TITLE

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ABSTRACT

Subject headings: infrared: galaxies — submillimeter: galaxies — galaxies: starburst — methods: data analysis

1. INTRODUCTION

1.1. *Lilly-Madau formalism*

1.2. *SED fitting as a standard technique of mass and redshift estimation*

SED fitting is now a standard technique of deriving stellar mass and photometric redshifts for a large set of galaxies. In this method multi-band photometry for a given galaxy is fitted to a series of a templates predicted by a certain stellar population synthesis (SPS) model. The best-fit template gives the parameters of the galaxy, including its redshift and mass. Historically, SPS models were using restframe optical photometry. One caveat is the degeneracy between the dust extinction and age of the stellar population, as both make the color of galaxy red, i.e. galaxy can be red because it is intrinsically red with no young massive star and ongoing star-formation, or it can be very dusty, or it can be metal-rich and metals effectively absorb light in the bluer bands. Solution to this is to implement restframe near-IR where light suffers much less extinction (comparing to restframe UV and optical) and thus the degeneracy can be broken. We aim to build the largest sample of galaxies with optical and near-IR photometry over a large sky area. The natural choice for us then is to use optical Sloan Digital Sky Survey (SDSS) and IR all-sky data from Wide-Field Infrared Survey Explorer (WISE).

1.3. *problems associated with construction of the catalog*

Blending, poor spatial resolution in IR our method – template fitting

1.4. *Goal of this paper*

In this paper we present our technique for construction a catalog of galaxies with reliable SED data in optical and near-IR in Stripe 82 field. We discuss data selection, sources identification in different bands and problems associated with it.

2. DATA DESCRIPTION

2.1. *SDSS and Stripe 82*

The imaging component of the SDSS, which was done in five broad bands ($u'g'r'i'z'$), has covered 14,555 deg^2. In most area, the SDSS only scanned for one pass at

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an exposure time of 53.9 seconds per band, and thus is rather shallow (for example, the r'-band 5 σ limiting magnitude is 22.2 mag). For this reason, in most cases the SDSS can only probe the normal galaxy population up to $z \approx 0.4$. However, the Stripe 82 region, which is a long stripe along the equator that spans $20^h < RA < 4^h$ and $-1.26^o < Dec < 1.26^o$, is the exception. It was repeatedly scanned ($\sim$ 70-90 times, depending on RA) for calibration purpose during the survey (Adelman-McCarthy et al. 2007), and thus the combined scans can reach much better sensitivities.

A number of teams have created deep Stripe 82 stacks and made them available to public. The first such stacks were produced by Annis et al. (2014) based on the data obtained up to December 2005 (20-35 runs), which achieved 1-2 magnitude deeper limits than the single-pass SDSS images. Several other teams (e.g., Jiang et al. 2009; Huff et al. 2014) produced different stacks using different procedures to optimize the image qualities.

Jiang et al. (2014; hereafter J14) released a new version of stacks using only the images that were taken under the best weather conditions. These stacks are $\sim$ 0.2 mag deeper than those produced by Annis et al. (2014), reaching 5 σ limits of 23.9, 25.1, 24.6, 24.1, 22.8 mag in $u'g'r'i'z'$, respectively, and also have better PSF characteristics. We adopt these stacks in our work.

2.2. *Structure of SDSS Stripe 82 files*

We use description from J14 to present the structure of optical data. An SDSS run (strip) consists of six parallel scanlines, identified by camera columns (Figure **??**). The scanlines are 13.5 arcmin wide, with gaps of roughly the same width, so two interleaving strips make a stripe that consists of total 12 scanlines (columns). Their names in the direction of increasing declination are: $col01 \rightarrow col07 \rightarrow col02 \rightarrow col08 \rightarrow col03 \rightarrow col09 \rightarrow col04 \rightarrow col10 \rightarrow col05 \rightarrow col11 \rightarrow col06 \rightarrow col12$.

The size of each co-added SDSS image is 2854 x 2048 pixels, or roughly 18.8' x 13.5' (RA x Dec), with a pixel size of 0.396$''$ and an average full width at half maximum (FWHM) of $\sim$ 1.5$''$ in u-band, $\sim$ 1.3$''$ in g-band, and $\sim$ 1$''$ in r-, i-, and z-bands. In total there are 401 SDSS images in each column and overall $12 \cdot 401 \cdot 5 = 24,060$ SDSS images in all 5 bands. Each SDSS image has a corresponding weight.fits image, that records relative weights at individual pixels.

2.3. *WISE and unWISE*

WISE (Wright et al. 2010) is a near-to-mid IR space telescope launched in 2009 and has performed an all-sky imaging survey in four bands at 3.4, 4.6, 12, and

22 μm (denoted as W1, W2, W3, and W4, respectively). By the end of survey operations in February 2011 it has completed three mission phases, namely WISE Cryogenic Survey, WISE 3-band Survey and NEOWISE Post-Cryo Survey (Mainzer et al. 2011).

The WISE team made the AllWISE Data Release 1 in 2013 November. The image products included in this release, known as the "Atlas Images", are the stacks of the images from two complete sky coverage epochs taken in all three mission phases, and reach the nominal 5 σ limits in four bands are 0.054, 0.071, 0.73, and 5.0 mJy, respectively (see Cutri et al. 2013; for details). To optimize the detection of isolated sources, the single-exposure images were convolved with the individual point spread function (PSF) during the stacking process. However, this operation has the drawback that it reduces the spatial resolution of the final stacks,", which is not desirable in many applications. To deal with this problem, Lang (2014; hereafter L14) reprocessed all the WISE images independently without the PSF convolutions, and produced the stacks that preserve the original WISE spatial resolutions. These image products of L14, dubbed as the "unWISE" images, have the PSF full-width at half maximum (FWHM) values of 6$''$ in W1, W2 and W3 and 12$''$ in W4. We use these unWISE images for this work.

2.4. *Structure of unWISE files - once again maybe I need to omit it in the paper*

The unWISE coadds are on the same tile centers as the WISE tiles with 18,240 images per band, 1.56 x 1.56 degrees each. The tiles are named by their RA, Dec center: tile "0591p530" is at RA = 59.1, Dec = +53.0 degrees; i.e., the first four digits of the tile name is $int(RA \cdot 10)$, then "p" for +Dec and "m" for -Dec, then three digits of $int(abs(Dec) \cdot 10)$. For each tile and band w1-w4, several images are produced, we shall list only the ones that we make use of:

– unwise-0000p000-w1-img-m.fits - "Masked" image, 2048 x 2048 pixels, TAN projected at 2.75"/pixel. Background-subtracted, in units of "Vega nanomaggies" per pixel: $mag = -2.5 \cdot (log_{10}(flux) - 9)$. This is the science image, the word "masked" means that some pixels have no unmasked pixels and no measurement at all: pixel value 0 and infinite uncertainty.

– unwise-0000p000-w1-std-m.fits - Sample standard deviation (scatter) of the individual-exposure pixels contributing to this coadd pixel.

Three unWISE images centered at the same RA cover the whole width of Stripe 82 in Dec (-1.26 δ ¡ +1.26). We shall call three such unWISE images a frame. There may be up to 72 SDSS images within one frame.

3. OVERVIEW OF METHODS FOR ANALYSIS

The most critical factor in SED fitting is consistent photometry in the involved bands, i.e., the photometry should include the same fraction of light across all bands so that the colors are defined in a consistent manner. This is challenging in our case because the spatial resolutions of WISE are at least 6$\times$ worse than that of the SDSS. For this reason, the objects detected in WISE often suffer blending. Even for relatively isolated WISE sources, the photometric apertures appropriate for the

(low resolution) WISE images cannot guarantee the same fraction of light being included as what is done in the (high resolution) SDSS images. Such a systematic offset, which is different for every galaxy, severely skews the SED fitting.

To best address this problem, we opt to use the TPHOT software, which recently emerged as a robust and flexible tool to perform "template fitting". The basic idea is to use a high-resolution image (here an image from the SDSS) as the prior to build the morphological template of the source under question, convolve this template with the PSF of the low-resolution image (here the corresponding image from the unWISE), and fit this degraded template to the low-resolution image to obtain the total flux that is within the aperture as defined by the high-resolution image. In this way, we get reliable color information (i.e., flux ratio) in the most consistent manner.

While TPHOT is much more user-friendly as compared to its predecessors, running this software is still nontrivial. It not only requires careful tuning of parameters but also several tedious preparatory steps with both the high- and the low-resolution images. Here we detail our procedures.

3.1. *Preparing WISE and SDSS images*

TPHOT requires that the low- and the high-resolution images have the integer multiple of their pixel scale ratio, and also have the same orientation and the same World Coordinate System (WCS) reference position, the latter of which is defined by the FITS keywords (CRVAL1, CRVAL2). We chose to change the SDSS images to match the unWISE images, because an unWISE image is always oriented to North-up and East-left and encompasses multiple SDSS footprints.

The change to the SDSS images was done by using the SWarp software (Bertin et al. 2002). The reference pixel (CRPIX1 and CRPIX2) for the SDSS images can now be outside of the image itself to as far as 0.7 deg.

$\approx$ 15% of the SDSS images lay at the interface between two adjacent WISE images. Such SDSS images were duplicated and each copy was assigned with different reference pixels, thus increasing the number of SDSS images from 4812 to 5556 per band.

The WISE images were rescaled from 2.75 "/pix to 2.772 "/pix using SWarp. The pixel scale ratio of WISE images and SDSS images is thus an integer: $2.772/0.396 = 7$.

Center pixels of saturated sources in the WISE standard deviation images have zero values and that is an invalid input for TPHOT. IRAF/`imcalc` task was used to detect such pixels and change its value to "9999".

3.2. *Input SDSS source catalog*

Problem

Due to the great depth, roughly 24.6 AB and $\approx 1''$ PSF FWHM r-band was chosen as a reference band. Centroids, morphology, and other non-amplitude parameters of the detected sources are then fixed to the values from this reference band. Sensitivity, FWHM and local background varies in SDSS from band to band, so neither aperture, nor Kron flexible elliptical aperture (Kron 1980) can produce consistent colors in 5 optical bands, which is crucial for the subsequent SED fitting.

General solution

To remedy this problem, all individual images in $g'r'i'z'$ bands are convolved to the PSF of the corresponding image in the band with the worst PSF FWHM, namely u-band. For the price of losing some sources due to blending in the reference band, matched to the u-band, we extract more robust fluxes. Matching one images in one band to the PSF of the image in the different band requires knowledge of the corresponding kernel - a PSF matching function between two images. *Here I write about the variation of the PSF in one band in Stripe82 due to the geometrical distortions and different seeing which leads to the task of constructing of the PSF for each individual image* Construction of the 27,780 PSFs in Stripe 82 (5,556 per band) is the most time-consuming part of the project.

PSF construction

Our strategy for the PSF construction can be described as follows. PSF is built as a combination of selected point-like sources on the image. Generally, large amount of such sources is needed to build a correct PSF that is independent of small variations in profiles of the sources *I know it should be said, but I am not sure this is the best way.* The first selection of point sources that contribute to the PSF model is performed using a comparison of the core magnitude vs. total magnitude. The ratio between these two quantities represents a concentration of the source. SExtractor MAG_APER and MAG_BEST were used to quantify core and total magnitudes respectively. Size of the aperture depends on the particular band, but in general is $\approx$ X''. The second selection involved magnitude cuts (saturated and faint sources were removed) and use of the stellarity index. The later was estimated using SExtractor CLASS_STAR parameter. Sources with CLASS_STAR<XX were rejected. The last selection only left the source in the final sample if it is not close to the edge of the image and does not have another nearby source within XX''.

Finally, each SDSS image has 20 to 160 point-like sources that contribute to the PSF model. Lower value appears in a few images when there are not enough bright point sources (mostly in the less sensitive u-band), while the cut in the maximum number of the point sources was performed in order to have stable performance of the `IRAF/psf` task. *I know it sounds ugly, but I don't want to write the IRAF sometimes crashes when you supply more than 160 stars.* Visual inspection is given to all constructed PSFs. If it shows some features, such as elongation, gradient of the background due to the nearby (within up to several arcmin) source, or faint non-detected blended source in the vicinity of the main profile, then manual selection of the point sources and reconstruction of the PSF is performed. `IRAF/seepsf` is used to take the PSF, computed by the `IRAF/psf` and build a 21x21 pixel output FITS image, consisting of the sum of the analytic function and the residual. All PSF images are subsequently normalized to the unity total counts using `wcstools/sumpix` (Mink 1998) and `IRAF/imarith` tasks. Kernels are constructed using `IRAF/lucy` task that uses algorithm developed by Lucy (1974) and Richardson (1972).

I rewrote till this phrase
matching all 5 bands to the PSF of the u-band
* catalog construction with SExtractor in dual mode,

using r_matched_u band for detection - J14 catalogs are not matched between the bands, resulting in different number of objects in different bands.
- SNR at which the source is rejected is too high and there are a lot of sources that are identified in several bands when we perform our own photometry that were not included in J14 catalog.
- Bright and saturated objects are detected as multiple sources, none of which is at the center of such object making correct SED fitting impossible.
On Figure **??** we show a comparison of the original catalog from J14 (sources within green regions) and our catalog (sources within red regions). In the next 2 subsections we show the strategy for catalog construction with consistent optical colors in all 5 SDSS bands.

To construct a consistent optical catalog we run SExtractor in the dual mode - the first image is used for detection and astrometry information, while the second is used solely for photometry. We take r mathced u image as detection image and supply consequently all 5 bands to extract photometry of the sources and reject sources with SNR ¡ 5 based on the r matched u flux. R matched u catalogs as well as corresponding segmentation maps also serve as an input to the TPHOT to derive consistent photometry on near-IR bands. Our parent catalog now consists of 26,585,000 sources. We notice that very few sources were rejected at this stage - objects that appear almost undetectable had FLUX_AUTO / FLUX-ERR_AUTO larger than 5 or even 7.

* correction of the error magnitudes in g ,r ,i and z matched u bands

Photometry comparison between original x-band and x matched u-band catalogs shows a systematic underestimation of the errors associated with the source's flux (Figure 3.4). We believe that the reason for this was that we supplied to SExtractor science images matched to the u-band while the weight images were not matched to the u-band. This was the reason for high SNR ratios and low rejection rate for the faint sources. To correct for that we use STILTS code [Taylor, 2006] to match x-band and x matched u catalogs in 5 bands and for each separate image we calculate the mean ratio of the flux error before and after PSF matching. All magnitude errors in a given image are then multiplied by this coefficient. Figure 3.5 shows coefficients for all 5556 images for 4 bands matched to the u-band. We did not apply IRAF/psfmatch task to the u-band, but still calculated that correcting coefficient because r matched u FITS file was used as detection image in SExtractor. All coefficients for this band are less than 1. (CHECK THIS!)
We anticipate that while corrected values account for statistical error, there should also be a systematic error in magnitude that needs to be taken care of. We performed a series of tests where different constant errors were added in quadrature to the reported magnitude error and then the goodness of fit on the graph z spec vs z phot was checked. We found that correlation is the tightest when 0.04 magnitude error is added in quadrature (so final error cannot be smaller than 0.04). Each source in each band was assigned by a error in magnitude that was calculated using the following equation:

$$magerr\_corrected = \sqrt{0.04^2 + (\frac{1.0857}{SNR} \cdot correction\_coefficient)^2}$$

** masking area around bright stars
** removing double objects
** star-galaxy separation

3.3. *preparatory work with input files to TPHOT*

* SWarping of unWISE files

We use SWarp to change the pixel scale of all unWISE images from original 2.75 to 2.772 to match the integer pixel scale ratio with SDSS images = 7. Now we construct unWISE PSF functions that is to be convolved with SDSS PSF to produce kernels - one of the most important set of the input files to TPHOT. *PSF construction

WISE Atlas Images are constructed by coadding many single-exposure images (IV.4.f). Because the number and relative orientation of single-exposures differ significantly between Atlas Tiles, and because the single-exposure PSFs vary with focal plane location (IV.4.c.iii), the PSF will be different for every Atlas Image and will vary with position on any given Atlas Image. (*http* : *//wise2.ipac.caltech.edu/docs/release/allsky/expsup/sec4_4c.html*)

There are 240 unWISE images within Stripe 82 footprint per band. Bands w3 and w4 are too shallow and no reasonable flux can be extracted for the vast majority of optical sources in these bands, so for the purpose of this project we only use w1 and w2 bands. We followed the strategy from the previous section (i.e., running SExtractor, selecting potential PSF stars using STILTS) to construct PSF for all 480 images with two major differences in the procedure: 1) Center pixels of saturated sources in unWISE standard deviation images (unwise-0000p000-w1-std-m.fits) always have zero value and that is an invalid input for TPHOT. We use IRAF/imcalc to detect such pixels and change its value to "9999". 2) We construct each PSF function using IRAF/psf interactive mode. This was done to perform more robust selection of stars as 3 PSFs from one unWISE frame are convolved with up to 72 SDSS PSFs and thus its quality is crucial - incorrect PSF profile leads to wrong flux estimation associated with such sources and also characteristic positive and negative ring-shaped patterns in the residuals.
After running the IRAF/seepsf task we get PSF FITS images, 19x19 pixels each. All unWISE PSFs are then normalized to unity total counts using IRAF/imarith and sub-sampled in size by the factor of 7 using

IRAF/imlintran (to 133x133 pixels) to match the pixel scale ratio between unWISE and SDSS images. Result is presented on Figure 3.6 * kernel construction We use r matched u band as a detection band for the optical sources and also as a high-resolution image for the template fitting. We run the same algorithm to create 5556 r matched u PSFs (not to be mixed up with the r matched u PSF that we use to change FWHM of the original r-band). IRAF/lucy is used to convolve normalized r matched u PSF with normalized and sub-sampled unWISE PSF to create kernels. These kernels serve as one of the inputs for TPHOT.

* naming convention

Both final and intermediate results are a combination of SDSS and unWISE data and we introduce our new naming convention that is used throughout the project. E.g. file kernel.w1.0000p015_12r_u_111.fits is a kernel made by convolution of the PSF function of the file unwise-0000p015-w1-img-m.fits and PSF function of the file S82_12r_111.fits in r-band, that has been previously matched to the PSF of the u-band.

4. REDSHIFT AND MASS ESTIMATION

The availability of near-IR filters helps improving the z_phot accuracy beyond z ≈ 1.3, where the 4000A break goes out of the z 0 filter and the Lyman break is not yet detectable in the u - band. (from 1809.03373.pdf)

4.1. *TPHOT*

parameters, limitations, computation on the cluster

4.2. *Final catalog with photometric redshifts*

matching by the source number comparison output fluxes from TPHOT to the unWISE catalogs

4.3. *EAZY*

redshift determination, matching to the spectroscopic redshifts comparison of the redshift with and without unWISE data (similar results) star-galaxy separation final cleaning of the catalog – removing of bright stars and duplicated sources

5. RESULTS
6. DISCUSSION
7. SUMMARY

REFERENCES

J.K. Adelman-McCarthy, AGUEROS M.A., ALLAM S.S., ANDERSON K.S.J., ANDERSON S.F., ANNIS J., BAHCALL N.A., BAILER-JONES C.A.L., BALDRY I.K., BARENTINE J.C., BEERS T.C., BELOKUROV V., BERLIND A., BERNARDI M., BLANTON M.R., BOCHANSKI J.J., BOROSKI W.N., BRAMICH D.M., BREWINGTON H.J., BRINCHMANN J., BRINKMANN J., BRUNNER R.J., BUDAVARI T., CAREY L.N., CARLILES S., CARR M.A., CASTANDER F.J., CONNOLLY A.J., COOL R.J., CUNHA C.E., CSABAI I., DALCANTON J.J., DOI M., EISENSTEIN D.J., EVANS M.L., EVANS N.W., FAN X., FINKBEINER D.P., FRIEDMAN S.D., FRIEMAN J.A., FUKUGITA M., GILLESPIE B., GILMORE G., GLAZEBROOK K., GRAY J., GREBEL E.K., GUNN J.E., DE HAAS E., HALL P.B., HARVANEK M., HAWLEY S.L., HAYES J., HECKMAN T.M., HENDRY J.S., HENNESSY G.S., HINDSLEY R.B., HIRATA C.M., HOGAN C.J., HOGG D.W., HOLTZMAN J.A., ICHIKAWA S.-I., ICHIKAWA T., IVEZIC Z., JESTER S., JOHNSTON D.E., JORGENSEN A.M., JURIC M., KAUFFMANN G., KENT S.M., KLEINMAN S.J., KNAPP G.R., KNIAZEV A.Y., KRON R.G., KRZESINSKI J., KUROPATKIN N., LAMB D.Q., LAMPEITL H., LEE B.C., LEGER R.F., LIMA M., LIN H., LONG D.C., LOVEDAY J.

J. Annis, M. Soares-Santos, M. A. Strauss, A. C. Becker, S. Dodelson, X. Fan, J. E. Gunn, J. Hao, Ž. Ivezić, S. Jester, L. Jiang, D. E. Johnston, J. M. Kubo, H. Lampeitl, H. Lin, R. H. Lupton, G. Miknaitis, H.-J. Seo, M. Simet, and B. Yanny. The sloan digital sky survey coadd: 275 deg² of deep sloan digital sky survey imaging on stripe 82. *ApJ*, 794:120, October 2014. doi:10.1088/0004-637X/794/2/120. URL http://adsabs.harvard.edu/abs/2014ApJ...794..120A.
E. Bertin, Y. Mellier, M. Radovich, G. Missonnier, P. Didelon, and B. Morin. The terapix pipeline. In D. A. Bohlender, D. Durand, and T. H. Handley, editors, *Astronomical Data Analysis Software and Systems XI*, volume 281 of *Astronomical Society of the Pacific Conference Series*, page 228, 2002. URL http://adsabs.harvard.edu/abs/2002ASPC..281..228B.

R. M. Cutri, E. L. Wright, T. Conrow, J. W. Fowler, P. R. M.
Eisenhardt, C. Grillmair, J. D. Kirkpatrick, F. Masci, H. L.
McCallon, S. L. Wheelock, S. Fajardo-Acosta, L. Yan,
D. Benford, M. Harbut, T. Jarrett, S. Lake, D. Leisawitz, M. E.
Ressler, S. A. Stanford, C. W. Tsai, F. Liu, G. Helou,
A. Mainzer, D. Gettings, A. Gonzalez, D. Hoffman, K. A.
Marsh, D. Padgett, M. F. Skrutskie, R. P. Beck, M. Papin, and
M. Wittman. Explanatory supplement to the allwise data
release products. Technical report, November 2013. URL
http://adsabs.harvard.edu/abs/2013wise.rept....1C.

E. M. Huff, C. M. Hirata, R. Mandelbaum, D. Schlegel, U. Seljak,
and R. H. Lupton. Seeing in the dark - i. multi-epoch alchemy.
MNRAS, 440:1296–1321, May 2014.
doi:10.1093/mnras/stu144. URL
http://adsabs.harvard.edu/abs/2014MNRAS.440.1296H.

L. Jiang, X. Fan, F. Bian, J. Annis, K. Chiu, S. Jester, H. Lin,
R. H. Lupton, G. T. Richards, M. A. Strauss, V. Malanushenko,
E. Malanushenko, and D. P. Schneider. A survey of z ~ 6
quasars in the sloan digital sky survey deep stripe. ii. *AJ*, 138:
305–311, July 2009. doi:10.1088/0004-6256/138/1/305. URL
http://adsabs.harvard.edu/abs/2009AJ....138..305J.

L. Jiang, X. Fan, F. Bian, I. D. McGreer, M. A. Strauss, J. Annis,
Z. Buck, R. Green, J. A. Hodge, A. D. Myers, A. Rafiee, and
G. Richards. The sloan digital sky survey stripe 82 imaging
data: Depth-optimized co-adds over 300 deg^2 in five filters.
ApJS, 213:12, July 2014. doi:10.1088/0067-0049/213/1/12.
URL http://adsabs.harvard.edu/abs/2014ApJS..213...12J.

R. G. Kron. Photometry of a complete sample of faint galaxies.
ApJS, 43:305–325, June 1980. doi:10.1086/190669. URL
http://adsabs.harvard.edu/abs/1980ApJS...43..305K.

D. Lang. unwise: Unblurred coadds of the wise imaging. *AJ*,
147:108, May 2014. doi:10.1088/0004-6256/147/5/108. URL
http://adsabs.harvard.edu/abs/2014AJ....147..108L.

L. B. Lucy. An iterative technique for the rectification of
observed distributions. *AJ*, 79:745, June 1974.
doi:10.1086/111605. URL
http://adsabs.harvard.edu/abs/1974AJ.....79..745L.

A. Mainzer, J. Bauer, T. Grav, J. Masiero, R. M. Cutri, J. Dailey,
P. Eisenhardt, R. S. McMillan, E. Wright, R. Walker,
R. Jedicke, T. Spahr, D. Tholen, R. Alles, R. Beck,
H. Brandenburg, T. Conrow, T. Evans, J. Fowler, T. Jarrett,
K. Marsh, F. Masci, H. McCallon, S. Wheelock, M. Wittman,
P. Wyatt, E. DeBaun, G. Elliott, D. Elsbury, T. Gautier, IV,
S. Gomillion, D. Leisawitz, C. Maleszewski, M. Micheli, and
A. Wilkins. Preliminary results from neowise: An enhancement
to the wide-field infrared survey explorer for solar system
science. *ApJ*, 731:53, April 2011.
doi:10.1088/0004-637X/731/1/53. URL
http://adsabs.harvard.edu/abs/2011ApJ...731...53M.

D. J. Mink. Wcstools: an image astrometry toolkit. In
AAS/Division of Dynamical Astronomy Meeting, volume 30 of
Bulletin of the American Astronomical Society, page 1144,
September 1998. URL
http://adsabs.harvard.edu/abs/1998DDA....29.0806M.

W. H. Richardson. Bayesian-based iterative method of image
restoration. *Journal of the Optical Society of America
(1917-1983)*, 62:55, January 1972. URL
http://adsabs.harvard.edu/abs/1972JOSA...62...55R.

E. L. Wright, P. R. M. Eisenhardt, A. K. Mainzer, M. E. Ressler,
R. M. Cutri, T. Jarrett, J. D. Kirkpatrick, D. Padgett, R. S.
McMillan, M. Skrutskie, S. A. Stanford, M. Cohen, R. G.
Walker, J. C. Mather, D. Leisawitz, T. N. Gautier, III,
I. McLean, D. Benford, C. J. Lonsdale, A. Blain, B. Mendez,
W. R. Irace, V. Duval, F. Liu, D. Royer, I. Heinrichsen,
J. Howard, M. Shannon, M. Kendall, A. L. Walsh, M. Larsen,
J. G. Cardon, S. Schick, M. Schwalm, M. Abid, B. Fabinsky,
L. Naes, and C.-W. Tsai. The wide-field infrared survey
explorer (wise): Mission description and initial on-orbit
performance. *AJ*, 140:1868-1881, December 2010.
doi:10.1088/0004-6256/140/6/1868. URL
http://adsabs.harvard.edu/abs/2010AJ....140.1868W.

APPENDIX

APPENDIX

A. PROSPECTIVE AUTOMATION OF THE DECOMPOSITION PROCESS

B. ACKNOWLEDGMENTS