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MID-IR VARIABILITY OF QUASARS: TYPICAL VALUES AND EXTREME OUTLIERS

Nicholas P. Ross[1], Aaron Meisner[2], Daniel Stern[3], David J. Schlegel[2], Matthew Graham[4], Arjun Dey[5], Roberto J. Assef[6], Saavik K. Ford,[7], Barry L. McKernan[7], Mislav Balokovic[6], Murray Brightman[4], Andrew Drake[4], Peter R. Eisenhardt[3],

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ABSTRACT

In this paper we present the mid-infrared, light-curves for 248 quasars that show large, > 0.5 mag peak-to-peak variation, in either the W1 or W2 (3.4 or 4.6 μm) bands. Our motivation is to quantify and understand the ubiquity and processes involved in luminous AGN obscuration. The quasars are part of the SDSS-I/II or SDSS-III: BOSS Quasar surveys, a superset of over 300,000 objects with at least one epoch of spectroscopy. The IR light curves are from the WISE, NEOWISE and NEOWISE-R missions. Critically we employ new DECaLS data, and find objects that were 'traditional' blue quasars (and appear so in SDSS) are now red in color in DECaLS, and are often extended. In particular, SDSS J110057

Subject headings: WISE, QSOs

1. INTRODUCTION

The reprocessing of UV/optical photons by micron sized carbonates and silicates around an AGN central engine leads to the prodigious emission of infrared (IR) emission (Elitzur (See 2014, for review on AGN infrared emission); Netzer (2015, for a review on the Unified Model of Active Galactic Nuclei) and Draine (2003) for a review on dust).

With the energy released by the accretion of material onto a galactic central engine black hole being comparable to the energy released in nuclear fusion (REFs!!) having a full accounting of the bolometric output from a luminous AGN, i.e. a quasar, is a critical part of any contemporary galaxy and AGN model and evolutionary theory (e.g. current Illustrious and EAGLE refs??). Thus, identifying AGN in the IR, and in particular at $\sim$10μm where the AGN contribution to the SED peaks (REFs) is of key interest. Indeed, many studies have explored the utilization of mid-IR (3-30mum rest) to identify and characterize AGN and quasars (Lacy et al. 2004; Stern et al. 2005; Martínez-Sansigre et al. 2006; Richards et al. 2009; Donley et al. 2012; Stern et al. 2012; Banerji et al. 2013; Assef et al. 2013; Richards et al. 2015; Timlin et al. 2016).

Along with the raw energy output, of further critical importance to understanding in detail the physical processes of the AGN, and the potential for "feedback" on the host galaxy, is the time-dependent nature of the obscuring, dusty material. Although this is thought to be a dusty rotating "torodial" structure on $\sim$parsec scales, apart from a few very local case studies (e.g. VLT MIR interferometry objects) we are currently very ignorant to the geometry and topology of the AGN IR emitting region.

As such, observing, and characterizing the MIR *light curves* (LCs) of luminous AGN, would garnish major clues into the variable nature of the energy output of the central engine, along with key tests and constraints on the "AGN unified model".

In this paper*Letter*, we use the data from the Wide-Field Infrared Survey Explorer (WISE; Wright et al. 2010), and in particular the NEOWISE-R mission (Mainzer et al. 2014; Meisner et al. 2016), combined with the Sloan Digital Sky Survey quasar catalogs (DR7Q Schneider et al. 2010) and Dark Energy Camera Legacy Survey (DECaLS Lang et al. 2016) to identify 105 quasars (from a sample of 105,000) with large changes, $|\Delta$ mag$| > 0.5$, in their MIR LCs. This is the first time a sample of quasars with varying MIR photometry has been observed. (IS THIS TRUE??!?!!!)

In Section 2 we describe our datasets and methods for finding the MIR variable quasars, including false positive checks. In Section 3 we present our sample and the place the Extreme-IR Changers in context of the general QSO population. In Section 4 we *potentially* say "something" about obscuration rates and draw our conclusions. The (online) Appendix gives the full details or our sample. Because of established conventions, we report SDSS magnitudes on the AB zero-point system (Oke & Gunn 1983; Fukugita et al. 1996), while the WISE magnitudes are calibrated on the Vega system (Wright et al. 2010).

2. DATA

We utilize three large datasets for our investigations: the 5-band, optical Sloan Digital Sky Survey (SDSS; all the usual refs), the 3-band optical Dark Energy Camera

npross@roe.ac.uk
[1] Institute for Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, United Kingdom
[2] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 92420, U.S.A.
[3] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Mail Stop 169-221, Pasadena, CA 91109, USA
[4] California Institute of Technology, 1200 East California Boulevard, Pasadena, CA 91125, USA
[5] Steward Observatory, 933 North Cherry Avenue, Tucson, AZ 85721, U.S.A.
[6] Universidad Diego Portales, Av Republica 180, Santiago, Regi on Metropolitana, Chile
[7] Department of Astrophysics is located in the Rose Center for Earth and Space, American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024, U.S.A

Legacy Survey (Lang et al. 2016, DECaLS), and data from the WISE mission. Crucially, data from all three surveys is combined, details of which can be found at `legacysurvey.org`. We summarize the salient details here.

2.1. *Optical Data*

2.1.1. *SDSS and SDSS-III: BOSS*

The SDSS is described in full detail elsewhere (Fukugita et al. 1996; Gunn et al. 1998; York et al. 2000; Hogg et al. 2001; Lupton et al. 2001; Stoughton et al. 2002; Smith et al. 2002; Pier et al. 2003; Ivezić et al. 2004; Gunn et al. 2006; Tucker et al. 2006; Padmanabhan et al. 2008). The third incarnation of the SDSS, SDSS-III is described in Eisenstein et al. (2011) with the Baryon Oscillation Spectroscopic Survey (BOSS) being detailed in Dawson et al. (2013). The final data release paper from SDSS-III was the Data Release 12 (Alam et al. 2015).

We use the SDSS Seventh Data Release Quasar Catalog (DR7Q; Schneider et al. 2010; Shen et al. 2011) and the SDSS-III Twelve Data Release (DR12Q; **?**). SDSS quasar targets with $i \leq 19.1$ were selected if the colors were consistent with being at redshift $z \lesssim 3$, and $i \leq 20.2$ objects were selected if $z \gtrsim 3$, as outlined in Richards et al. (2002). BOSS quasar targets are selected to a magnitude limit of $g \leq 22.0$ or $r \leq 21.85$, with the primary goal to select quasars in the redshift range $2.2 \leq z \leq 3.5$ as described by Ross et al. (2012, and references therein). In both SDSS and BOSS, quasar targets are also selected if they are matched within $2''$ ($1''$ in the case of BOSS) of an object in the Faint Images of the Radio Sky at Twenty-cm (FIRST) catalog of radio sources (Becker et al. 1995). Both the SDSS DR7Q and BOSS DR12Q include quasars that were selected by algorithms other than the main quasar selections; these sources appear in the catalog due to being targeted by the respective galaxy selections, being a 'serendipitous' (Stoughton et al. 2002) or 'special' (Adelman-McCarthy et al. 2006) target in SDSS, or an 'ancillary' target in BOSS (Dawson et al. 2013; Alam et al. 2015; **?**).

2.1.2. *SDSS and SDSS-III: BOSS*

The Dark Energy Camera Legacy Survey (DECaLS; Lang et al. 2016) is taking deep 3-band g, r, z imaging over 10,000deg of the Northern Sky that is accessible from the Cerro Tololo International Observatory site. As of writing the DECaLS is ongoing, with the latest data release being the Data Release 3 (DECaLS DR3).

2.2. *Infrared Data*

As noted in **?** and Meisner et al. (2016), after its initial launch, cryogenic mission, and a period of hibernation, the WISE satellite was reactivated, and recommenced surveying the sky in its two shorter wavebands, $W1$ and $W2$. This W1/W2 survey is referred to as NEOWISE-Reactivation or NEOWISER.

We directly use the data from Meisner et al. (2016) which employs an adaptation of the unWISE Lang (2014) image coaddition framework.

From Aaron's email Oct 13, 2016. http://legacysurvey.org/dr3/catalogs

But if you look at the Tractor catalog column descriptions, you will see that DR3 includes sparse WISE W1/W2 light curves for every optically detected source (WISE_LC*). These WISE light-curves are measured by forced-photometry of time-resolved unWISE coadds. Currently, in the DECaLS footprint, there are typically four epochs, sometimes five, and very rarely only three. These light curves typically span a ∼4-5 year time baseline, ∼2010-2014.

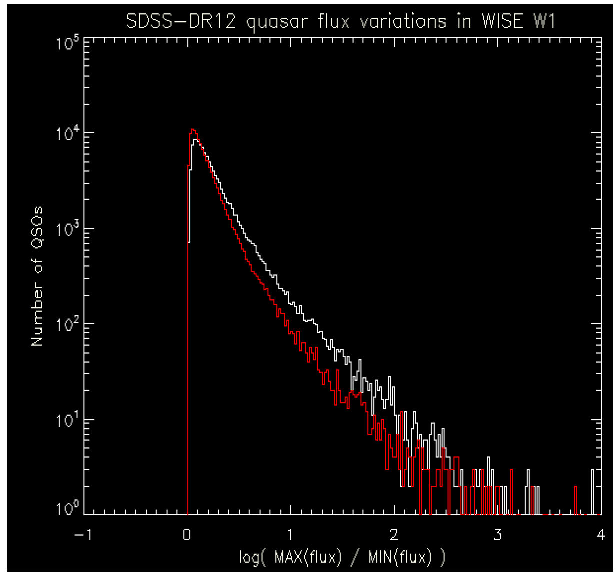

FIG. 1.— **All from DJS's email:** The distribution of the maxima and minima flux in $W1$ for the ∼240k high-confidence quasars in the SDSS-III: BOSS DR12. The red distribution is if one replaces fluxes with a mean flux+measurement error for each observation. Note, since the log is being plotted, the difference between the two lines shows a significant variable population. There are ∼1000 quasars where the $W1$ flux varies by more than a factor of 2 with a > 5 sigma confidence. Some have a poor χ^2 fits.

The distribution of the maxima and minima flux in $W1$ for the ∼240k high-confidence quasars in the SDSS-III: BOSS DR12 is given in Figure 1.

2.3. *"False Postive Checks"*

Figure 2 is the distribution of (max-min)/error in the MIR fluxes. (Should also be looking at the SDSS stars as a control sample (dont have those on my laptop). The WISE magnitude range for those stars will be quite different, though, since they have the same optical magnitude range but are fainter in WISE.)

A link to the key properties of our sample can be `found here`.

W1 and W2 lightcurves for ∼200,000 SDSS spectroscopic quasars were extracted from Data Release 3 (DR3) of the Dark Energy Camera Legacy Survey (DECaLS). These light curves span from the beginning of the WISE mission (2010 January) through the first-year of NEOWISER operations (2014 December). In detail, the W1/W2 light curves are obtained by performing forced photometry at the locations of DECam-detected optical sources. This forced photometry is performed on time-resolved unWISE coadds, each of which represents a stack with depth of coverage ∼12 exposures. A given sky location is observed by WISE for ∼1 day once every six months, which means that our forced photometry light curves typically have four coadd epochs available. Coadd epochs of a given object are separated by a minimum of six months and a maximum of four years. Our coaddi-

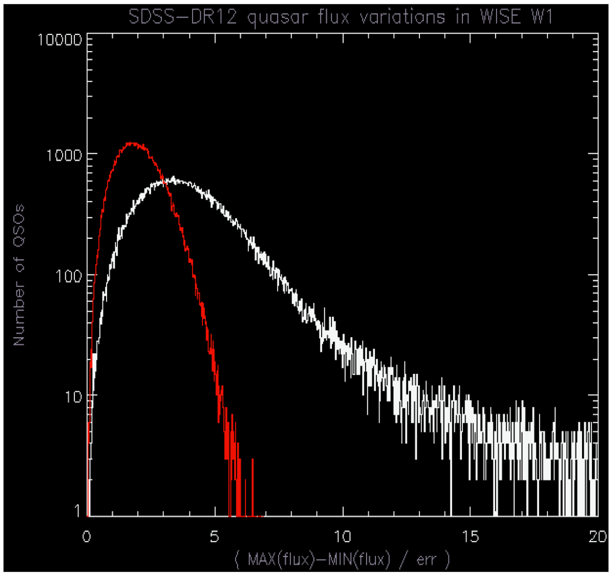

FIG. 2.— **All from DJS's 2nd email:** Here, "err" is the quadrature sum of the errors at the minimum and maximum fluxes. The red histogram is the expected distribution if these objects had no variability, and the errors were normally-distributed for each of the epochs. This shows that $\sim 6,000$ quasars are $> 10\sigma$ detections of variability in W1.

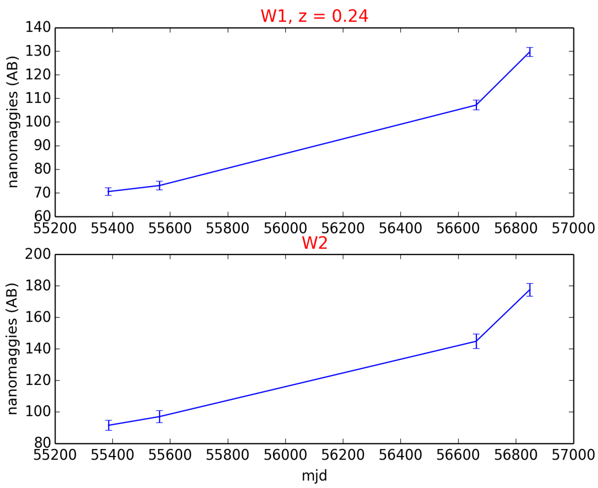

FIG. 3.— qso_lightcurves_0.5_1.0/lc_s003.png

tion removes the possibility of probing variability on $\lesssim$1 day time scales, but it allows us to push ~1.4 magnitudes deeper than individual exposures while removing virtually all single-exposure artifacts (e.g. cosmic rays and satellites).

~30,000 of the SDSS quasars with such W1/W2 lightcurves available are "IR-bright", in the sense that they are above both the W1 and W2 single exposure thresholds and therefore detected at very high significance in our coadds. For this ensemble of objects, the typical variation in each quasar's measured (W1-W2) color is 0.06 magnitudes, which includes statistical and systematic errors expected to contribute variations at the few hundredths of a mag level. The typical measured single-band scatter is 0.07 magnitudes in each of W1 and W2. A full characterization of the typical mid-IR quasar variability will be presented separately (Ross et al., in preparation).

We undertook a search for extreme outliers relative to these trends. Specifically, we selected objects with the following characterisitcs.

- Monotonic variation in both W1 and W2.
- W1 versus W2 *flux* correlation coefficient >0.9.
- > 0.5 mag peak-to-peak variation in either W1 or W2.

This yielded a sample of 248 sources. 31 of these are assumed to be blazars due to the presence of FIRST radio counterparts. Another 22 are outside of the FIRST footprint, leaving 195 quasars in our IR-variable sample. We randomly selected five of these objects for follow-up spectroscopy with Palomar DBSP on the night of 30 January 2017. WISE J1052+1519, one of these five, faded by 0.75 (0.9) mags in W1 (W2), and thus became 0.15 mags bluer in (W1-W2), making it a significant outlier in both single-band and IR color variability.

3. RESULTS

Figures 3 and 4 shows what the typical NEOWISER data look like for a non-typical quasar. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aliquam porta sodales est, vel cursus risus porta non. Vivamus vel pretium velit. Sed fringilla suscipit felis, nec iaculis lacus convallis ac. Fusce pellentesque condimentum dolor, quis vehicula tortor hendrerit sed. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos. Etiam interdum tristique diam eu blandit. Donec in lacinia libero.

3.1. *Color Changes*

From Aaron's email: Figure 5 shows the variations in the $(W1-W2)$ color, which is pretty narrow. Overplotted is a Gaussian distribution, centered at -3.8 mmag and with standard deviation of 0.06 mags (with a fit-by-eye ;-)

This histogram includes ~37,500 data points from ~9000 bright quasars, that is, brighter than single-exposure detection limit in both W1 and W2.

*NPR: It'd be friggin *awesome* if we could actually show a W1W2W3 RGB image of a quasar changing color!!!*

Figure 6 has the same data as Fig 5, now in a scatterplot of $\Delta(W1)$ versus $\Delta(W2)$. There is clearly some variation, and it is well-correlated between W1 and W2. The red line is $x = y$. (I would guess this is real variation, but I'm still a little bit scared that you could have e.g. correlated background level issues in the coadds that imprint onto the fluxes.)

3.2. *Extreme IR Variable Quasars vs. the general Quasar population*

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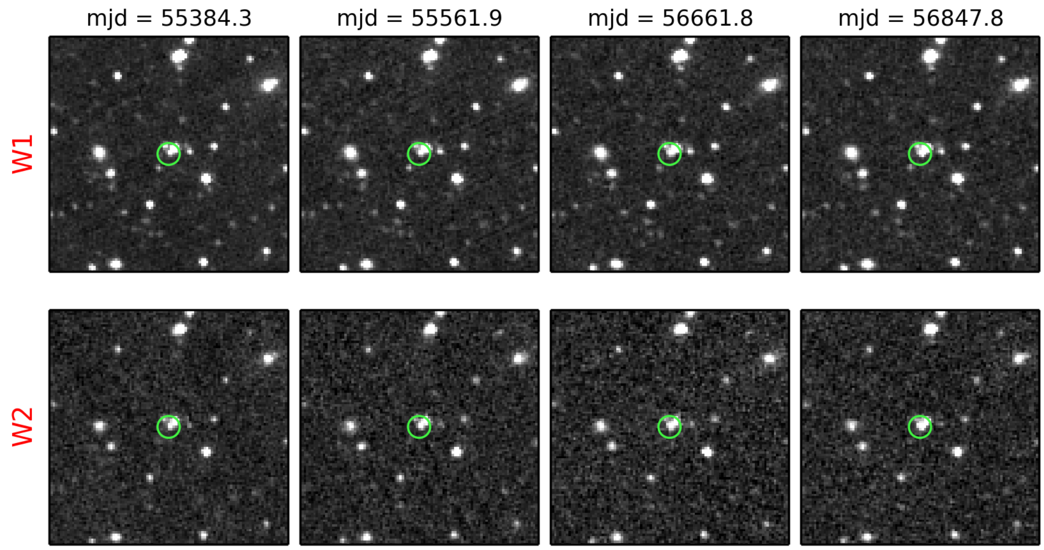

FIG. 4.— qso_finders_0.5_1.0/finder_s003.png

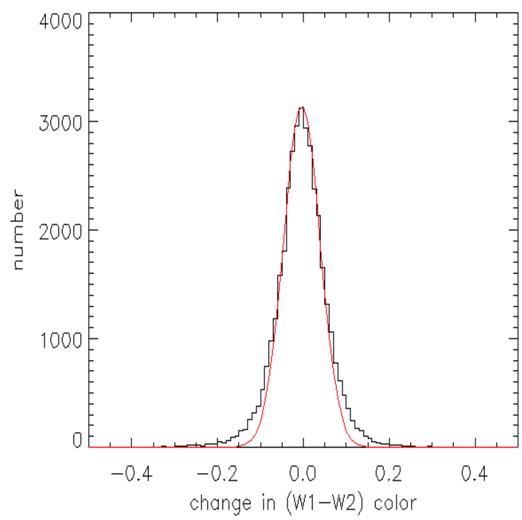

FIG. 5.— The the variations in $(W1 - W2)$ color using ∼37,500 data points from ∼9000 bright quasars. Overplotted is a Gaussian distribution, centered at -3.8 mmag and with standard deviation of 0.06 mags (with a fit-by-eye ;-).

4. SDSS J110057.71-005304.5

4.1. *General Observational Details*

SDSS J110057.71-005304.5, hereafter J110057, was discovered by the Sloan Digital Sky Survey in 2000. J110057 was imaged in Run 756 (which makes up Stripe 10), and satisfied a number of spectroscopic targettings flags (SERENDIP_BLUE, ROSAT_D, ROSAT_C, ROSAT_B, QSO_SKIRT, ROSAT_A) making it a quasar target. A spectrum was obtain on MJD 51908, on Plate 277, Fiber 212, and the spectrum of a $z = 0.378 \pm 0.00003$ was

In the DECaLS, the DECaLS brick containing J110057.71-005304.5.

number of exposures in g : 8
number of exposures in r : 3
number of exposures in z : 9

$56707.146 <= g_M JD <= 56727.201$ $56367.091 <= r_M JD <= 56367.230$ $56383.159 <= z_M JD <= 57398.350$

As can be seen, the $g-$ and $r-$band observations have fairly limited time spans, and are separated by roughly a year. The z-band observations span almost 3 years. The DESI imaging brick name is 1651m010.

Second epoch spectrum from BOSS.

Third epoch spectrum from Palomar.

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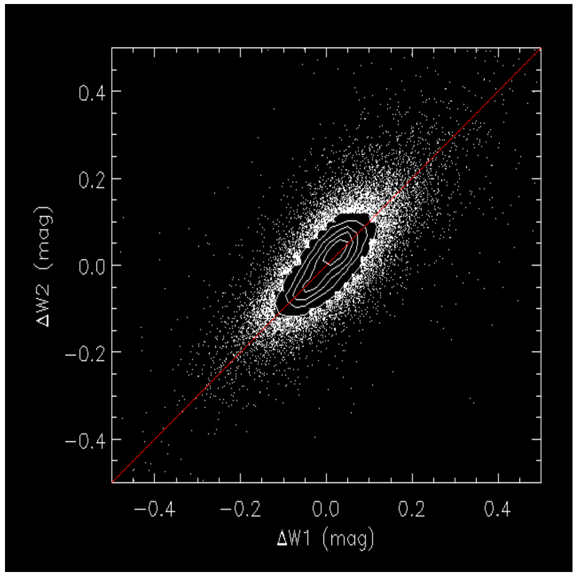

FIG. 6.— The the variations in $(W1 - W2)$ color using ∼37,500 data points from ∼9000 bright quasars. Overplotted is a Gaussian distribution, centered at -3.8 mmag and with standard deviation of 0.06 mags (with a fit-by-eye ;-).

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5. DISCUSSION AND CONCLUSIONS

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Our conclusions are thus:

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6. ACKNOWLEDGMENTS

We thank the IPAC team for the Explanatory Supplement to the WISE All-Sky and AllWISE Data Release Products resource. NEOWISE and NEOWISE-R makes use of data from WISE, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, and NEOWISE, which is a project of the Jet Propulsion Laboratory/California Institute of Technology. WISE and NEOWISE are funded by the National Aeronautics and Space Administration.

This research made use of the NASA Astrophysics Data System. This research also made use of the `astropy.org` codebase (proper citation). The data and code used herein will become publicly available at upon publication of the paper.

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Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy. The SDSS-III web site is http://www.sdss3.org/. SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, University of Cambridge, University of Florida, the French Participation Group, the German Participation Group, the Instituto de Astrofisica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

Facilities: SDSS, BOSS, WISE, CTIO Blanco+DECam

APPENDIX

TECHNICAL DETAILS

All good papers have to have an Appendix.

REFERENCES

Adelman-McCarthy J. K., et al., 2006, ApJS, 162, 38
Alam S., et al., 2015, ApJS, 219, 12
Assef R. J., et al., 2013, ApJ, 772, 26
Banerji M., McMahon R. G., Hewett P. C., Gonzalez-Solares E., Koposov S. E., 2013, MNRAS, 429, L55
Becker R. H., White R. L., Helfand D. J., 1995, ApJ, 450, 559
Dawson K., et al., 2013, AJ, 145, 10
Donley J. L., et al., 2012, ApJ, 748, 142
Draine B. T., 2003, ARA&A, 41, 241
Eisenstein D. J., Weinberg D. H., et al., 2011, AJ, 142, 72
Elitzur M., 2014, MNRAS, 438, 3340???3351
Fukugita M., Ichikawa T., Gunn J. E., Doi M., Shimasaku K., Schneider D. P., 1996, AJ, 111, 1748
Gunn J. E., et al., 1998, AJ, 116, 3040
Gunn J. E., et al., 2006, AJ, 131, 2332
Hogg D. W., Finkbeiner D. P., Schlegel D. J., Gunn J. E., 2001, AJ, 122, 2129
Ivezić Ž., et al., 2004, Astronomische Nachrichten, 325, 583
Lacy M., et al., 2004, ApJS, 154, 166
Lang D., 2014, AJ, 147, 108
Lang D., Hogg D. W., Schlegel D. J., 2016, AJ, 151, 36
Lupton R., Gunn J. E., Ivezić Z., Knapp G. R., Kent S., 2001, in F. R. Harnden Jr., F. A. Primini, & H. E. Payne ed., Astronomical Data Analysis Software and Systems X Vol. 238 of Astronomical Society of the Pacific Conference Series, The SDSS Imaging Pipelines. p. 269
Mainzer A., et al., 2014, ApJ, 792, 30
Martínez-Sansigre A., Rawlings S., Lacy M., Fadda D., Jarvis M. J., Marleau F. R., Simpson C., Willott C. J., 2006, MNRAS, 370, 1479
Meisner A. M., Lang D., Schlegel D. J., 2016, ArXiv e-prints
Netzer H., 2015, ARA&A, 53, 365
Oke J. B., Gunn J. E., 1983, ApJ, 266, 713
Padmanabhan N., et al., 2008, ApJ, 674, 1217
Pier J. R., Munn J. A., Hindsley R. B., Hennessy G. S., Kent S. M., Lupton R. H., Ivezić Ž., 2003, AJ, 125, 1559
Richards G. T., et al., 2002, AJ, 123, 2945
Richards G. T., et al., 2009, AJ, 137, 3884
Richards G. T., et al., 2015, ApJS, 219, 39
Ross N. P., et al., 2012, ApJS, 199, 3
Schneider D. P., et al., 2010, AJ, 139, 2360
Shen Y., et al., 2011, ApJS, 194, 45
Smith J. A., et al., 2002, AJ, 123, 2121
Stern D., et al., 2005, ApJ, 631, 163
Stern D., et al., 2012, ApJ, 753, 30
Stoughton C., et al., 2002, AJ, 123, 485
Timlin J. D., et al., 2016, ApJS, 225, 1
Tucker D. L., et al., 2006, Astronomische Nachrichten, 327, 821
Wright E. L., et al., 2010, AJ, 140, 1868
York D. G., et al., 2000, AJ, 120, 1579