because of masking around the brightest stars ($3.5 < V < 4.5$; HR3665, HR4471, HR4540, HR4689, HR5511) and related 'timed out' frames.

There is a dedicated pipeline for reducing and a system for archiving the UKIDSS data (Hambly et al. 2008). However, we did not use the fully reduced data product catalogues for the GAMA regions when we incorporated UKIDSS LAS data into our selection criteria. This was partly because of known problems with the deblending algorithm, and also our desire to have control over aperture matched photometry. Reduced LAS images, the detector frames, were obtained from the archive. These were scaled to a common background and gain, and $YJHK$ mosaics were produced using the Astromatic SWarp program (Bertin et al. 2002). Each GAMA region has pixel aligned 20 GB mosaics for each band, alleviating problems due to multiple edge extractions and allowing us to use matched aperture photometry. The latter is important for improving the quality of the galaxy colours, and our star-galaxy separation. SEXTRACTOR (Bertin & Arnouts 1996) was run in dual mode on the J and K images, with the source positions and sizes defined in the K band, using default parameters. This catalogue was then matched to an initial SDSS catalogue (for GAMA) within a 2″ tolerance using STILTS (Taylor 2005), with the nearest match chosen when there were multiple matches. Figure 3 shows the J and K-band LAS coverage used for target selection prior to AAT observations in 2009. While the UKIDSS coverage has since been nearly completed and may be used for targeting in 2010, any analysis considering completeness as a function of position will need to take account of the UKIDSS coverage prior to the 2009 observations.

The output from SEXTRACTOR gives a number of flux mea-

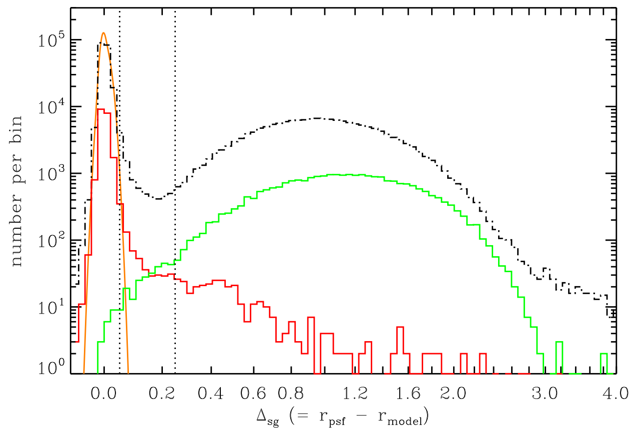

Figure 4. Histogram of $\Delta_{\rm sg}$ for Stripe 82 data. The x-axis stretch is linear in $\ln(1 + \Delta_{\rm sg})$ (bin size is 0.02). The dash-dotted histogram represents all objects, while the red histogram represents objects with confirmed stellar redshifts ($-0.002 < z < 0.002$), and the green histogram represents extra-galactic sources with $0.002 < z < 0.35$. Note the y-axis is on a logarithmic scale and the orange curve shows a double Gaussian fit to the stellar peak (FWHM ~ 0.025). The vertical dotted lines show the range for marginally-resolved sources ($0.05 < \Delta_{\rm sg} < 0.25$).

surements. Here we generally use the standard AUTO magnitude, based on an elliptical aperture defined using Kron's (1980) algorithm. These AUTO magnitudes are used for K-band selection and for $J - K$ colours as part of the star-galaxy separation criteria. More details on the near-IR image reduction including matched-aperture UKIDSS-SDSS photometry will be given in a future paper. For early tests of our star-galaxy separation using Stripe 82 data (§ 3.1), we used the available UKIDSS pipeline APERMAG3 measurements, which are determined using $2.0''$ circular apertures.

3 TARGET SELECTION

3.1 Star-galaxy separation

Automatic separation of stars and galaxies from images has typically been done using shape or intensity profile measurements (e.g., MacGillivray et al. 1976; Maddox et al. 1990). The SDSS star-galaxy separation parameter (Strauss et al. 2002) is defined as

$$\Delta_{\rm sg} = r_{\rm psf} - r_{\rm model} \quad (1)$$

where $r_{\rm psf}$ and $r_{\rm model}$ are the r-band PSF and model magnitudes. The value deviates from zero when the de Vaucouleurs or exponential profile fit accounts for more flux than only using a PSF fit, i.e., a significant deviation from zero indicates that the intensity profile is not well matched to the PSF. Figure 4 shows a histogram in this parameter for objects with $17.8 < r_{\rm petro} < 19.8$ that are not deblended from a saturated object. Also shown are objects with confirmed stellar redshifts and galaxies with $0.002 < z < 0.35$ (from Stripe 82). The cut $\Delta_{\rm sg} > 0.24$ was the constraint used for star-galaxy separation in the SDSS MGS.[3] With this selection, some galaxies that are compact will be missed, particularly as we target fainter than $r = 17.8$.

[3] $\Delta_{\rm sg} > 0.3$ is the MGS criteria quoted in Strauss et al. (2002) but the limit was later reduced to 0.24 following the change in the model magnitude code at DR2 (Abazajian et al. 2004).

Our first cut is to select objects with $\Delta_{\rm sg} > 0.05$ (nominally marginally or well resolved). This removes the Gaussian core of objects that are unresolved, which are almost all stars and quasars.[4] However, this cut is still too inclusive of stars for targeting efficiency so further cuts need to be applied. In particular, the $0.05 < \Delta_{\rm sg} < 0.25$ region probably includes many double-star systems as well as marginally-resolved galaxies. The latter are selected using colour cuts based on our UKIDSS-SDSS matched catalogue.

A UKIDSS-SDSS star-galaxy separation was determined using data from Stripe 82. Figure 5(a) shows a plot of $(J - K)_{\rm apermag3}$ versus $(g - i)_{\rm model}$ for objects with $\Delta_{\rm sg} < 1.0$ and $17.8 < r_{\rm petro} < 19.8$ (i.e. fainter than SDSS MGS within GAMA selection). A colour-colour diagram using these bands was utilized by Ivezić et al. (2002) to assess the success of SDSS star-galaxy separation.

From selected sources, we fit the stellar locus with a quadratic. A new star-galaxy separation parameter is defined as the $J - K$ separation from the locus, which is shown by the blue dashed line. The parameter is given by

$$\Delta_{\rm sg,jk} = J_{\rm AB} - K_{\rm AB} - f_{\rm locus}(g - i) \quad (2)$$

where

$$f_{\rm locus}(x) = \begin{cases} -0.7172 & x < 0.3 \\ -0.89 + 0.615x - 0.13x^2 & \text{for} \quad 0.3 < x < 2.3 \\ -0.1632 & x > 2.3 \end{cases} \quad (3)$$

Figure 5(b) shows $\Delta_{\rm sg,jk}$ versus $(g - i)_{\rm model}$, with symbols representing samples that have measured redshifts. The cut $\Delta_{\rm sg,jk} > 0.20$ is used to select extra-galactic sources among the objects with $0.05 < \Delta_{\rm sg} < 0.25$ (the success and completeness of this UKIDSS-SDSS star-galaxy separation are presented later in § 5.1).

Not all objects have measured $J - K$. For these objects we lower the $\Delta_{\rm sg}$ cut for fainter objects to $\Delta_{\rm sg} > f_{\rm sg,slope}(r_{\rm model})$ where

$$f_{\rm sg,slope}(x) = \begin{cases} 0.25 & x < 19.0 \\ 0.25 - \frac{1}{15}(x - 19) & \text{for} \quad 19.0 < x < 20.5 \\ 0.15 & x > 20.5 \end{cases} \quad (4)$$

Figure 6 shows the distribution in $\Delta_{\rm sg}$ versus $r_{\rm model}$, with the cut shown by the red dashed line. This is appropriate because the sky density of objects that are galaxies compared to double stars, in the marginally-resolved region, is increasing toward fainter magnitude limits.

In summary, the overall star-galaxy separation is given by

$$\begin{array}{ll} \Delta_{\rm sg} > 0.25 & \text{OR} \\ \Delta_{\rm sg} > 0.05 \ \text{AND} \ \Delta_{\rm sg,jk} > 0.20 & \text{OR} \\ \Delta_{\rm sg} > f_{\rm sg,slope}(r_{\rm model}) \ \text{AND no } J - K \text{ measurement.} & \end{array} \quad (5)$$

Only objects satisfying these criteria are targeted in the main survey.

The GAMA UKIDSS selection was based on non-pipeline SEXTRACTOR magnitudes. Thus, the final star-galaxy separation (Eq. 2) was determined using AUTO mags for $J - K$ and SDSS model mags for $g - i$ (data from Stripes 9–12). Figure 7 shows the use of these magnitudes for star-galaxy separation. This demonstrates that the stellar locus fit applies to AUTO mags equally well.

[4] Note that even with UKIDSS-SDSS colour selection selecting objects with $\Delta_{\rm sg} < 0.05$ would result in a large stellar contamination to our galaxy sample.

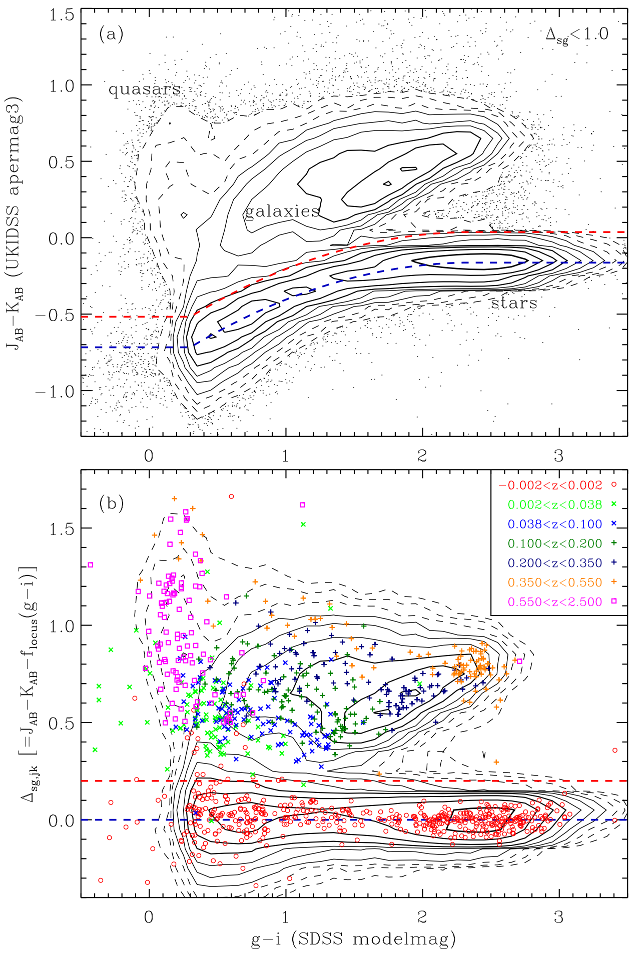

Figure 5. (a): Star-galaxy separation in colour-colour space. Objects were selected from Stripe 82 with $\Delta_{\rm sg} < 1.0$ and $17.8 < r_{\rm petro} < 19.8$. The blue dashed line represents a fit to the stellar locus over the range $0.3 < g - i < 2.3$ and constant $J - K$ either side of the fitted range (Eq. 3); while the red dashed line is $+0.2$ in $J - K$ from this fit. **(b):** $J - K$ star-galaxy separation parameter versus $g - i$ for populations over different redshift ranges. From objects with measured redshifts in Stripe 82, 500 stars and 100 in each extra-galactic redshift range were selected at random. The red line shows the $\Delta_{\rm sg,jk}$ cut.

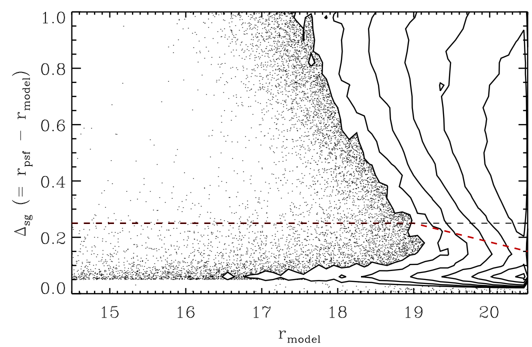

Figure 6. Star-galaxy separation regions. Above $\Delta_{\rm sg} = 0.25$, objects are selected as a spectroscopic target regardless of $J - K$ colour (as per AAT observations in 2008 and SDSS MGS). Below the thick dashed red line, objects are selected if they satisfy the $J - K$ star-galaxy separation criteria ($\Delta_{\rm sg,jk} > 0.2$). While above the red line but with $\Delta_{\rm sg} < 0.25$ (triangular region at $r > 19$), objects are selected if $\Delta_{\rm sg,jk} > 0.2$ or there is no $J - K$ measurement.

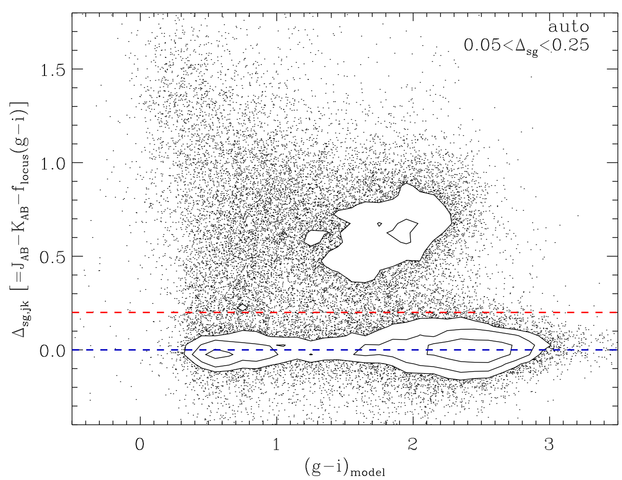

Figure 7. $J - K$ star-galaxy separation parameter versus $g - i$ for marginally-resolved sources with $r_{\rm model} < 20.5$, using SExtractor magnitudes. This differs from Fig. 5(b) in magnitude type used for J and K, and in using only sources with $0.05 < \Delta_{\rm sg} < 0.25$ but going to fainter magnitudes. The red line shows the $\Delta_{\rm sg,jk}$ cut.

3.2 Magnitude limits

The main scientific goal of GAMA that drives the choice of the minimum width of the survey geometry, and the magnitude selection, is the measurement of the halo mass function (Driver et al. 2009). We chose r-band selection because it is most directly correlated with spectral S/N obtained (the filter falls in the middle range of the spectrograph). This ensures a high redshift success rate for a given target density. The r-band limits were chosen to give an average target density up to an order of magnitude higher than the SDSS MGS ($90\,{\rm deg}^{-2}$) and 2dFGRS ($140\,{\rm deg}^{-2}$). Given the limitations of efficient observing over two or three lunations each year, three fields were chosen covering 6 hours in RA. We compromised between area and depth by choosing a limit of $r < 19.4$ in G09 and G15 ($670\,{\rm deg}^{-2}$), and $r < 19.8$ in G12 ($1070\,{\rm deg}^{-2}$). These were defined using Petrosian magnitudes, following the strategy of the SDSS MGS.

In consideration of measuring the stellar mass function, we included a near-IR selection using SDSS z-band and UKIDSS K-band. To ensure reliability and reasonable redshift success rate, these were also constrained by an r-band selection ($r_{\rm model} < 20.5$). The choice of SDSS model magnitudes rather than Petrosian is a consequence of the noise statistics. For Petrosian magnitudes, the noise is well behaved to $r \simeq 20$ (Stoughton et al. 2002), while for fainter objects the model magnitudes are more reliable. Figure 8 shows the pipeline-output magnitude errors versus magnitude. Also, the K-band selection was based on AUTO magnitudes, and both AUTO and model magnitudes use elliptical apertures. The additional selections were a small sample to $z_{\rm model} < 18.2$ and a sample to $K_{\rm AB,auto} < 17.6$.

Within the GAMA regions, the main survey selections are given by:

$$\begin{array}{ll} r_{\rm petro} < 19.4 & \textsc{or} \\ r_{\rm petro} < 19.8 \;\; \textsc{and} \;\; \text{in the G12 area} & \textsc{or} \\ z_{\rm model} < 18.2 \;\; \textsc{and} \;\; r_{\rm model} < 20.5 & \textsc{or} \\ K_{\rm AB,auto} < 17.6 \;\; \textsc{and} \;\; r_{\rm model} < 20.5\,. & \end{array} \qquad (6)$$

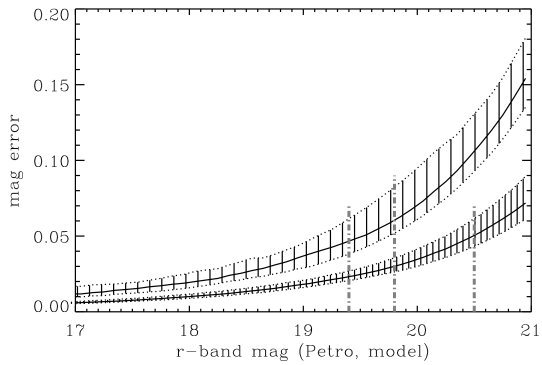

Figure 8. Magnitude errors versus magnitude. The solid lines show the median errors obtained from the SDSS catalogue, with the regions representing the inter-quartile range (top for Petrosian, lower for model magnitudes). The vertical dash-dotted lines represent the r-band limits used in this paper (19.4 and 19.8 using Petrosian, and 20.5 using model magnitudes).

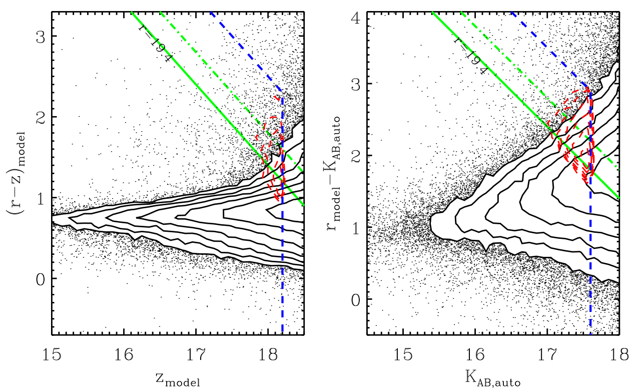

Figure 9. Colour versus magnitude distribution for a near-IR sample. The black contours and points represent potential galaxy targets. The blue dashed lines show the limits imposed by our selection including the constraint $r_{\rm model} < 20.5$. The green lines show $r = 19.4$ and 19.8 limits. The red contours represent most of the additional targets not selected by the $r_{\rm petro}$ limits. These contours extend below the solid green line because of differences between Petrosian and model magnitudes.

Including the near-IR selections increases the G12 target density marginally (to $1080\,{\rm deg}^{-2}$) while increasing the G09 and G15 target density to $720\,{\rm deg}^{-2}$. Figure 9 shows the colour bias for the near-IR selections. The z-band selection is complete to $(r-z)_{\rm model} < 2.3$ at the faint limit, while the K-band selection is complete to $r_{\rm model} - K_{\rm AB,auto} < 2.9$ at the faint limit. A $z_{\rm model} < 18.2$ selection is formally missing 0.3% of objects because of the $r_{\rm model}$ limit, while a $K_{\rm AB,auto} < 17.6$ selection is formally missing about 1% of objects. This is after applying star-galaxy separation. However, only very red objects are missed, which are more likely to be stars in spite of the star-galaxy separation or have incorrectly measured colours caused by mismatched apertures in the case of $r - K$ (the practical impact of these joint limits is discussed later in § 5.4).

3.3 Masking

In order to avoid targeting galaxies with bad photometry because they are near bright stars or satellite trails, an explicit mask was constructed. The bright-stars mask was based on stars down to $V <$ 12 in the Tycho 2, Tycho 1 and Hipparcos catalogues. For each star, a scattered-light radius ($\mathcal{R}_{\rm s}$) was estimated based on the circular region over which the star flux per pixel is greater than 5 times the sky noise level. For each potential target, a mask parameter was defined as follows

$$\begin{array}{lll} {\rm MASK\_IC\_12} = 1 & & d \leqslant \mathcal{R}_{\rm s} \\ {\rm MASK\_IC\_12} = \mathcal{R}_{\rm s}/d & {\rm for} & \mathcal{R}_{\rm s} < d \leqslant 5\mathcal{R}_{\rm s} \\ {\rm MASK\_IC\_12} = 0 & & d > 5\mathcal{R}_{\rm s} \end{array} \quad (7)$$

where d is the distance to a $V < 12$ star with radius $\mathcal{R}_{\rm s}$. In other words, the MASK_IC_12 value decreases from unity when $d \leqslant \mathcal{R}_{\rm s}$ to 0.2 when $d = 5\mathcal{R}_{\rm s}$. A similar mask parameter MASK_IC_10 was defined using only $V < 10$ stars. In addition, objects within an SDSS-database mask for holes, satellite trails and bleeding pixels had these mask values set to unity. After testing, we chose to select only objects with MASK_IC_10 < 0.5 and MASK_IC_12 < 0.8.

The largest masked areas are shown in Fig. 3. These are between 0.01 and $0.07\,{\rm deg}^2$ each. Most of the separate masked areas are significantly smaller ($< 0.001\,{\rm deg}^2$ or $< 1'$ in radius). Overall, the total masked area is about $1\,{\rm deg}^2$ and the unmasked area of the survey is estimated to be $143\,{\rm deg}^2$.

The mask was insufficient to remove all or nearly all objects with bad photometry. Therefore, as per SDSS selection, objects were selected to be NOT SATUR from the FLAGS column in the PHOTOOBJ table. This basically excludes deblends of bright stars but will also reject galaxies that are blended with saturated stars. These however are likely to have bad photometry and falsely bright magnitudes. The stars causing this saturation, not accounted for by the Tycho mask, are probably around $V \sim 13$.

The saturated-flag masking is not ideal. This is particularly the case for large nearby galaxies for which the angular size of the galaxy is a significant factor in determining the excluded sky area. In other words, the probability of a large galaxy having SATUR set depends primarily on its size rather than the area of the diffracted and scattered light around stars. To increase the completeness of the input catalogue for large galaxies, exceptions for the mask and not-saturated criteria were made for galaxies from the Uppsala General Catalog (UGC; Cotton et al. 1999) and Updated Zwicky Catalog (UZC; Falco et al. 1999). In addition, exceptions to the not-saturated criteria were made for a selection of visually inspected galaxies that have NOT SATUR_CENTER. There are only 86 objects with an exception flag set (selected as part of the visual classification process described in § 3.5).

In summary, the criteria for including objects is given by:

$$({\rm MASK\_IC\_10} < 0.5 \;\; {\rm AND} \;\; {\rm MASK\_IC\_12} < 0.8 \;\; {\rm AND} \;\; {\rm NOT\ SATUR}) \;\; {\rm OR} \;\; \text{the exception flag is set.} \quad (8)$$

3.4 Surface brightness limits

In addition to the implicit surface brightness (SB) limits from star-galaxy separation and detection, an explicit SB limit was applied given by

$$15.0 < \mu_{r,50} < 26.0 \quad (9)$$

where $\mu_{r,50}$ is the effective SB in ${\rm mag\,arcsec}^{-2}$ within the 50% light radius in the r-band (eq. 5 of Strauss et al. 2002). Anything of lower SB is very likely to be an artifact, and anything of higher SB is a star.

Figure 10 shows the distribution of objects in $r_{\rm fibre}$ versus $\mu_{r,50}$ for GAMA main-survey targets. The lower limit of 15.0 does remove some objects, probably stars, not rejected by the masking or star-galaxy separation criteria (Eq. 5). The limit for $\mu_{r,50}$ of 26.0 is 1.5 magnitudes deeper than the SDSS MGS cut, and is the point at which most of the objects are clearly artifacts. Note that the SDSS photometric pipeline is not complete for $\mu_{r,50} > 23$ (figs. 2–3 of Blanton et al. 2005). Additional low-SB candidates could be recovered by searching coadded g, r and i images (Kniazev et al. 2004). Nevertheless without deeper imaging, the data will remain incomplete at low SB well before our explicit limit.

In addition to the explicit SB limits given in Eq. 9, which we use to reject objects from our science catalogue, we include a restriction on the fibre magnitudes:

$$17.0 < r_{\rm fibre} < 22.5 \qquad (10)$$

for targets allocated to the AAOmega observation schedule. This is a practical restriction, with a bright limit to avoid significant crosstalk in the spectrograph and a faint limit because the redshift success is very low. Selected fibre bright targets without a known redshift will be observed with a 2m-class telescope, and, in principle, selected fibre faint targets will be observed with an 8m-class telescope. At the bright end, a more restrictive cut on star-galaxy separation is also justified (see later in § 5.2).

3.5 Visual classification

Sources with, for example, $\mu_{r,50} > 23$ have a high probability of being artifacts, deblends of stars, or the outer parts of galaxies. One of us (J. Liske) has written code to facilitate the visual classification of such sources. A VIS_CLASS variable, initially with zero value, could be changed to the following for each source on inspection:

1 possibly a target,
2 not a target (no evidence of galaxy light),
3 not a target (not the main part of a galaxy).

First, sources with the following flags all equal to zero, EDGE, BLENDED, CHILD, MAYBE_CR, MAYBE_EGHOST, were assumed to be good, essentially isolated, and not included in any testing (VIS_CLASS set to 255). About 50% of targets satisfy these criteria. From the remaining objects, sources were selected for visual classification if any of the following conditions applied: $\mu_{r,50} > 23$, $r_{\rm fibre} > 21$, $r_{\rm fibre} < 17$, MASK_IC_12 > 0.2, $r_{\rm model} < 15.5$, $r_{\rm petro} < 15.5$, $r_{\rm fibre} < r_{\rm model}$, $r_{\rm fibre} < r_{\rm petro}$, near UGC galaxy, within $3''$ of another target, Petrosian radius $> 10''$. These indicate that the object could be the result of deblending of a large galaxy, artifact or bright star, e.g., diffraction spikes. In addition to the above criteria, other objects were included in the above process. Objects with the same PARENTID as an already classified VIS_CLASS = 3 object were selected. (The above selection was not developed in one go and there have been several iterations.) Finally objects, with the same PARENTID, that are the brightest and nearest to any object to be tested were included. Objects that could be part of the same galaxy were viewed together where possible. One had to be certain to classify objects as 3 only if the main part was identified as a target.

The above selection produced a sample of about 12 500 objects for visual classification, by six observers. Every selected object was classified by three different observers. Of the selected potential main-survey targets (Fig. 10), VIS_CLASS=1 was set in 92% of cases, VIS_CLASS=2 in 5% of cases, and VIS_CLASS=3 in 3% of cases, based on agreement between two or all three classifiers, 9% and 90% of cases, respectively. Some of the ambiguous cases were double checked, and a single-observer classification was selected in 1% of cases. Objects with values of 2 or 3 were removed from the schedule of AAT observations, i.e., targets must satisfy

$$\textsc{vis\_class} \neq 2 \ \ \textsc{and} \ \ \textsc{vis\_class} \neq 3\,. \qquad (11)$$

In addition, the VIS_CLASS $= 3$ objects can be used to improve the photometry of some large galaxies by coadding in the flux of the galaxy parts (or the 'parent' photometry can be used).

3.6 Number of targets

The total number of objects that are within the GAMA regions (§ 2.1), main-survey magnitude limits (Eq. 6) and $\Delta_{\rm sg} > 0.05$, is 143 728. Applying the stricter star-galaxy separation (Eq. 5) reduces the sample to 132 073. Removing objects by masking (Eq. 8), the SB limits (Eq. 9) and visual checking (Eq. 11), reduces the sample to 120 038. Of these, 825 were not included in the AAOmega observation schedule because they do not satisfy the fibre magnitude limits (Eq. 10). A more restictive star-galaxy separation can be applied for brighter targets (discussed later and given in Eq. 12) that reduces the sample to 119 852. This is considered to be the main-survey sample. Note these numbers apply to AAT observations in 2009, the numbers may change slightly with addition of complete J-K UKIDSS coverage for observations in 2010.

Separating the main survey into r, z and K limited samples, the numbers are 114 520, 61 418 and 57 657, respectively. An $r_{\rm petro} < 19.4$ limit produces a sample of 96 386.

3.7 Additional targets

In order to assess the spectro-photometry of the AAOmega spectra, three or four stars, classified as REDDEN_STD or SPECTROPHOTO_STD by SDSS, were observed in each configuration. These also had a bright fibre magnitude limit of 17 as per the main-survey targets.

The aim is to obtain high completeness (99%), at least in terms of spectra obtained and ideally in terms of confirmed redshifts, for the main survey. This is set to reduce systematic uncertainties in GAMA's position dependent science cases, and is possible because a given patch of sky is potentially observed by $\sim$ 5–10 2dF tiles depending on the local density of targets (see Robotham et al. 2009 for a description of the tiling strategy). Given this requirement, targeting becomes increasingly inefficient as the survey progresses (fewer targets without a redshift per tile). Filler targets were introduced to provide useful redshifts outside the main survey, and thus, maximise fibre usage. These have no high-level requirement on completeness. The filler selections are given by: (F1) objects with detection in the Faint Images of the Radio Sky at Twenty-cm (FIRST) survey and matched to SDSS with $i_{\rm model} < 20.5$ including unresolved sources; (F2) $19.4 < r_{\rm petro} < 19.8$ galaxy targets in G09 and G15, aiming for equal depth with G12; and (F3) $g_{\rm model} < 20.6$ or $r_{\rm model} < 19.8$ or $i_{\rm model} < 19.4$ in G12, investigating variation in magnitude-type and wavelength on selection. In total, there are about 50 000 filler targets.

4 SPECTROSCOPY

4.1 Existing data sets

While the GAMA target density is significantly higher than SDSS or 2dFGRS, the redshifts obtained by these and other surveys provide a non-negligible starting baseline. We incorporate a number of

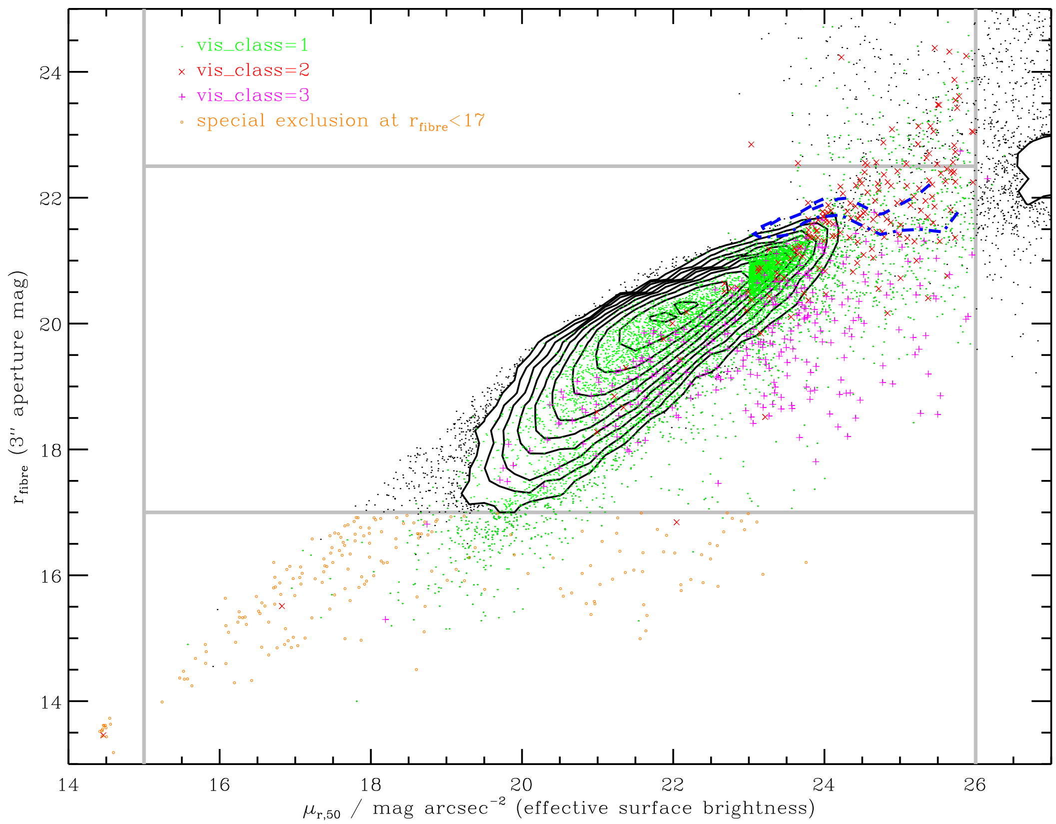

Figure 10. Bivariate distribution of $r_{\rm fibre}$ versus $\mu_{r,50}$. The black contours and points represent objects that are not masked and pass star-galaxy separation. The grey lines outline the selection limits: $15.0 < \mu_{r,50} < 26.0$ is the restriction for the science catalogue; while objects with fibre magnitudes fainter than 22.5 or brighter than 17.0 are not included in the AAOmega observation schedule. The green dots represent objects with VIS_CLASS=1; the red crosses VIS_CLASS=2, and the pink crosses VIS_CLASS=3. The small orange circles at $r_{\rm fibre} < 17$ are probably stars based on a stricter star-galaxy separation criteria (§ 5.2). The blue dash-dotted (dashed) line corresponds to 50% (30%) redshift success rate for objects on or near the line.

different surveys into our catalogue, defining a redshift quality Q, where necessary, as per the Colless et al. (2001) scheme such that $Q = 1$ means very poor or no redshift, $Q = 2$ means a possible but doubtful redshift, $Q = 3$ means a probable redshift, and $Q = 4$ or $Q = 5$ means a reliable redshift. The surveys included are given in Table 3.

From the $Q \geqslant 3$ non-GAMA redshifts in the GAMA regions as outlined in the table, about 40 000 are unique (considering matches within $1''$ to be the same object). The number of main survey targets with one of these redshifts is 19 446, matching within $1''$ except for some large galaxies within $3''$ of a 6dFGS or UZC redshift. Objects with $Q \geqslant 3$ redshifts are given a lower priority in the AAOmega observation schedule.

4.2 AAOmega observations in 2008 and 2009

GAMA observations with the multi-object spectrograph AAOmega on the AAT took place in 2008 (Jan 12, Feb 29 to Mar 15, Mar 30 to Apr 05) and 2009 (Feb 27 to Mar 05, Mar 27 to Apr 02, Apr 17 to Apr 23). The 2dF robotic fibre positioner (Lewis et al. 2002) feeds a bench-mounted dual-beam spectrograph (Sharp et al. 2006). Two plates are used: while one is being configured (fibres placed), the other plate is in the focal plane feeding light to the spectrograph. There are up to 392 science fibres available in a single configuration. Excluding broken fibres, 20–25 fibres used for sky subtraction and 3 or 4 spectroscopic standards (§ 3.7), we targeted between 320 and 350 GAMA targets per configuration. Total exposure times used were typically 1 hour ($3 \times 20\,{\rm min}$). We observed up to 8 configurations in a single night for a total of 267 observations over the two years (91 015 spectra). The spectral coverage was from 370 to 880 nm.

The priorities assigned to targets were different between the two years. The tiling scheme is described in detail by Robotham et al. (2009). Here, we summarize the priorities. In 2008 the targets consisted only of the r-band selection with $\Delta_{\rm sg} > 0.25$ (there was insufficient UKIDSS coverage at the time), without an already known redshift (§ 4.1) except for some cross-check data. The priorities were from high-to-low: (i) $r < 19.0$; (ii) $19.0 < r < 19.8$ in G12 within $\pm 0.5^\circ$ of the celestial equator; (iii) $19.0 < r < 19.4$ in G09 and G15, and remaining $19.0 < r < 19.8$ in G12. In addition, clustered targets in any of these categories were given a higher priority. A clustered target was defined as one within $40''$ of another target, where $40''$ is approximately the closest two fibres can be placed. This was to maximise the chances of observing as many close pairs as possible over three years of observations. In 2009, now including UKIDSS selection for the star-galaxy separation and magnitude limits, the priorities were: (i) clustered unobserved main-survey targets; (ii) unobserved main survey or clustered failed main survey, where failed means that a GAMA spectrum has been obtained with $Q \leqslant 2$; (iii) failed main survey; (iv) from F1, F2, F3 filler targets, and $Q = 3$ spectra taken with the old 2dF spectrographs (e.g., 2dFGRS).

Table 3. Other spectroscopic data in the GAMA regions. Tables were obtained from the survey websites or the VizieR service.

survey	file/table	reference	no. of redshifts[a]	no. $Q \geqslant 3$	no. main survey unique[b]
SDSS	DR7 SPECOBJALL	Abazajian et al. (2009)	27514	26687[c]	13170
2dFGRS	VII/250/2dfgrs	Colless et al. (2003)	11490	11180	3840
MGCz	VII/240/mgczcat	Driver et al. (2005)	4008	3835	1883
2SLAQ-LRG	J/MNRAS/372/425/catalog	Cannon et al. (2006)	2256	2109	227
6dFGS	DR3 SPECTRA	Jones et al. (2009)	299	270	55
UZC	J/PASP/111/438/catalog	Falco et al. (1999)	255	209[d]	13
2QZ	VII/241/2qz	Croom et al. (2004)	5359	4317[e]	224
2SLAQ-QSO	2slaq_qso_public.cat	Croom et al. (2009)	2414	2098[e]	34

[a]The number of redshifts quoted are all those in the GAMA regions including duplicates and non-GAMA targets.
[b]The number corresponds to unique main survey targets with a $Q \geqslant 3$ redshift from the survey (prior to GAMA). In the case of multiple matches within $1''$, the highest Q value match is used (nearest in case of equal Q): Q is limited to $\leqslant 4$ for all surveys except SDSS.
[c]SDSS quality is given by $Q = 1 + (\text{ZCONF} > 0.2) + (\text{zwarning\_okay AND ZCONF} > 0.7) + (\text{ZCONF} > 0.9) + (\text{ZCONF} > 0.99)$ where each term in brackets takes the value of unity if the condition is true and zero otherwise, and zwarning_okay takes the value unity if the following warning flags EMAB_INC, AB_INC, 4000BREAK are all zero.
[d]UZC quality is given by: $Q = 3$ if UZC class is 0 or 1 (secure identification), and $Q = 2$ if UZC class is 2, 3 or 4 (some confusion regarding identification).
[e]2QZ and 2SLAQ-QSO quality is given by: $Q = 3$ if original quality code was 11 (good identification and redshift); $Q = 2$ if 22, 12 or 21; and $Q = 1$ if 33, 23 or 32.

Table 4. GAMA spectra from AAT observations in 2008 and 2009

description	number
total spectra obtained	91015
spectroscopic standards	1059
unique targets	87753
repeated targets	2203
$Q \geqslant 3$ unique targets[a]	82696
$r < 19.0$ & $\Delta_{\rm sg} > 0.25$	40103
main survey r-selected	38994
main survey z, K-selected	1847
F1: radio selected	105
F2: $19.4 < r < 19.8$ in G09 & G15	1029
F3: filler selection in G12	68
other[b]	550

[a]The unique targets with redshifts are identified in the rows below. The $r < 19.0$ selection corresponds to the higher priority targets in the first year of AAT observations. The numbers shown in each row below this row do not include contributions already accounted for. Below the main survey are the F1–F3 filler targets (§ 3.7).
[b]The 'other' objects are mostly objects whose UKIDSS photometry has undergone revision since the second year of AAT observations, and VIS_CLASS=3 objects that were observed prior to implementation of the visual classification.

From the first two years of observing, first-pass reductions with 2DFDR (Croom et al. 2004) and RUNZ (Saunders et al. 2004) have resulted in a 94 per cent redshift success rate ($Q \geqslant 3$) for 82 696 unique redshifts, 80 944 for the main survey (79 599 with $z > 0.002$). Table 4 gives a breakdown of the spectra obtained. Including spectra from other surveys, results in 100 012 $Q \geqslant 3$ redshifts for the main survey (98 497 with $z > 0.002$). Table 5 gives the target numbers and redshift completeness for various main survey selections. The r-limit only selection and the prioritisation in the first year is the main cause of differing $Q \geqslant 3$ completeness factors between each sub-sample.

The details of spectroscopic data reduction, including new defringing and sky-subtraction techniques, redshifting, comparison with other spectra, spatial and magnitude completeness will be described in future GAMA papers. In the next section, we use the first-pass redshifts to illustrate some issues related to the target selection.

5 RESULTS

5.1 Star-galaxy separation

There are two star-galaxy separation parameters used in the GAMA selection. Figure 11(a) shows the observed bivariate distribution of main survey targets in these parameters. The red line shows the cut used for our target selection. This removes nearly 9 000 sources or about 7% of potential targets to $\Delta_{\rm sg} > 0.05$. Figure 11(b,c) show the distributions of galaxies ($z > 0.002$) and stars that have confirmed redshifts, 1.5% are stellar, using all available spectroscopic data. The additional $J - K$ selection was necessary for sources with $r > 17.8$ in order to be complete for compact galaxies. This is seen by the confirmed galaxy contours extending to the left of $\Delta_{\rm sg} = 0.25$ in Fig. 11(b), which would otherwise have been missed by using only a $\Delta_{\rm sg} > 0.25$ cut. Note that the targeting completeness is lower at $\Delta_{\rm sg} < 0.25$, 60% compared to nearly 90% overall, because this UKIDSS-SDSS selection was not available for AAT observations in 2008.

The figure also shows that the regions of high stellar contamination are, not surprisingly, at low $\Delta_{\rm sg}$ or $\Delta_{\rm sg,jk}$. Thus a lower contamination could be obtained by using a cut $\Delta_{\rm sg}+\Delta_{\rm sg,jk} > 0.4$, for example, with minimal rejection of genuine galaxies. This would work well because there is no strong correlation between the two parameters.

An estimate of the completeness of the current selection in terms of selecting galaxies can be obtained by assuming that there is no significant correlation between $\Delta_{\rm sg}$ and $\Delta_{\rm sg,jk}$. Consider the galaxy distribution in Fig. 11(b). The fraction of galaxies at $\Delta_{\rm sg,jk} < 0.2$ is 2.3% (not including galaxies with no $J - K$ measurement) and the fraction at $\Delta_{\rm sg} < 0.25$ is 1.7% after adjusting the latter for the lower targeting completeness. Thus the predicted fraction of galaxies at $\Delta_{\rm sg,jk} < 0.2$ and $\Delta_{\rm sg} < 0.25$ (in the lower-left hand corner of the plot) is only 0.04%. Thus, the galaxy selection from the star-galaxy separation is > 99.9% complete when

Table 5. Main survey target numbers and redshift completeness for the three separate GAMA regions, galaxy fractions (from $Q \geqslant 3$ redshifts), and median galaxy redshifts. The redshift completeness is defined as the number of objects with a $Q \geqslant 3$ redshift divided by the number of targets (regardless of whether they have been observed spectroscopically).

selection	Region G09 no. targets	Region G09 $Q \geqslant 3$	Region G12 no. targets	Region G12 $Q \geqslant 3$	Region G15 no. targets	Region G15 $Q \geqslant 3$	fraction $z > 0.002$	median redshift
$r_{\rm petro} < 16.0$	363	95.0%	397	97.5%	481	96.9%	99.1%	0.052
$16.0 < r_{\rm petro} < 17.8$	3335	99.2%	4644	99.3%	4666	99.0%	98.5%	0.116
$17.8 < r_{\rm petro} < 19.0$ & $\Delta_{\rm sg} > 0.25$	14387	98.2%	15599	96.1%	16016	93.1%	99.0%	0.185
$17.8 < r_{\rm petro} < 19.0$ & $\Delta_{\rm sg} < 0.25$	160	83.8%	206	60.7%	153	55.6%	66.3%	0.260
$19.0 < r_{\rm petro} < 19.4$ & $\Delta_{\rm sg} > 0.25$	11886	90.6%	11600	76.4%	11724	62.6%	98.9%	0.243
$19.0 < r_{\rm petro} < 19.4$ & $\Delta_{\rm sg} < 0.25$	201	77.1%	345	46.1%	223	33.6%	80.7%	0.228
$19.4 < r_{\rm petro} < 19.8$ & $\Delta_{\rm sg} > 0.25$	0	0.0%	17281	70.1%	0	0.0%	99.5%	0.263
$19.4 < r_{\rm petro} < 19.8$ & $\Delta_{\rm sg} < 0.25$	0	0.0%	853	38.9%	0	0.0%	93.7%	0.254
$z_{\rm model} < 18.2$ and not r-selected	604	63.1%	270	25.2%	510	38.2%	58.4%	0.470
$K_{\rm AB,auto} < 17.6$ and not rz-selected	1931	46.5%	348	19.0%	1669	29.5%	97.3%	0.368
all main survey	32867	91.6%	51543	80.9%	35442	79.5%	98.5%	0.196

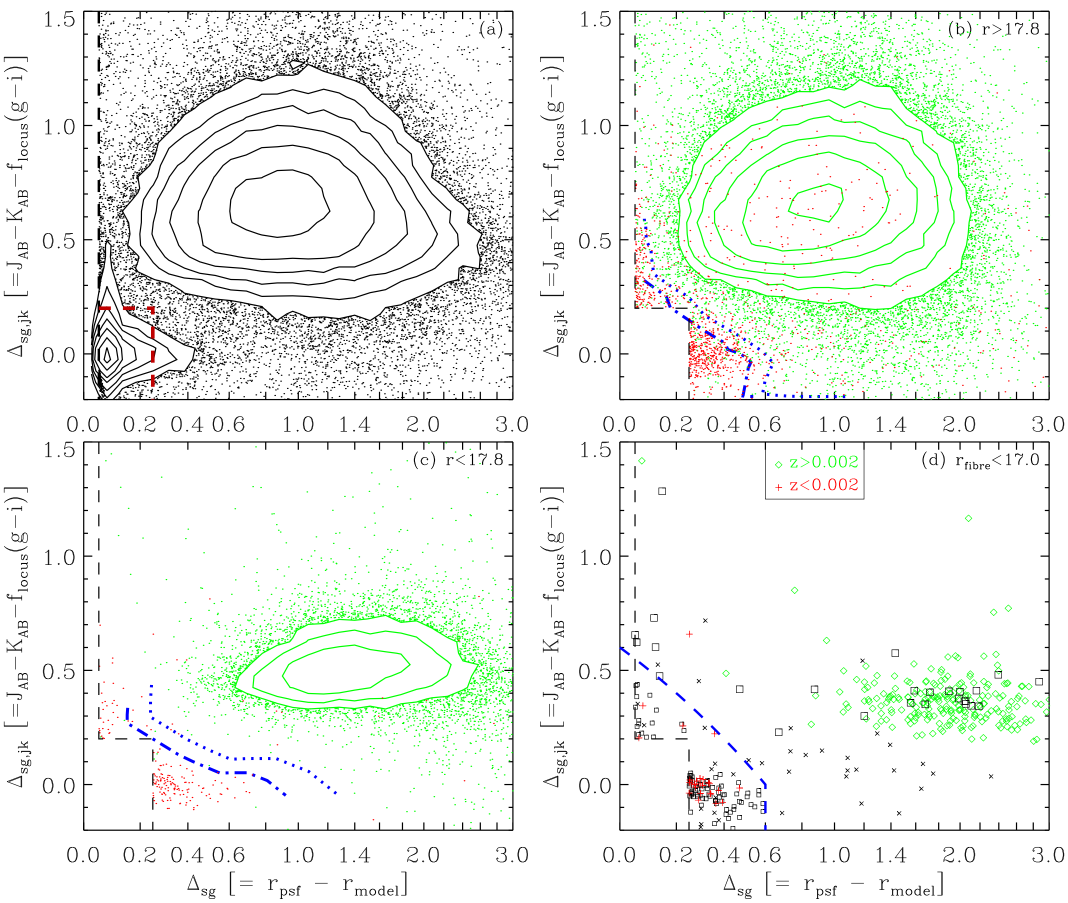

Figure 11. Results of star-galaxy separation. **(a):** The distribution of main survey targets with a $J-K$ measurement, extended to all objects with $\Delta_{\rm sg} > 0.05$, are shown with black contours and points. The red dashed line shows the cut used for target selection. **(b,c):** The distribution of objects ($r_{\rm petro} > 17.8, < 17.8$) with confirmed galaxy redshifts are shown with green contours and points, while objects with stellar redshifts are shown with red points. The blue dotted (dash-dotted) line corresponds to 50% (70%) stellar contamination for objects on or near the line (determined by interpolation in the $r < 17.8$ sample). **(d):** Objects with $r_{\rm fibre} < 17.0$, not included in the AAOmega observation schedule, are shown. Red crosses and green diamonds represent objects with confirmed stellar and galaxy redshifts. Black crosses (squares) represent objects where the fibre magnitude is brighter (fainter) than the Petrosian magnitude. The smaller squares and crosses are the potential targets excluded by the criteria of Eq. 12: these are also shown as small orange circles in Fig. 10. The blue dashed line divides the small and large squares.

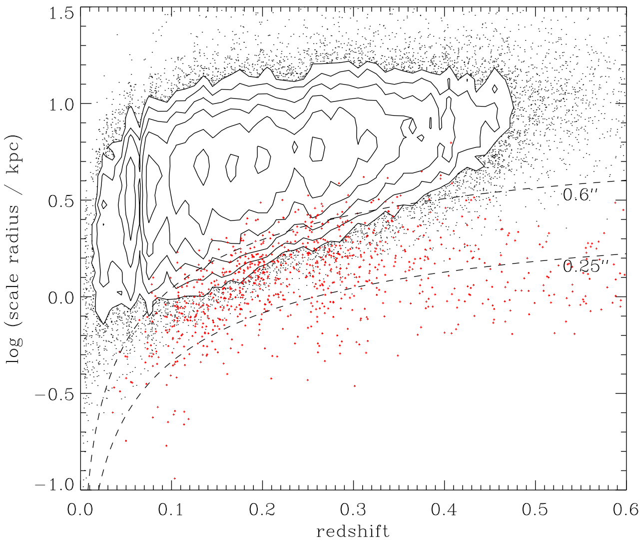

Figure 12. Scale radius, de Vaucouleurs or exponential profile from PHOTO, versus redshift. The black contours and points represent galaxies selected using $\Delta_{\rm sg} > 0.25$, while red crosses represent the $J-K$ selected sample with $0.05 < \Delta_{\rm sg} < 0.25$. The dashed lines correspond to constant observed angular size.

there are J and K measurements. This assumes there is no significant population of galaxies with $\Delta_{\rm sg} < 0.05$ within our magnitude limits.

The SDSS pipeline PHOTO also determines the scale radii of the de Vaucouleurs and exponential profile fits (eq. 9 & 10 of Stoughton et al. 2002). Taking the best fit and averaging the scale radii in the r- and i-bands for each galaxy, we determined the completeness in this measure of size. The cut $\Delta_{\rm sg} > 0.25$ is complete down to a scale radius $\sim 0.6''$, while our star-galaxy separation (Eq. 5) is plausibly complete down to a scale radius $\sim 0.25''$.[5] Figure 12 shows the scale radius in kpc versus redshift for confirmed galaxies in the main survey. Without the additional selection, the target selection would be significantly incomplete, $\sim 20\%$ missed, for galaxies with observed radii between $0.25''$ and $0.6''$. Of course, one could have used this scale radius directly as a star-galaxy separation parameter but, without higher resolution imaging, the systematic errors are presumably larger in this than $\Delta_{\rm sg}$.

This compact galaxy selection is critical for studies with a direct interest in the size evolution of galaxies (e.g., Trujillo et al. 2006; Taylor et al. 2009). Targeting all objects with $\Delta_{\rm sg} > 0.05$ would have resulted in $\sim 9\,000$ extra objects, which would have been a very inefficient way to target compact galaxies. Future higher S/N and higher resolution imaging (optical and near-IR) will improve the efficiency of this type of selection, providing a test of whether GAMA target selection has missed significant numbers of compact galaxies.

[5] We note that the PHOTO scale radius values should be interpreted with some caution at small sizes, less than half the typical PSF width. Taylor et al. (2009) advocate treating objects with scale radii $< 0.75''$ as having an upper limit of $0.75''$, i.e., the true value is poorly determined even though PHOTO has determined that the object is likely to be resolved.

5.2 Bright galaxies

Objects with $r_{\rm fibre} < 17.0$ are not allocated to the AAOmega schedule to avoid crosstalk between fibres, and we do not need to consider these objects for this target selection. However, it is necessary for analyses at low redshift, e.g. measuring luminosity functions, to determine a realistic completeness of galaxy selection at bright magnitudes. Figure 11(d) shows the distribution in the star-galaxy separation parameters for these potential targets. There are 485 using our normal selection criteria, of which, 296 have redshifts from SDSS and other surveys ($Q \geqslant 3$; Table 3). One possibility would be to observe all remaining 189 targets with a 2m-class telescope. However, most of these are probably stars and a more restrictive criterion could be used. This is given by

$$\begin{array}{ll} r_{\rm fibre} > 17.0 & \textsc{or} \\ (\Delta_{\rm sg} + \Delta_{\rm sg,jk} > 0.6 \;\; \textsc{or} \;\; \Delta_{\rm sg} > 0.6 & \textsc{and} \\ r_{\rm fibre} > r_{\rm petro}) \,. & \end{array} \quad (12)$$

The $\Delta_{\rm sg}$-$\Delta_{\rm sg,jk}$ cut is shown by the blue dashed line in Fig. 11(d), while targets that satisfy the last criteria are shown as squares as opposed to crosses. Sources with fibre magnitude brighter than Petrosian are indicative of a 'possible' galaxy blended with a star, however, the star light dominates the fibre magnitude, which is not deblended. Using the above cut results in 299 sources with 266 redshifts (89% complete). This cut should be used when assessing completeness at the bright end of GAMA targets. This was applied before computing the $r_{\rm petro} < 16$ target numbers and completeness given in Table 5.

5.3 Low surface brightness galaxies

The completeness in the low SB regime depends on redshift success and source detection, and there is the additional issue of the accuracy of the flux measurements. These will be described in detail in a future paper on luminosity functions (Loveday et al. in preparation). Here we note only that the redshift success rate is primarily a function of $r_{\rm fibre}$ as shown in Fig. 10. The success rate is 50% at $r_{\rm fibre} \sim 21.5$. This does not include any coadding of GAMA spectra over two or more observations, and there may be improvement after re-reduction.

5.4 Redshift distributions and near-IR selections

Not accounting for incompleteness, 50% of the galaxy redshifts are in the range 0.13–0.27, 90% are in the range 0.06–0.39 and 99% are in the range 0.02–0.53. Figure 13 shows the redshift histograms for various galaxy samples ($z > 0.002$) within the main survey, and median redshifts are given in Table 5. The near-IR selections have a higher average redshift. Note that the redshift distribution within each sub-sample may be biased by non-GAMA redshifts and the dependence of redshift success rate on magnitude, for example. These are corrected for in Fig. 13 by binning in $g-i$ to determine completeness factors. The histogram for each sub-sample is determined by weighting each object with a redshift by $1/c$ where c is the redshift completeness in each bin (with bin size of 0.2 for $0 < g-i < 3$). This colour is used because of its correlation with redshift [Fig. 5(b)].

Figure 14(a) shows observed $r-z$ versus redshift for the z-selected sample, with the targets fainter than 19.4 in r shown by red points. The extra selection is mostly picking up luminous galaxies in the redshift range 0.4–0.6 (recalling that this is of lower completeness than the $r < 19.4$ selection). The number density of tar-

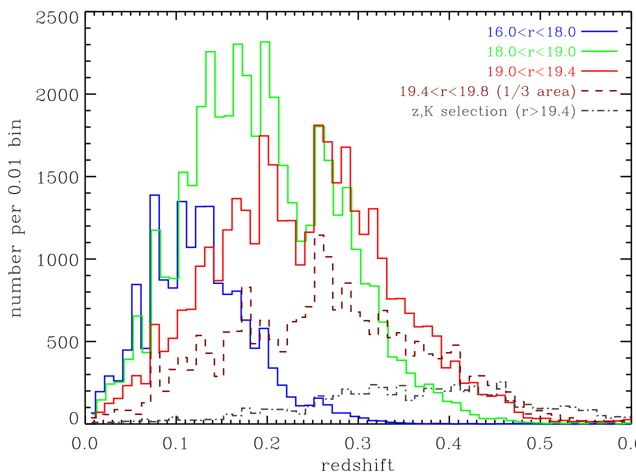

Figure 13. Redshift distributions for selected main-survey samples. The numbers have been projected to completion of the main survey using empirical completeness determined in $g-i$ bins.

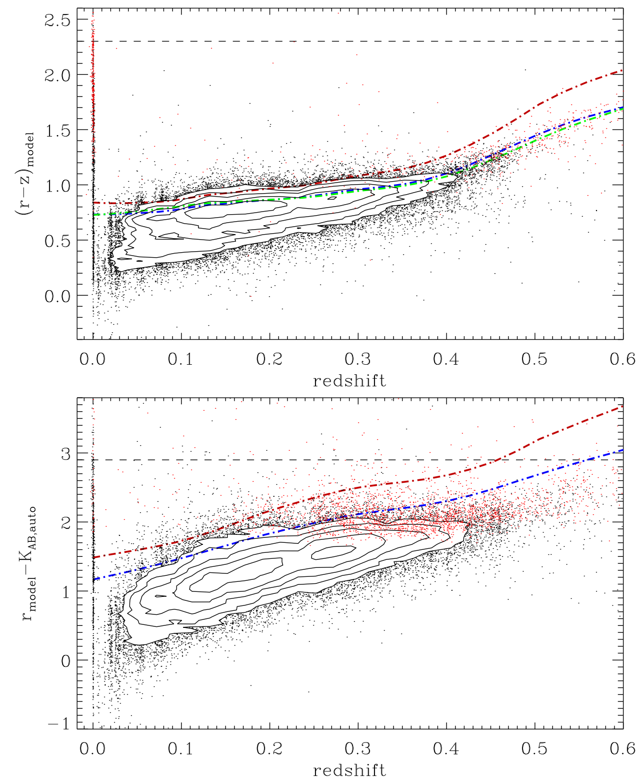

Figure 14. Observed colour versus redshift for (a) the $z_{\rm model} < 18.2$ sample and (b) the $K_{\rm AB,auto} < 17.6$ sample. The black contours and points represent the data within $r_{\rm petro} < 19.4$ (or $z_{\rm model} < 18.2$ for the K-selected sample), while the red points represent the remaining fainter selection. The dash-dotted lines represent the observed colours of SSP models with $z_{\rm form} = 6$ (12.5 Gyr old at $z = 0$, 7.5 Gyr at $z = 0.5$): red ($Z = 0.05$, Bruzual & Charlot 2003), blue ($Z = 0.04$, alpha-enhanced abundances, Percival et al. 2009), and green ($Z = 0.02$, empirical stellar spectra, Maraston et al. 2009). The horizontal dashed line represents the completeness limit at the faint end of the samples given the $r_{\rm model} < 20.5$ limit (Fig. 9).

gets drops off well before the colour bias limit. Simple stellar population (SSP) tracks are shown with a formation redshift of six (see caption for references). Some objects are apparently redder than the old SSP tracks. This is presumably mostly because of photometric errors, however, certain dust geometries can in principle redden galaxies beyond the colour of old stellar populations. Dusty galaxies can lie on, and slightly redder than, the red sequence (Wolf et al. 2005). Note that most of the targets in the range $1.2 < r-z < 2.5$ are a stellar contamination.

Figure 14(b) shows observed $r_{\rm model} - K_{\rm AB,auto}$ versus redshift for the K-selected sample, with the targets fainter than 19.4 in r and 18.2 in z shown by red points. The extra selection is mostly picking up red galaxies in the redshift range 0.2–0.5. The tracks show that the K selection is possibly incomplete for maximally old super-solar metallicity populations at redshift > 0.45 (from one of the models). There are many sources significantly redder than the tracks, however, this is most probably because of the mismatch in apertures between the surveys (model versus AUTO mags, different deblending algorithms). For most purposes, it would be adequate to assume the selection is K-band limited only.

6 SUMMARY

The GAMA survey is designed to be a highly complete redshift survey with a target density several times that of SDSS. The survey covers three $48\,{\rm deg}^2$ regions near the celestial equator centred on 9 h, 12 h and 14.5 h (Fig. 2). The input catalogue is drawn from the SDSS and UKIDSS. The main-survey limits are $r_{\rm petro} < 19.4$, $z_{\rm model} < 18.2$ and $K_{\rm AB,auto} < 17.6$ ($K < 15.7$) across all the regions, and $r_{\rm petro} < 19.8$ over the G12 region (Eq. 6). This corresponds to a main survey of 119 852 targets. The near-IR selections have a joint constraint with $r_{\rm model} < 20.5$, which has minimal impact on the use of the near-IR selections (Figs. 9 & 14). The GAMA survey lies between that of the SDSS-MGS $r < 17.8$ and VVDS-wide $I_{\rm AB} < 22.5$ magnitude-limited samples in the depth-area plane (Fig. 1). In terms of K-band selection (Fig. 3), GAMA covers an area ~ 15 times that of the similar-depth Hawaii+AAO $K < 15$ survey.

In order to be highly complete at the high-SB end of the galaxy distribution, an intensity profile parameter (Eq. 1) and a colour-colour parameter (Eq. 2) are used jointly for star-galaxy separation. The $\Delta_{\rm sg,jk}$ parameter makes use of $J-K$ and $g-i$ colours. Either parameter works reasonably well in separating stars and galaxies (Figs. 4–7). A joint selection (Eq. 5) increases the completeness while stellar contamination in the sample remains at less than 2%. Judging by the joint distribution of confirmed galaxies in these parameters (Fig. 11), the completeness is high because the bivariate density drops significantly prior to the limit of our selection. This is particularly important when considering the size evolution of galaxies (Fig. 12). The incompleteness at the low-SB end is significant, both in source detection and redshift success rate, which is about 50% at $r_{\rm fibre} = 21.5$ (Fig. 10). Some improvement over the SDSS MGS is made by visually checking low-SB targets ($\mu_{r,50} > 23$), rather than using automatic checks, by increased redshift success rate, and by eventually including further integrations of sources with failed redshifts.

The GAMA survey has completed two out of a three-year time allocation for spectroscopy with AAOmega on the AAT. To date, 100 012 redshifts have been confirmed for the main survey, including 80 944 from AAOmega. Of these, 98.5 per cent are extragalactic. We expect that this galaxy redshift survey will form a core of a fundamental database for many studies in extragalactic astronomy.

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