VST ATLAS First Science Results

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The VST ATLAS is a *ugriz*-imaging survey targeting ~ 4500 square degrees of the southern sky. It reaches similar magnitude limits to the Sloan Digital Sky Survey in the north, i.e., $r \sim 22.5$, but ATLAS has better median seeing of 1 arcsecond full width half maximum. ATLAS is a companion survey to the VISTA Hemisphere Survey, which supplies *YJHK* imaging over much of its area. In addition, the Wide-field Infrared Survey Explorer (WISE) satellite supplies a further four mid-infrared bands. Together these surveys complement each other and provide excellent multi-wavelength data for both Galactic and extragalactic science projects.

Survey description

The VLT Survey Telescope (VST) ATLAS imaging exposures are 2 × 60 s in *u*-band, 2 × 50 s in *g*-band and 2 × 45 s in *riz*-bands. The *iz* images are observed in grey time and the *ugr* in dark. The median seeing of 1 arcsecond is well sampled by the 0.21-arcsecond pixels of VST OmegaCAM. The current status of the VST ATLAS in the *ugriz* band can be queried[1]. Ultimately we are targeting most of the available high latitude sky in the northern and southern Galactic Caps. So far we have covered approximately 2200 square degrees in each band with a little less coverage in *ugr* and somewhat more in *iz*. Thus the survey which started in September 2011 is roughly at its half-way point. The survey is unique in terms of southern surveys in having *u*-band sensitivity and the ATLAS Chilean *u*-band extension (Principal Investigator [PI]: L. Infante) doubles the *u*-band exposure to four minutes. As well as VHS supplying *YJHK* imaging, ATLAS is well complemented by the WISE satellite near-infrared (NIR) survey covering 3.4–22 μm. The WISE survey depth is particularly well matched to ATLAS in the W1 (3.4 μm) and W2 (4.6 μm) bands and several of the science aims, outlined in the following sections, exploit this complementarity. The OmegaCAM Science Archive[2] will publish ATLAS data, and federate it with GALEX, WISE and the VISTA surveys, to facilitate these multi-wavelength analyses.

$z < 2.5$ quasar redshift surveys

ATLAS has two routes to quasar surveys at lower redshifts: via ultraviolet excess (UVX) selection by virtue of its *u*-band sensitivity; via "KX" selection using the W1 (3.4 μm) band. Both these methods distinguish the power-law spectra of quasars from the thermal spectra of stars at their respective wavelength extremes. Chehade et al. (in prep.) have made the first spectroscopic follow-up of quasars selected using ATLAS+WISE, using the Two-degree-Field Galaxy Redshift Survey (2dF) and AAOmega at the Australian Astronomical Telescope (AAT). They found that while UV selection wins at the faintest magnitudes ($g < 22.5$), NIR selection using (g-i):(i-W1) significantly increases the quasar number counts by around ~ 15% in the fields where it has been applied to $g < 22$, mostly comprising a population of dust-reddened quasars (see Figure 1a), leading to quasar sky densities of up to 95 per square degree. We now have a sample of ~ 10 000 quasars with which to analyse the luminosity functions and clustering in a more complete and fainter redshift survey than the best previous surveys, such as 2SLAQ. The ATLAS quasar surveys will provide future targets for the ESO 4MOST fibre spectrograph and will also gain X-ray coverage with the eROSITA satellite, soon to be launched.

$5 < z < 6$ quasar redshift surveys

The combination of WISE and ATLAS shows further potential. Findlay et al (in prep.) have shown that the (r-z):(i-W1) colour–colour plane (see Figure 1b) can easily distinguish $5 < z < 6$ quasars from red stars and galaxies, since previously discovered SDSS quasars in this redshift range lie in a valley between the loci of stars and galaxies. This immediately reduces background contamination for such quasar searches by about two orders of magnitude to $i = 21.5$ even before a g-band dropout technique is applied. Using the combination of these techniques, it should be possible to add significantly to the relative dearth of known quasars in this redshift range and so bridge the gap between the $z \sim 5$ and $z \sim 6$ quasar luminosity functions. Increasing the numbers of

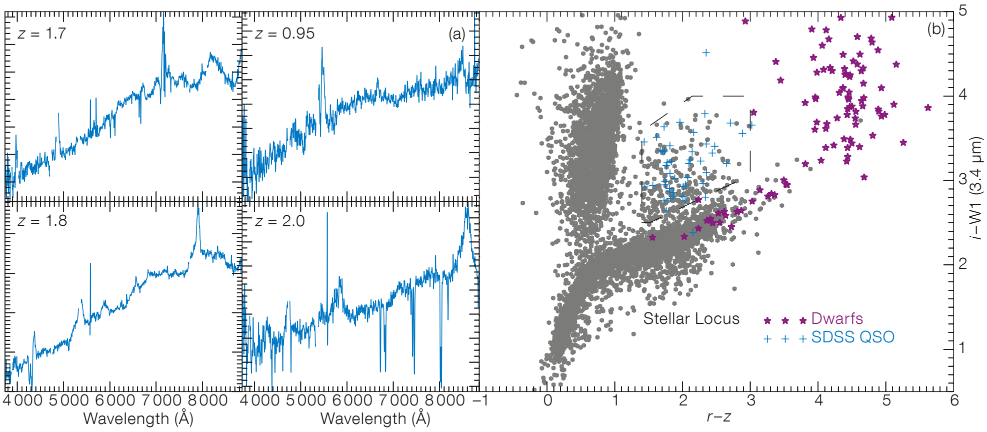

Figure 1. (a) Four examples of a new population of dust-absorbed red quasars at $z < 2.5$ selected from (g-i):(i-W1) colour–colour plot by a combination of WISE and ATLAS. Spectra are from AAT 2dF AAOmega. (b) WISE and ATLAS (r-z):(i-W1) colour–colour plot shows high efficiency in isolating previously discovered SDSS $5 < z < 6$ quasars.

5 < z < 6 quasars will also provide the sightlines required to characterise better the properties of the intergalactic medium (IGM) at redshifts approaching the end of reionisation.

New UV-bright quasars for helium reionisation studies

VST ATLAS provides a unique opportunity to select rare UV-transmitting high-redshift quasars to study the reionisation epoch of He. Far-UV spectra of background quasars obtained with the Hubble Space Telescope (HST) probe the redshifted Lyman-α transition of singly ionised helium, with strong absorption signalling that He is not yet fully ionised (e.g., Worseck et al., 2011). To date, very few quasars allow for such analysis due to the near-ubiquitous occurrence of strong Lyman continuum absorption by neutral hydrogen at longer wavelengths. Current quasar catalogues have been almost fully exploited, yielding high-quality helium absorption spectra of only 19 quasars. The very low predicted surface density of quasars for He absorption spectroscopy with HST (~ 6 per 1000 square degrees; Worseck & Prochaska, 2011) requires large-area surveys. Moreover, the optical colours of most of these quasars are degenerate with stellar colours (see Figure 2, upper), and only the combination with multi-wavelength photometry from the Galaxy Evolution Explorer (GALEX; UV) and WISE (mid-IR) allows their selection at high efficiency. With VST ATLAS it is now possible to extend these multi-wavelength studies to the southern hemisphere, complementing similar efforts with Sloan Digital Sky Survey (SDSS) and the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). Confirmation of quasar candidates is under way (see Figure 2, lower) to maximise the number of potential targets for He reionisation studies before the end of HST's lifetime.

Luminous red galaxy surveys out to z ~ 1

Using ATLAS *gri* colour cuts at z ~ 0.35 and z ~ 0.55 and *riz* cuts at z ~ 0.68, new catalogues containing up to one million luminous red galaxies (LRGs) can be made. One aim is to use the angular clustering of the LRGs to test the evidence for non-Gaussianity found in similar SDSS LRG samples. Again there may be a possibility to extend the LRG redshift range to z ~ 1 by incorporating WISE data in (i-z):(z-W1) galaxy colour cuts. But the prime aim is to use the ATLAS LRGs to measure the strength of the Integrated Sachs–Wolfe (ISW) effect in the southern hemisphere by cross-correlating with Planck cosmic microwave background data. Such a cross-correlation is only predicted in cosmological models with an accelerating expansion. Previously Sawangwit et al. (2010) found only a weak ISW effect at z = 0.35 and z = 0.55 and a null result at z = 0.68. It is therefore important to repeat this test of the accelerating expansion in the south. Since the test cannot be made at high redshift, the southern hemisphere ATLAS data will provide the only decisive independent new evidence for universal acceleration.

GAMA and VST ATLAS

The Galaxy And Mass Assembly (GAMA) project originated as a large optical spectroscopic survey on the AAT with complementary imaging data from the far-UV to the radio, via optical, NIR, mid-IR and far-IR (Driver et al., 2011). GAMA is the first multi-wavelength spectroscopic survey covering hundreds of square degrees over a 5 Gyr lookback time.

Since 2008, GAMA has executed a comprehensive and complete spectroscopic survey down to r_{AB} = 19.8 (i.e., two magnitudes deeper than the main SDSS survey) in five roughly equal-sized areas covering a large range in right ascension: three equatorial 60 square degree regions (G09, G12 and G15), a 50 square degree patch overlapping with the Canada France Hawaii Telescope Legacy Survey (CFHTLS) W1 (G02) and another of similar size centred within the VST ATLAS survey (G23). The latter, defined as 339 < RA < 351 degrees and –35 < Dec < –30 degrees, is currently only 37 % complete spectroscopically, but is due to be completed by autumn 2014.

GAMA represents the highest priority target areas for the Herschel-ATLAS, VST ATLAS/KiDS, VISTA VIKING and Hyper SuprimeCam surveys. The G23 region was specifically motivated for future Australian SKA Pathfinder (ASKAP) DINGO observations free from any known bright continuum sources. Crucially, G23 enables unique science that is not possible in the other GAMA regions, as interferometric radio facilities, such as ASKAP, produce a dramatically larger, noisier beam-width at the equator due to the lack of rotation of the sky. To provide complementary UV star formation rates (SFRs), the entire G23 region has been covered in the final six months of GALEX operations to 3000 s depth (double that of the GAMA equatorial fields). G23 combined with

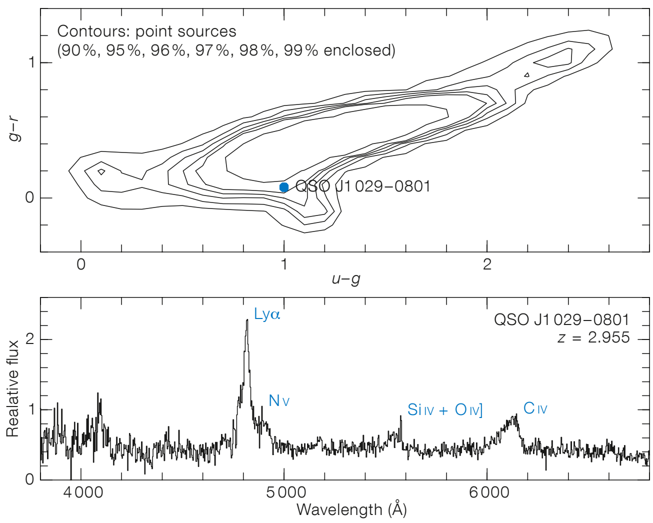

Figure 2. Upper: VST ATLAS *ugr* selection of candidate quasars with UV flux at lower wavelengths than the H I Lyman limit where He II 304 Å Lyman alpha absorption may be detected. Lower: The spectrum of the above candidate for helium reionisation studies.

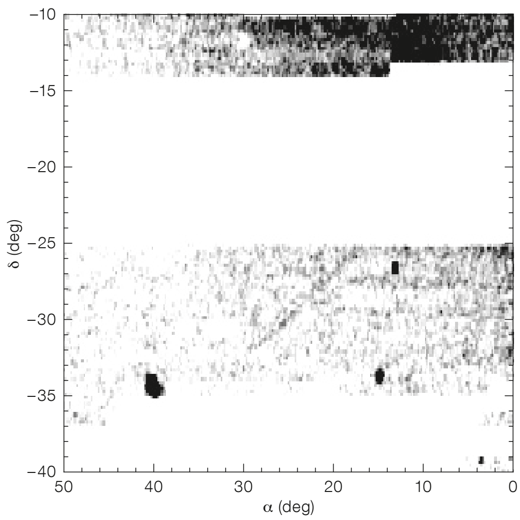

Figure 3. The spatial density variation of stellar sources in the combined g- and r-bands over part of the ATLAS survey of the southern Galactic Cap.

ASKAP will be capable of measuring whether the cosmic H I has remained static or declined to within a factor of two over a 4 Gyr baseline.

G23 will thereby provide a unique multi-wavelength database from the far-UV to the radio, that is not possible with the equatorial regions, for the investigation of the conversion of gas into stars as a function of redshift, stellar mass, age and metallicity. Additionally, by using a state-of-the-art group catalogue (like the one already created for the GAMA equatorial fields by Robotham et al. [2011]), a new door in extragalactic astronomy is opened on how galaxy formation processes (e.g., mass–metallicity relation, SFRs, morphologies, etc) correlate with halo mass.

Galactic archaeology with ATLAS

A simple diagnostic for the overall quality of the ATLAS photometric calibration is to examine the uniformity of stellar density maps selected from a relatively narrow colour and magnitude range. With a sensible choice of colour–magnitude loci these maps can, in addition, be used as a first pass probe of nearby Milky Way and satellite foreground populations. An example of this, cut from more extensive coverage of the south Galactic Cap available in autumn 2012, is shown in Figure 3.

In addition to the obvious density enhancements due to previously known satellites such as the Fornax and Sculptor dwarfs, toward the bottom of the map, and the globular cluster NGC 288 right of centre, are two stellar streams. The broad enhancement in stellar density from the Sagittarius dwarf southern stream is visible towards the top and a newly discovered stellar stream near the centre, pointing just south of the Fornax dwarf. This new stream can be traced quite clearly over about 10 degrees before petering out to the south and being lost to the north in a gap in coverage.

The likely nature of the stream can be inferred from its angular width and comparing on-stream *vs.* off-stream colour–magnitude diagrams; it is found to be consistent with the stream being at a distance of around 20 kpc and originating from an old metal-poor low velocity dispersion satellite. This suggests that the stream most likely comes from a disrupted globular cluster, and in the current coverage there is no sign of any obvious progenitor. When further observations for this region have been fully processed, many of the gaps in coverage should be filled and further exploration of the stream, and of other nearby stellar populations, can be made.

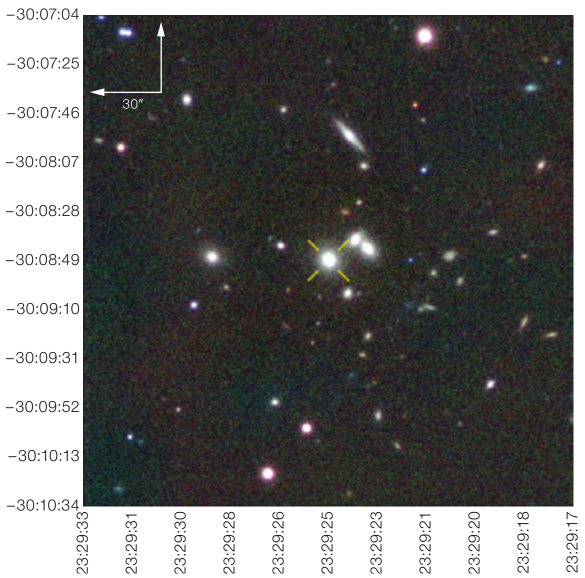

Figure 4. A *gri* composite image of a $z \sim 0.1$ galaxy group identified by ORCA in the VST ATLAS survey. The brightest group member is denoted by the yellow cross at the centre of the image.

The SAMI galaxy survey

VST ATLAS imaging has formed part of the target selection for the new survey being carried out using SAMI (the Sydney-AAO Multi-object Integral field spectrograph) on the AAT. SAMI can target 13 galaxies at once over a 1 degree diameter field of view. The target is to build a sample of 3400 galaxies, spanning a large range in both mass and environment to address key questions in galaxy formation, including: the primary physical mechanisms causing environmental suppression of star formation and morphological changes in galaxies; the frequency of inflows and outflows of gas and how they influence galaxy properties; the distribution of angular momentum in the galaxy population and how mass is built up.

SAMI is targeting galaxies in field and group environments, using the GAMA survey as input, together with clusters selected over the southern sky. VST photometry is particularly crucial for target selection in the SAMI clusters, as no other optical multi-band imaging exists over the cluster regions. The photometry, together with 2dFGRS redshifts, forms the basis for SAMI target selection, with further AAOmega redshifts being measured to give complete sampling across each cluster. The SAMI team has already observed over 100 galaxies using VST photometry for selection, and these, together with further observations, will shed light on numerous issues in galaxy formation.

Galaxy groups and clusters

Based on a pilot band-merged *gri* galaxy catalogue, a 50 square degree region of VST ATLAS has been searched for galaxy clusters. In the absence of photometric redshifts, we identify clusters via the red sequence using the overdense red-sequence cluster algorithm (ORCA; Murphy et al. 2012). This algorithm is robust to systematic magnitude errors and does not require redshift data. The initial search yielded 93 clusters, an example of which is shown in Figure 4, but analysis suggests that some are spurious detections arising from the fragmentation of stellar haloes. Future work will reduce the level of stellar contamination in the source catalogue. Comparison against calibrated measurement of sequence normalisations in *g-r* and *r-i* from the Geach et al. (2011) ORCA cluster catalogue suggest this group has a redshift of $z \sim 0.1$. Five-band photometric redshifts will be used in the future to better determine the redshifts of VST clusters identified with ORCA.

References

Driver, S. P. et al. 2011, MNRAS, 413, 971
Geach, J. E., Murphy, D. N. A. & Bower, R. G. 2011, MNRAS, 413, 3059
Murphy, D. N. A., Geach, J. E. & Bower, R. G. 2012, MNRAS, 420, 1861
Robotham, A. S. G. et al. 2011, MNRAS, 416, 2640
Sawangwit, U. et al. 2010, MNRAS, 402, 2228
Worseck, G. & Prochaska, J. X. 2011, ApJ, 728, 23
Worseck, G. et al. 2011, ApJ, 733, L24

Links

[1] VST ATLAS status: http://astro.dur.ac.uk/Cosmology/vstatlas/
[2] OmegaCam Science Archive: http://surveys.roe.ac.uk/osa/