Draft version May 5, 2020
Typeset using LaTeX **twocolumn** style in AASTeX63

The CatWISE2020 Catalog

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ABSTRACT

The CatWISE2020 Catalog consists of 1,890,715,640 sources over the entire sky selected from WISE and NEOWISE survey data at 3.4 and 4.6 μm (W1 and W2) collected from 2010 Jan. 7 to 2018 Dec. 13. This dataset adds two years to that used for the CatWISE Preliminary Catalog (Eisenhardt et al. 2020), bringing the total to six times as many exposures spanning over sixteen times as large a time baseline as the AllWISE catalog. The other major change from the CatWISE Preliminary Catalog is that the detection list for CatWISE2020 was generated using "crowdsource" software (Schlafly et al. 2019), while the Preliminary Catalog used the detection software used for AllWISE. These two factors result in roughly twice as many sources in CatWISE2020. The scatter with respect to Spitzer photometry at faint magnitudes in the COSMOS field, which is out of the Galactic plane and at low ecliptic latitude (corresponding to lower WISE coverage depth) is similar to that for the CatWISE Preliminary Catalog. The 90% completeness depth for CatWISE2020 is at roughly W1=17.7 and W2=17.5, about 1.7 mag deeper than in the Preliminary Catalog. From comparison to Gaia, CatWISE2020 motions are over a dozen times more accurate than those from AllWISE. The CatWISE catalogs are available in the WISE/NEOWISE Enhanced and Contributed Products area of the NASA/IPAC Infrared Science Archive.

Keywords: catalogs, infrared:stars, proper motions

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1. INTRODUCTION

The CatWISE Preliminary Catalog (Eisenhardt et al. 2020), which was released via NASA's Infrared Science Archive in August 2019, consists of 900,849,014 sources over the entire sky selected from WISE (Wright et al. 2010) and NEOWISE (Mainzer et al. 2014) survey data at 3.4 and 4.6 μm (W1 and W2) collected from 2010 to 2016. This dataset includes four times as many exposures and spans over ten times as large a time baseline as the AllWISE catalog (Cutri et al. 2013), as illustrated in Figure 1. CatWISE adapts AllWISE software to measure the sources in co-added images created by the unWISE team from six month subsets of these data, each representing one coverage of the inertial sky, or epoch (Meisner et al. 2018). The Preliminary Catalog includes the measured motion of sources in 8 epochs over the 6 year span of the data, which are ten times more accurate than those from AllWISE. The Preliminary Catalog has been used to identify some of the coldest brown dwarfs identified to date (Marocco et al. 2019, 2020; Meisner et al. 2020).

Nevertheless, further significant improvements are possible. The most important caveat for the CatWISE Preliminary Catalog is that the number of sources per square degree has relatively small variation over the sky (Figure 2). This is likely a consequence of the source detection methodology used for the Preliminary Catalog (Eisenhardt et al. 2020), which, while optimal for isolated point sources, results in significant incompleteness in high source density regions such as the Galactic plane.

The CatWISE2020 Catalog addresses this issue by using an updated version of the unWISE catalog (Schlafly et al. 2019) as the detection list. In addition, CatWISE2020 includes two more years of survey data from NEOWISE than does the Preliminary Catalog, increasing the number of epochs to 12 and the time span to over 8 years (Figure 1). As a result, the CatWISE2020 Catalog has more than twice as many sources as the CatWISE Preliminary Catalog. In the Galactic plane, the CatWISE2020 source density is five times higher than in the CatWISE Preliminary Catalog (Figure 2).

Eisenhardt et al. (2020) presents a detailed description of the CatWISE Preliminary Catalog. Here we describe updates to the processing steps used for the CatWISE2020 Catalog relative to the Preliminary Catalog (§2), assess the astrometric and photometric performance of CatWISE2020 using comparisons to *Gaia* and *Spitzer* data (§3), and provide information on accessing the CatWISE2020 Catalog (§4). The Appendix summarizes known issues in the CatWISE2020 Catalog. The CatWISE website is https://catwise.github.io.

2. CATWISE2020 PROCESSING UPDATES

A full description of the processing steps for the CatWISE Preliminary Catalog is given in Eisenhardt et al. (2020), and we only describe changes for CatWISE2020 processing here. Coordinates in the CatWISE 2020 Catalog are in the ICRS system at epoch MJD=57170 (2015 May 28), while in the Preliminary Catalog they are in J2000 at epoch MJD=56700.

2.1. *unWISE Coadds*

The CatWISE2020 Catalog is based on the combination of W1 and W2 exposures in the two sky coverages used for the AllWISE data release (Cutri et al. 2013) and in the ten additional sky coverages from the NEOWISE 2019 data release[1], while the Preliminary Catalog uses AllWISE and the six additional sky coverages from the NEOWISE 2017 Data Release[2]. The full depth unWISE coaddition from Meisner et al. (2018a) is used for both source detection and aperture photometry in the CatWISE Preliminary Catalog. CatWISE2020 uses the full depth unWISE coaddition of the AllWISE and NEOWISE 2019 Data Release for aperture photometry, while source detection for CatWISE2020 is described in §2.2.

The CatWISE Preliminary Catalog used the 8 individual unWISE epoch coadds from Meisner et al. (2018c) for point source photometry and astrometry, with an adjustment to the world coordinate system (WCS) for the AllWISE epochs, as described in Eisenhardt et al. (2020). CatWISE2020 uses 12 unWISE epoch coadds constructed using the methodology given in Meisner et al. (2019), without the adjustment to the AllWISE epochs. This results in small astrometric offsets for CatWISE2020 (see §3.3).

2.2. *Detection*

The narrow distribution over the sky in detected sources per square degree for the CatWISE Preliminary Catalog (Figure 2) means that the source density is no higher in the Galactic plane than at the Galactic poles (in fact it is slightly lower in Galactic plane, as shown in the upper left panel; of Figure 3). The unWISE Catalog (Schlafly et al. 2019) uses a crowded-field point-source photometry code called "crowdsource" which detects far more sources in high density regions. Additional information about crowdsource is provided in Schlafly et al. (2018). The unWISE Catalog measures source fluxes

[1] http://wise2.ipac.caltech.edu/docs/release/neowise/neowise_2019_release_intro.html
[2] http://wise2.ipac.caltech.edu/docs/release/neowise/neowise_2017_release_intro.html

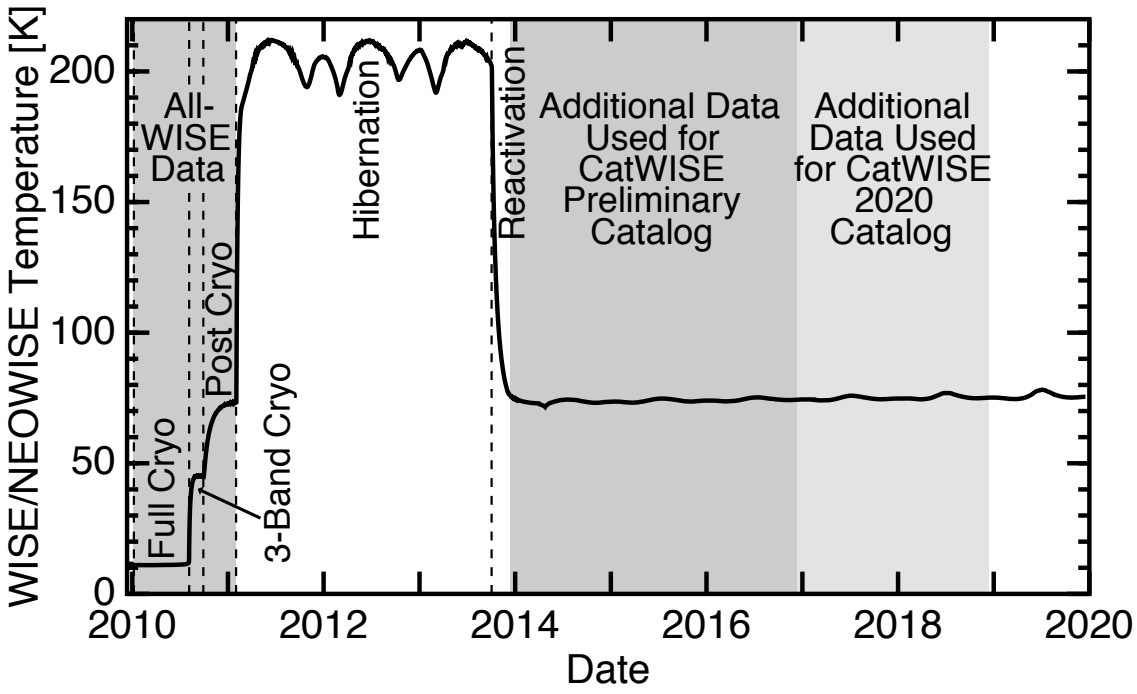

Figure 1. Temperature of the *WISE* beamsplitter assembly vs. date. This temperature is close to that of the telescope and W1 and W2 detectors. Dashed lines indicate the transitions from full cryogenic to 3-band cryogenic phases, to the post-cryogenic phase, and to the start of hibernation and reactivation. Darker gray shading indicates the date ranges of data used for the CatWISE Preliminary Catalog, and lighter gray the additional data included in the CatWISE2020 Catalog. AllWISE included only the left portion of the shaded range.

and static positions in the full-depth coadded image, with the measurements carried out independently in W1 and W2, while CatWISE selects sources simultaneously in both bands, measuring their fluxes, positions, and motions in epoch coadds. As noted in Eisenhardt et al. (2020), for CatWISE2020 we therefore decided to replace the CatWISE Preliminary Catalog detection step (which uses MDET, the Multiband Detection software of Marsh & Jarrett 2012) with an updated version of the unWISE Catalog (hereafter UUC)[3].

The unWISE Catalog of Schlafly et al. (2019) is based on the NEOWISE 2018 Data Release, while the UUC used for the CatWISE2020 detection list is based on the NEOWISE 2019 Data Release. CatWISE2020 begins with the band-merged UUC, where photometry for W1 and W2 sources within $2\farcs4$ is matched. CatWISE measures sources in order of decreasing signal-to-noise ratio (S/N). To generate a single S/N-ordered detection list from the unWISE photometry in both bands, CatWISE2020 determines an average flux uncertainty σ_{avg} for each band from the mean of the flux uncertainty of sources whose flux F is within $\pm 0.5\%$ of the median flux in the band. The S/N in each band is calculated from F/σ_{avg}, and the W1 and W2 S/N values are root-sum-squared to determine a combined S/N for each source.

Figure 2 shows the resultant histogram of source densities for CatWISE2020 compared to the CatWISE Preliminary Catalog and Reject Table, and Figure 3 compares the distribution of source density over the sky.

2.3. *Source Measurement*

As for the CatWISE Preliminary Catalog, CatWISE2020 used an adapted version of the WPHOT software developed for the AllWISE pipeline to carry out source photometry, astrometry, and motion estimation, processing separately epochs taken with ascending vs. descending survey scan directions, and then merging the results (Eisenhardt et al. 2020). For CatWISE2020 however, we did not allow WPHOT to add new sources ("active deblending") to improve the χ^2 of the fit to a source, as the crowdsource algorithm (§2.2) already provides a much more complete set of detected sources

[3] The updated unWISE Catalog is available at https://faun.rc.fas.harvard.edu/unwise/neo5/band-merged

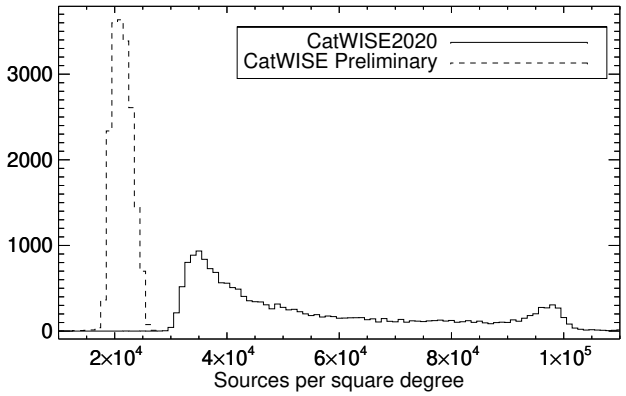

Figure 2. Source density distribution for the CatWISE2020 catalog compared to the CatWISE Preliminary Catalog. Deeper data, and a more effective detection of sources in crowded fields results in a broader distribution and a greater number of sources per square degree.

than does the MDET algorithm used for the CatWISE Preliminary Catalog.

2.3.1. *Uncertainties*

In the CatWISE Preliminary Catalog, a minimum motion uncertainty of 10 mas yr^{-1} was enforced, while for CatWISE2020, this floor was reduced to 1 mas yr^{-1}.

2.4. *The CatWISE2020 Catalog*

Like the CatWISE Preliminary Catalog, CatWISE2020 Catalog sources are required to:

1) be from the tile where that source is furthest from the tile edge (i.e. flagged as "primary,")
and
2a) have W1 SNR ≥ 5 with no identified artifacts (a value of 0 in the left character of *ab_flags*)
or
2b) have W2 SNR ≥ 5 with no identified artifacts (a value of 0 in the right character of *ab_flags*).

There are 1,890,715,644 sources that meet these criteria. The 341,799,385 sources that fail to meet these criteria go into the reject file for their tile. Individual tile reject files typically contain 11,000 sources, although near the Galactic center they can contain over 120,000 sources due to the large number of artifacts. There are 187 formatted columns of information about each source in the tile catalog files. Reject files have one additional column, indicating if the source is primary in its tile. Descriptions of most of the columns are available in §II.1.a of the AllWISE Explanatory Supplement (Cutri et al. 2013), and §2.5 provides additional information about CatWISE2020 columns.

The individual CatWISE2020 Catalog and Reject files for the 18,240 tiles were transferred to the NASA Infrared Science Archive (IRSA), where they were merged into the IRSA database. Information regarding access to the catalog is provided in §4.

CatWISE2020 source designations should have the prefix CWISE for objects in the CatWISE2020 Catalog, and CWISER for objects in the CatWISE2020 Reject Table. The designation for each source, based on its coordinates for the J2000 equinox following the IAU truncation convention and without the leading CWISE or CWISER prefix, is given by the field *source_name* which is the first column in the files. For example, the quasar 3C 273 is CWISE J122906.70+020308.6.

2.5. *CatWISE2020 Catalog Column Descriptions*

There are 187 formatted columns of information about each source in the CatWISE2020 Catalog. The CatWISE2020 Reject Table adds a column to indicate whether the source is primary in its tile (see §2.4). Descriptions of nearly all the columns can be obtained from IRSA at https://irsa.ipac.caltech.edu/data/WISE/CatWISE/gator_docs/catwise_colDescriptions.html. Most of the columns have the same names as in the AllWISE Catalog, and are described in §II.1.a of the AllWISE Explanatory Supplement (Cutri et al. 2013). Table A1 of Eisenhardt et al. (2020) provides information about selected columns in the CatWISE catalogs that augments or supersedes the information provided by IRSA.

The Galactic coordinates (*glon* and *glat*) for sources in the CatWISE Preliminary Catalog were calculated incorrectly and were hidden in the IRSA release. In CatWISE2020, these columns are more accurate and now are shown in the IRSA release, but should not be used for astrometry. Two columns (*w1fitr* and *w2fitr*) remain hidden in the IRSA release of CatWISE2020, for reasons explained in Table A1 of Eisenhardt et al. (2020). Finally, CatWISE2020 includes a new column (*unwise_objid*) which provides the updated unWISE Catalog (§2.2) identification corresponding to the source. Note that these identifications end in "r02" to avoid confusion with unrelated sources in the unWISE Catalog of Schlafly et al. (2019).

3. PERFORMANCE CHARACTERIZATION

The additional data, longer baseline, and different detection software lead to an improvement on some key performance parameters for CatWISE2020 with respect to the CatWISE Preliminary Catalog. Following the performance characterization strategy adopted in Eisenhardt et al. (2020), we focus on the completeness and reliability of the CatWISE2020 catalog at both the bright (W1,W2 $<$ 8 mag, §3.1.1) and faint end (W1,W2 $>$

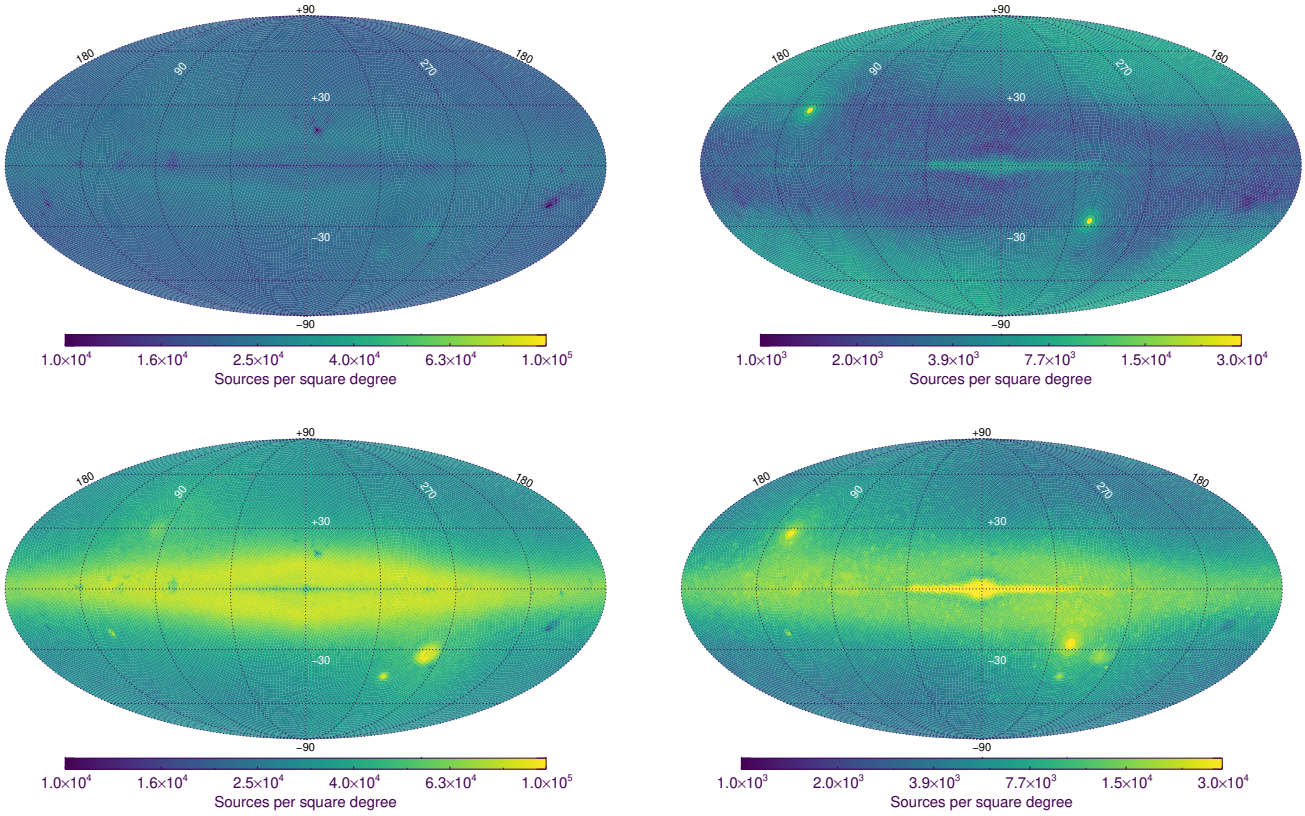

Figure 3. CatWISE Preliminary (top) and CatWISE2020 (bottom) Catalog (left) and Reject (right) source density.

12 mag, §3.1.2), the photometric performance (§3.2), and the astrometric performance (§3.3). *Spitzer* data was used as external truth for photometric comparison, while *Gaia* DR2 was used for astrometric comparison.

3.1. *Completeness and Reliability*

3.1.1. *Bright Sources*

CatWISE completeness and reliability for sources with W1 or W2 <8 mag were assessed using an updated version of the *WISE* Bright Star List (BSL) as a truth set. The list was generated by the *WISE* team for artifact flagging (see §4.4.g.vi in the *WISE* All-Sky Release Explanatory Supplement; Cutri et al. 2012), and updated for our performance assessment of the CatWISE Preliminary catalog (see Eisenhardt et al. 2020).

CatWISE completeness was determined as the percentage of sources that have astrometric matches in CatWISE as a function of BSL magnitude. Differential CatWISE reliability was determined as the percentage of sources that have astrometric matches in the BSL as a function of CatWISE magnitude. We used a relatively large matching radius of $5\farcs5$ (corresponding to two *WISE* pixels) to account for the poorer centroiding accuracy expected for highly saturated sources.

Figure 4 shows the results for completeness. CatWISE2020 appears slightly less complete than both the CatWISE Preliminary and AllWISE Catalogs. While the CatWISE Preliminary Catalog achieves $\sim$ 99% completeness in the BSL W1$\sim$ 5.5 − 8 mag and BSL W2$\sim$ 5 − 8 mag ranges, CatWISE2020 has slightly lower completeness, peaking at 98% in the 5.5<W1<6.25 mag range. CatWISE2020 completeness drops sharply for stars brighter than $\sim$ 4.5 mag, in a similar fashion to the CatWISE Preliminary Catalog, falling to $\sim$ 50% by W1$\sim$ 4.3 mag and W2$\sim$ 3.6 mag. CatWISE2020 completeness also declines slightly for stars fainter than 6.25 mag to $\sim$94% at W1,W2$\sim$ 8 mag. As discussed in Eisenhardt et al. (2020), AllWISE completeness remains above 90% even for stars as bright as 0.25 mag, and should therefore be the catalog of choice for bright star science that requires a complete sample.

CatWISE2020 achieve comparable or better reliability than the CatWISE Preliminary and AllWISE Catalogs for stars in the 8.5 <W1< 2.8 mag and 8.5 <W2< 2 mag range, with reliability consistently above 97%, as can be seen in Figure 5.

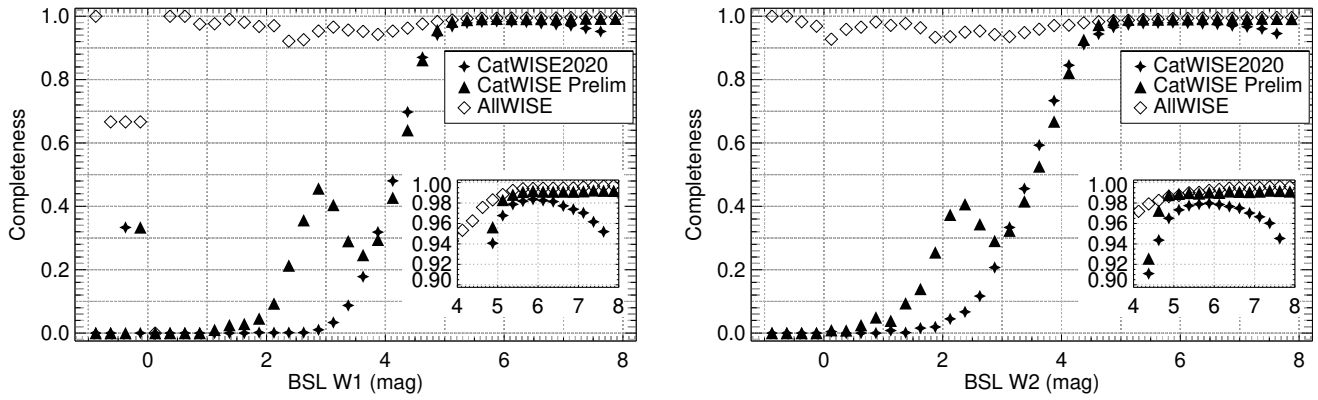

Figure 4. Differential completeness of the CatWISE2020 Catalog as a function of the Bright Star List's W1 (left) and W2 (right), compared to AllWISE and the CatWISE Preliminary Catalog.

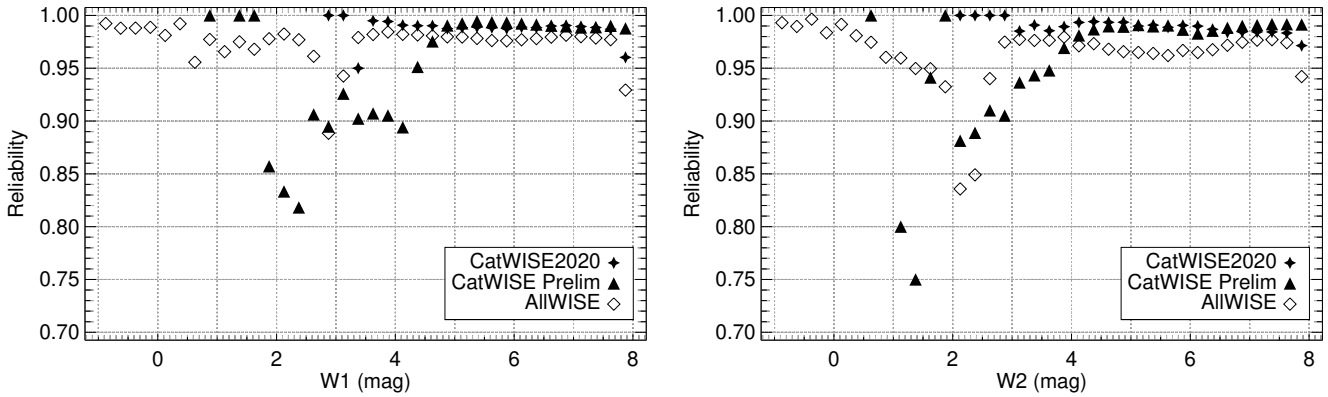

Figure 5. Differential reliability of the CatWISE2020 Catalog as a function of CatWISE W1 (left) and W2 (right), compared to AllWISE and the CatWISE Preliminary Catalog.

3.1.2. *Faint Sources*

Completeness and reliability were assessed for faint sources in an area of ~ 94 deg^2 by comparison with the *Spitzer* South Pole Telescope Deep Field (SSDF) survey (Ashby et al. 2013).

We used the same method described in §3.1.1, except that we used a smaller matching radius of 2.″5. The results are shown in Figures 6 and 7.

CatWISE2020 consistently achieves greater completeness than the CatWISE Preliminary Catalog with typical completeness of 99% across the 12 <[3.6]< 17.1 mag and 12 <[4.5]< 17 mag range. Figures 6 shows that the 50% completeness limit for CatWISE2020 is $[3.6] = 18.3$ mag, while in [4.5] the completeness remains above 55% all the way down to $[4.5] = 18.1$ mag, the coverage depth of the SSDF (cf. 17.8 mag and 17.4 mag for the CatWISE Preliminary Catalog).

CatWISE2020 reliability at this coverage depth is better than 99% for sources brighter than 14.5 mag, similar to the CatWISE Preliminary Catalog, in both W1 and W2. For fainter sources, the CatWISE2020 reliability is slightly worse than the CatWISE Preliminary Catalog, in particular in the 14.5–16 mag range in both W1 and W2 (and down to 16.8 mag in W1), with reliability of ∼1% below that achieved by the CatWISE Preliminary Catalog. At fainter magnitudes, CatWISE2020 remains a fraction of a percent less reliable than the CatWISE Preliminary Catalog in W1, while it becomes a fraction of a percent more reliable than the CatWISE Preliminary Catalog in W2.

Given that in the same brightness range CatWISE Preliminary Catalog completeness significantly deteriorates compared to CatWISE2020, we consider CatWISE2020 performance overall superior to the CatWISE Preliminary Catalog for faint stars over the range assessed.

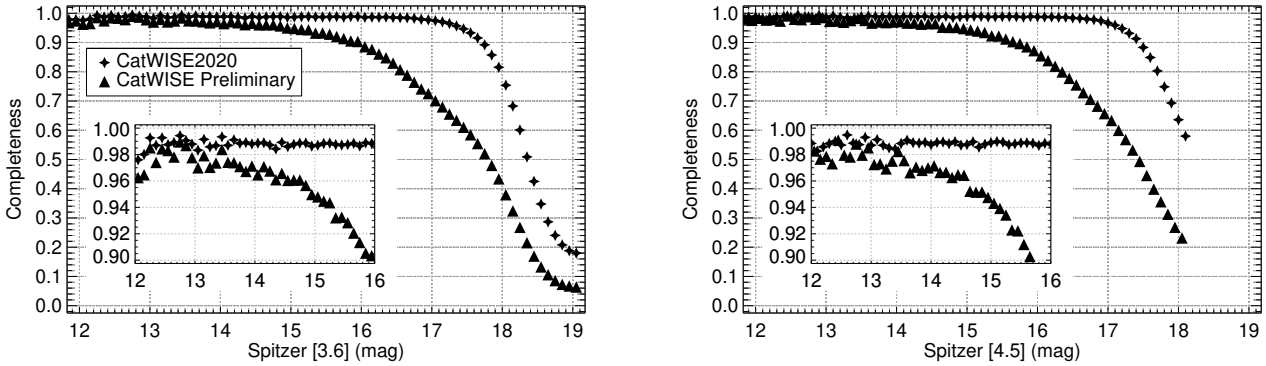

Figure 6. Completeness of the CatWISE2020 and Preliminary Catalog vs. *Spitzer* 3.6μm (left) and 4.5μm (right) magnitude for sources in the SSDF.

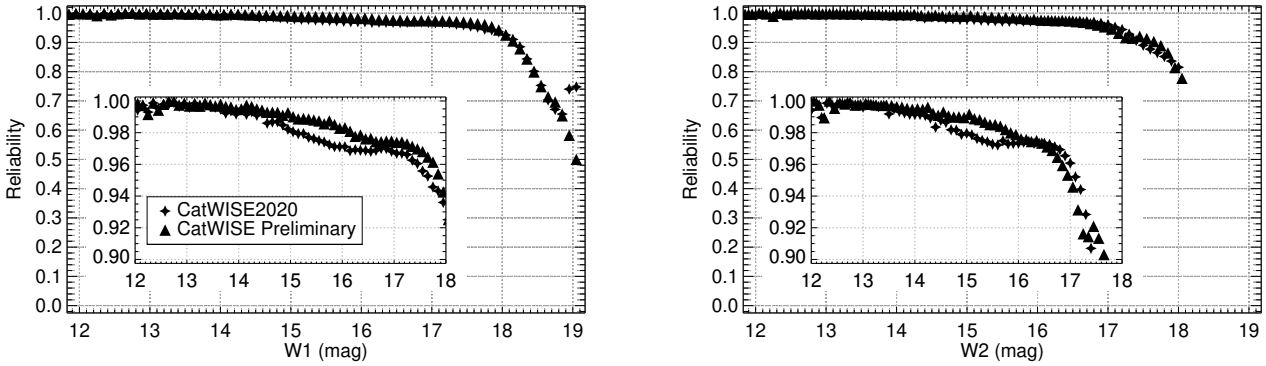

Figure 7. Reliability of the CatWISE2020 and Preliminary Catalog as a function of W1 (left) and W2 (right), for sources in the SSDF.

3.2. *Photometric properties*

We assessed CatWISE2020 photometric depth using the COSMOS field. The COSMOS field is an important benchmark for assessing CatWISE performance, because of the wealth of data available for it in the literature, and because it is near the ecliptic ($\beta = -11°$), and is at fairly high Galactic latitude ($b = 41°$). While the high Galactic latitude implies lower confusion, proximity to the ecliptic implies high zodiacal emission and low survey coverage from *WISE*, making COSMOS a representative base for performance estimates.

Figure 8 compares CatWISE Preliminary Catalog (left) and CatWISE2020 (right) PSF-fitting photometry to 2.″9 radius aperture photometry from the *Spitzer* S-COSMOS program (Sanders et al. 2007). These observations were obtained using long integration times (20 minutes), so the S-COSMOS data are much deeper than CatWISE. The closest CatWISE source within 2.″75 was taken as the match to the S-COSMOS source. Because the CatWISE photometry is measured via point source fitting, S-COSMOS sources were required to have $< 10\%$ flux increase between the 1.″9 and 2.″9 radius apertures. In addition, because the W1 band is significantly bluer than the [3.6] band, S-COSMOS sources at [3.6] were required to have $-0.1 \leq [3.6] - [4.5] \leq 0$ (see Figures 2 and 3 in §VI.3.a of the All-Sky Explanatory Supplement; Cutri et al. 2012). While necessary for comparing W1 and [3.6] photometry, the color cut significantly reduces the numbers of sources for comparison.

The comparison between the CatWISE Preliminary and CatWISE2020 and *Spitzer* photometry is consistent in both bands. CatWISE photometry becomes ~ 0.1 mag fainter than *Spitzer* beyond 16th mag, possibly due to the increasing incidence of extragalactic sources at faint magnitudes.

3.3. *Astrometric properties*

3.3.1. *Astrometric Assessments in Selected Tiles*

We assessed the astrometric performance of CatWISE2020 in four representative tiles. These are the same four tiles we chose for the astrometric assessment of the CatWISE Preliminary Catalog (Eisenhardt et al. 2020), and are the following:

- the North Ecliptic Pole tile (NEP, tile 2709p666), a field with maximal *WISE* coverage and average source density;

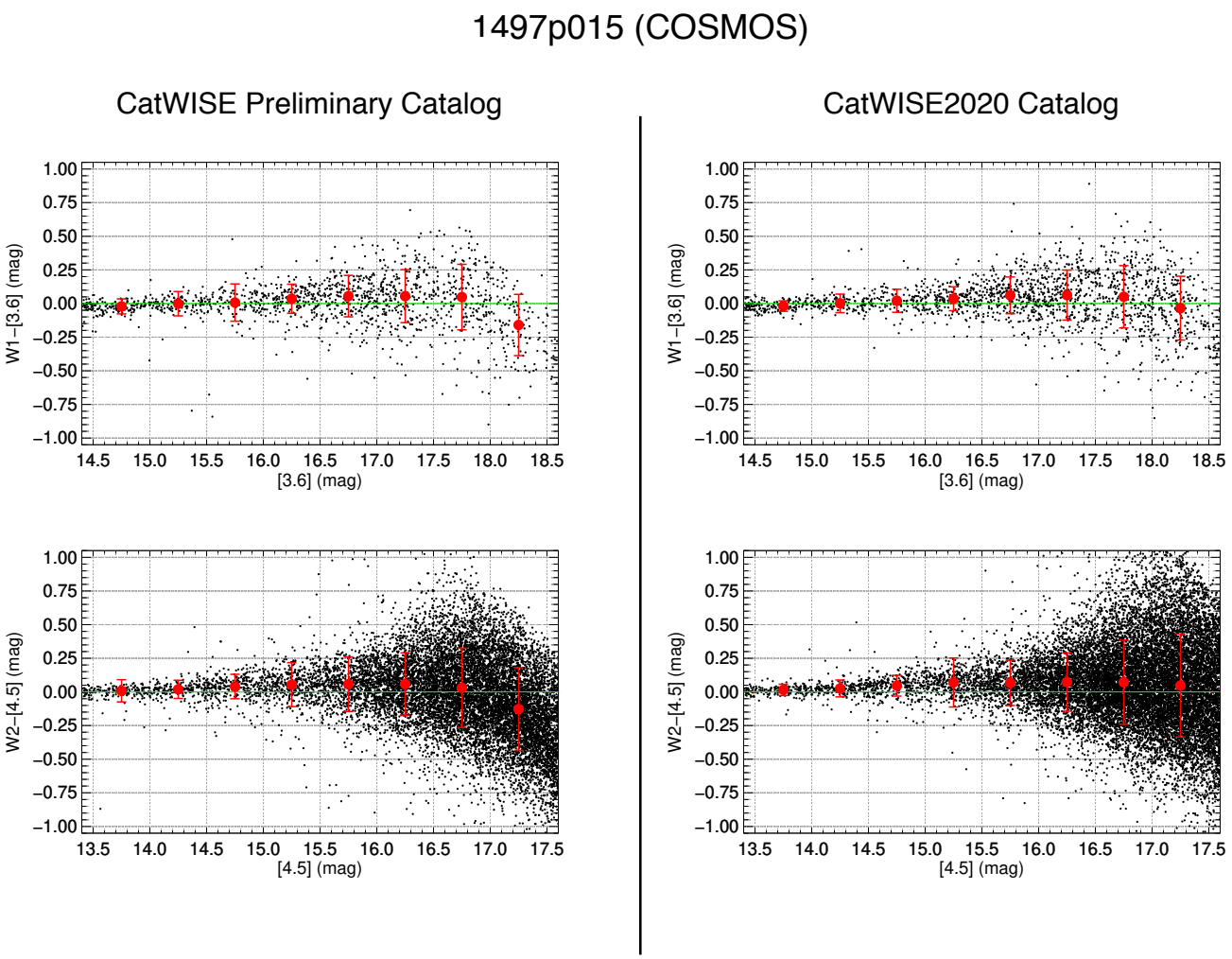

Figure 8. Comparison of CatWISE Preliminary (left) and CatWISE2020 (right) photometry to *Spitzer* photometry for COSMOS. *Top*: Difference between CatWISE W1 PSF and *Spitzer* S-COSMOS 2.″9 radius aperture photometry at [3.6], for sources with $-0.1 < [3.6] - [4.5] < 0$ and $< 10\%$ flux increase from the 1.″9 to 2.″9 aperture. Median differences and standard deviations in 0.5 mag bins are shown by the red points and error bars. *Bottom*: The analogous comparison for CatWISE W2 and *Spitzer* [4.5] photometry, but without the restriction on *Spitzer* source color.

- the South Ecliptic Pole tile (SEP, tile 0890m667) a field with with maximal *WISE* coverage and high source density (the SEP tile contains part of the LMC);
- the Galactic Center tile (GC, tile 2657m288) a field with average *WISE* coverage and maximal source density; and
- the COSMOS tile (tile 1497p015), representative of most of the sky, i.e. a field with average *WISE* coverage and average source density.

The astrometric performance of CatWISE was assessed following the same method described in Eisenhardt et al. (2020), which we briefly summarise here.

We chose *Gaia* DR2 (Gaia Collaboration et al. 2018; Lindegren et al. 2018) as the external truth. In each of the four chose tiles, we cross-matched all sources with *Gaia* DR2 using a 5.″5 radius (corresponding to two *WISE* pixels), and retained only *Gaia* counterparts that have measured proper motion. *Gaia* astrometry was used to move the *Gaia* counterparts to the CatWISE epoch, and the standard deviation between the CatWISE motion-fit and *Gaia* position and motion values was computed, using the IDL *robust_sigma* function. The results are shown in Figures 9 to 12.

We quantitatively characterized the performance of CatWISE2020 using the same ten metrics used in Eisenhardt et al. (2020):

- $\sigma_{\rm min}$ and $\sigma_{\mu,\,\rm min}$ are the accuracy floor for positions and motions, respectively, determined as the median dispersion with respect to *Gaia* in the 8 <W1,W2< 10 mag interval. In the GC we restrict to 8 <W1,W2< 9 mag since the astrometric accuracy starts deteriorating significantly beyond W1,W2∼9 mag (see Figure 11).

- $\rm W1_{min}$, $\rm W2_{min}$, $\rm W1_{\mu,\,min}$, and $\rm W2_{\mu,\,min}$ are the W1 and W2 mag at which $\sigma_{\rm min}$ and $\sigma_{\mu,\,\rm min}$ are exceeded by no more than 20 mas and 5 mas $\rm yr^{-1}$, respectively.

- $\rm W1_{500}$ and $\rm W2_{500}$ are the W1 and W2 mag at which the accuracy on positions reaches 500 mas.

- $\rm W1_{\mu,\,100}$ and $\rm W2_{\mu,\,100}$ are the W1 and W2 mag at which the accuracy on motion reaches 100 mas $\rm yr^{-1}$.

The results for the four representative tiles are summarized and compared to CatWISE Preliminary values in Table 1.

All ten metrics show improved astrometric performance with respect to CatWISE Preliminary. For brighter sources, $\sigma_{\rm min}$ and $\sigma_{\mu\,\rm min}$ are typically 25% and 6% smaller in CatWISE2020, with two exceptions. In COSMOS, $\sigma_{\rm min}$ deteriorated from 27.3 to 42.8 mas. Inspection of the top row of Figure 10 suggests that the asymptotic performance is actually comparable for CatWISE2020 and the Preliminary Catalog, with a precision floor of ∼40 mas $\rm yr^{-1}$. The Preliminary Catalog however shows a dip in the measured motion sigma at W1,W2∼9 mag, which drives the $\sigma_{\rm min}$ to low values. Because the number of sources in this brightness regime is much lower compared to the fainter brightness regime, we suspect that that our metric may be affected by small number statistic fluctuations. For the same reason, in the SEP tile $\sigma_{\mu\,\rm min}$ increased from 7.4 to 8.6 mas $\rm yr^{-1}$.

$\rm W1_{min}$ and $\rm W2_{min}$ are between 0.5 mag and 2 mag fainter than in CatWISE Preliminary, reaching down to 14.5 mag in both W1 and W2 in a low density field like COSMOS. $\rm W1_{\mu,\,min}$ and $\rm W2_{\mu,\,min}$ show a 1 mag improvement in COSMOS, remain unchanged in the GC, while becoming 1 mag shallower in the two Ecliptic poles. In the SEP, Figure 9 (third row) shows that for sources brighter that 14th mag in both W1 and W2, noise in the measured statistics for the Preliminary Catalog may lead to a somewhat spuriously faint $\rm W1_{min}$ and $\rm W2_{min}$. For the NEP, the trend for both CatWISE Preliminary and CatWISE2020 appears smooth, so the measured metric is reliable in both catalogues (see third row of Figure 12).

Similar to the findings for the CatWISE Preliminary Catalog, the above metrics are independent of coverage and source density, with the exception of the GC, where CatWISE2020 achieves a precision floor of ∼390 mas and 20 mas $\rm yr^{-1}$ for positions and proper motions respectively, down to a depth of only 8.5–9.0 mag in W1 and W2. The astrometric performance degrades rapidly for fainter magnitudes (see below for further details), but as can be seen in Figure 11, the main improvement in the GC is the increased overall depth of the catalog, now extending down to W1,W2 = 16 mag.

For fainter sources, $\rm W1_{500}$, $\rm W2_{500}$, $\rm W1_{\mu,\,100}$ and $\rm W2_{\mu,\,100}$ retain the clear dependence on source density and coverage that was already noticed by Eisenhardt et al. (2020) in the Preliminary Catalog. All these metrics in CatWISE2020 are ∼0.5 mag deeper in all tiles (e.g. in COSMOS they go from ∼17.0 to ∼17.5). The only exceptions here are the $\rm W1_{500}$ for the NEP and the $\rm W2_{\mu,\,100}$ for the SEP, that are slightly shallower in CatWISE2020. In both cases, however, these metrics are close to the S/N 5 depth, and small number statistics noise is to be expected, because of the small number of CatWISE sources that have a counterpart in *Gaia* at such brightness.

$\rm W1_{\mu,\,100}$ and $\rm W2_{\mu,\,100}$ become ∼2 mag deeper at the ecliptic poles, thanks to the higher coverage. Because of the of the much higher source density at the SEP, and therefore the higher confusion noise, $\rm W1_{500}$ and $\rm W2_{500}$ are much shallower at the SEP than the NEP. The motion metrics do not seem to be affected.

As mentioned in §2.1, CatWISE2020 did not apply the WCS adjustments to the Meisner et al. (2019) coadds for the AllWISE epochs. To assess the possible impact on the astrometric performance we looked for systematic offsets between CatWISE2020 and *Gaia* DR2 in both position and motions. For every source in the COSMOS tile we computed the R.A. and Dec. offset with respect to their *Gaia* DR2 counterpart (i.e. $\rm R.A._{CatWISE}$–$\rm R.A._{Gaia} \times \cos Dec_{CatWISE}$ and $\rm Dec_{CatWISE}$–$\rm Dec_{Gaia}$), as well as the proper motion difference, and then looked at the distribution of such differences for CatWISE2020 and CatWISE Preliminary. Inspection of Figure 13 reveals that the positions do not show any significant systematic offset with respect to *Gaia*, with at most a ∼7 mas offset in R.A., well below our precision floor (∼40 mas). The proper motion, on the other hand, displays clear systematic offsets of ~ -22 mas $\rm yr^{-1}$ in R.A. and ~ -7 mas $\rm yr^{-1}$ in Dec., at or below our measured precision floor. The CatWISE Preliminary Catalog shows more modest motion offsets of ~ -5 mas $\rm yr^{-1}$ and $\sim +5$ mas $\rm yr^{-1}$ in motion, while also displaying a modest offset in Dec of ~ -25 mas,$^{-1}$. All offsets are in

Table 1. CatWISE Astrometric Performance Evaluation Fields

	0890m667		1497p015		2657m288		2709p666	
	SEP, LMC		COSMOS		GC		NEP	
l (deg)	276.5		237.3		359.8		96.4	
b (deg)	−30.2		41.4		0.6		29.5	
β (deg)	−89.6		−10.2		−5.4		89.6	
	Prelim.	2020	Prelim.	2020	Prelim.	2020	Prelim.	2020
Exp.	7154	9230	90	140	86	133	7839	10000
#	71462	209518	58961	75639	63368	231239	61702	142975
$\sigma_{\rm min}$ (mas)	52.9	40.5	27.3	42.8	526.4	391.2	37.7	25.8
$W1_{\rm min}$ (mas)	11.0	11.5	12.5	14.5	8.0	8.5	12.0	12.0
$W1_{500}$ (mag)	15.1	16.0	17.0	17.5	8.4	9.0	18.5	18.0
$W2_{\rm min}$ (mag)	11.0	12.0	12.5	14.5	8.0	8.5	12.0	12.5
$W2_{500}$ (mag)	15.0	16.0	16.8	17.5	8.3	9.0	19.0	20.5
$\sigma_{\mu,\rm min}$ (mas yr^{-1})	7.4	8.6	8.5	8.0	22.2	20.0	7.3	7.0
$W1_{\mu,\rm min}$ (mag)	14.5	13.5	13.5	14.5	9.0	9.0	15.5	14.5
$W1_{\mu,100}$ (mag)	18.2	18.5	16.8	17.5	>11.0	11.5	>19.0	21.0
$W2_{\mu,\rm min}$ (mag)	14.5	13.5	13.5	14.5	9.0	9.0	15.5	14.0
$W2_{\mu,100}$ (mag)	>20.5	19.0	16.7	17.5	>11.5	11.5	>20.0	20.5

NOTE— l, b, and β are the Galactic longitude, Galactic latitude, and ecliptic latitude for the center of the tile, in degrees. Exp. indicates the number of exposures for the tile, # the number of sources (combining catalog and reject entries). The subsequent metrics are described in detail in §3.3.

this case below the precision floor for this tile. The larger motion offsets in CatWISE2020 arise from the fact that astrometric registration of the L1b *WISE* frames for the AllWISE epochs (and, therefore, the unWISE coadds generated from them) did not take into account the reference stars motion. This effect was corrected in the set of unWISE coadds used for the CatWISE Preliminary Catalog, but not in those used for CatWISE2020. The systematic offset seen in CatWISE2020 is therefore a consequence of the spurious drift of the astrometric reference frame between the earliest epochs, and the subsequent NEOWISE L1b frame, where the reference stars motion was instead accounted for.

The effect described above results in higher motion χ^2 in CatWISE2020 compared to the Preliminary Catalog, especially for bright stars, where the systematic offset dominates over the measured uncertainties. This is perhaps most noticeable in the COSMOS tile (bottom row of Figure 10, but it is present in all four test tiles. On the other hand, the R.A. and Dec. χ^2 are lower in CatWISE2020, since the systematic offset in this case is negligible and the increased depth and improved deblending leads to more accurate centroiding.

3.3.2. *Fast Movers*

In Eisenhardt et al. (2020) we discussed the performance of the CatWISE Preliminary Catalog on a sample of cold, fast moving brown dwarfs in the Solar neighborhood. Re-assessment of the CatWISE2020 performance on the same sample of brown dwarfs reveals that the motion accuracy is comparable in the two versions of the catalog. Moreover, thanks to a more effective deblending of partly blended sources, CatWISE2020 successfully measures WISE J163940.83–684738.6 and WISEPC J205628.90+145953.3, the only two objects in our sample of 19 test objects that were missing from the Preliminary Catalog.

One feature common to all of the fast moving brown dwarfs considered in this analysis is that their fast motion leads to multiple (spurious) detections, since they are essentially "smeared" in the full-depth unWISE coadds used for source detection. These multiple apparitions (up to seven for the fastest objects) are then passed through our photometry- and motion-measuring software. The first detection processed by WPHOT gets accurate motion and magnitude measurements, while the subsequent detections get progressively worse measurements. Those with the lowest S/N are typically dis-

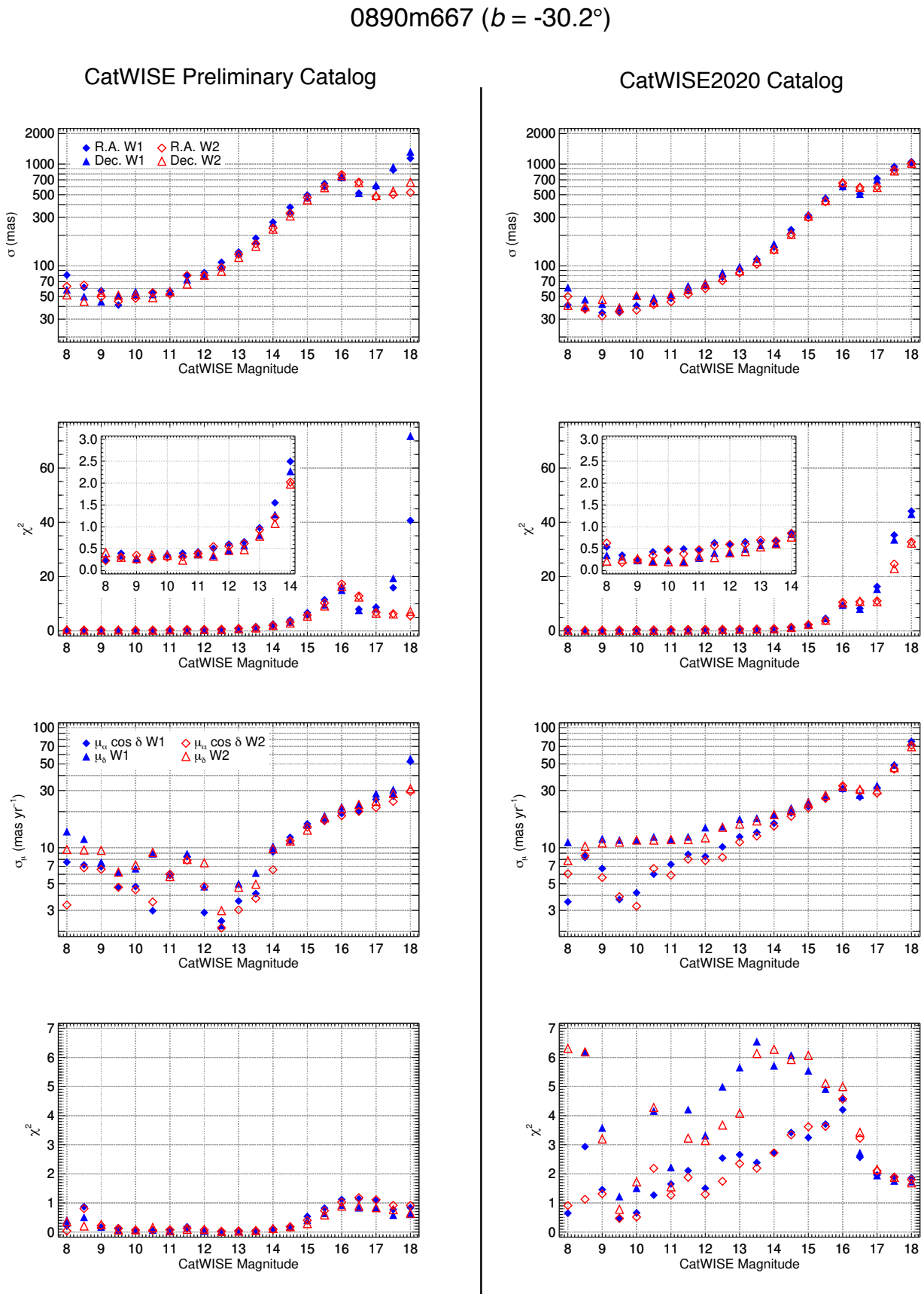

Figure 9. CatWISE Preliminary Catalog (left) and CatWISE2020 Catalog (right) astrometric performace with respect to *Gaia* DR2 in the south Ecliptic Pole tile (0890m667). From top to bottom: the 1-σ dispersion between CatWISE and *Gaia* R.A. (specifically, $\Delta\alpha\cos(\delta)$) and Dec.; the median χ^2 computed taking into account CatWISE catalog uncertainties, *Gaia* catalog uncertainties, and the uncertainty introduced by the translation of *Gaia*'s positions to the CatWISE epoch; the 1-σ dispersion between CatWISE and *Gaia* proper motion; the median χ^2 computed taking into account CatWISE catalog proper motion uncertainties and *Gaia* DR2 proper motion uncertainties.

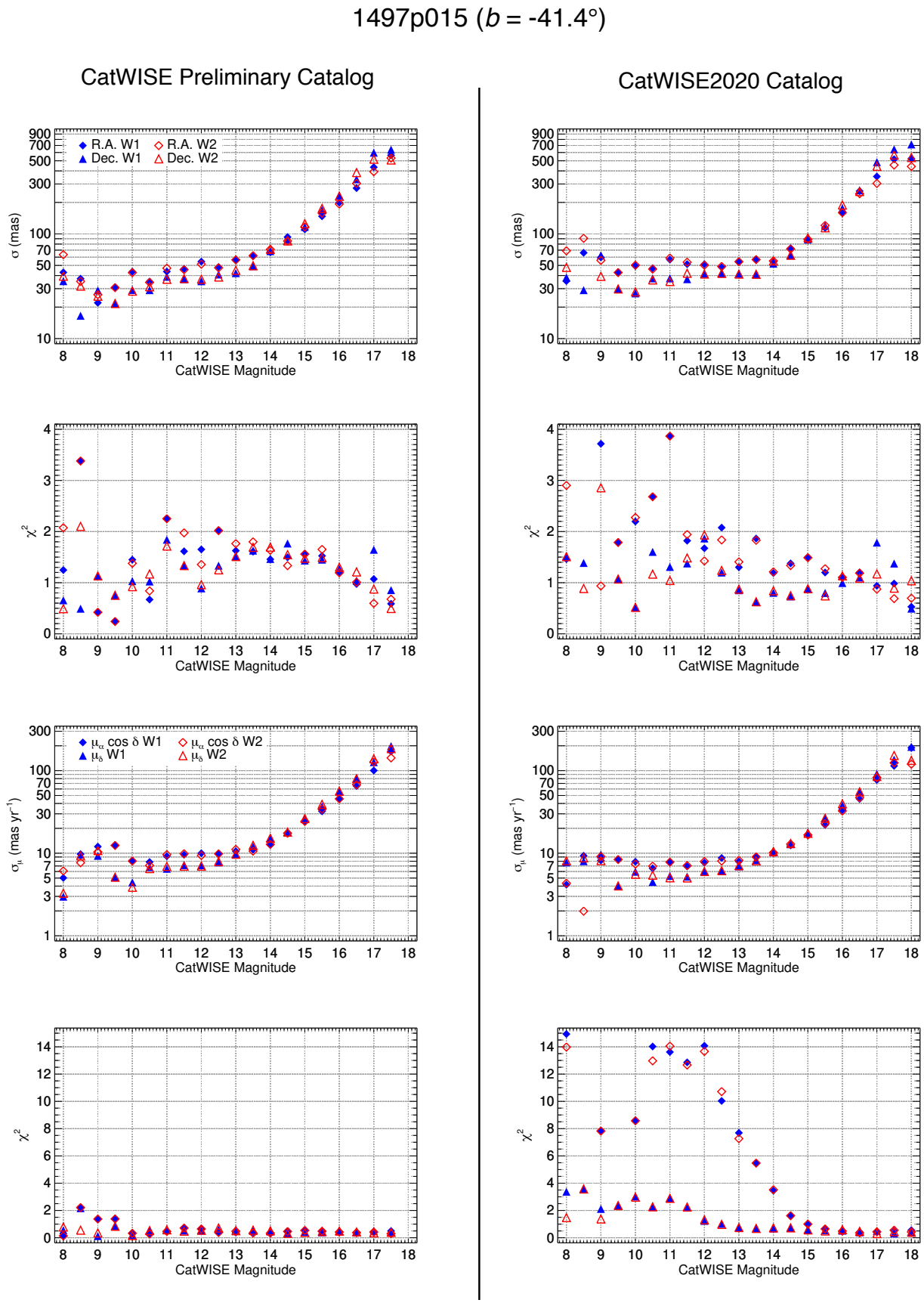

Figure 10. Same as Figure 9 but for the COSMOS tile (1497p015)

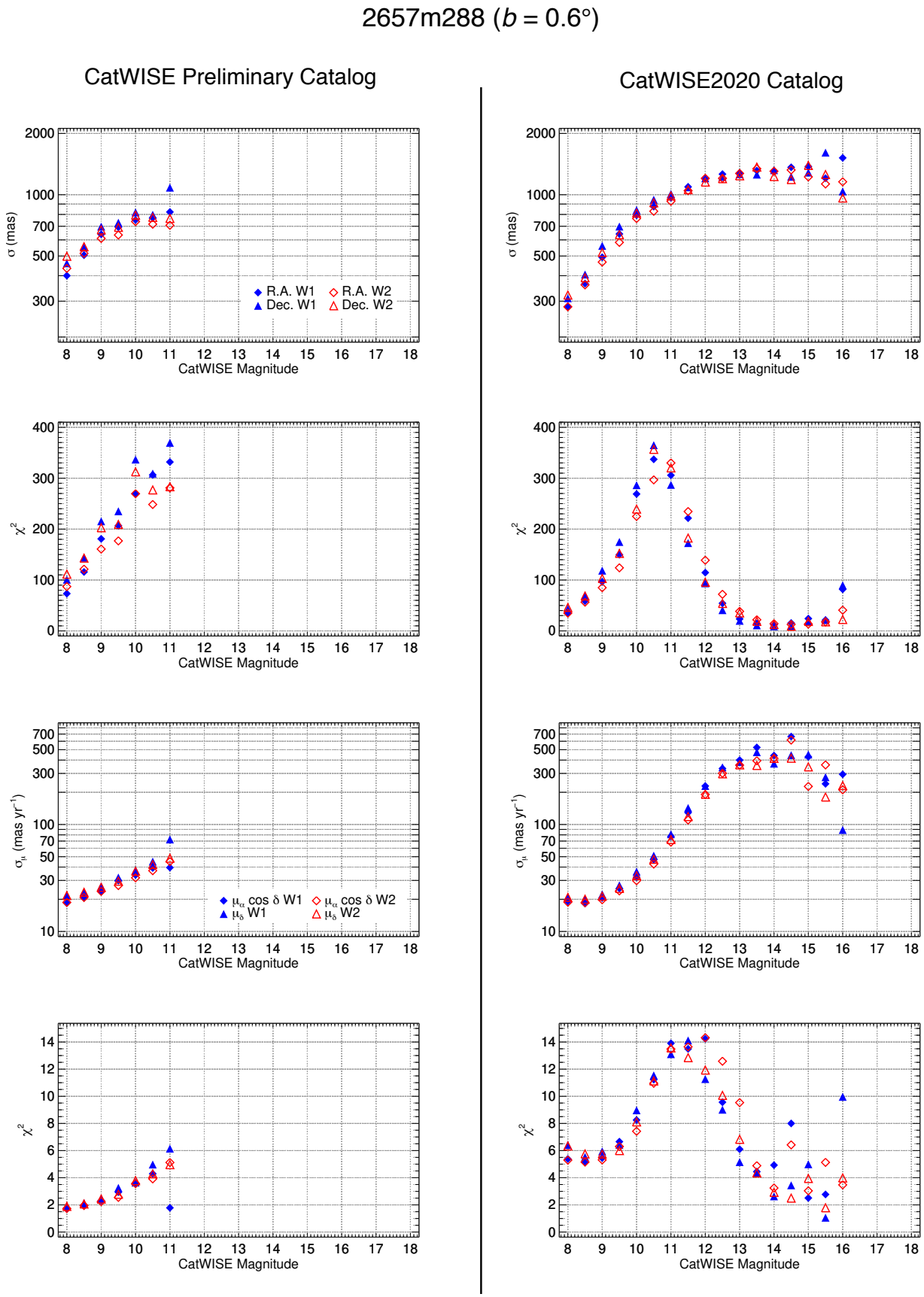

Figure 11. Same as Figure 9 but for the Galactic Center tile (2657m288)

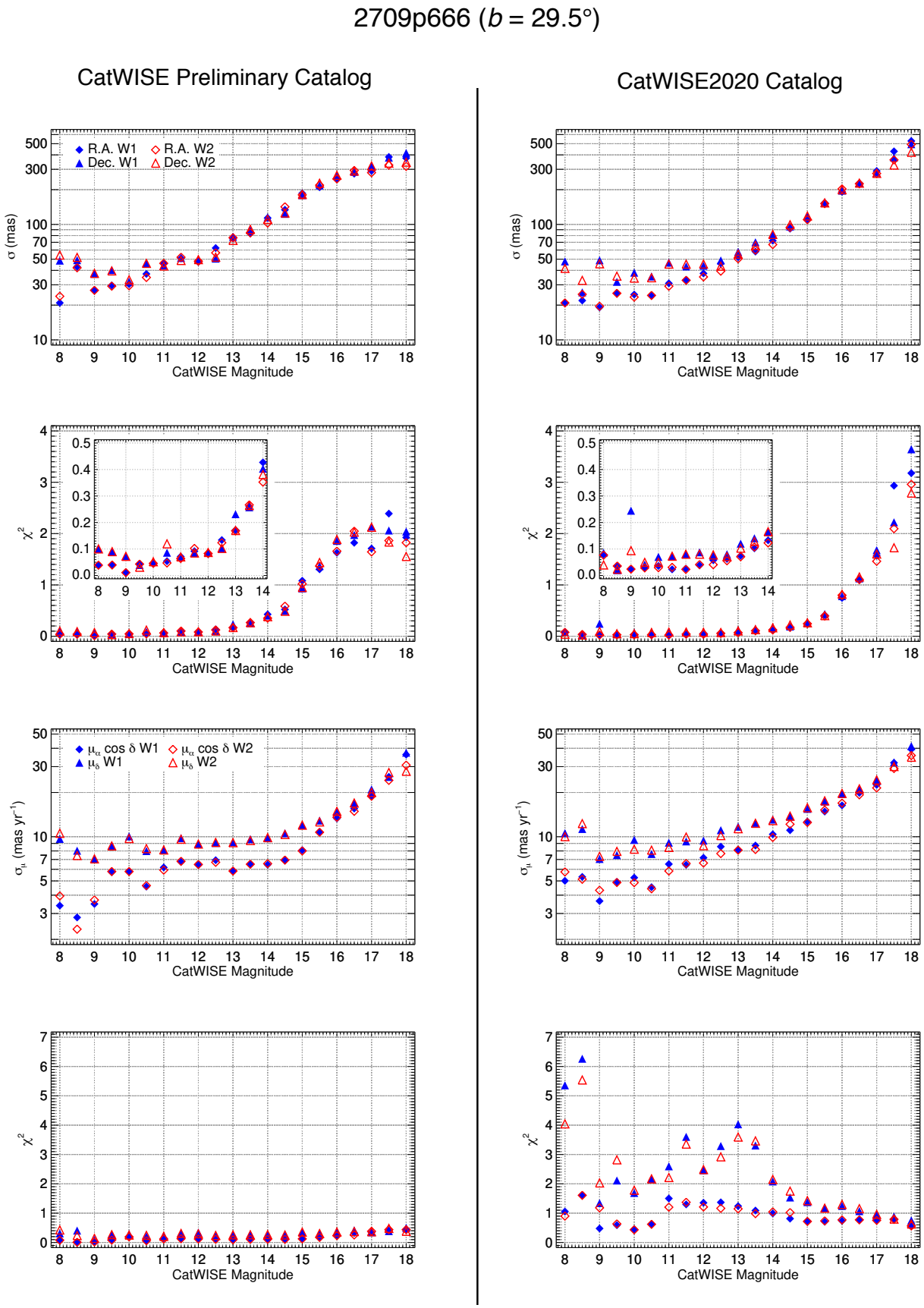

Figure 12. Same as Figure 9 but for the North Ecliptic Pole tile (2709p666)

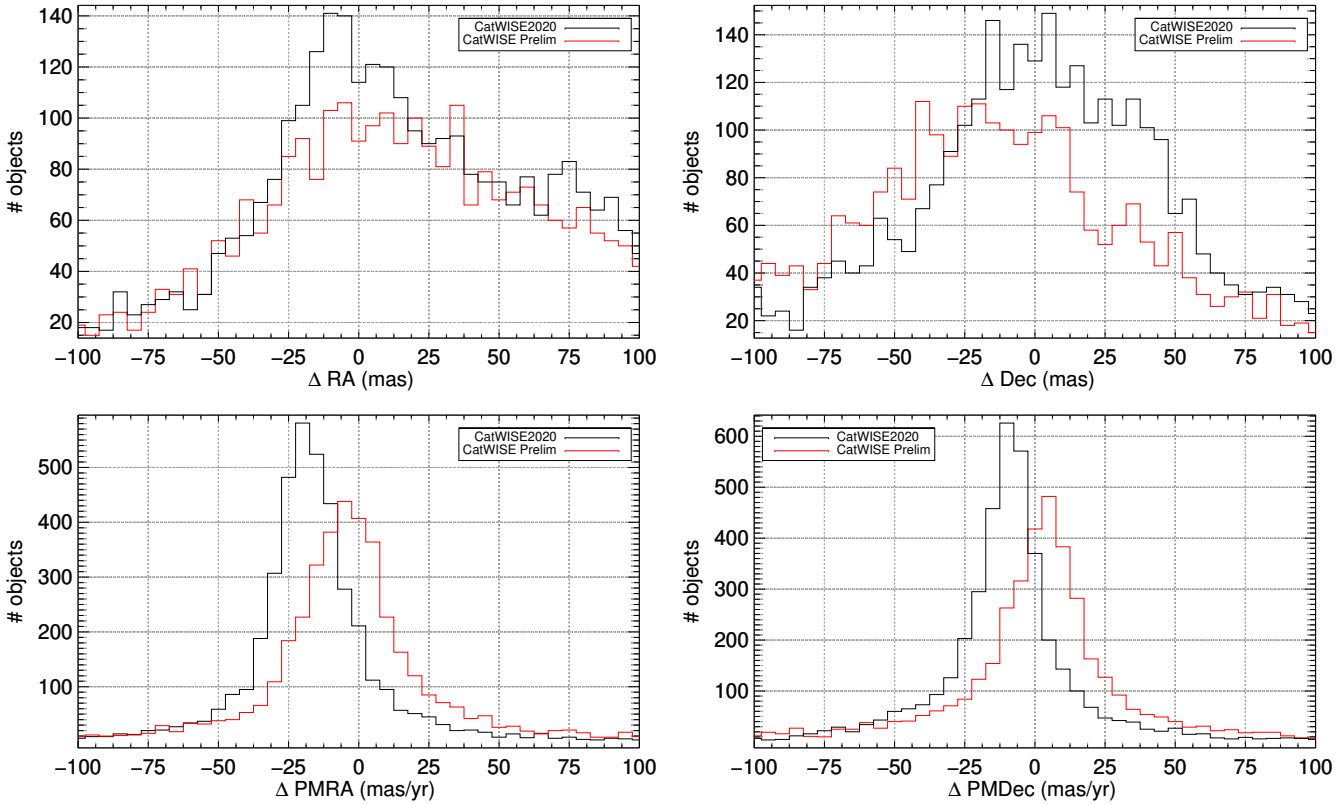

Figure 13. The distribution of RA and Dec. offsets with respect to *Gaia* DR2 (top left and right) and proper motion differences (bottom row) for all sources in the COSMOS tiles.

carded in the Reject Table, but the higher S/N ones remain in the catalog. For example the fastest moving brown dwarf, WISE J085510.83–071442.5, appears five times in the CatWISE2020 Catalog, with three of those five apparitions having motion measurements consistent with the literature values.

4. DATA ACCESS

The merged files for the 18,240 tiles for the CatWISE2020 Catalog and Reject Table are available from IRSA (https://irsa.ipac.caltech.edu) in the WISE/NEOWISE Enhanced and Contributed Products area. IRSA's catalog search tools allow for complex search queries. IRSA also hosts the AllWISE Explanatory Supplement (Cutri et al. 2013), which provides full details on the AllWISE processing algorithms, and includes descriptions of the AllWISE Catalog columns, many of which are applicable to CatWISE. §2.5 provides additional information about CatWISE2020 columns.

The individual tile files have also been transferred to a data repository at the National Energy Research Scientific Computing Center (NERSC), and are available at https://portal.nersc.gov/project/cosmo/data/CatWISE/2020 in 18,240 pairs of gzipped ASCII files (one catalog and one reject file per tile) in IPAC table format, organized into 359 directories, one for each decimal degree of right ascension from 0° to 358° (there are no tiles beginning with 359). Text files providing the format and a brief description of the columns in the catalog and reject files are also provided there. As for the CatWISE Preliminary Catalog, the catalog and reject files for tiles near the ecliptic poles (listed in Table 1 in Eisenhardt et al. 2020), where a single PSF per band was used for processing, include the string "opt0" in their names. Files for tiles where different PSFs were used for ascending and descending scans include the string "opt1" in their names.

Current information about CatWISE data products is provided at https://catwise.github.io.

ACKNOWLEDGMENTS

CatWISE uses data products from *WISE*, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory (JPL)/California Institute of Technology (Caltech), funded by the National Aeronautics and Space Administration (NASA), and from *NEOWISE*, which is a JPL/Caltech project

funded by NASA. Characterization of CatWISE performance uses data from *Gaia* and from *Spitzer*. CatWISE is led by JPL/Caltech, with funding from NASA's Astrophysics Data Analysis Program (ADAP), and is also supported in part by ADAP grant NNH17AE75I at Lawrence Berkeley Laboratory. FM acknowledges support from the NASA Postdoctoral Program at the Jet Propulsion Laboratory, administered by Universities Space Research Association under a contract with NASA.

APPENDIX

A. CAVEATS

The CatWISE2020 Catalog contains a number of features that users should be aware of. Among these are:

- Although the CatWISE2020 Catalog represents a dramatic improvement over the CatWISE Preliminary Catalog, CatWISE performance in general is less good in the Galactic plane. Figure 11 and Table 1 illustrate this.
- The completeness for bright sources is low (Figure 4). However, the CatWISE2020 Catalog has much better reliability for bright sources than does the CatWISE Preliminary Catalog (Figure 5). For example, the brightest W2 source, CWISE J170848.49-293208.6 with W2=2.063, appears to correspond to HD154782.

Additional features present in the CatWISE2020 Catalog include:

- Small systematic offsets are present in CatWISE astrometry with respect to *Gaia* (see §2.1, §3.3, and Figure 13). Because adjustments were made to the WCS for the AllWISE epochs for the CatWISE Preliminary Catalog but not for CatWISE2020, these are different between the two catalogs.
- Because of coordinate singularities, CatWISE tile Point Spread Functions (see §3.2 of Eisenhardt et al. 2020) within a few degrees of the equatorial poles used a unnecessarily large range of rotation angles, resulting in smearing of these PSFs.
- Tabulated position uncertainties are significantly smaller than measured position scatter with respect to *Gaia*, as illustrated in the second row of Figure 10 (right column).
- Magnitude and position uncertainties occasionally round to 0.
- The aperture magnitudes are the result of averaging fluxes in the CatWISE2020 Catalog, while in the Preliminary Catalog, the aperture magnitudes from the ascending and descending epochs were averaged.
- A floor of 1 mas yr^{-1} was imposed on the tabulated motion uncertainties for CatWISE2020, while for the CatWISE Preliminary Catalog the floor was 10 mas yr^{-1}. The lower CatWISE2020 uncertainty floor is now significantly smaller than the minimum measured scatter with respect to *Gaia* motion, as illustrated in the right columnn of the third row in Figures 9 to 12, contributing to large motion χ^2 values for CatWISE2020.
- CatWISE source designations (*source_name*) include a lower case letter suffix to distinguish sources that would otherwise have the same designation. In the CatWISE Preliminary Catalog, the first such source (usually the brightest) did not receive a suffix while subsequent such sources did, beginning with "b". In CatWISE2020, the first such source receives an "a" suffix.
- Sources in the updated unWISE catalog detection list may be omitted from the CatWISE2020 Reject Table if they are too near tile edges, probably due to the fitting region used by WPHOT being truncated. This does not affect the CatWISE Preliminary Reject Table because the MDET software does not find sources this close to tile edges.

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