

Data Collection	ATLAS DR2
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Abstract

The data being released are the VLT Survey Telescope (VST) ATLAS stacked reduced images and associated source lists taken from the start of observations by VST in August 2011, through to end September 2013 under ESO id 177.A-3011. Basic data reduction was done at the Cambridge Astronomical Surveys Unit (CASU). The passbands covered are the SDSS u, g, r, i, z bands reaching approximately the same depth ($r \sim 22$) as the SDSS survey in the Northern Hemisphere. Seeing is specified to be between 1-1.4 arcsec. The total sky coverage in DR2 is $\sim 2000\text{--}3000\text{deg}^2$ of sky depending on band, out of the target of $\sim 4000\text{deg}^2$ at high Galactic latitudes. Each ATLAS tile comprises a stacked pawprint composed of 2 pawprints offset by 25 arcsec in X and 85 arcsec in Y which takes out most of the inter-chip gaps between the 32 OmegaCAM CCDs. There are also 2 arcmin overlaps in both RA and Dec between tiles to allow cross-calibration in the final data release. The ATLAS survey is particularly aimed at survey cosmology but can be exploited for many other branches of extragalactic and Galactic astronomy. Its wide wavelength coverage from the u to the z bands complements the VISTA Hemisphere and VIKING Surveys in the $YJHK$ bands. A full description of the ATLAS survey is given by Shanks et al (2015, 1502.05431 2). DR2 is a “superseding” release i.e. it also includes and improves on the data released in ATLAS DR1 using updated reductions and supplying improved magnitude zeropoints.

Overview of Observations

Table 1 summarises the basic characteristics of the ATLAS DR2 data release:

Table 1 – Basic VST ATLAS DR2 summary					
	u	g	r	i	z
Exposure (s)	2x60s	2x50s	2x45s	2x45s	2x45s
No. of Tiles	2135	2451	2646	3183	3165
No. of Stacked Pawprints	2719	2847	3190	4465	4632
~Area (deg ²)	1995	2290	2473	2974	2957
Median Mag Lim.	21.99	23.14	22.67	21.99	20.87
Median Sky Bri.	22.34	21.90	20.92	19.78	18.85
20mag e ⁻ /s	29	177	160	101	29
Median Seeing (")	1.02	0.95	0.90	0.81	0.84

Notes: Rows (2,3), The number of stacked pawprints is more than the number of tiles covered because of the inclusion of repeated observations in DR2. Row (5): Median 5σ AB point source magnitude limit in 2 arcsec aperture for ATLAS DR2. Row (6): Median sky brightness in AB mags/arcsec². Row (7): fluxes for AB 20mag point sources, normalized to airmass 1.3. All magnitude limits and sky brightnesses are in a system close to SDSS AB.

These exposure times are longer than the ~ 55 s of SDSS to take into account the 0.21 arcsec pixels of VST OmegaCam compared to the 0.4 arcsec SDSS pixels and slightly brighter skies for ATLAS in i and z and produces approximately similar S/N as SDSS in all bands. Note that ATLAS OBs are

generally composed of a concatenation of 17 tiles in a given band, taken in fixed Declination strips in the direction of increasing RA. The *ugr* images are taken in dark time and the *iz* images are taken in grey/bright time.

Images and source lists for all ESO Grades are being supplied. The specified survey quality is limited to ESO Grade A, B and occasionally C, in cases where only a single tile in a 17 tile concatenation was at C grade. Otherwise C and D grade tiles either have been or will be repeated. But all available data are being supplied in this release, partly because $\sim 4\%$ of images have no ESO grades available. This causes the total number of stacked pawprints (17853) to be larger than the total number of tiles observed (13580) (see also Table 1). The TL_RA and TL_DEC header keywords are identical for all data belonging to the same tile. The most recent stacked pawprint of a given tile and filter is generally the one with OBSTATUS = Completed.

Including stacked pawprints + confidence maps + source lists, DR2 comprises 53559 files.

Fig. 1 below shows the ATLAS coverage at 1/10/13 on which the DR1 release is based. A different map applies to each band.

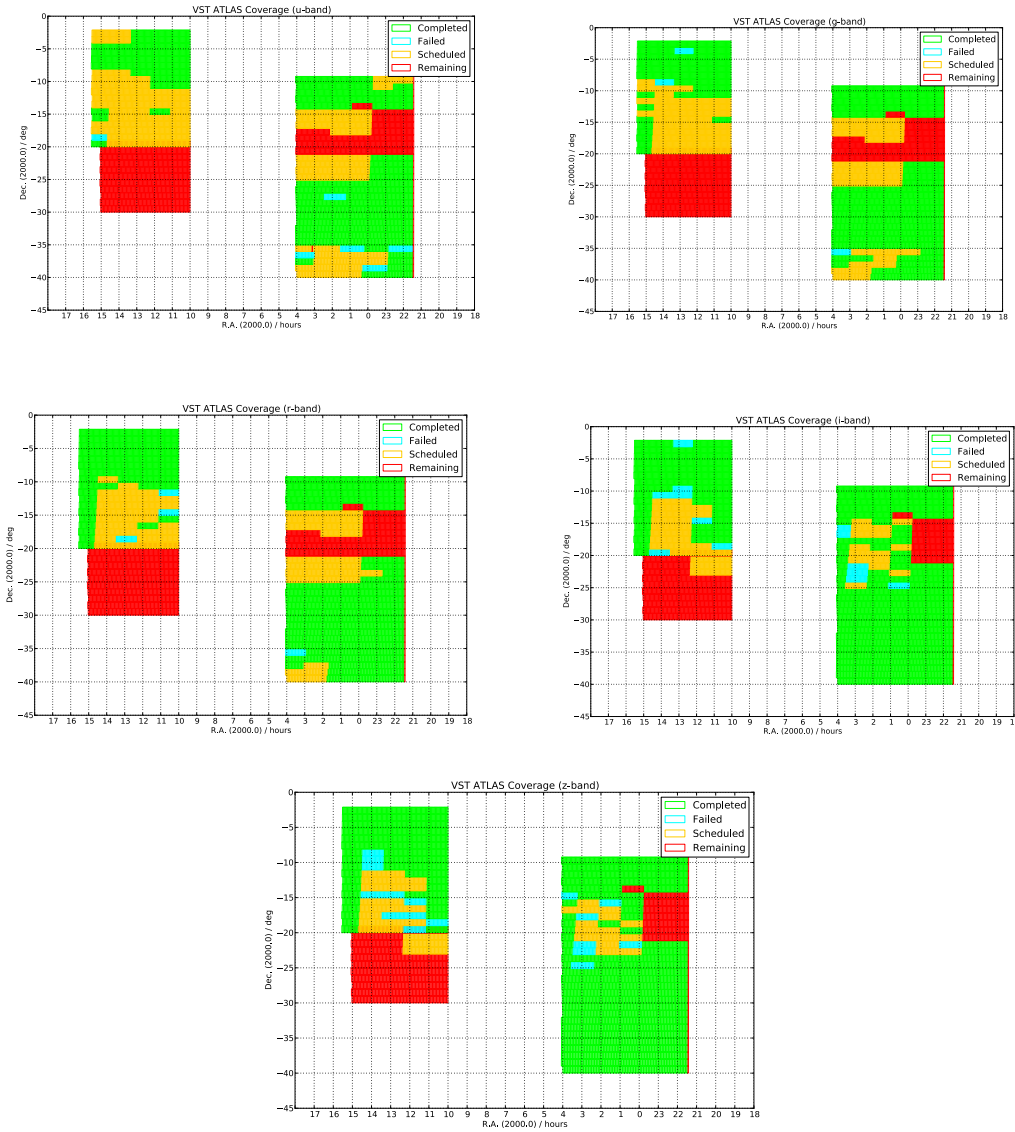


Fig.1. VST ATLAS coverage of tiles in the DR2 data release. From top left ugriz bands. Green means tiles successfully completed by end of September 2013. Blue means failed, yellow means OB submitted and red means no OB submitted by this same date. DR2 includes most of the tiles marked green and blue.

Release Content

The imaging data comprises the combination of the two individual pawprint images which goes to make an ATLAS stacked pawprint in each tile. Each file is in a multi-extension fits (MEF) format with an extension for each of the 32 OmegaCam CCDs in the stacked pawprint. Individual CCDs originally contained 2048x4096 pixels and the stacked pawprint extensions contain approximately 2165x4500 pixels to cover the two 25"x85" offset CCDs that make up each extension in a stack. Along with the imaging data, we are also releasing statistical confidence maps in the same format. The seeing is specified to be <1.4 arcsec FWHM and the distributions by passband are shown in Fig. 2. The distribution of limiting magnitudes at the 5σ detection level by passband is shown in Fig. 3. DR2 comprises a total of 53559 CASU data files (including stacked pawprints + confidence maps + source lists) occupying a total of ~ 10 Tb uncompressed or ~ 6 Tb in its default Rice compression. The total area covered is ~ 2000 - 3000 deg². The 2-pointing dither leaves 14 small ($2 \times 80 \times 20$ arcsec²) holes amounting to 1/3% of the total area. Since different bands are observed at different times some tiles have currently only partial passband coverage..

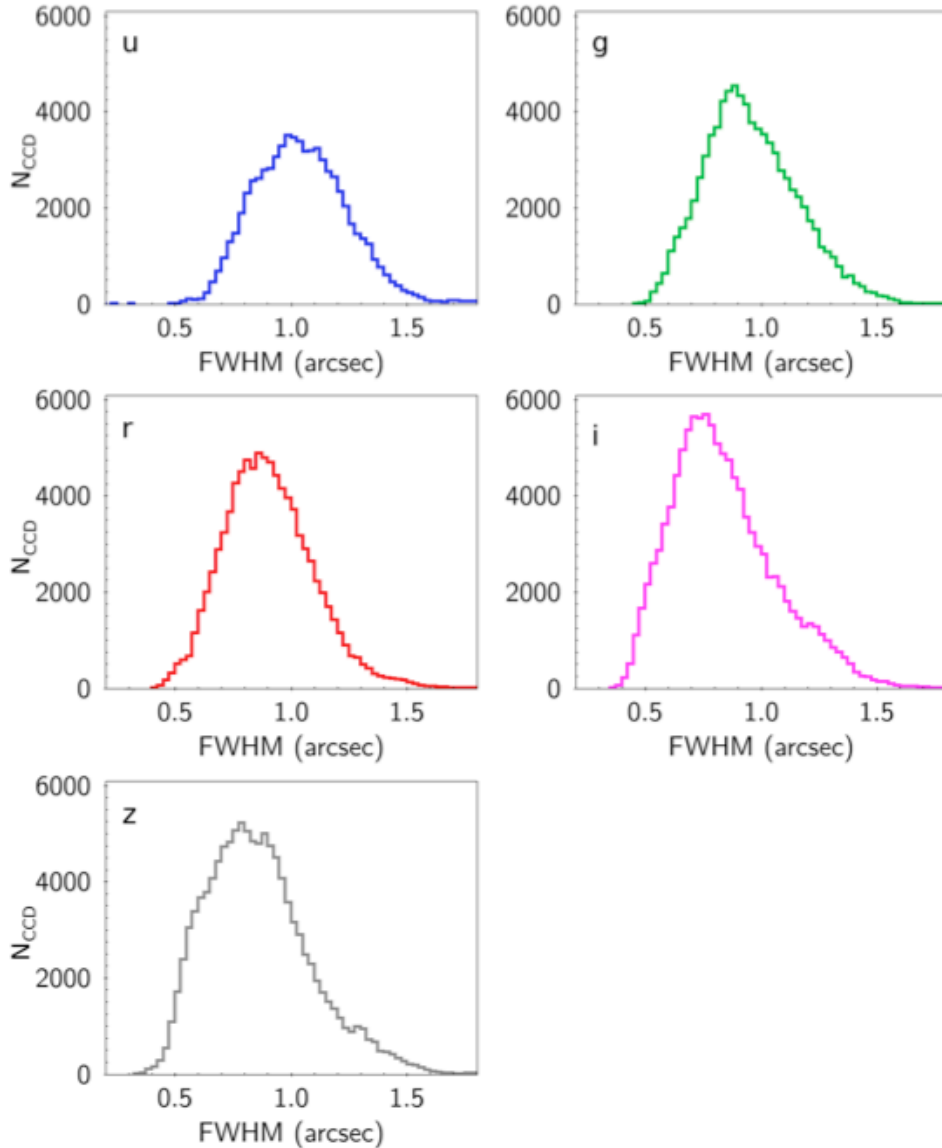


Fig. 2. Seeing (FWHM) distributions from ATLAS data release DR2.

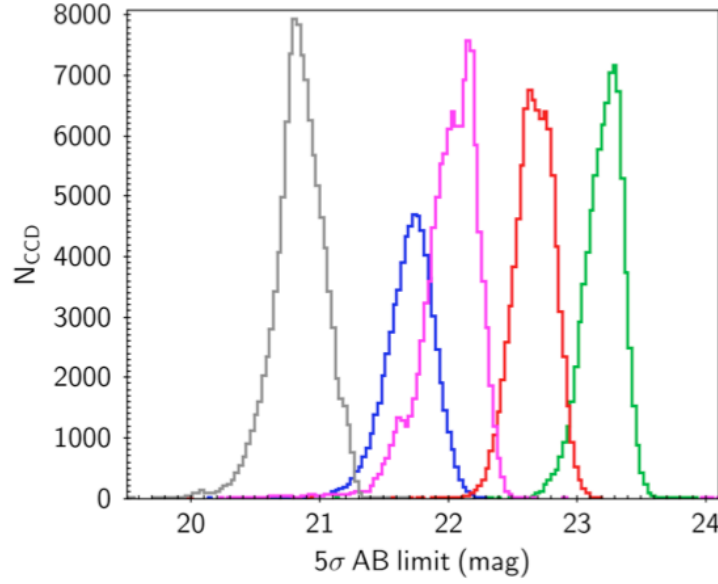


Fig. 3. ATLAS(APASS) 5σ AB magnitude limit distributions for DR2 point sources in u (blue), g (green), r (red), i (purple) and z (grey). The median magnitude limits are given in Table 1. Note that the magnitudes used in this figure are offset with respect to the SDSS AB system as indicated in equns 6-10 of Shanks et al (2015, arXiv:1502.05432). These offsets are small except in u (+0.27mag) and explain the differences seen with the median magnitude limits given in Table 1.

The source list data covers the same pixel areas as the stacked pawprints (see above). The derived object source lists are also stored as multi-extension FITS files using FITS binary tables, one for each image extension with the primary header unit containing the telescope and observation-specific information. The source list extension headers contain a copy of the relevant detector-specific information. Each detected object has an attached set of descriptors, forming the columns of the binary table and summarising derived position, shape and intensity information. During further processing stages ancillary information such as the sky properties, seeing and so on are derived from the source lists and stored in the FITS headers attached to each source list extension. All derived parameters are stored as floating point numbers. A full description of the source list columns is given at

<http://apm49.ast.cam.ac.uk/surveys-projects/vst/technical/catalogue-generation>

Release Notes

Astrometric calibration is via the numerous unsaturated 2MASS point sources available in each tile. By stacking residuals from a series of standard Tangent Plane astrometric fits based on 2MASS we can see (as in the example in Fig. 4 below) that there are no significant astrometric distortions over the whole field of view. The individual detector astrometric solutions achieve rms accuracies of around 70-80mas per star - generally dominated by rms errors in 2MASS stars. Even at high Galactic latitudes there are sufficient calibrators to give systematic residuals at the ~ 25 mas level per detector. The global systematics from stacking multiple solutions are better than this as can be seen in Fig. 4. A Tangent Plane projection (TAN) is being used for all data products.

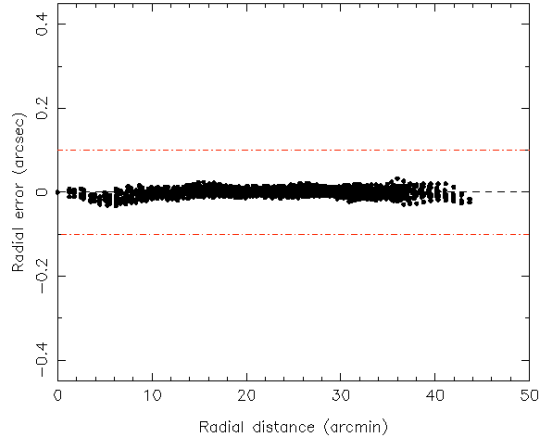


Fig. 4. Astrometric VST-2MASS residuals for stars as a function of distance from tile centre.

The original ATLAS(ESO) photometric calibration of each pointing for DR1 was based on the limited number of standard fields observed by VST each night. This calibration was in a VST Vega-like system, but as the average standard star SED and the detector response drops rapidly in the UV it would be surprising if there were not issues in at least the *u*-band calibration. Note that these zero-points are still based on the original source lists rather than the illumination-correction fixed source lists (see below). An improved AB calibration for DR2 based on the AAVSO Photometric All-Sky Survey (APASS-<http://www.aavso.org/apass>) is described in the Data Reduction and Calibration section below.

In addition there are available a few extra calibration OBS taken with shorter exposures in photometric conditions to give an independent photometric calibration of tiles within the ATLAS footprint of the *ugriz* sequences from <http://www-star.fnal.gov/Southern-ugriz/www/Fieldindex.html>. In the overall header there is the keyword HIERARCH ESO OBS NAME which contains the OB name. This will include the word "standards" if it is one of the short exposure standard star fields. In total, twelve of these fields lie within the ATLAS region, split evenly between our SGC and NGC areas. Ultimately these can be used along with the 2arcmin tile overlaps and external surveys such as - <http://www.aavso.org/apass>) to anchor the global calibration in the final ATLAS release.

Also included are *ugriz* images and source lists centred on the William Herschel Deep Tile at $00^{\text{h}}22^{\text{m}}33.3^{\text{s}} +00^{\circ}20'57''$ (J2000) and overlapping SDSS Stripe 82. These deeper data were used to test the ATLAS depth in the early stages of the survey and full details are given in Table 2 of Shanks et al (2015 arXiv:1502.05432). These files are identified in the headers by the OBJECT keyword being set to "ATLAS depth test".

There are a few other tiles included that are not in the ATLAS footprint. These are mainly observations taken in error at the telescope.

Data Reduction and Calibration

The data processing of the science products released in this data release comes from version 1.0 of the VST Data Flow System (VDFS) pipeline running at the Cambridge Astronomical Survey Unit (CASU), but unlike VPHAS did not require the additional use of the nebulosity filter prior to source extraction. Saturated stars can be automatically flagged post-processing according to use needs. The reflection artefacts around heavily saturated bright stars can generate spurious detections but the contamination is reduced if source lists are matched during band-merging. As specified in the Survey Management Plan, source lists for individual pawprints are supplied with no attempt to reject overlaps. Such a catalogue will be produced for the final, globally calibrated survey. The astrometric reference catalogue is 2MASS. The Vega photometric reference system currently is based on the *ugriz* standards specified by ESO, but the DR2 ATLAS release also includes AB zeropoints based on science data matches with the APASS survey. The illumination correction is already made from a comparison of each month of data from all VST public surveys

with the APASS survey. This correction has been applied to source list photometry but not to image pixels. (CASU have developed software to apply the illumination correction to image pixels. Since scattered light is also present in dark sky science images the optimum way to use this correction depends on the end-user requirements so this correction is not routinely applied to the stored images). Global calibration will be addressed in the final release. Stellar aperture corrections are supplied for each photometric aperture used in the source list and these can be used to estimate total fluxes or magnitudes for stars. PSF magnitudes will be produced for the final data release. Source fluxes in the binary tables are in ADUs and require corrections for aperture loss, airmass (relative to unity), and application of the appropriate magnitude zeropoint. The relevant information is supplied in the source list headers. No correction for Galactic extinction has been applied or supplied, in part because the correction is specific to the extinction model adopted.

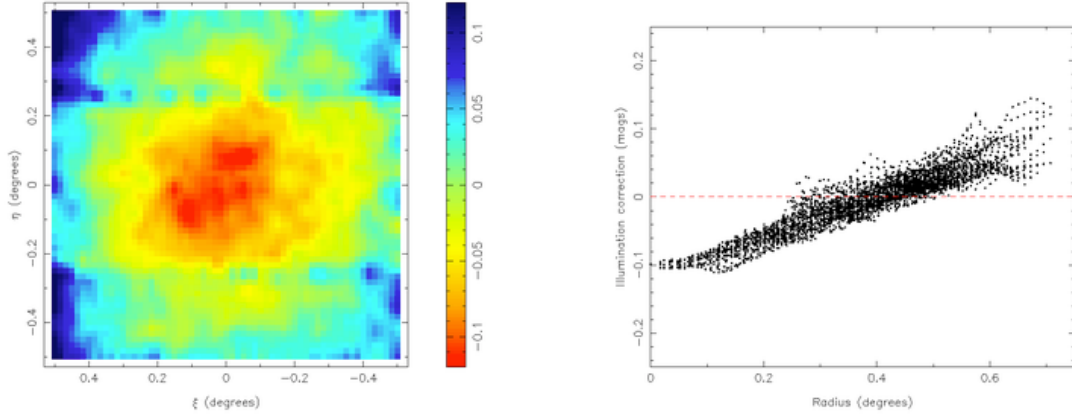


Fig 5. The illumination correction in the i-band as measured by residuals from APASS photometry. The released source lists have had the illumination correction applied based on source position in the image plane.

Data Quality

The astrometric calibration is uniform across the survey to an *rms* accuracy of 25mas relative to 2MASS. Indeed, various fields scattered across the ATLAS area have already been used as the basis for 2dF fibre observations with no astrometric problem. The main problem in the released images is a non-uniform photometric response across the field caused by the presence of scattered light in the VST flat-fields, with a pattern across the pawprint which typically looks like that shown in Fig. 5. The scattered light is made up of multiple components having different symmetries and scales causing effects ranging in scale from ten arcsec with x-y rectangular symmetry, e.g. due to scattering off masking strips of CCDs, to large fractions of the field due to radial concentration in the optics and to non-astronomical scattered light entering obliquely in flats. The illumination correction removes the dominant reproducible components of this effect in the source lists leaving the zeropoint across the field uniform to $\sim \pm 0.003 \text{ mag}$. (We note that after the recent VST baffling improvements, and particularly after January 2014, the size of the illumination correction required has dropped by more than a factor of two and in current data the range is approximately ± 0.05 magnitudes). In addition, one detector, #82, otherwise known as CCD #10 in the MEF extensions, had a gain which intermittently varied by up to 0.5 mag until the video board replacement in June 2012; this may not always be taken out by the flatfield.

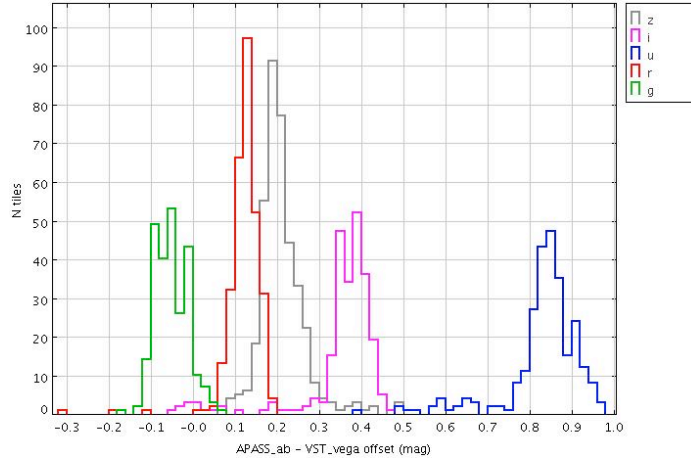


Fig. 6. The *ugriz* distributions of APASS AB-VST Vega offsets for $m < 16$ mag stars from ~ 240 tiles in the SGP GAMA region.

The original (ATLAS-ESO) magnitude zeropoint calibration and error (MAGZPT and MAGZRR in the header) was good to ± 0.05 mag between tiles across the survey, as estimated from a comparison with APASS $m < 16$ stellar magnitudes (see Fig. 6). This zeropoint calibration applied in the Vega magnitude system across all filters and epochs. In this calibration, zeropoints of colour indices may thus be good to $\sim \pm 0.07$ mag.

With DR2 two new magnitude zeropoints are now available based on APASS stellar photometry to ~ 16 mag. The APASS zeropoint (APASSZPT in the header) and its error (APASSZRR) is based on a comparison of APASS and ATLAS stars in the $13 < m < 16$ mag range within each stacked pawprint. The number of stars that contributed to each pawprint zeropoint is given by APASSNUM. The ATLAS-APASS nightly zeropoint and error (NIGHTZPT and NIGHTZRR in the header) is based on the average of all the APASS zeropoints measured on a given night in a particular passband. The number of APASS zeropoints that contributed to this nightly zeropoint is given by NIGHTNUM.

We estimate the accuracy of the ATLAS(APASS) nightly zeropoint from a comparison with SDSS in its 120deg^2 overlap area with ATLAS in the NGC. The ATLAS(APASS) - SDSS magnitude standard deviations are ± 0.035 , ± 0.013 , ± 0.013 , ± 0.012 and ± 0.055 mag in *ugriz*, in most bands a significant improvement over the ATLAS(ESO) - SDSS comparison (± 0.045 , ± 0.027 , ± 0.037 , ± 0.035 and ± 0.073 in *ugriz*). The ATLAS-APASS nightly zeropoint is therefore recommended for use in ATLAS DR2.

Quality of magnitudes have been better checked for point sources than for galaxies. It may be possible to extend depth for galaxies by specific smoothing of image before source detection.

Contamination of the source list by spurious sources is at the $< 5\%$ level down to the limiting magnitudes estimated in the headers. The source lists are estimated to be $\sim 50\%$ complete at the quoted 5σ limiting magnitudes.

Finally, in Fig. 7 we show for a science example, colour-colour diagrams for $g < 22.5$ stars in one ATLAS tile as recently used to select quasars for the 2dF QSO Dark Energy Survey pilot at the Anglo-Australian Telescope (AAT).

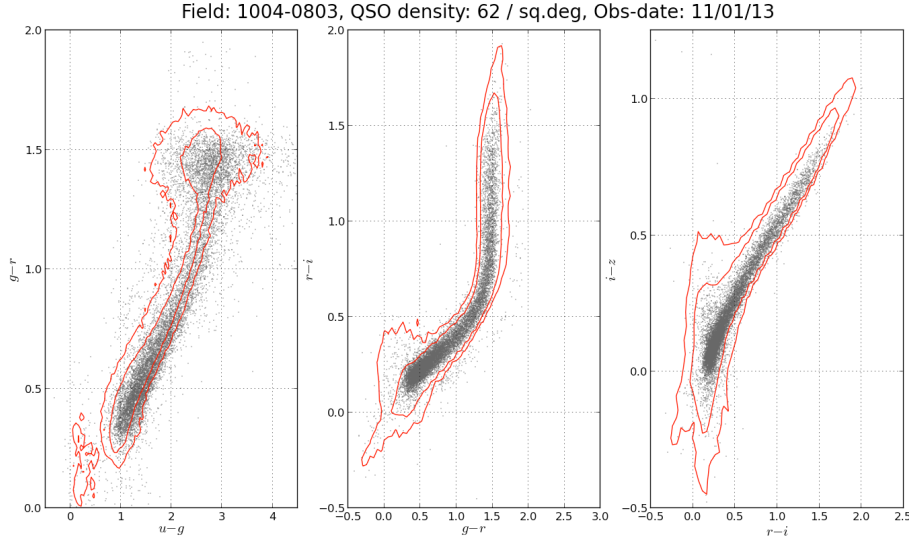


Fig. 7. *ugr*, *gri* and *riz* colour-colour diagrams for stellar objects to $g \sim 22.5$ in an ATLAS tile as used to select QSO targets for AAT 2dF. The red contours are from SDSS selected stars for comparison.

Known issues

The illumination correction for scattered light in the flatfields has only been applied to source lists and not the image pixels. This problem will have to be addressed before attempting surface photometry of very large galaxies but even then the additive scattered light present in all images may preclude achieving reliable surface photometry at faint magnitudes.

We also note the occasional presence of pickup noise in some observations at the level of ± 10 ADU caused by guide/wavefront sensor readout happening at same time as science frame read-out. A similar pickup pattern occurs on all 32 detectors and is fixable in post-processing. This problem was (mostly) fixed by some modifications to control software in Autumn 2012.

Note that in observations taken in approximately the first 2 months of the survey, ie before 3/10/11, the 25 arcsec dither in X(\sim RA) between the two pawprints that make up the stacked pawprint was gradually reduced as each of the 17 tiles in a Group for a given RA range was observed, due to a VST technical problem. This means that the main CCD gaps in the Dec direction are not filled in as well as they should be in the stacked pawprint. Data taken after the above date were taken as concatenations and should be unaffected by this problem.

For source lists, the correct keyword values that characterise the observation at large (e.g. T/EXPTIME, MJD-OBS, TELESCOP etc) are to be taken from the primary header, and not from the extension header

Previous Releases

DR1 was the first data release for VST ATLAS. DR1 is now superseded by the current release DR2. DR2 therefore improves on the data released in DR1 and includes 94 new files for the DR1 period 8/11-9/12 as listed below. The main reason most were omitted was because they were ESO test data. Although "ATLAS depth test" usually appears in the header, this is a misnomer for these files since they were generally made as part of an ESO "Concatenation test" when ATLAS moved to use concatenations of observing blocks. But much of these data is good quality and so they are now included in DR2. The other files listed below are either Survey data that was inadvertently missed out of DR1 or data that was taken in error outside the survey footprint.

o20110820_00087_st_cat.fits	o20110820_00087_st.fits.fz	ATLAS depth test ->	Concatenation test
o20110820_00089_st_cat.fits	o20110820_00089_st.fits.fz	"	"
o20110820_00091_st_cat.fits	o20110820_00091_st.fits.fz	"	"
o20110820_00093_st_cat.fits	o20110820_00093_st.fits.fz	"	"
o20110820_00095_st_cat.fits	o20110820_00095_st.fits.fz	"	"

o20110820_00097_st_cat.fits	o20110820_00097_st.fits.fz	“	“
o20110820_00099_st_cat.fits	o20110820_00099_st.fits.fz	“	“
o20110820_00101_st_cat.fits	o20110820_00101_st.fits.fz	“	“
o20110820_00103_st_cat.fits	o20110820_00103_st.fits.fz	“	“
o20110820_00105_st_cat.fits	o20110820_00105_st.fits.fz	“	“
o20110820_00107_st_cat.fits	o20110820_00107_st.fits.fz	“	“
o20110820_00109_st_cat.fits	o20110820_00109_st.fits.fz	“	“
o20110820_00111_st_cat.fits	o20110820_00111_st.fits.fz	“	“
o20110820_00113_st_cat.fits	o20110820_00113_st.fits.fz	“	“
o20110820_00115_st_cat.fits	o20110820_00115_st.fits.fz	“	“
o20110820_00117_st_cat.fits	o20110820_00117_st.fits.fz	“	“
o20110820_00119_st_cat.fits	o20110820_00119_st.fits.fz	“	“
o20110821_00091_st_cat.fits	o20110821_00091_st.fits.fz	“	“
o20110821_00093_st_cat.fits	o20110821_00093_st.fits.fz	“	“
o20110821_00095_st_cat.fits	o20110821_00095_st.fits.fz	“	“
o20110821_00097_st_cat.fits	o20110821_00097_st.fits.fz	“	“
o20110821_00099_st_cat.fits	o20110821_00099_st.fits.fz	“	“
o20110830_00029_st_cat.fits	o20110830_00029_st.fits.fz	RA, Dec	outside survey area
o20110830_00031_st_cat.fits	o20110830_00031_st.fits.fz	“	“
o20110830_00033_st_cat.fits	o20110830_00033_st.fits.fz	“	“
o20110830_00035_st_cat.fits	o20110830_00035_st.fits.fz	“	“
o20110830_00037_st_cat.fits	o20110830_00037_st.fits.fz	“	“
o20110831_00022_st_cat.fits	o20110831_00022_st.fits.fz	ATLAS depth test ->	Concatenation test
o20110831_00024_st_cat.fits	o20110831_00024_st.fits.fz	“	“
o20110831_00026_st_cat.fits	o20110831_00026_st.fits.fz	“	“
o20110831_00028_st_cat.fits	o20110831_00028_st.fits.fz	“	“
o20110831_00030_st_cat.fits	o20110831_00030_st.fits.fz	“	“
o20110831_00032_st_cat.fits	o20110831_00032_st.fits.fz	“	“
o20110831_00034_st_cat.fits	o20110831_00034_st.fits.fz	“	“
o20110831_00036_st_cat.fits	o20110831_00036_st.fits.fz	“	“
o20110831_00038_st_cat.fits	o20110831_00038_st.fits.fz	“	“
o20110831_00040_st_cat.fits	o20110831_00040_st.fits.fz	“	“
o20110831_00042_st_cat.fits	o20110831_00042_st.fits.fz	“	“
o20110831_00044_st_cat.fits	o20110831_00044_st.fits.fz	“	“
o20110831_00046_st_cat.fits	o20110831_00046_st.fits.fz	“	“
o20110831_00048_st_cat.fits	o20110831_00048_st.fits.fz	“	“
o20110831_00050_st_cat.fits	o20110831_00050_st.fits.fz	“	“
o20110831_00052_st_cat.fits	o20110831_00052_st.fits.fz	“	“
o20110831_00054_st_cat.fits	o20110831_00054_st.fits.fz	“	“
o20110924_00166_st_cat.fits	o20110924_00166_st.fits.fz	ATLAS Survey data	
o20110929_00042_st_cat.fits	o20110929_00042_st.fits.fz	Subsequently re-observed	
o20111119_00042_st_cat.fits	o20111119_00042_st.fits.fz	ATLAS Survey data	

The 6 files following were included in DR1 and are now deprecated/dropped from DR2 because they represent observations whose exposure was interrupted:

o20110904_00013_st_cat.fits o20110904_00013_st.fits.fz
o20110907_00005_st_cat.fits o20110907_00005_st.fits.fz
o20110904_00066_st_cat.fits o20110904_00066_st.fits.fz

The time coverage of the release now extends to 9/13 with entirely new data from 9/12 to 9/13 being delivered.

Data Format

Files Types

The CASU image files are in multi-extension FITS (MEF) format with an extension for each of the 32 CCDs in each stack. The CASU derived object source lists are also stored in multi-extension FITS files as FITS binary tables, one extension for each image extension with the primary header unit containing the telescope and observation-specific information. The source list extension headers contain a copy of the relevant detector-specific information.

Both CASU images and source list filenames are in the form o20110914_00092 where the night of observation is followed by the ESO VST nightly run number. The suffix *_st* indicates that the image or source list is based on a stacked pawprint. A suffix *_cat* indicates that the file corresponds to a source list. A suffix *_conf* indicates that the file contains the statistical confidence map for the tile. The file type *fits.fz* indicates Rice compressed FITS file and these can be de-compressed using e.g. CFITSIO *funpack*.

Source list Columns

A full description of the CASU source list columns is given at <http://apm49.ast.cam.ac.uk/surveys-projects/vst/technical/catalogue-generation>

Acknowledgements

Please use the following statement in your articles when using these data:

Based on data products from observations made with ESO Telescopes at the La Silla Paranal Observatory under program ID 177.A-3011(A,B,C,D,E,F)(see Shanks et al 2015, MNRAS, 451, 4238).