FULL-DEPTH COADS OF THE WISE AND FIRST-YEAR NEOWISE-REACTIVATION IMAGES

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ABSTRACT

The Near Earth Object Wide-field Infrared Survey Explorer (NEOWISE) Reactivation mission released data from its first full year of observations in 2015. This data set includes ~2.5 million exposures in each of W1 and W2, effectively doubling the amount of WISE imaging available at 3.4 \( \mu \)m and 4.6 \( \mu \)m relative to the AllWISE release.

We have created the first ever full-sky set of coadds combining all publicly available W1 and W2 exposures from both the AllWISE and NEOWISE-Reactivation (NEOWISER) mission phases. We employ an adaptation of the unWISE image coaddition framework, which preserves the native WISE angular resolution and is optimized for forced photometry. By incorporating two additional scans of the entire sky, we not only improve the W1/W2 depths, but also largely eliminate time-dependent artifacts such as off-axis scattered moonlight. We anticipate that our new coadds will have a broad range of applications, including target selection for upcoming spectroscopic cosmology surveys, identification of distant/massive galaxy clusters, and discovery of high-redshift quasars. In particular, our full-depth AllWISE+NEOWISER coadds will be an important input for the Dark Energy Spectroscopic Instrument selection of luminous red galaxy and quasar targets. Our full-depth W1/W2 coadds are already in use within the DECam Legacy Survey (DECaLS) and Mayall z-band Legacy Survey (MzLS) reduction pipelines. Much more work still remains in order to fully leverage NEOWISER imaging for astrophysical applications beyond the solar system.

Key words: infrared: general – methods: data analysis – surveys – techniques: image processing

1. INTRODUCTION

The Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) has performed a full-sky imaging survey in four broad mid-infrared bandpasses centered at 3.4, 4.6, 12, and 22 \( \mu \)m, labeled W1–W4 from blue to red. WISE has dramatically enhanced our knowledge of the mid-infrared sky, and publicly released numerous catalog and imaging data products of high value to the astronomical community.

WISE was launched in 2009 December, and undertook a seven-month, full-sky survey in all of W1–W4 from early 2010 January until early 2010 August. Due to the depletion of cryogen, W4 and W3 became unusable in early 2010 August and late 2010 September, respectively. Nevertheless, WISE continued surveying the sky through 2011 January in W1 and W2, including a portion of the mission referred to as NEOWISE (Mainzer et al. 2011). WISE was placed in hibernation in 2011 February, but it was reactivated in 2013 October and recommenced surveying the sky in W1 and W2. This W1/W2 survey is referred to as NEOWISE-Reactivation (NEOWISER) and is expected to continue until 2017. The first-year NEOWISER data products, including all single-exposure images, were publicly released in 2015 March. Importantly, the NEOWISER images are of very nearly the same high quality as those of the pre-hibernation WISE mission (Mainzer et al. 2014).

Several data products consisting of full-sky, stacked WISE imaging are currently available for the first 13 months of data. The WISE team has created a set of “Atlas” coadds smoothed by the point-spread function (PSF) using the first seven months of data (the All-Sky release), and the first 13 months of data (the AllWISE release). In an independent processing effort, Lang (2014) has produced custom “unWISE” stacks analogous to the AllWISE Atlas images, but at the full spatial resolution of the instrument. These unWISE stacks are optimized for forced photometry, and have proven to be an important input for eBOSS target selection (Lang et al. 2014; Myers et al. 2015; Prakash et al. 2015).

However, until now, no full-sky set of W1/W2 coadds combining all pre- and post-reactivation exposures has existed. The primary motivation for such a data product is the enhanced depth achieved relative to AllWISE-only coadds. Among other benefits, this added depth will improve the utility of WISE for selecting higher-redshift spectroscopic targets, in particular for the upcoming Dark Energy Spectroscopic Instrument (DESI, Levi et al. 2013). Furthermore, folding in two additional scans of WISE data at each sky location allows time-dependent artifacts to be nulled, largely eliminating spatial nonuniformities in image quality and derivative catalogs.

Here we present a new set of full-sky coadds generated by combining all publicly available W1/W2 exposures from the AllWISE and NEOWISER programs, using an adaptation of the unWISE methodology of Lang (2014). These “full-depth” coadds are publicly available online.5

In Section 2 we briefly describe the W1/W2 single-exposure data set from which our coadds are constructed. In Section 3, we review the important aspects of the unWISE coaddition framework we employ and list the processing features that are newly introduced in this work. In Section 4 we describe an empirical photometric calibration we derived in order to combine pre- and post-reactivation WISE images. In Section 5 we describe our rejection of time-dependent artifacts, particularly scattered moonlight. In Section 6 we describe our procedure for recovering Moon-contaminated exposures.

5 http://unwise.me
Section 7 we highlight some important aspects of the full-sky set of full-depth coadds generated by our processing. In Section 8 we present a catalog-level validation of the improvements in WISE depth that result from doubling the amount of W1/W2 imaging. We conclude in Section 9 with a brief discussion of the work that still remains to be done with existing and future NEOWISER imaging.

2. DATA

The WISE single-exposure ‘L1b’ images represent the input data for our W1/W2 coadds. Specifically, for each L1b frame set, we make use of the per-band -int-, -msk-, and -unc- images, which respectively give the measured sky intensity and associated per-pixel bitmask values and uncertainty estimates. We have obtained a local copy of these files for every publicly available frame set, including those from the AllWISE release (∼2.8M frame sets) and first-year NEOWISER release (∼2.5M frame sets). In all we have analyzed ∼5.3M frame sets in each of W1 and W2, corresponding to a total of ∼32M L1b image files, ∼71 TB of input image data, and ∼33 × 10^12 pixels.

In addition to L1b images, we also make use of several catalog-level WISE data products. During the photometric calibration described in Section 4, we select the sources used for photometric calibration based on the AllWISE Source Catalog (Cutri et al. 2012, 2013, 2015). Also, to flag and reject bright solar system planets (Section 5), we employ the WISE Known Solar System Object Possible Association List for each mission phase (Cutri et al. 2012, 2013, 2015).

3. IMAGE COADDITION METHODOLOGY

To stack the W1/W2 single exposures, we make use of the unWISE coaddition framework of Lang (2014), and perform our image processing with an adaptation of the codebase from that work. We briefly mention a few of the salient aspects of the unWISE coaddition methodology here; for a full discussion see Lang (2014).

Like the official WISE Atlas coadds, unWISE processing divides the sky into a set of 18,240 1.56′ × 1.56′ tiles arranged along iso-declination rings. Whereas the Atlas images are smoothed by the WISE PSF, the unWISE code uses Lanczos interpolation to preserve the native WISE angular resolution during coaddition, creating stacked outputs that are 2048 pixels on a side, with 2775 pixels. PSF-convolved coadds, like the Atlas stacks, are optimal for source detection, and may also be preferable to native-resolution coadds for studying extended features. Indeed, when generating the AllWISE catalog, the Atlas coadds are used almost exclusively for the purpose of obtaining a deep/clean list of source detections, while photometric/astrometric measurements are performed in the optimal way by jointly modeling all individual exposures. One could imagine performing WISE forced photometry in a similar way, by fitting in the space of unblurred single-exposure pixels, which would be more principled than attempting to model coadded unWISE images. Nevertheless, full-resolution WISE coadds provide a significant computational convenience during forced photometry, and have proven valuable even for precision cosmology projects such as eBOSS.

During the course of this work, various modifications have been made to the original unWISE codebase and methodology of Lang (2014). Here we highlight the important updates/changes:

1. We include all publicly available NEOWISER W1 and W2 exposures, approximately doubling the number of input L1b frames relative to the processing of Lang (2014).
2. We adopt custom zero-points based on repeat photometry at the ecliptic poles. In contrast, the unWISE processing of Lang (2014) adopted zero-points extracted from the L1b header metadata.
3. We explicitly reject exposures contaminated by the Moon and/or solar system planets. No such rejection was included in the unWISE W1/W2 coadds of Lang (2014), although these and other artifacts were addressed to some extent via general-purpose outlier rejection.
4. In this work we attempt to recover Moon-affected frames by applying polynomial background level corrections to the contaminated exposures.

The outputs generated in this work follow the same data model as those of Lang (2014). For each tile, a stacked intensity image is created, as well as auxiliary maps of useful quantities such as the per-pixel inverse variance and integer coverage. Like those of Lang (2014), our coadds have units of Vega nanomaggies. All WISE magnitudes quoted throughout this paper are in the Vega system.

4. CUSTOM PHOTOMETRIC CALIBRATION

In order to combine frames across multiple mission phases, it is necessary to place all exposures on a common photometric calibration so that the multiplicative scalings of all input images are consistent. Each L1b image includes a MAG2P header keyword that gives the nominal Vega zero-point of that exposure. These zero-points are essentially predictions of system throughput based on predictors such as temperature of the beam-splitter assembly, and have been found to differ by up to several per cent relative to zero-point variations measured empirically with single-exposure photometry of calibrator sources (e.g., Cutri et al. 2013, Section V.3.a.iii.1).

We therefore sought to derive an empirical relative photometric calibration across all mission phases accurate at a level below 1%. To do so, we analyzed repeat measurements of compact sources near the ecliptic poles, where WISE has gathered data every ∼95 minutes throughout the entire mission. Specifically, our sample consists of moderately bright, unsaturated compact sources with |β| > 85°, avoiding a wedge defined by −90° < λ < 25° near the south ecliptic pole to exclude the LMC. We omit the LMC because of its complex diffuse background structure and crowding, which are nonoptimal for the purpose of extracting accurate photometry of compact sources. The positions and average magnitudes of our moderately bright source sample were drawn from the AllWISE Source Catalog, selecting W1 sources with 10.6 < W1 < 13.1 and W2 sources with 9.2 < W2 < 11.7, always requiring W1 > 2mpro < 13.1 and W2 > 9.2 < w2mpro < 11.7, with w2mpro < 11.7, always requiring w?cc_map = 0 in the band of interest.

These spatial, magnitude, and flag cuts yield samples of ∼109,000 (∼27,000) unique calibrator sources in W1 (W2). We perform aperture photometry using dja_phot with a 27.5′ radius for each calibrator source in every L1b exposure in which it appears sufficiently far from the image boundary. This

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6 A nanomag is a linear unit of flux such that a source of 1 nanomag corresponds to a magnitude of 22.5.

7 http://www.ast.cam.ac.uk/~rgm/IDL/idlutils_doc.html#DJS_PHOT
results in a catalog of $\sim$45M ($\sim$15M) W1 (W2) single-epoch aperture fluxes (in units of DN), which will form the basis for our derived time-dependent zero-points. The typical calibrator source contributes $\gtrsim$400 epochs of photometry.

We desired a photometric calibration with time resolution of one day. To achieve this, we grouped our single-exposure aperture photometry measurements in two ways. First, for each unique source, we lumped all of its All-Sky phase measurements together to obtain its median flux (DN) in our aperture photometry system during this phase. This is justified because the photometric zero-points in the All-Sky release are known to be remarkably stable (Jarrett et al. 2011). Indeed, using our single-exposure photometry database for the ecliptic pole, we were able to confirm that the All-Sky zero-point was stable at the $\leq$2 mmag level in both bands. Next, for every aperture flux after the All-Sky phase, we calculated a multiplicative enhancement factor implied by the ratio of that measurement to the appropriate source’s median All-Sky phase flux. We then grouped these flux enhancement factors into one-day bins, and quote the median per bin as the change in multiplicative image scaling relative to the All-Sky zero-point. For the All-Sky phase zero-points, we adopted the $M_{AG2P}$ values of 20.752 in W1 and 19.596 in W2.

Figure 1 shows our derived zero-points for each WISE mission phase as compared to the $M_{AG2P}$ values obtained from the L1b headers. In general, our per-day zero-points agree reasonably well with the $M_{AG2P}$ values, although there are often differences at the level of 1%, and at times disagreement at the level of several per cent. In some cases the empirically measured time trends within a particular mission phase show qualitative disagreement with the header metadata (e.g., both the W1 and W2 zero-points during the NEOWISE mission phase). When scaling each L1b image according to its zero-point during coaddition, we employ an interpolation scheme meant to avoid directly using our somewhat noisier per-day measurements. Specifically, we create a smooth approximate representation of the measured per-day zero-point time-series, based on a series of polynomials and error functions, tapering between segments such that the resulting curve is smooth. The smooth curves used to retrieve zero-point values for L1b images during coaddition are plotted as black lines in Figure 1.

The systematic differences shown in Figure 1 between the north and south ecliptic poles suggest that our per-day zero-point measurements should only be trusted at the level of a few millimagnitudes. We note that the “ubercal” algorithm (Padmanabhan et al. 2008) would provide the optimal means for performing our photometric calibration, allowing us to jointly fit the single-exposure photometry of all frames, not just those at the survey poles. This approach, while computationally intensive, would make averaging measurements of calibrators at the two poles unnecessary and completely eliminate the need for extrapolating calibrations at the poles to the rest of the sky.

5. REMOVING TIME-DEPENDENT ARTIFACTS

The WISE scan strategy is such that a typical sky location will be observed at intervals of approximately six months, with each six-monthly “visit” yielding a series of $\sim$12 exposures over a $\sim$1 day time span. Within the AllWISE release, most of the sky contains just two visits of W1/W2 imaging. Incorporating exposures from both the AllWISE and NEOWISER phases effectively doubles this value to four visits everywhere on the sky. If we coadded the AllWISE+NEOWISER data naively, without concern for time-dependent artifacts, we would risk corrupting regions of the sky that were pristine during the AllWISE phase. Instead, we have found that by leveraging the added redundancy of extra NEOWISER visits while carefully addressing time-dependent artifacts, we can create full-depth coadds that are nearly artifact-free over the entire sky.

The dominant time-dependent artifact in W1/W2 images is off-axis scattered light from the Moon, which can significantly contaminate images at angular separations of up to many tens of degrees. This contamination manifests itself in L1b exposures as a strongly spatially variable background level, which in certain images can be smooth, but in others can show a very complex morphology.

In the unWISE processing of Lang (2014), no steps were taken specifically to mitigate scattered moonlight in W1 and W2. However, that analysis did address Moon contamination in W3 and W4. Lang (2014) inspected all W3/W4 exposures flagged with the $MOON$/$MA$$\ddot{A}$$N$ED$\ddot{A}$ bit, and discarded those frames with abnormally large standard deviations of the pixel value, indicative of a strongly varying background level (see Lang 2014 Section 2 for full details). In the present work we have applied this same Moon rejection criterion to W1 and W2 frames. Because of the added redundancy of two extra NEOWISER scans, we are thus able to reject many W1/W2 frames that are contaminated by moonlight, while still retaining sufficient artifact-free coverage everywhere on the sky to avoid leaving any holes in the stacks. Scattered moonlight only affects frames at $|\beta| < 30^\circ$, and of these 4.8% (6.8%) in W1 (W2) are contaminated. Although these percentages may seem small, the WISE scan strategy is such that groups of $\sim$12 exposures per band near the same sky location will be contaminated during one time period of enhanced moonlight, which can significantly corrupt the affected coadds and/or lead to considerable nonuniformities in coverage.

Figure 2 shows the dramatic improvement achieved toward maintaining a consistent coadd background level by virtue of folding in NEOWISER data and applying the frame-level Moon rejection cut, for a tile with severe Moon contamination during the AllWISE phase.

A second, less common type of time-dependent artifact results when bright solar system planets (Mars, Jupiter, and Saturn) pass through the WISE field of view. These planet sightings are prominent in the unWISE stacks of Lang (2014), because no steps were taken to address such occurrences. In constructing our new full-depth coadds, we have used the Known Solar System Possible Association List to identify all exposures in which Mars, Jupiter, or Saturn falls within the WISE field of view. We discard such frames completely during coaddition and make no attempt to recover them. Bright planets are also accompanied by scattered light halos a few degrees in size. Therefore, we additionally use ephemerides to identify all frames within $2.5^\circ$ of these planets. During coaddition, such frames are initially ignored. However, we later attempt to recover such frames according to the procedure described below in Section 6.

6. RECOVERING CONTAMINATED FRAMES

Although we are able to dramatically reduce the impact of Moon contamination on our coadds with the exposure rejection procedure of Section 5, we would ideally like to recover as
much Moon-contaminated data as possible, rather than simply discard it all outright. To that end, we have added an afterburner step to our coaddition procedure, during which we attempt to salvage frames that were flagged with \texttt{MOON-MASKED} and displayed abnormally large standard deviations of the pixel values. The procedure we employ is a variant of that described in Section 6.4.1 of Meisner \& Finkbeiner (2014).

The first two rounds of unWISE coaddition still proceed exactly as described in Lang (2014). These steps yield a Moon-free stack that we subsequently use as a reference image to compare against each Moon-contaminated frame and to derive low-order corrections for that frame.

For each frame initially rejected on the basis of Moon contamination, we first resample the exposure onto the coadd astrometry. We then divide the exposure into quadrants, which we analyze separately. For each quadrant, we will attempt to model the Moon contamination with a polynomial offset as a function of L1b \((x, y)\) pixel coordinates. We begin by masking out the brightest and faintest 5\% of pixels in the reference coadd, since pixels with bright compact sources will not be...
very informative for modeling the background level. We then fit the difference between the masked L1b quadrant and masked reference coadd with a fourth-order polynomial in L1b \((x, y)\) coordinates. We evaluate the chi-squared of this model, using the reference coadd’s per-pixel values of standard deviation to construct per-pixel uncertainty estimates.

For each quadrant, we deem the polynomial correction to be a satisfactory description of the scattered moonlight if the mean per-pixel chi-squared is less than 2.5. In that case, we then subtract the polynomial correction from the quadrant, and consider the quadrant “recovered.” Quadrants with poor chi-squared are discarded and remain excluded from the coadd.

Once a list of all recovered quadrants has been assembled, these are accumulated into the existing reference coadd to produce a final set of outputs for the tile under consideration. Our per-exposure weights assigned to L1b images are determined from the \(-unc\)-L1b uncertainty maps, so to the extent that \(-unc\)-values are elevated in Moon-contaminated frames, recovered quadrants will be naturally downweighted relative to artifact-free exposures. In future unWISE processings, it may be desirable to further tune the relative weighting of frames with and without Moon contamination.

There is no rigorous justification or optimization underlying our decision to use fourth-order polynomials to correct each
Our methodology is simply meant to mirror that of Meisner & Finkbeiner (2014), where per-quadrant fourth-order polynomials proved quite successful in rectifying W3 L1b images. For future unWISE releases, it should be possible to perform a more thorough optimization of the polynomial order, either globally or by introducing higher-order terms into each quadrant’s correction only when warranted by improved goodness-of-fit.

Figure 3. Illustration of the procedure by which we recover Moon-contaminated exposures, as described in Section 6. Shown here is quadrant 2 of W1 exposure 05245b140. This quadrant was successfully recovered. The polynomial background correction is subtracted from every pixel in the L1b quadrant, but is shown masked for the sake of comparison to the masked L1b quadrant.

Figure 4. Large portion of the south Galactic cap near the ecliptic plane is shown in W2. Top: unWISE coadds from Lang (2014) based on the AllWISE release imaging and without rejection of Moon-contaminated frames. Bottom: same region of sky in our new AllWISE+NEOWISER stacks, with double the redundancy in sky coverage and rejection/recovery of Moon-contaminated frames. It is clear that the scattered moonlight, which appears as a series of vertical streaks, has been largely removed in W2, although some traces still remain. The two dotted red boxes show locations where Jupiter passed through the WISE field of view. The imprints of such planet sightings have now been removed.
Large-scale ($\gtrsim 1^\circ$) diffuse structures are problematic for the unWISE coaddition procedure, which performs background-matching by subtracting a scalar background level from each exposure. This effectively imposes a $\sim 0^\circ.8$ high-pass filter, which can lead to ringing. Because our per-quadrant corrections are computed with respect to templates that are themselves unWISE coadds, the resulting stacks inherit but do not amplify the ringing artifacts associated with extended background structure.

Figure 3 provides an illustration of our polynomial background modeling procedure applied to a single L1b quadrant. We were able to recover 54% of Moon-contaminated data in W1 and 33% in W2. We also apply this polynomial correction procedure to frames that we flagged as potentially affected by scattered light halos from bright solar system planets. We categorically exclude $\text{qual\_frame} = 0$ exposures, making no attempt to recover such frames.

7. OVERVIEW OF RESULTS

Figures 4 and 5 show large-scale renderings of our full-depth coadds over portions of south Galactic cap. It is apparent that the Moon contamination has been completely eliminated in W1 and dramatically reduced in W2. It is possible that simply folding in additional NEOWISER W2 frames from forthcoming data releases will diminish the remaining Moon imprint to such an extent that no additional processing modifications will be required to address this issue.

Figure 6 shows zoom-ins of a field at low ecliptic latitude, illustrating visually the reduction in statistical noise that has been achieved by doubling the number of input exposures.

Given that we imposed various frame-level cuts to eliminate time-dependent artifacts, it is reasonable to ask whether we have created any zero-coverage holes as a result. We have checked all 18,240 of our integer coverage maps, and find that every pixel has $\gtrsim 18$ epochs in W1 and $\gtrsim 15$ epochs in W2.
8. CATALOG-LEVEL VALIDATION

It is important to quantify the effect of increased coverage on the W1/W2 depths achieved by catalogs based on our AllWISE+NEOWISER coadds relative to those based on the AllWISE-only coadds of Lang (2014). A complete characterization should systematically explore a range of ecliptic and Galactic latitudes, to consider the full spectrum of interplay between decreased statistical noise and confusion. For isolated sources in the limit of sky noise, we would expect a doubling of the W1/W2 imaging data to increase the depth in each band by 0.38 mag.

8.1. DECaLS Flux Uncertainties

The only existing catalogs based on our AllWISE+NEOWISER coadds are those from DR2 of the DECam Legacy Survey8 (DECaLS, Schlegel et al. 2015), which include W1–W4 forced photometry for all optically detected sources. On the other hand, optical sources in DECaLS DR1 are accompanied by forced photometry of the unWISE coadds from Lang (2014). Therefore, comparing the uncertainties on W1/W2 fluxes in DR2 versus DR1 can allow us to obtain estimates of the increases in forced-photometry depth for regions of low ecliptic and high Galactic latitude.

To make such a comparison, for each of W1 and W2, we select a sample of isolated DECaLS DR2 sources with type = “PSF,” wise_fracflux < 0.1, more than one DECam observation, and WISE signal-to-noise ratio (S/N) within the range 10 ± 1. We then obtain a DR1–DR2 comparison sample by cross-matching these DR2 objects with sources of DR1 type = “PSF,” using a 1″ matching radius. The resulting comparison samples contain ~415,000 objects. For such sources, we find median reductions in the uncertainties of forced photometry flux of 1.38 × in W1 and 1.30 × in W2. The corresponding median increase in coverage is 1.9 × in both bands, leading us to expect a decrease in flux uncertainties by a factor of 1.38 × based purely on reduced statistical noise.

These values are not intended to represent the enhanced depths that would result from comparing WISE-selected catalogs that begin with a source detection step on the WISE coadds. Since the DR2 forced photometry does not attempt to account for faint, infrared-only sources that are newly revealed in the AllWISE+NEOWISER stacks, the reduction factors for photometric uncertainty that we have derived serve mostly as quantitative confirmation of the decreased statistical noise shown in Figure 6. Much more work is needed to characterize the increased sensitivity of WISE to faint infrared-only sources due to the inclusion of NEOWISER imaging.

8.2. Optical–IR Colors

Optical–IR color–color diagrams provide another way to illustrate the improved accuracy of faint W1/W2 source fluxes derived from our AllWISE+NEOWISER coadds. We focus on the (r − W1, r − z) color–color plane that DESI will use to select luminous red galaxy targets. Such color–color diagrams are shown in Figure 7. As can be seen clearly in the bottom two panels, there are two narrow loci of objects. The bluer locus in r − W1 corresponds to stars, while the redder locus corresponds to extragalactic sources.

We focus on a region of ~100 square degrees centered at (R.A., decl.) = (242°5, 8°5). To compare DR1 and DR2 W1 fluxes, we select a sample with S/Nr > 10 and SNW1 > 10 in both data releases, using a match radius of 0″2. We also require SNW1 > 5 in DR2. There are 1.1 million such sources, and each row of Figure 7 contains a subset of these segmented by DR2 W1 magnitude. Importantly, the DR1 and DR2 plots in each row contain identical numbers of sources, so darker values

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8 http://legacysurvey.org
in the DR2 column are indicative of tighter color–color loci rather than a larger total number of objects.

For moderately faint sources (15 < $W_1$ < 17), both DR1 and DR2 show very sharply defined loci, perhaps with a slightly sharpened stellar locus in DR2. For faint (16 < $W_1$ < 17) and very faint (17 < $W_1$ < 18) sources, both loci become significantly sharper.

8.3. Comparison with AllWISE Source Catalog

To further validate the forced photometry derived from our new coadds, we compared DECaLS DR2 fluxes to those in the AllWISE catalog. We focus on the same region of ~100 square degrees as in Section 8.2. For a comparison sample, we select all DECaLS sources with type = “PSF” that are one-to-one matched with an AllWISE catalog source (4″ radius). This sample consists of ~450,000 objects per DECaLS data release. We find good agreement between the AllWISE and DECaLS photometry over many orders of magnitude in flux. Therefore, to highlight small systematic discrepancies, Figure 8 shows (DECaLS – AllWISE) residuals as a function of AllWISE magnitude.

These plots are strongly influenced by details of the DECaLS and AllWISE catalog-making algorithms/implementations, and therefore disagreements are not necessarily indicative of problems with our updated unWISE coadds. In all cases (both bands and both DECaLS data releases), there is a gradual upturn in the median difference toward fainter AllWISE magnitudes. Because this feature is present at similar levels in both DR1 and DR2, it cannot be attributed to our inclusion of NEOWISER images or updates to the coaddition methodology of Lang (2014). Presumably the upturn results from a Malmquist bias wherein faint objects with slightly over-estimated AllWISE fluxes preferentially end up above the catalog’s S/N threshold, whereas those with slightly underestimated fluxes are preferentially discarded. In contrast, the DECaLS catalogs make no cut on WISE S/N.

A second notable trend is that the DR2 fluxes appear to be offset by +28 mmag (+18 mmag) relative to the DR1 fluxes. We believe this effect is due to slight post-reactivation increases in the W1/W2 PSF FWHM. DR1 and DR2 reductions both approximated the WISE PSF in each band as a mixture of Gaussians, with the FWHM values trained exclusively on pre-hibernation data. We simulated the effect of performing forced photometry with a PSF that is slightly narrower than that of the real data, and find that the PSF need only increase in FWHM by 2.8% in W1, or 1.8% in W2, to

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Figure 8. Comparison of DECaLS DR1 and DR2 forced photometry against AllWISE Source Catalog photometry, for a region of ~100 square degrees centered at (R.A., decl.) = (242°.5, 8°.5). Red lines indicate 25th, 50th, and 75th percentile values of the (DECaLS – AllWISE) residuals in each bin of AllWISE magnitude. Plots in the top row pertain to W1, and plots in the bottom row to W2. We believe that the $W_1$ (W2) offsets of approximately +28 (+18) mmag in DR2 relative to DR1 are the result of using pre-hibernation PSFs during forced photometry, despite slight increases in the actual FWHM values post-reactivation. The color scale is logarithmic in source density.
create the observed effect. This level of increase in FWHM seems plausible—subtracting our coadds from those of Lang (2014) in the sky region of interest reveals visually evident residuals suggestive of an increased FWHM. For future DECaLS data releases, it will be crucially important to implement forced photometry models that account for PSF variations as a function of time and are pixelized rather than analytic.

9. CONCLUSION AND FUTURE WORK

We have created a full-sky set of W1/W2 coadds that combine all publicly available exposures from both the AllWISE and NEOWISER releases. Doubling the amount of WISE imaging relative to the AllWISE release has resulted in improved W1/W2 depths and allowed the elimination of nearly all time-dependent artifacts. Our new AllWISE+NEOWISER W1/W2 coadds are publicly available via http://unwise.me.

Although the present analysis constituted a significant data processing endeavor, it represents only a small fraction of the work that must be done to maximize science return from the NEOWISER imaging data set. Creation of time-resolved coadds spanning the AllWISE-NEOWISER time baseline of about five years would enable a wealth of important time-domain projects, ranging from searches for brown dwarfs to studies of infrared quasar variability. As additional years of NEOWISER data become publicly available, it will be necessary to continue updating the full-depth AllWISE+NEOWISER coadds to maximize the achieved W1/W2 depths. Finally, the creation of WISE-selected (as opposed to forced photometry) catalogs based on deep coadds that incorporate NEOWISER images will be needed to permit a variety of exciting discoveries.

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