THE 6DF GALAXY SURVEY AND ITS FINAL REDSHIFT RELEASE

Heath Jones (AAO), Matthew Colless (AAO), Mike Read (Edinburgh), Will Saunders (AAO), Tom Jarrett (IPAC/Caltech), Tony Fairall (Cape Town), Quentin Parker (AAO/Macquarie) and the 6dFGS Team

In spring 2007 the final tranche of redshift data from the 6dF Galaxy Survey will be released, thereby completing the redshift component of the project. The 6dF Galaxy Survey (6dFGS; Jones et al. 2004, 2005) is a combined redshift and peculiar velocity survey spanning the 17000 sq. deg. of southern sky unobscured by our own Galaxy (|b| >10 deg.). Observations were carried out using the Six Degree Field (6dF) fibre-fed multi-object spectrograph at the UK Schmidt Telescope (UKST) over 2001–2006. The main survey targets were selected to give near-complete samples with (K, H, J, r_F, b_J) < (12.65, 12.95, 13.75, 15.60, 16.75), and these were supplemented with 11 additional special-interest samples. Ultimately, 136k spectra were obtained from an initial target list of 179k sources, which yielded around 120k clear redshifts. The 6dFGS website (http://www.aao.gov.au/local/www/6df/) gives ongoing survey information.

Aspects unique to 6dFGS are its near-infrared selection, wide angular coverage, and dedicated peculiar velocity survey. All of these attributes make it an ideal survey for conducting a census of galaxy mass in the nearby universe, as well as large scale bulk motion. Peculiar velocities aside, the redshift survey of 6dFGS is comparable to the highly successful 2dF Galaxy Redshift Survey (2dFGRS; Colless et al. 2001) and the Sloan Digital Sky Survey (SDSS; York et al. 2000) in terms of size and coverage. While the median redshift of 6dFGS (z=0.054) is roughly half that of SDSS and 2dFGRS, its areal coverage exceeds both surveys several times over. Its co-moving volume is roughly equivalent to 2dFGRS and its larger fibre apertures (6.7 arcsec) ensure substantially greater spectroscopic coverage of individual galaxies than the others. Finally, since the 6dFGS sample is nearer, it furnishes large numbers of targets bright enough for the peculiar velocity survey. The nearer redshifts also obviate the need for significant evolutionary corrections, unlike the higher redshift Sloan and 2dFGRS samples. Like those surveys, its legacy will be a permanent public database, which will be unique in its combination of scope, depth and southern aspect. The complementary 2MASS Redshift Survey (2MRS; Huchra et al., in prep, Erdogdu et al. 2006a), uses the 6dFGS in the south to provide a shallower all-sky redshift survey of 23k galaxies to K = 11.25 (z = 0.02).

Incremental public data releases for 6dFGS in 2002, 2004 and 2005 have seen the survey used in a wide range of applications beyond the main survey aims. The First Data Release (DR1, March 2004) alone yielded new redshifts for approximately 250 southern Abell clusters (z < 0.1) without any previous redshift (Andernach et al. 2005). Other examples include: studies of large scale structure (Fleenor et al. 2005, 2006, Proust et al. 2006, Radburn-Smith et al. 2006, Doyle & Drinkwater 2006), luminosity and stellar mass functions (Jones et al., in prep., Jones et al. 2006), the influence of local density and velocity distributions (Erdogdu et al. 2006a,b, Inoue & Silk 2006), as well as galaxy groups and their properties (Brough et al. 2006a,b, Forbes et al. 2006, Firth et al. 2006, Kilborn et al. 2006). The 6dFGS has also been used in the study of special-interest samples such as extragalactic radio sources (Sadler et al. 2006, Mauduit & Mamon 2007, Mauch & Sadler 2007) and infrared luminous galaxies (Hwang et al. 2007). Future surveys with next generation radio telescopes such as MIRANdA and SKA (Johnston et al. 2007) will also benefit from the legacy of 6dFGS, as they probe comparable volumes in HI with the benefit of prior redshift information across most of the southern sky.

Final 6dFGS Redshift Release

The 6dFGS Online Database (http://www.wfau.roe.ac.uk/6dFGS) is maintained by the Wide Field Astronomy Unit of the Institute for Astronomy at the University of Edinburgh. The creation of an Australian mirror-site (based at the AAO) will coincide with the final redshift release. Data are grouped into 15 inter-linked tables consisting of the master target list, all input catalogues, and their photometry. Users can obtain FITS and JPEG files of 6dFGS spectra, 2MASS and SuperCOSMOS postage stamp images in JHK and $b_J r_F$ where available, and a plethora of tabulated values for observational quantities and derived photometric and spectroscopic properties. The database can be queried in either its native Structured Query Language (SQL) or via an HTML web-form interface. Fuller descriptions are given in Jones et al. (2004) and at the database site.

Database tables can be queried individually or jointly. Alternatively, positional cross-matching (R.A. and Dec.) can be done between database sources and those in a user-supplied list uploaded to the sites. Search results can be returned as HTML-formatted tables, with each entry linked to individual GIF frames showing the 6dFGS spectrum alongside its $b_J r_F JHK$ postage stamp

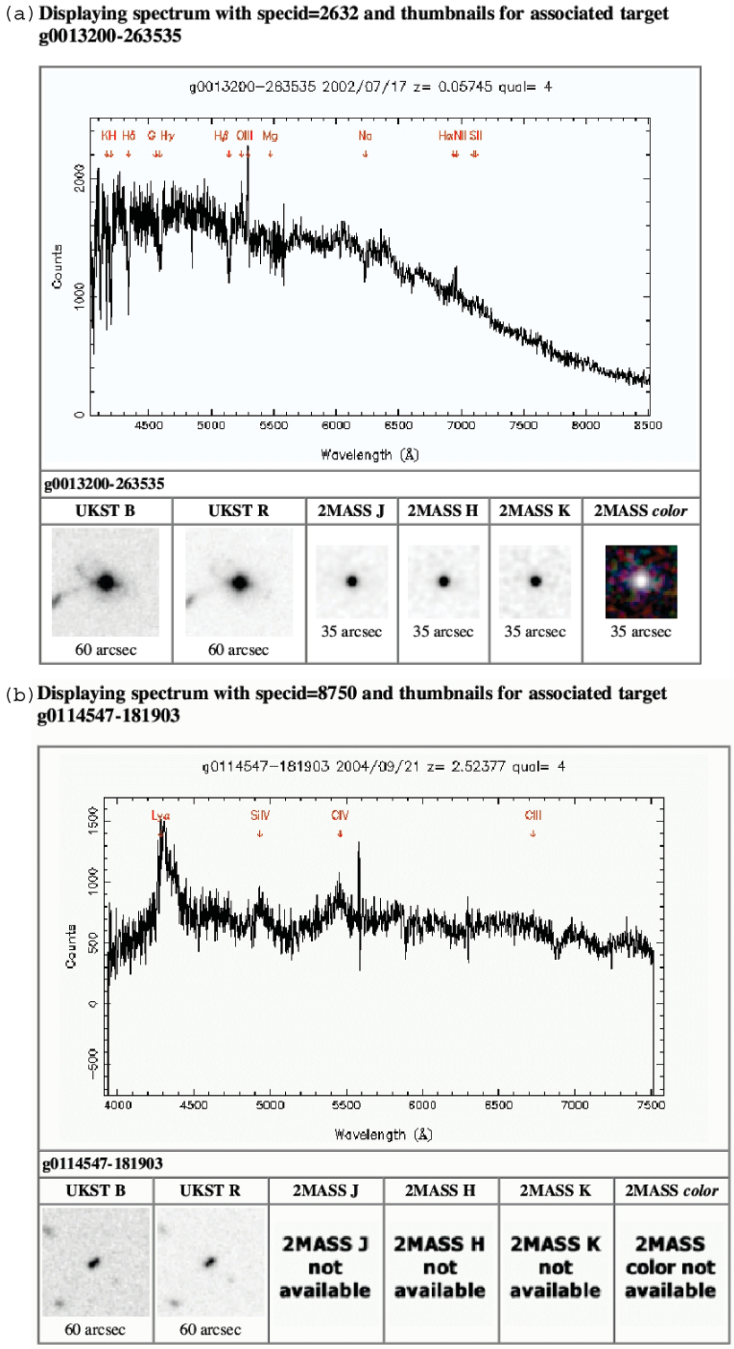


Figure 1: Example spectroscopic and photometric frames from the 6dFGS online database for (a) a nearby bright galaxy at z = 0.057, and (b) a candidate double QSO at z=2.524. 2MASS frames are only available for sources selected as part of the original 6dFGS primary samples, where available in one or more of *JHK*.

images. Individual object FITS files of the same data can also be accessed in this way. Most 6dFGS spectra consist of two halves, observed separately through different gratings, and subsequently spliced together to join around 5600 Å. Figure 1 shows examples of the way data are presented in the database.

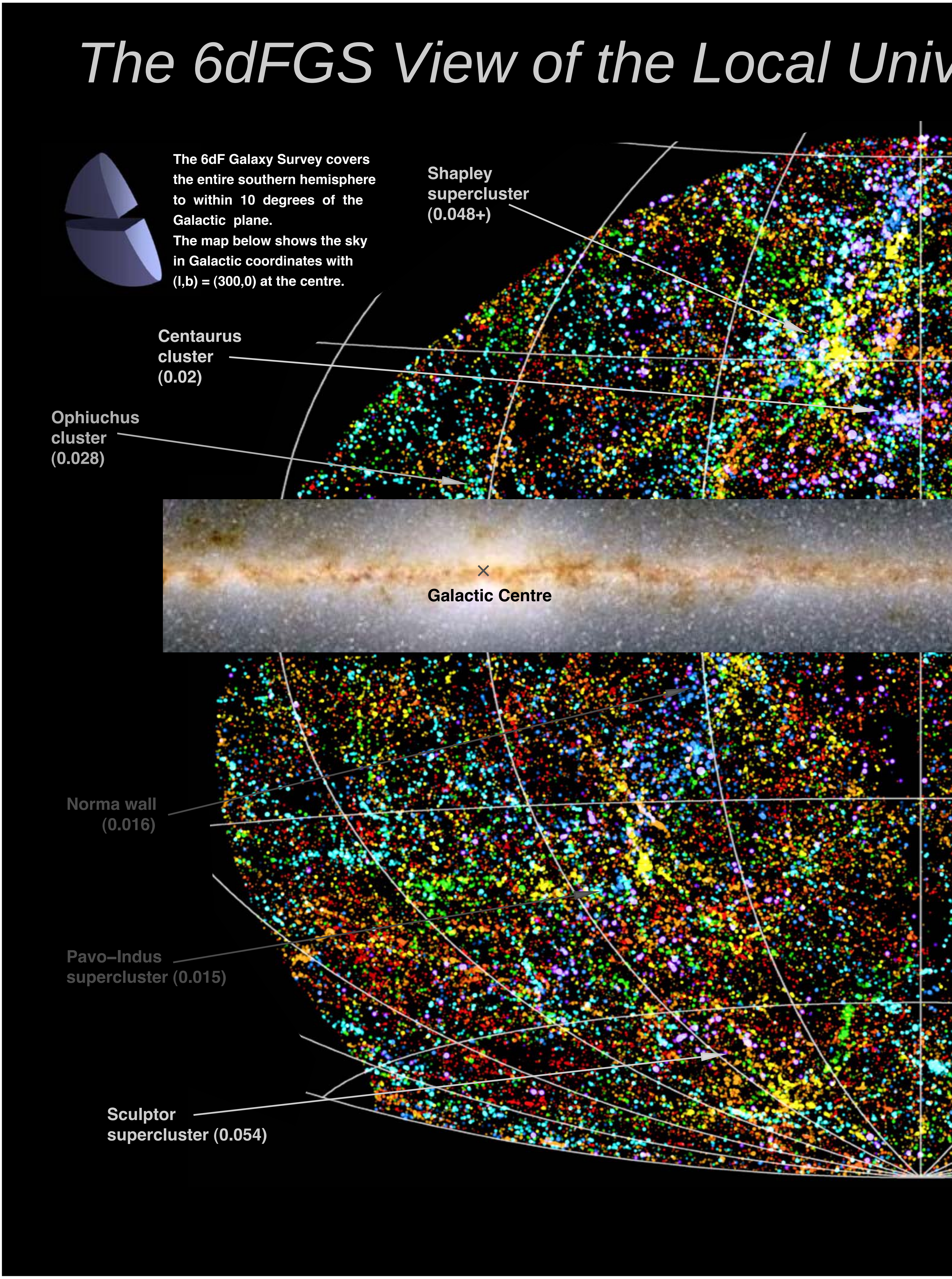
Long database returns can also be emailed to the user as a comma-separated variable (CSV) ASCII file. Furthermore, the FITS files of all objects found through a search can be emailed to the user as a single tar file under a *tarfile saveset* option. Separate downloads in the form of ASCII files are also available from the database web site. These include a master catalogue of the original target lists (incorporating the 2dFGRS and ZCAT (Huchra et al. 1992) literature redshifts not in the database proper), as well as a CSV file of the spectral observations. Final completeness maps (calculated from the revised target lists, after 2MASS and SuperCOSMOS magnitude revisions) will be made available at a future date.

All of the changes previously implemented for the Second 6dFGS Data Release (DR2; Jones et al. 2005) have been retained, with some modifications. In particular, some fields rejected from earlier releases on technical grounds have been fixed and included. The final data span observations from May 2001 to January 2006 inclusive. New changes include:

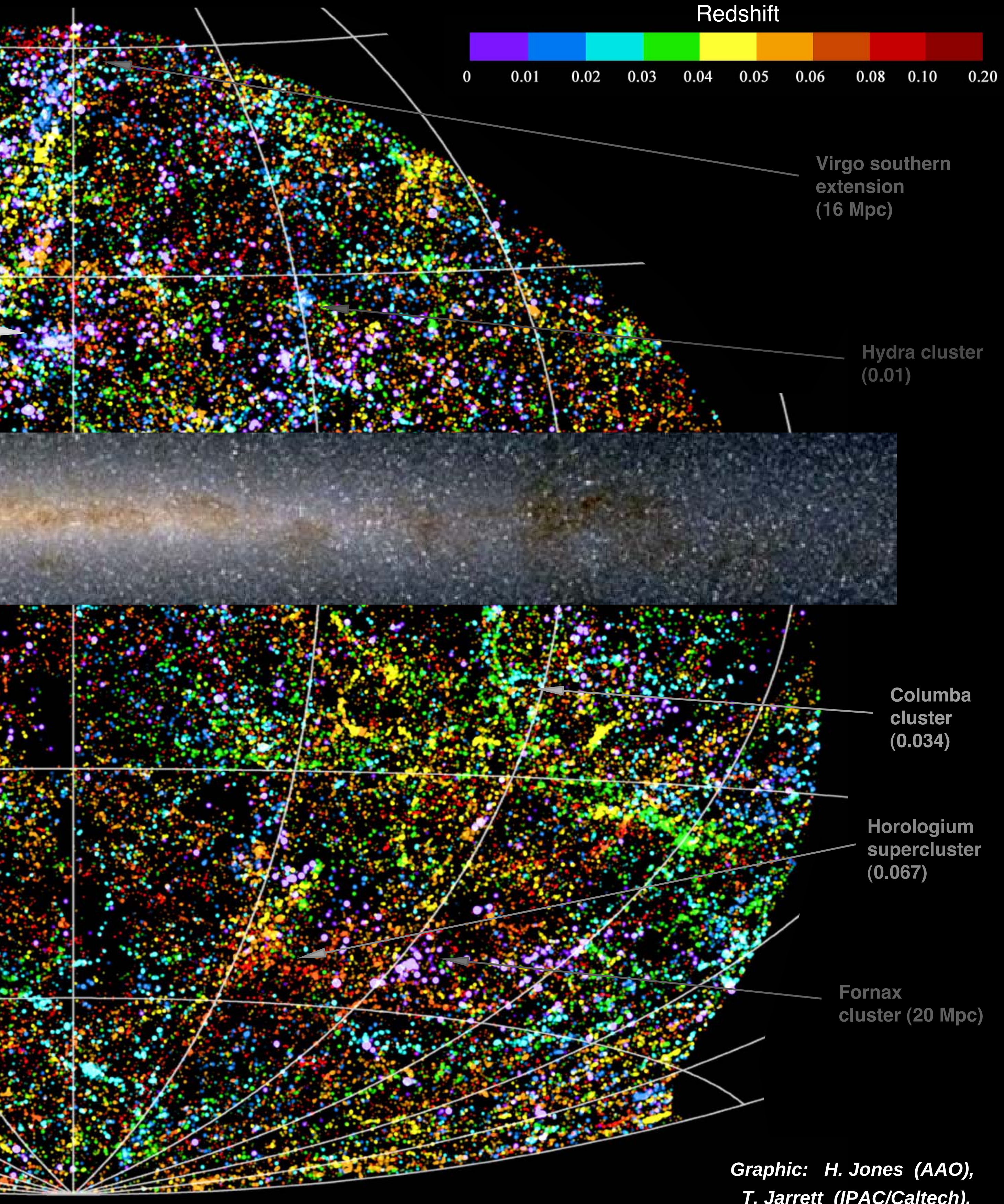
1. Revised 2MASS Names: Between the creation of the initial 6dFGS target list in 2001 and the final 2MASS XSC data release in 2004, the 2MASS source designations changed by the last two digits in both the R.A. and Dec. components of the source name. We have updated the database with the new 2MASS names while retaining the old ones for reference.

2. Revised 2MASS Photometry: The *JHK* total magnitudes used to select 6dFGS sources were also revised by 2MASS between 2001 and 2004. These new values have been put into the database while the old magnitudes used for 6dFGS target selection have been kept.

3. Revised SuperCOSMOS Photometry: The SuperCOSMOS magnitudes used by 6dFGS were also revised between 2001 and 2004. The updating of these


The 6dFGS View of the Local Univ
The 6dF Galaxy Survey covers the entire southern hemisphere to within 10 degrees of the Galactic plane.
The map below shows the sky in Galactic coordinates with (l,b) = (300,0) at the centre.
Shapley supercluster (0.048+)
Centaurus cluster (0.02)
Ophiuchus cluster (0.028)
Galactic Centre
Norma wall (0.016)
Pavo–Indus supercluster (0.015)
Sculptor supercluster (0.054)

Universe



Graphic: H. Jones (AAO), T. Jarrett (IPAC/Caltech).

Galactic Plane image courtesy of 2MASS.

values for the final release has been more comprehensively done than was the case for DR2 due to improvements in our matching algorithm. Historical $b_J r_F$ magnitudes have been retained as per the definitions created for DR2.

4. Redshift Completeness: The 2MASS and SuperCOSMOS photometry revisions have imparted a small but important scatter between the old and new versions of $b_J r_F JHK$, especially $b_J r_F K$. They have a non-negligible impact on estimates of 6dFGS redshift completeness at the faint end. New target lists have been compiled using the revised magnitudes, the completeness estimates were recalculated, and the results are presented in Jones et al. (2007, in prep.).

5. Fibre Cross-talk: Instances of fibre cross-talk, in which bright spectral features from one spectrum overlap with an adjacent one, have been reviewed and are flagged in the database for the first time. Cross-talk is an uncommon occurrence (occurring in approximately 1 percent of all spectra), and it only affects the redshifts for spectra with fewer real features than false ones.

6. Highest Redshift Sources: Very occasionally, spurious features due to cross-talk or poor sky-subtraction led to erroneously high redshifts. All sources with $z > 1$ were re-examined and re-classified (and/or re-redshifted) where necessary. Notable examples of high redshift 6dFGS sources are the candidate double QSOs g0114547-181903 ($z = 2.524$) shown in Figure 1(b) and g2052000-500523 ($z = 1.036$).

7. Orphan Fields: The final data release includes (for the first time) data from 29 orphan fields, which are flagged. These are fields that, for various reasons, are missing either the V or R half of the spectrum. They have a reduced redshift yield because of the restricted access to redshifted spectral features.

8. Re-examination of All Q = 2 Spectra: A re-examination of all previously-classified redshift quality $Q = 2$ sources has been carried out to improve the identification of $z \sim 1$ QSOs. (See Jones et al. 2004 for a description of the redshift quality Q scale.) Many QSOs were poorly identified in the early stages of the survey due to the absence of suitable QSO templates for redshifting.

9. Image Examination of All Q = 6 Sources: Initially 6212 sources were classified as redshift quality $Q = 6$ (i.e. Galactic sources with $z = 0$) on the basis of their spectra and redshifts alone. Once spectral and imaging data were assembled in the 6dFGS database (side-by-side for the first time), it became straightforward to check their spectral classifications against the postage-stamp images. Several redshift misidentifications were found which were subsequently re-redshifted and updated.

10. Anomalous K–z Sources with Q = 3, 4: The K–z relation was used to identify anomalous redshifts ($Q = 3, 4$; i.e. reliable extragalactic redshifts) outside the envelope normally spanned by this relation at typical 6dFGS redshifts. The hundred or so objects deemed to have anomalous K–z values were re-examined and re-redshifted where necessary.

11. Correction of Slit-Vane Shifted Fields: Midway through the survey it became apparent that the magnetically-held vane supporting the spectrograph slit was shifting occasionally between exposures. The resulting spectra from affected fields show a small wavelength offset (between 0.75 and a few Å), dependent on fibre number. Instances of shifting were found by comparing the wavelength of the [OI]λ5577.4 Å sky line (as measured from the 6dFGS spectra) to its true value. A search found 125 affected fields able to be fit and redshift-corrected in this way. Those galaxies with slit-vane corrected redshifts are flagged with the correction size.

12. Correction for Template Offset Values: Various tests comparing 6dFGS redshifts to independent measurements found small systematic offsets in the case of a couple of redshift templates. Corrections have been applied to redshifts from these templates for the final release.

13. Telluric Sky Line Subtraction: For the final release we have re-spliced spectra and incorporated telluric absorption line removal.

The changes discussed above are outlined in more detail in the paper accompanying the final redshift release for the 6dFGS (Jones et al., in prep). Prospective 6dFGS database users are urged to consult this paper, as well as those of the earlier data releases (Jones et al. 2004, 2005) for a comprehensive coverage of the 6dF Galaxy Survey.

Large Scale Structures in the Southern Sky

The wide sky coverage of the 6dF Galaxy Survey affords the most detailed view yet of southern large-scale structures out to $cz \sim 30000$ km s^{-1}. The 6dFGS improves upon the sky coverage of the all-sky PSCz survey (Saunders et al. 1990), and goes 1.5 mag deeper than the 2MRS. While prominent southern structures such as Shapley, Hydra-Centaurus and Horologium-Reticulum have received attention in their own right over recent years, an equally detailed large-scale census of connecting structures (and the voids between them) has remained unavailable until now.

The double-page spread on pages 18 – 19 shows the *z* < 0.2 universe as seen by 6dFGS in the plane of the sky, projected in Galactic coordinates. Familiar large-scale concentrations such as Shapley are immediately obvious, and several of the major structures have been labelled. At *z* < 0.02, filamentary structures such as the Centaurus, Fornax and Sculptor walls interconnect their namesake clusters in a manner typical of large structures generally. At *z* ~ 0.006 to 0.01 the Centaurus wall crosses the Galactic plane Zone of Avoidance (ZoA) and meets the Hydra wall at the Centaurus cluster. The Hydra wall then extends roughly parallel to the ZoA before separating into two distinct filaments at the adjacent Hydra/Antlia clusters, both of which extend into the ZoA. Behind these, at *z* = 0.01 to 0.02, is a separate filament incorporating the Norma and Centaurus-Crux clusters, and encompasses the Great Attractor region (Woudt et al. 2004, Radburn-Smith et al. 2006, and references therein). Beyond these, at *z* = 0.04 to 0.05, lies the Shapley Supercluster complex, a massive concentration of clusters thought to be responsible for 10 percent of the Local Group motion (Raychaudhury et al. 1989, Reisenegger et al. 2000, Bardelli et al. 2000) or even more (Quintana et al. 1995, Drinkwater et al. 1999).

Figure 2 shows an alternative projection of these structures as conventional radial redshift maps, cross-sectioned in declination. The plot has been limited to *z* < 0.05 to show the innermost redshifts in detail. The empty sectors correspond to the ZoA. Through Figure 2 we can confirm the extended filaments previously seen in the sky view, now seen bridging the main complexes at (α, δ, z) ~ (13.5 hr, –30 deg, 0.05) to the smaller one at (13.8 hr, –30 deg, 0.04), and on to lower redshifts, all the way down to Hydra-Centaurus.

Erdogdu et al. (2006a) have used spherical harmonics and Wiener filtering to decompose the density field and predict the velocity field of the 2MRS (*z* < 0.05). The

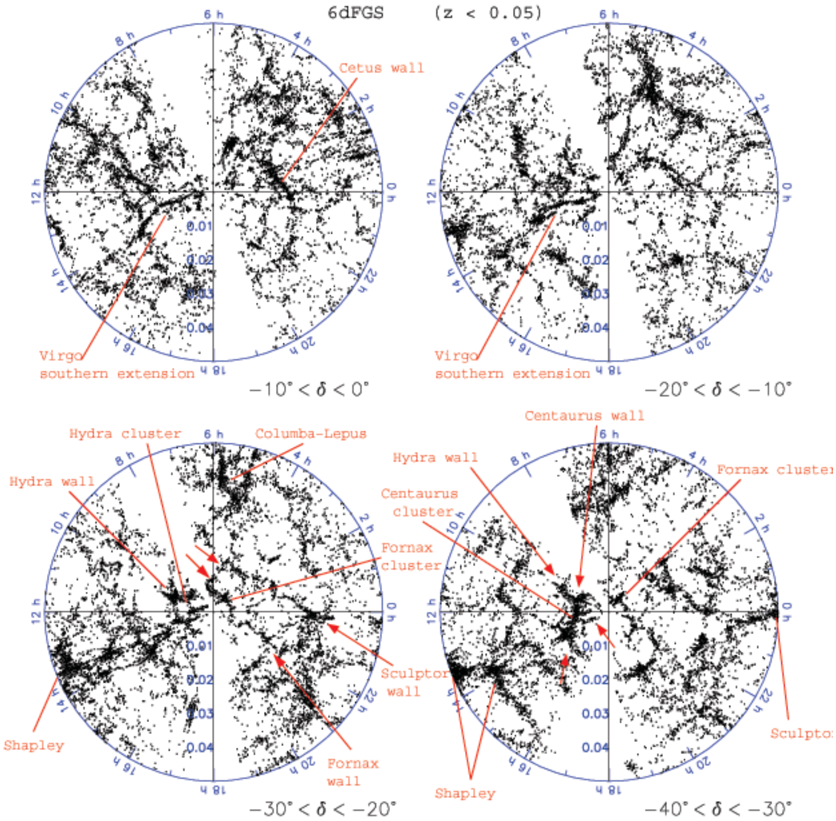


Figure 2: 6dFGS redshift maps out to *z* = 0.05, spanning southern declinations from *d* = 0 to –40° in slices of width 10°.

correspondence between the largest-scale superclusters and voids seen in both surveys is clear. Our southernmost projection (–90 deg < *d* < –60 deg; not shown in Figure 2) does not confirm the three tentative superclusters of Fairall & Woudt (2006), although this region is where 6dFGS coverage is sparsest, with low completeness between 0 hr and 6 hr and around the pole (poor sky coverage), and at 11 hr to 17 hr (ZoA). Projection effects are also evident, due to the wide R.A. span of single fields at polar declinations.

Work is currently underway cataloguing new clusters and groups from 6dFGS using a minimal spanning tree algorithm (Fairall et al., in prep.). At the same time, a preliminary list of ~500 void regions has been compiled as a reference for future work on under-dense regions. The results of these and other 6dFGS analyses will be reported in future editions of the AAO Newsletter.

References

Andernach, H., et al. 2005, in Nearby Large-Scale Structures and the Zone of Avoidance, ASP Conference Series v329, A. P. Fairall and P. A. Woudt eds., p283
Bardelli, S., et al., 2000, MNRAS, 312, 540
Brough, S., et al., 2006a, MNRAS, 369, 1351
Brough, S., et al., 2006b, MNRAS, 370, 1223
Colless, M., et al., (2dFGRS team), 2001, MNRAS, 328, 1039
Doyle, M. T., Drinkwater, M. J., 2006, MNRAS, 372, 977
Drinkwater, M. J., et al. 1999, PASA, 16, 113
Erdogdu, P., et al., 2006a, MNRAS, 373, 45
Erdogdu, P., et al., 2006b, MNRAS, 368, 1515
Fairall, A. P., Woudt, P. A., 2006, MNRAS, 366, 267
Firth, P., et al., 2006, MNRAS, 372, 1856
Fleenor, M. C., et al., 2005, AJ, 130, 957
Fleenor, M. C., et al., 2006, AJ, 131, 1280
Forbes, D. A., et al., 2006, *PASA*, 23, 38
Huchra, J. P., et al., 1992, The Center for Astrophysics Redshift catalog (ver 2002), Bull.C.P.S. 41, 31
Hwang, H. S, et al., 2007, MNRAS, 375, 115
Inoue, K. T., Silk, J., 2006, ApJ, 648, 23
Johnston, S., et al., Science Case for MIRANdA, (http://www.atnf.csiro.au/projects/mira/)
Jones, D. H., et al., 2004, MNRAS, 355, 747
Jones, D. H., et al., 2005, PASA, 22, 277
Jones, D. H., et al., 2006, MNRAS, 369, 25
Kilborn, V. A., et al., 2006, MNRAS, 371, 739
Mauch, T., Sadler, E. M., 2007, MNRAS, 375, 931
Mauduit, J.-C., Mamon, G. A., 2007, ArXiv Astrophysics e-prints, (astro-ph/0704.3431)
Proust, D., et al., 2006, A&A, 447, 133
Quintana, H., et al., 1995, AJ, 110, 463
Radburn-Smith, D. J., et al., 2006, MNRAS, 369, 1131
Raychaudhury, S., 1989, Nature, 342, 251
Reisenegger, A., et al., 2000, AJ, 120, 523
Sadler, E. M., et al., 2006, ArXiv Astrophysics e-prints, (astro-ph/0612019)
Saunders, W., et al., 1990, MNRAS, 242, 318
Woudt, P. A., et al., 2004, A&A, 415, 9
York, D. G., et al., (SDSS team), 2000, AJ, 120, 1579

STATUS OF THE AAO INSTRUMENTATION GROUP – PATHWAY TOWARDS THE FUTURE

Sam Barden (Head of Instrumentation, AAO)

It has now been four years since I took over the helm of the Instrumentation Group here at the AAO. Ever since I first arrived, I have been working hard to keep the group funded and viable. Thanks to the efforts of the Australian funding agencies, the AATB, the Director, the Executive Officer, and my excellent team, I am pleased to report that we are now entering a period of relative stability in our funding and are much better positioned to focus on projects with strategic value to the Australian astronomical community. I present here the current set of projects that our group is pursuing and, in particular, discuss the options that we are studying for a new instrument for the AAT.

Recent History and Current Path

Over the past couple of years, the Instrumentation group has seen the successful commissioning of the AAOmega spectrograph (AAO Newsletter 109, February 2006 and AAO Newsletter 110, August 2006), the delivery of the FMOS/Echidna fibre positioner (AAO Newsletter 111, February 2007), and involvement in the Gemini WFMOS effort (AAO Newsletter 105, July 2004 and AAO Newsletter 107, February 2005).

Unfortunately, the WFMOS effort has been on hold for over a year since the Gemini Board halted the concept studies in May 2006. However, we were recently invited by Gemini to resubmit our proposal for a new design effort that will commence in the latter part of this year and continue through mid-2008 for a Conceptual Design Review in advance of the November 2008 Gemini Board meeting. The AAO is collaborating with the same team as before (University of Durham, Johns Hopkins University, Rutherford Appleton Laboratories, NOAO, University of Oxford, and the University of Portsmouth) and looks forward to restarting this effort.

Although we are still firmly committed to the pursuit of making WFMOS a reality within the Gemini observatory, we are not dependent on that project for our financial future and we are now looking at a variety of options to ensure that new science capabilities are enabled on a reasonable timescale for our community. Funds from the NCRIS scheme for the development of a new instrument for the AAT are currently being used to look at a variety of instrument options. As indicated previously (AAO Newsletter 110, August 2006), one concept being explored is a non-thermal infrared