APOGLIMPSE Data Description

Three Dimensional Stellar Kinematics of the Galactic Bar and Disk: Where APOGEE Meets GLIMPSE

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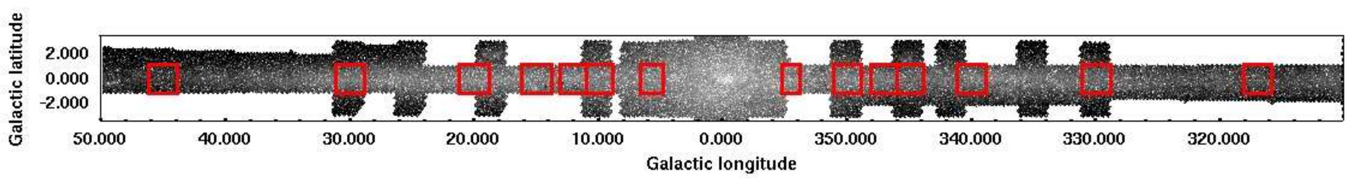

Contents

1 Quick Start

This Spitzer Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) project re-images 53 square degrees (14 fields) of the inner Galactic plane (galactic longitudes $|l|$= 5-46 °) that have also been targeted by the APOGEE/APOGEE-2 surveys– Sloan III and IV programs to obtain high resolution H band spectroscopy for hundreds of thousands of red giants. The data will be combined with the original GLIMPSE observations of the Galactic plane in 2004-2005 to measure the proper motions of the sources along the Galactic plane over the past decade. We will refer to this project as "APOGLIMPSE" in this document. Data products (source list files, source designations, image file names) also use the APOGLIMPSE, APOGL or APOGLM term in their names. For two of the 14 fields, closest to the Galactic center, there are three 1.2 second exposures at each position at Galactic longitudes l=5°to 6.5°and l=354° to 355°; b=-1° to +1°. These two innermost fields extend the Galactic center coverage of GLIMPSE Proper with the same style of coverage. For the remaining 12 areas, there are three High Dynamic Range (HDR) mode (10.4 second and 0.4 second) exposures at each position at Galactic longitude areas within l=9° to 46°and l=316° to 351°; b=-1° to +1° (see Figure 1).

The data have been processed by the Wisconsin GLIMPSE IRAC pipeline. For those who are familiar with GLIMPSE data, APOGLIMPSE data products are very similar. There are two types of source lists: a high reliability point source Catalog and a more complete point source Archive. The other main product is the set of mosaicked images. APOGLIMPSE is a Spitzer "Warm Mission" program. After the cryogen depletion in May 2009, the observatory is operating using only IRAC's 3.6 and 4.5 μm channels.

This APOGLIMPSE data release contains source lists (8,349,258 Catalog sources and 20,599,383 Archive sources) and mosaic images (with and without background matching and gradient correction) for the entire survey region. The source lists are a result of doing photometry on each IRAC frame, averaging all detections of a single band (in band-merge), then doing the merging of all wavelengths, including 2MASS J,H, and K_s, at a given position on the sky (cross-band merge).

GLIMPSEI[1], GLIMPSEII, GLIMPSE3D, Vela-Carina, GLIMPSE360, Deep GLIMPSE, GLIMPSE Proper and APOGLIMPSE data products are available at the Infrared Science Archive (IRSA). We have processed the SMOG and Cygnus-X data to provide consistency with our other GLIMPSE products and those data are also available at IRSA.

- irsa.ipac.caltech.edu/data/SPITZER/GLIMPSE/

[1] Although originally known as GLIMPSE, we will use the acronym GLIMPSEI to avoid confusion between it and other GLIMPSE Galactic plane programs

2 APOGLIMPSE Survey and Data Products Overview

2.1 Project Overview

APOGLIMPSE is the eighth in a series of large area projects to map regions of the Galactic plane using the Spitzer Space Telescope (SST; Werner et al. 2004) Infrared Array Camera (IRAC) (Fazio et al. 2004). The APOGLIMPSE project (Benjamin et al. 2016) is a Warm Mission Spitzer Cycle 13 Science Program (PID 13117) that re-mapped 14 areas comprising 53 square degrees of the inner Galactic plane (parts of the GLIMPSEI, GLIMPSEII, GLIMPSE3D and Deep GLIMPSE areas) to measure proper motions and variability. The combination of Spitzer proper motions for millions of sources and APOGEE (Majewski et al. 2017) radial velocities will be used to constrain models of stellar kinematics for the Galactic bar(s) and disk.

Warm Mission Spitzer has two IRAC bands, centered at approximately 3.6 μm and 4.5 μm. The Galactic longitudes covered by APOGLIMPSE are l=5° to 46°and 316 to 355°. The latitude width is about 2° centered at b=0.0°. Figure 1 shows the area observed by the APOGLIMPSE program. For 12 of the 14 areas observed, APOGLIMPSE has three visits on each sky position with 0.4 and 10.4 second High Dynamic Range (HDR) exposures (12 second and 0.6 second frametimes) providing a large dynamic range of sensitivity. For the remaining two areas, closest to the Galactic center, there are three 1.2 second exposures (2 second frametimes) at each position.

Table 1 shows the APOGLIMPSE areas and the dates of observation for each longitude segment. The data were reduced by the Wisconsin GLIMPSE IRAC pipeline. Data from SSC pipeline version S19.2 were used. The APOGLIMPSE program produced enhanced data products in the form of a point source Catalog, a point source Archive, and mosaicked images. There is a small amount of overlap between some of the APOGLIMPSE fields. For our data products, we have combined the data from these areas (see Table 1) into one set of images and source lists.

Table 2 summarizes the approximate coverages, wavelengths observed, integration times, and observation dates for the larger Galactic plane projects. See Benjamin et al. (2003), Churchwell et al. (2009) and the GLIMPSE web site (www.astro.wisc.edu/glimpse/) for more description of the GLIMPSE projects and pipeline processing.

This document describes the data products from the APOGLIMPSE survey. The organization of this document is as follows: §2 gives an overview of the APOGLIMPSE survey and data products; §3 discusses the quality checks and validation of the source lists; §4 provides an overview of the data products; and §5 provides a more detailed description of data formatting. A complete discussion of the Source Quality Flag is given in Appendix A. This document contains numerous acronyms, a glossary of which is given at the end.

Table 1. Observation Dates for the APOGLIMPSE Survey

Spitzer Field Name	APOGEE Name	longitude segment longitude range (deg)	observation dates[a]
APOGLIMPSE_1S[b]	355+00	354 to 355	20180101
APOGLIMPSE_2S	350+00	349 to 351	20180716-0720
APOGLIMPSE_3S[c]	347+00	346 to 348	20180702-0706
APOGLIMPSE_4S[c]	345+00	344 to 346	20170701-0704
APOGLIMPSE_5S	340+00	339 to 341	20170617-0619
APOGLIMPSE_6S	330+00	329 to 331	20161116-1120
APOGLIMPSE_7S	317+00	316 to 318	20161102-1104
APOGLIMPSE_1N[b]	006+00	5 to 6.5	20161202-1203
APOGLIMPSE_2N[c]	010+00	9 to 11	20161215-1217
APOGLIMPSE_3N[c]	012+00	11 to 13	20171224-1228
APOGLIMPSE_4N	015+00	14 to 16	20170720-0722
APOGLIMPSE_5N	020+00	19 to 21	20170102-0105
APOGLIMPSE_6N	030+00	29 to 31	20180116-0117
APOGLIMPSE_7N	045+00	44 to 46	20170815-0817

[a] dates in YearMoDa

[b] Three 1.2 second exposures were taken at each position on the sky. The remaining 12 areas were observed using HDR mode with three 10.4 second and 0.4 second exposures.

[c] There is a small amount of overlap between these APOGLIMPSE areas. For our data products we have combined the data from these areas into one set of images and source lists.

Table 2. APOGLIMPSE and Similar Spitzer Galactic Plane Surveys

Survey	Coverage	Approx. Area	Exp. Time	Date Obs	Reference
APOGLIMPSE [a]	l = 316°–46°, $b \approx$ -1°–+1°[c]	53 sq. deg.	3 × 10.4 s 3 × 1.2 s	Nov 2016-Jul 2018	Benjamin et al. (2016)
GLIMPSE I[b]	10°< $\|l\|$ <65°; $\|b\|$ < 1°	220 sq. deg.	2 × 1.2 s	Mar-Nov 2004	Churchwell et al. (2009)
GLIMPSE II[b]	$\|l\|$ < 10°; $\|b\|$ <1.5° [c]	54 sq. deg.	3 × 1.2 s[d]	Sep 2005;Apr 2006	Churchwell et al. (2009)
GLIMPSE 3D[b]	< $\|l\|$ < 31°;$\|b\|$ > 1°[c]	120 sq. deg.	3(2) × 1.2 s[e]	Sep 2006-May 2007	Churchwell et al. (2009)
Vela-Carina[b]	l=255°–295°; b ≈ -1.5°–+1.5°[c]	86 sq. deg.	2 × 1.2 s	Jan-Jul 2008	Zasowski et al. (2009)
GLIMPSE 360[a]	l=65°–76°,82°–102°,109°–265° $\|b\|$ < 3°[c]	511 sq. deg.	3 × 10.4 s	Sep 2009-Dec 2012	Whitney et al. (2008)
Deep GLIMPSE[a]	l = 265°–350°, b=-2°–+0.1° l = 25°–65°, b= 0°–+2.7°	208 sq. deg.	3 × 10.4 s	Mar 2012-Mar 2013	Whitney et al. (2011)
GLIMPSE Proper[a]	l = 355°–5°, $b \approx$ -2°–+2°[c]	43 sq. deg.	3 × 1.2 s	Dec 2015-Jul 2016	Benjamin et al. (2015)
SMOG[b]	l=102°–109°; b= 0°–3°	21 sq. deg.	4 × 10.4 s	Jan-Feb 2009	Carey et al. (2008)
Cygnus-X[b]	l= 76°–82°; b = -2.3°–+4.1°[c]	24 sq. deg.	3 × 10.4 s	Nov 2007;Aug,Nov 2008	Hora et al. (2007)

[a]IRAC bands [3.6] and [4.5] only. [b]IRAC bands [3.6],[4.5],[5.8] and [8.0]. [c]Irregular region; see survey documentation for details. [d]GLIMPSE II data products include the *Spitzer* Galactic Center survey (S. Stolovy; PID=3677) which has five visits. [e]Some portions of GLIMPSE3D use two visits and others have three.

Table 3. Sensitivity and Saturation Limits in mJy (magnitudes in parentheses)

Project	3.6 μm Lower	3.6 μm Upper[a]	4.5 μm Lower	4.5 μm Upper[a]
APOGLIMPSE Archive[b]	0.102 (16.10)	29175 (2.46)	0.079 (15.89)	22107 (2.28)
APOGLIMPSE Catalog[b]	0.099 (16.13)	1118 (6.00)	0.081 (15.86)	1134 (5.50)
APOGLIMPSE Archive[c]	0.382 (14.67)	8023 (3.86)	0.328 (14.35)	11118 (3.02)
APOGLIMPSE Catalog[c]	0.558 (14.25)	445 (7.0)	0.388 (14.17)	450 (6.5)
WISE[d]	0.06 (16.8)	110 (8.6)	0.10 (15.6)	60 (8.6)
GLIMPSEI	0.20 (15.4)	440 (7.0)	0.20 (14.9)	450 (6.5)

[a] Archive magnitudes are not nulled when brighter than the saturation limits, but these magnitudes are unreliable.

[b] Based on 3 visits of 12.0/0.6 second frames, photometry done on individual frames

[c] Based on 3 visits of 2.0 second frames, photometry done on individual frames

[d] WISE (Wright et al. 2010) central wavelengths are 3.3 μm and 4.7 μm.

Since the data processing for this survey is very similar to the previous GLIMPSE programs, this description is not repeated here. For the 12.0/0.6 second HDR mode data see §3 of the Deep GLIMPSE data description document (http://www.astro.wisc.edu/glimpse/deepglimpse_dataprod_v1.3.pdf). For the 2 sec frametime data please see §3 of the GLIMPSEI v2.0 Data Release document (http://www.astro.wisc.edu/glimpse/glimpse1_dataprod_v2.0.pdf, hereafter GLI Doc) for this discussion. The differences between the processing for GLIMPSEI v2.0 and the two APOGLIMPSE areas with the 2 second frametime data are:

- The criteria for including a 2MASS source was changed. In GLIMPSEI v2.0 processing, a GLIMPSE source would match to a 2MASS source only when the 2MASS source had a good K_s band measurement (photometric quality of "A"). This potentially left out sources that were K_s band "drop-outs" but detected in J and H bands. Here, we include a 2MASS match if the source has a photometric quality flag of A, B, C or D for the K_s band, or a quality flag of A or B in the H band.
- The 2MASS photometric quality flag is now included in our Source Quality Flag (SQF) (see Table 7 and Appendix A).
- The value of the flux calculation method flag has changed. For GLIMPSEI the method flag for the 2 sec frametime was 12 and for APOGLIMPSE it is 48.

The source lists are a result of doing photometry on each IRAC frame, averaging all detections of a single band (in-band merge), then doing the merging of all wavelengths, including 2MASS J, H, and Ks, at a given position on the sky (cross-band merge).

The APOGLIMPSE Catalog is a more reliable source list, and the Archive is a more complete list both in number of sources and flux measurements at each wavelength (less nulling of fluxes). The main differences between the Catalog and Archive are 1) fluxes brighter than a threshold that marks a nonlinear regime are nulled (removed) in the Catalog; 2) sources within 2″ of another are culled (removed) from the Catalog, whereas the Archive allows sources as close as 0.5″ from another; 3) sources within the PSF profile of a saturated source are culled from the Catalog but not the Archive; and 4) the Catalog has higher signal-to-noise thresholds and slightly more stringent acceptance criteria.

The single frame photometry source list fluxes were extracted from the IRAC frames using a modified version of DAOPHOT (Stetson 1987) to perform the PSF fitting.

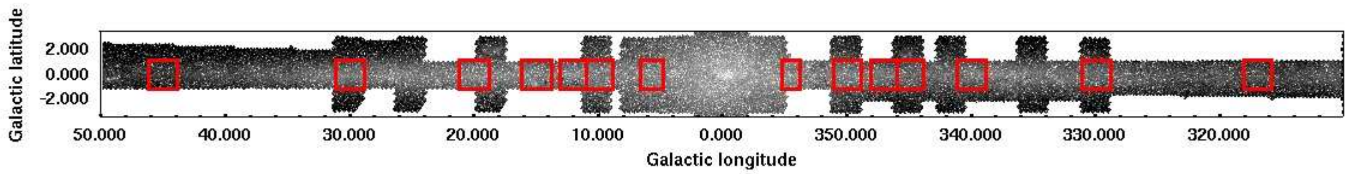

Figure 1: The area observed by the APOGLIMPSE survey is superimposed on an image of 3.6 μm GLIMPSEI, GLIMPSEII, GLIMPSE3D and Deep GLIMPSE. Source lists and enhanced images for the entire survey area have been delivered to IRSA.

See http://www.astro.wisc.edu/glimpse/glimpse_photometry_v1.0.pdf for more details about the point source extraction. The Warm Mission array-location-dependent photometric corrections (section 3.5 in http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/warmfeatures/) were applied to the source lists.

2.2 Data Products Overview

The APOGLIMPSE enhanced data products consist of a highly reliable Point Source Catalog (APOGLC), a more complete Point Source Archive (APOGLA), and mosaic images covering the survey area. The enhanced data products are:

1. The APOGLIMPSE Catalog (APOGLC, or the "Catalog") consists of the highest reliability point sources. Table 3 provides estimates for the sensitivity limits for the APOGLIMPSE Catalog in flux and magnitude units.‘ Figures 2 and 3 show the number of APOGLIMPSE Catalog sources as a function of magnitude for the two IRAC bands for the different observing modes. For each IRAC band the Catalog provides fluxes (with uncertainties), positions (with uncertainties), the areal density of local point sources, the local sky brightness, and a flag that provides information on source quality and known anomalies present in the data. Sources were bandmerged with the Two Micron All Sky Survey Point Source Catalog (2MASS; Skrutskie et al. 2006). 2MASS provides images at similar resolution to IRAC, in the J (1.25 μm), H (1.65 μm), and K_s (2.17 μm) bands. For each source with a 2MASS counterpart, the APOGLC also includes the 2MASS designation, counter (a unique identification number), fluxes, signal-to-noise, and a modified source quality flag. For some applications, users will want to refer back to the 2MASS Point Source Catalog for a more complete listing of source information. The APOGLIMPSE Catalog format is ASCII, using the IPAC Tables convention (irsa.ipac.caltech.edu/applications/DDGEN/Doc/ipac_tbl.html).

2. The APOGLIMPSE Archive (APOGLA or the "Archive") consists of point sources with less stringent selection critera than the Catalog. The information provided is in the same format as the Catalog. The number of Archive sources as a function of magnitude for each IRAC band is shown in Figures 2 and 3. The Catalog is a subset of the Archive, but the entries for a particular source might not be the same due to additional nulling of magnitudes in the Catalog because of the more stringent requirements.

3. The APOGLIMPSE Image Atlas comprises mosaicked images for each band, each covering e.g. $3.1^\circ \times 2.4^\circ$with $1.2''$ pixels. These are 32-bit IEEE floating point single extension FITS formatted images covering the survey area. These images are in units of surface brightness

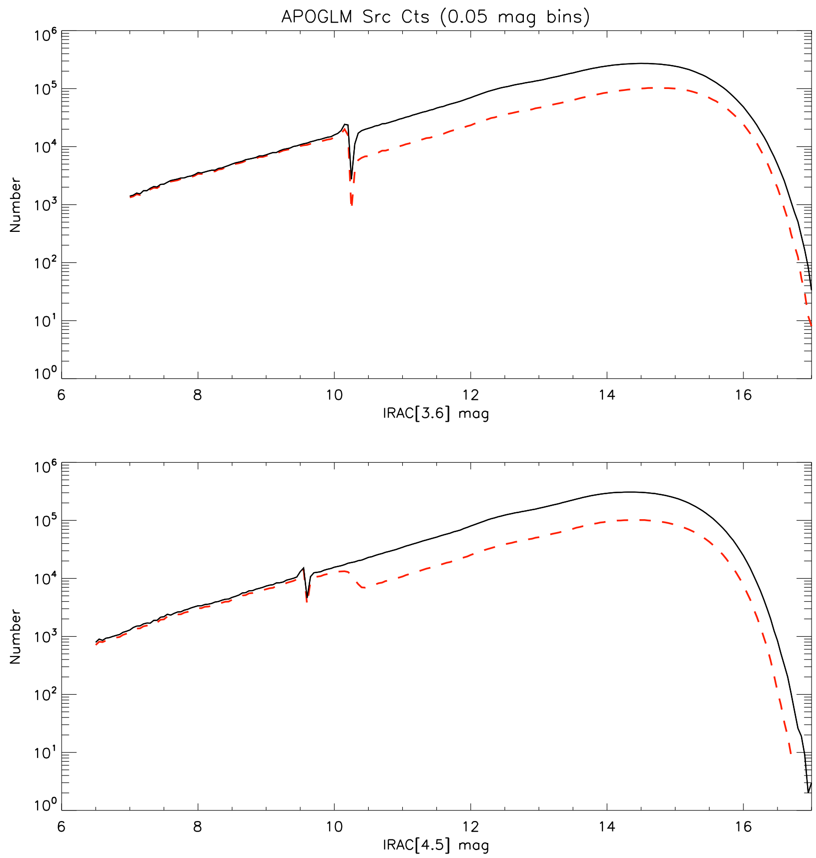

Figure 2: APOGLIMPSE Archive and Catalog source counts versus magnitude for IRAC [3.6] & [4.5] for the HDR mode data. APOGLIMPSE Archive data are plotted in the black line. Catalog data are plotted in the dashed red line. The glitch in the [3.6] plot at 10.25 and the [4.5] plot at 9.6 are at the boundary where either the 0.4 sec exposure data or the 10.4 second exposure data are used for photometry. The drop in the Catalog numbers is due to the culling of Catalog sources within the saturated source mask. For the 10.4 second exposure data, there are a lot more saturated sources which causes many more sources to be culled for the faint HDR data than the bright HDR data in the Catalog. The offset in the [4.5] drop is caused by the source selection criteria whereby [4.5] is dependent on [3.6] for validation. The [3.6] HDR transition is at 10.25 which is where the drop in the [4.5] Catalog source counts occurs.

MJy/sr. Mosaics of each band are also made for smaller e.g. $1.4^\circ \times 0.9^\circ$ areas, with a pixel size of $0.6''$. The $1.2''$ pixel mosaics are provided with and without background matching and gradient correction. Also included are quicklook 3-color jpeg images (red component from zodiacal light subtracted WISE 12 μm data) of the same size as the FITS images. In the background matched and gradient corrected mosaics we match instrumental background variations between the images. Instrument artifacts (Hora et al 2004; IRAC Data Handbook[2]) such as full array pull-up, first frame effect and frame pull-down are mostly removed from the images during the background matching. The background matching introduces large-scale gradients which are removed. This processing may be removing real sky variations so we provide these images *in addition* to the images that do not have the background matching.

[2]http://ssc.spitzer.caltech.edu/irac/dh/

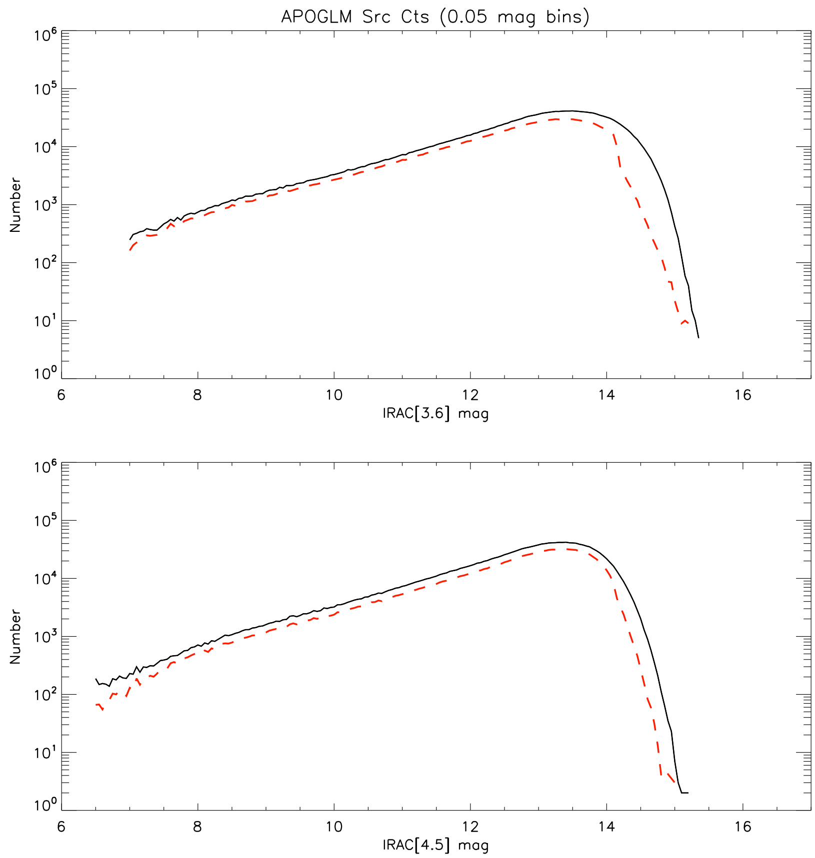

Figure 3: APOGLIMPSE Archive and Catalog source counts versus magnitude for IRAC [3.6] & [4.5] for the 1.2 second exposure data. APOGLIMPSE Archive data are plotted in the black line. Catalog data are plotted in the dashed red line.

The processing done to produce the background matched and gradient corrected images is described in §4.2.

3 Quality Checks and Source List Validation

This section describes some of the checks we have made on the quality and integrity of the Catalog and Archive point source lists. Since many of the checks for this data were also performed as part of GLIMPSE, additional information can be found in the following documents:

- *GLIMPSE Quality Assurance (GQA) document*: http://www.astro.wisc.edu/glimpse/GQA-master.pdf
- *Reliability and Completeness for GLIMPSE*: http://www.astro.wisc.edu/glimpse/cr_manuscript.pdf
- *Observation Strategy Validation Report*: http://www.astro.wisc.edu/glimpse/val.20040130.pdf
- *Addendum to the Validation Report*: http://www.astro.wisc.edu/glimpse/addendum4.pdf

These documents describe the GLIMPSEI data validation and the results of a reliability study using GLIMPSEI Observation Strategy Validation (OSV) data to develop source selection criteria. Additional details are given in §3.2 and §4.1 of the GLI Doc. A study of completeness in all the GLIMPSEs point source lists can be found in Kobulnicky et al. 2013.

3.1 Astrometric Accuracy

Sources bright enough to have 2MASS associations are typically within 0.3″ of the corresponding 2MASS position, as discussed in §4.1.3. Figure 4 shows a comparison of APOGLIMPSE source positions to the 2MASS PSC positions, in 0.02″ bins. The peak of the plot is at 0.1″ and the majority of the sources have positional differences less than 0.3″ , similar to previous GLIMPSE source lists. Fainter APOGLIMPSE sources are likely to have larger errors due to poorer centroiding. See §7 of the GQA for a more detailed discussion of positional accuracy.

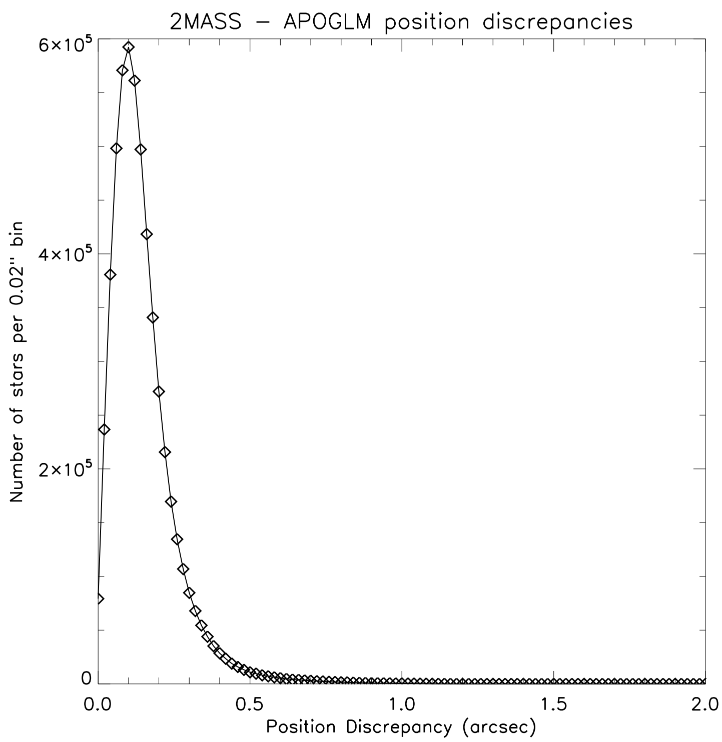

Figure 4: Comparison of APOGLIMPSE source positions to their corresponding 2MASS PSC positions from sources from the APOGLIMPSE Archive. The astrometric discrepancy plotted is the angular separation in arcseconds between the APOGLIMPSE position and the 2MASS position. Note that sources with 2MASS associates have APOGLIMPSE positions that are in part derived from the 2MASS position. Thus this is not a comparison of a pure IRAC-only position with the 2MASS position.

3.2 Photometric Accuracy

Figures 5 through 8 show the photometric uncertainty for the entire APOGLIMPSE survey region. There is a jump in uncertainties at the brighter magnitudes which shows the boundary between

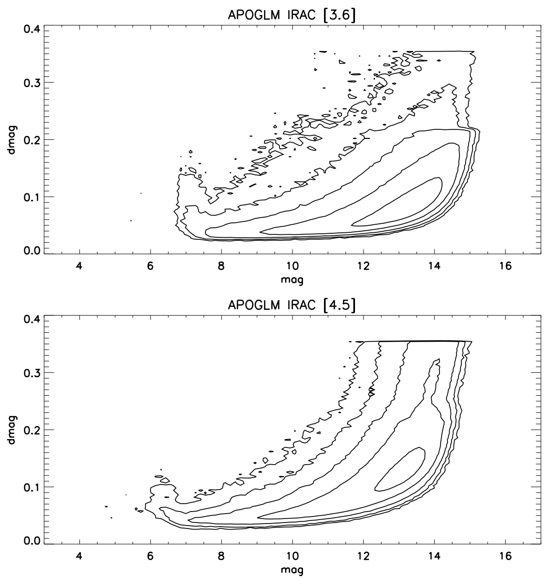

Figure 5: Magnitude uncertainty vs. magnitude for each IRAC band included in the APOGLIMPSE Archive for the 2 second frametime data. Contours show the density of sources. The lack of data above dmag of 0.362 is caused by the criterion that Archive data have signal to noise ratios of 3 or better.

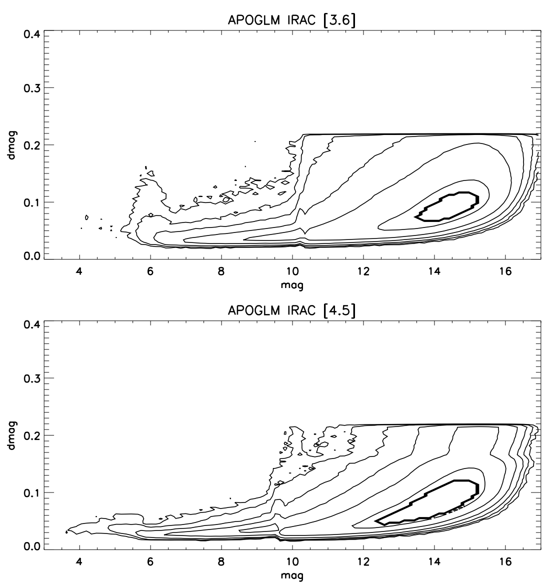

Figure 6: Same as in Figure 5 except the data included are from the 12 sec/0.6 sec frametime Archive. The "bump" at [3.6]=10.25 and [4.5]=9.6 is the boundary where the 0.6 sec frametime data are used for brighter sources and the 12 sec frametime data are used for fainter sources. The lack of data above dmag of 0.22 is caused by the criterion that Archive data have signal to noise ratios of 5 or better.

the 0.6 and 12 sec frametime photometry (with shorter exposures having larger errors).

The reliability of the flux uncertainities was studied by comparing the quoted error (dFi) with

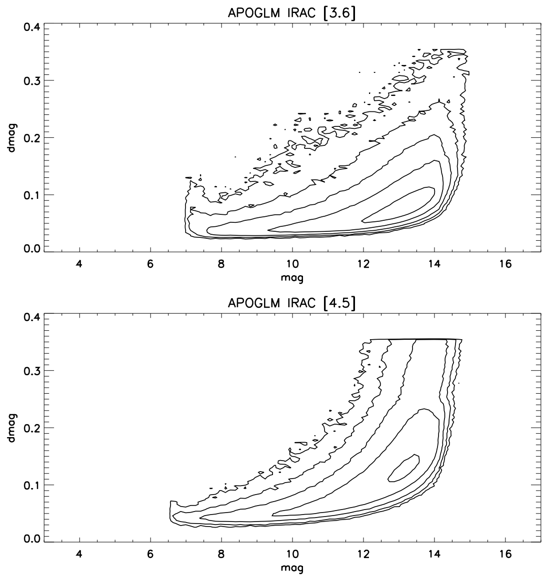

Figure 7: Same as in Figure 5 except the data included are from the 2 sec frametime Catalog.

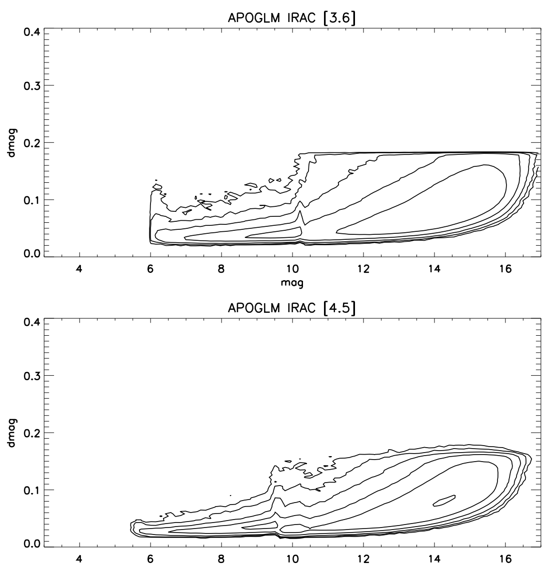

Figure 8: Same as in Figure 6 except the data included are from the 12 sec/0.6 sec frametime Catalog.

the root mean square (RMS) of the measurements (Fi_rms) for thousands of sources in a given flux range; if a large fraction of the sources have intrinsic variability, this method will produce an upper limit to the uncertainties. The DAOPHOT output uncertainties include a PSF fitting component, photon noise, read noise, and goodness of flat fielding; the strength of each component is not perfectly determined. Based on our comparison to the RMS of the measurements, we have decreased our photometry uncertainties produced by DAOPHOT by 5% in the [3.6] band and 35% in the [4.5] band for the HDR mode data. No adjustment was made for the 2 second frametime data.

Our goal was to achieve point source photometry accuracy of $\leq$0.2 mag. Table 4 shows a summary of the fraction of sources in the APOGLIMPSE Catalog and Archive that achieve this level. The results are consistent with GLIMPSEI (§4.3 of the GLI Doc) and other GLIMPSE projects.

Table 4. Photometric Accuracy of APOGLIMPSE Sources

Band (μm)	[3.6]	[4.5]
Catalog		
No. with error >0.2 mag	15797	176871
Total number of entries	7611375	7221488
% with errors >0.2 mag	0.21	2.45
Archive		
No. with error >0.2 mag	292470	617921
Total number of entries	18061655	19110881
% with errors >0.2 mag	1.62	3.23

Photometric accuracy for the GLIMPSEI and GLIMPSEII surveys was verified by comparison with more than 250 flux calibrators distributed throughout the GLIMPSEI and GLIMPSEII survey regions. The flux predictions were supplied by Martin Cohen (private communication). These calibrators span a wide range of fluxes in each IRAC band. The techniques used to produce the flux predictions are described in Cohen et al. (2003). There are 18 GLIMPSEI and GLIMPSEII flux calibrators that overlap the APOGLIMPSE coverage. The APOGLIMPSE fluxes of these 18 flux calibrators were compared to Martin Cohen's predictions. Uncertainties in both the extracted and predicted magnitudes were added in quadrature to produce the plotted error bars. Figure 9 shows the good agreement between the APOGLIMPSE fluxes and the predictions. Table 5 gives details about the number of flux calibrators used for each band (which can vary due to saturation and partial coverage on the survey boundaries), average differences (APOGLIMPSE magnitude minus the predicted magnitude), and RMS errors. We also compared the fluxes of more than 20 million matched sources in the overlap between the APOGLIMPSE, GLIMPSEI, GLIMPSEII, GLIMPSE3D and Deep GLIMPSE areas. The results are given in Figure 10 and show the good agreement between the two data sets. The variations shown in this figure are discussed in §5 of the Deep GLIMPSE documentation (http://www.astro.wisc.edu/sirtf/deepglimpse_dataprod_v1.3.pdf).

Table 5. Comparison of Flux Calibrators to Predicted Magnitudes

Band (μm)	[3.6]	[4.5]
No. Flux calibrators	10	18
Ave. [Observed-Predicted] mag	-0.005	-0.001
RMS error	0.051	0.032

3.3 Color-Color and Color-Magnitude Plots

Color-color and color-magnitude plots were made of the Catalog and Archive files (in approximately $2^\circ \times 2^\circ$ regions). An example set of color-color and color-magnitude plots is shown in Figures 11 & 12, respectively. The color-color plots generally show a peak near 0 color due to main sequence and giant stars. The outliers in Figure 11 (the points) comprise 0.4% of the sources. Sources with these unusual colors usually either have intrinsic color variations due to e.g., dust scattering

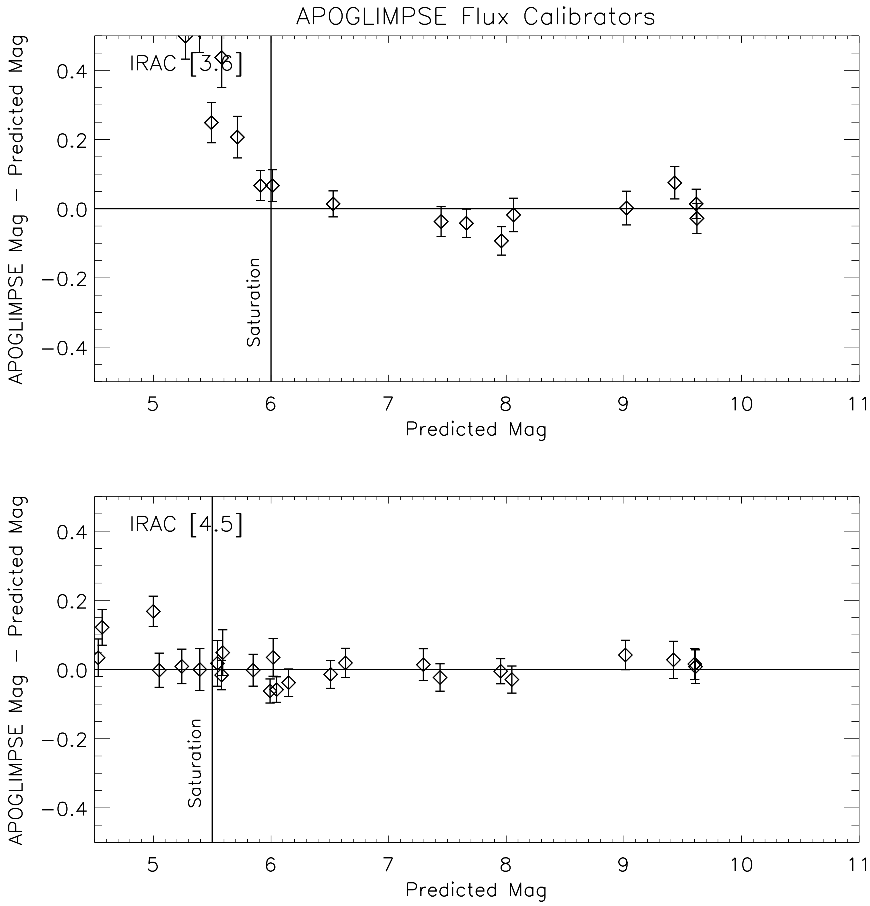

Figure 9: Comparison of APOGLIMPSE flux calibrators to predictions provided by Martin Cohen for each IRAC band. Error bars are the root-sum-of-squares of the errors of both the extracted and predicted magnitudes for each source. The vertical lines are the best estimates of the saturation limits.

or emission; or have poor flux extractions. The color-magnitude plots can be used to show the limiting magnitudes where the flux uncertainties become large and the colors begin to show large deviations. This is not significant in Figure 12 which demonstrates that our fluxes are accurate at the faint end. Postscript files of the color-color and color-magnitude plots for source lists for each of the 14 areas of the APOGLIMPSE survey are available from the GLIMPSE web site (www.astro.wisc.edu/glimpse/apoglimpse/ColorColor/ and www.astro.wisc.edu/glimpse/apoglimpse/ColorMag/).

3.4 Other checks

Spot checks include inspection of residual images to verify proper point source extraction; overplotting the positions of the sources in the Catalogs and Archives on mosaic images; and plotting Spectral Energy Distributions (SEDs) of several sources. In addition to these and other tests described in previous documents, our source lists have been extensively tested by users analyzing the data on evolved stars, YSOs, and other sources throughout the Galaxy and the Magellanic Clouds

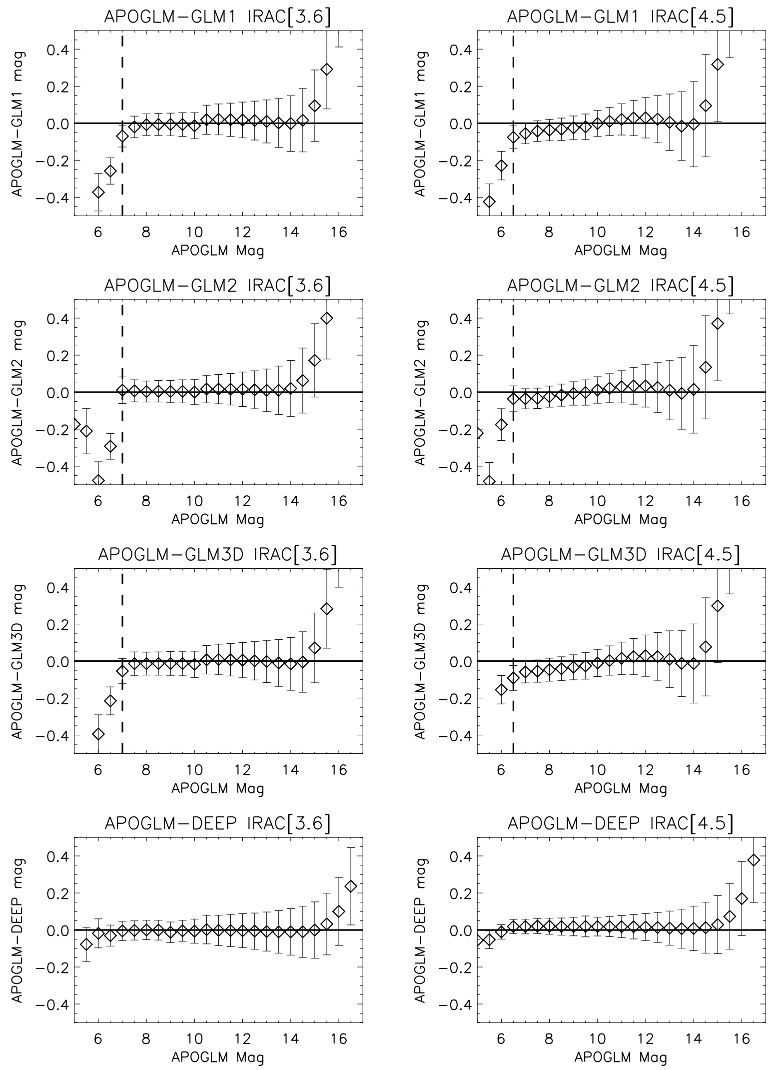

Figure 10: The average differences between APOGLIMPSE sources with matched GLIMPSEI, GLIMPSEII, GLIMPSE3D and Deep GLIMPSE sources in 0.5 mag bins. The error bars are the 'root squared sum' of the mean delta magnitudes for those binned sources for the two projects in each plot. The differences are well within the typical delta magnitudes sources at those magnitudes with the exception of the one bin at the saturation limit end and the last bin which is the faint limit end. The number of matched sources between APOGLIMPSE and GLIMPSEI is over 10 million; the number of matched sources between APOGLIMPSE and GLIMPSEII is over 4 million; APOGLIMPSE and GLIMPSE3D over 1 million and APOGLIMPSE and Deep GLIMPSE over 5 million matched sources.

(GLIMPSE, SAGE-LMC, SAGE-SMC).

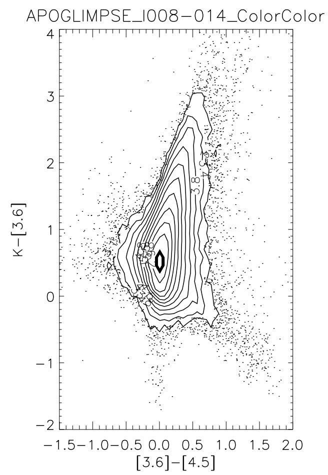

Figure 11: Color-color plot of the region l = 8°-14° *and* b=-1.0° to +1.0° for sources in the Archive. 10 contours are evenly spaced between log(# sources/mag^2)=2.0 and the log of maximum number of sources per square magnitude. The contours are labeled with the log of the number of sources per square magnitude. Outside of the lowest contour, the positions of individual sources are plotted.

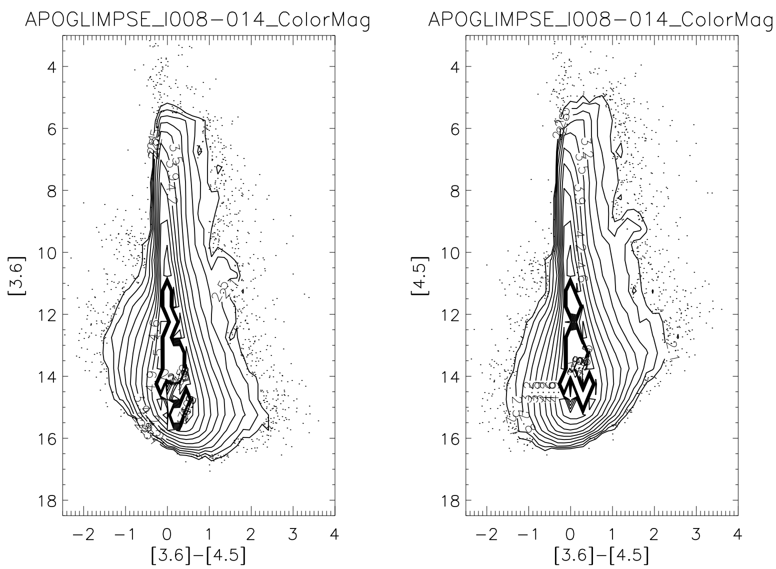

Figure 12: Same as Figure 13 except that these are Color-magnitude plots.

4 Data Products Description

Here we provide information on the fields and flags recorded for each point source provided in the Catalog or Archive. More detailed information on the file formats for the Catalog and Archive, as well as mosaics, can be found in the following section.

4.1 Catalog and Archive Fields and Flags

Each entry in the APOGLIMPSE Catalog and Archive has the following information:

designation	SSTAPOGLC GLLL.llll±BB.bbbb, SSTAPOGLA GLLL.llll±BB.bbbb
2MASS PSC names	2MASS designation, 2MASS counter
position	l, b, dl, db, ra, dec, dra, ddec
flux	mag_i, dmag_i, F_i, dF_i, F_i_rms (IRAC)
	mag_t, dmag_t, F_t, dF_t (2MASS)
diagnostic	sky_i, SN_i, $\mathrm{srcdens}_i$, # detections M_i out of N_i possible (IRAC)
	SN_t (2MASS)
flags	Close Source Flag, Source Quality Flag (SQF_i), Flux Method Flag (MF_i) (IRAC)
	Source Quality Flag (SQF_t) (2MASS)

where i is the IRAC wavelength number (IRAC bands 3.6, 4.5, 5.8 and 8.0 μm) and t is the 2MASS wavelength band (J, H, K_s). For the APOGLIMPSE Warm Mission data, bands [5.8] and [8.0] fields are always nulled since no data were taken at those wavelengths. We keep the same format as the previous GLIMPSE source lists.

Details of the fields are as follows:

4.1.1 Designation

This is the object designation or "name" as specified by the IAU recommendations on source nomenclature. It is derived from the coordinates of the source, where G denotes Galactic coordinates, LLL.llll is the Galactic longitude in degrees, and ±BB.bbbb is the Galactic latitude in degrees. The coordinates are preceded by the acronym SSTAPOGLC (APOGLIMPSE Catalog) or SSTAPOGLA (APOGLIMPSE Archive).

4.1.2 2MASS PSC information

The 2MASS designation is the source designation for objects in the 2MASS All-Sky Release Point Source Catalog. It is a sexagesimal, equatorial position-based source name of the form hhmmssss±ddmmsss, where hhmmssss is the right ascension (J2000) coordinate of the source in hours, minutes and seconds, and ±ddmmsss is the declination (degrees, minutes, seconds). The 2MASS counter is a unique identification number for the 2MASS PSC source. See www.ipac.caltech.edu/2mass/releases/allsky/doc/sec2_2a.html for more information about these fields.

4.1.3 Position

The position is given in both Galactic (l, b) and equatorial (α, δ) J2000 coordinates, along with estimated uncertainties. The pointing accuracy is $1''$ (Werner et al. 2004). The SSC pipeline does pointing refinement[3] of the images based on comparison with the 2MASS Point Source Catalog, whose absolute accuracy is typically $< 0.2''$ (Cutri et al. 2005). After applying the SSC geometric distortion corrections and updating to the 2MASS positions, the GLIMPSE point source accuracy is typically $\sim 0.3''$ absolute accuracy, limited by undersampling of the point-spread function. The

[3] irsa.ipac.caltech.edu/data/SPITZER/docs/irac/iracinstrumenthandbook/50/#_Toc296497447

position uncertainties are calculated by the bandmerger based on the uncertainties of individual detections, propagated through the calculation of the weighted mean position. Sources with 2MASS associates have positions in part derived from the 2MASS position.

4.1.4 Flux

For each IRAC band i = 3.6 and 4.5 μm and, when available 2MASS band t = J, H, and K_s, the fluxes are expressed in magnitudes (mag_i, mag_t) and in mJy (F_i, F_t). Each IRAC flux is the error-weighted average of all independent detections of a source. The 2MASS magnitudes and uncertainties are from the 2MASS All-Sky Release Point Source Catalog. They are the j_m, j_msigcom, h_m, h_msigcom, and k_m, k_msigcom columns from the 2MASS PSC. The zeropoints for converting from flux to magnitude are from Reach et al (2005) for the IRAC bands and Cohen et al. 2003 for 2MASS and given in Table 6. Magnitude uncertainties are typically <0.2 mag for the Catalog and < 0.3 mag for the Archive. Table 4 shows the percentages of sources meeting the 0.2 mag accuracy criterion.

Table 6. Zeropoints for Flux to Magnitude Conversion

Band	J	H	K_s	[3.6]	[4.5]	[5.8]	[8.0]
Zeropoints (Jy)	1594	1024	666.7	280.9	179.7	115.0	64.13

The IRAC flux/magnitude uncertainties (dF_i; $dmag_i$) are computed during the photometry stage and take into account photon noise, readnoise, goodness of flat fielding, and PSF fitting (Stetson 1987).

The rms deviation (F_i_rms) of the individual detections from the final flux of each source is provided. The F_rms is calculated as follows: F_rms=$\sqrt{\sum (F_j - < F >)^2/M}$ where j is an individual IRAC frame, $< F >$ is the average Flux, and M is the number of detections.

4.1.5 Diagnostics

The associated flux diagnostics are a local background level (sky_i) (i = 3.6 and 4.5 μm) in MJy/sr, a Signal/Noise (SN_i), a local source density ($srcdens_i$) (number of sources per square arcmin), and number of times (M_i) a source was detected out of a calculated possible number (N_i). The Signal/Noise is the flux (F_i) divided by the flux uncertainty (dF_i). The Signal/Noise for the 2MASS fluxes (SN_t) have been taken from the 2MASS PSC (the j_snr, h_snr and k_snr columns). The local source density is measured as follows: The individual IRAC frame is divided into a 3×3 grid, each of the nine cells being $1.71'$ x $1.71'$. A source density is calculated for each cell (number of sources per $arcmin^2$), and is assigned to each source in that cell. The local source density can be used to assess the confusion in a given region, along with the internal reliability. M_i and N_i can be used to estimate reliability. N_i is calculated based on the areal coverage of each observed frame; due to overlaps some areas are observed more often per band.

Detections (M) can be thrown out by exposure time (when combining 0.6 and 12 second frametime data, for example), or because they have bad SQF flags. Detections are also thrown out at the beginning of bandmerging for sensitivity or saturation reasons. If *any* detections without bad flags went into the final flux, then only those good detections are counted. If all detections had bad flags, then all are counted, and the final source will have some bad quality flags also. Bad in this context is 8=hot/dead pixel and 30=edge (see §4.1.6 and Appendix A for SQF details). N is all frames containing the position of the combined source in this band (*not* including the edge of the frame, within 3 pixels) for which the exposure time was used in the final flux. As for M, if *any* good detections are used, we only count the good detections, but if they're all bad we count all of them and set flags in the final source. For sources not detected in a band, the position of the final cross-band merged source is used for calculating N.

4.1.6 Flags

There are three types of flags: the Close Source Flag, the Source Quality Flag and the Flux Calculation Method Flag. The Close Source Flag is set if there are Archive sources that are within $3''$ of the source. The Source Quality Flag provides a measure of the quality of the point source extraction and bandmerging. The Flux Calculation Method Flag describes how the final Catalog/Archive flux was determined.

• The Close Source Flag is set when a source in the Archive is within $3.0''$ of the source. It was found (see §7 of the GQA) that the magnitudes of a source with nearby sources closer than about $2''$ are not reliably extracted and bandmerged. A source that has Archive sources within $2.0''$ of the source are *culled* from the Catalog. A source that has Archive sources within $0.5''$ of the source are *culled* from the Archive. The flag is defined as follows:

0=no Archive source within $3.0''$ of source
1=Archive sources between $2.5''$ and $3.0''$ of source
2=Archive sources between $2.0''$ and $2.5''$ of source
3=Archive sources between $1.5''$ and $2.0''$ of source
4=Archive sources between $1.0''$ and $1.5''$ of source
5=Archive sources between $0.5''$ and $1.0''$ of source
6=Archive sources within $0.5''$ of source

• The Source Quality Flag (SQF) is generated from SSC-provided masks and the GLIMPSE pipeline, during point source extraction on individual IRAC frames and bandmerging. Each source quality flag is a binary number allowing combinations of flags (bits) in the same number. Flags are set if an artifact (e.g., a hot or dead pixel) occurs near the core of a source - i.e. within $\sim$3 pixels. A non-zero SQF will in most cases decrease the reliability of the source. Some of the bits, such as the DAOPHOT tweaks (see Appendix A), will not compromise the source's reliability, but has likely increased the uncertainty assigned to the source flux. If just one IRAC detection has the condition requiring a bit to be set in the SQF, then the bit is set even if the other detections did not have this condition. Sources with hot or dead pixels within 3 pixels of source center (bit 8), those in wings of saturated stars (bit 20), and those within 3 pixels of the frame edge (bit 30) are culled from the Catalog. Each of the five bands has its own SQF. For the cross-band confusion flag and the cross-band merge lumping flag, when the condition is met for one of the bands, the bit is set for all the source's bands.

Table 7 gives the Source Quality Flag bits and origin of the flag (SSC or GLIMPSE pipeline).

The value of the SQF is $\sum 2^{(bit-1)}$. For example, a source with bits 1 and 4 set will have SQF = $2^0 + 2^3 = 9$. If the SQF is 0, the source has no detected problems. More information about these flags and a bit value key can be found in Appendix A.

Table 7. Source Quality Flag (SQF) Bits

SQF bit	Description	Origin
1	poor pixels in dark current	SSC pmask
2	flat field questionable	SSC dmask
3	latent image	SSC dmask
3	persistence (p)	2MASS
4	photometric confusion (c)	2MASS
8	hot, dead or otherwise unacceptable pixel	SSC pmask,dmask,GLIMPSE
9	electronic stripe (s)	2MASS
10	DAOPHOT tweak positive	GLIMPSE
11	DAOPHOT tweak negative	GLIMPSE
13	confusion in in-band merge	GLIMPSE
14	confusion in cross-band merge (IRAC)	GLIMPSE
14	confusion in cross-band merge (2MASS)	GLIMPSE
15	column pulldown corrected	GLIMPSE
19	data predicted to saturate	GLIMPSE
20	saturated star wing region	GLIMPSE
20	diffraction spike (d)	2MASS
21	pre-lumping in in-band merge	GLIMPSE
22	post-lumping in cross-band merge (IRAC)	GLIMPSE
22	post-lumping in cross-band merge (2MASS)	GLIMPSE
23	photometry quality flag	2MASS
24	photometry quality flag	2MASS
25	photometry quality flag	2MASS
30	within three pixels of edge of frame	GLIMPSE

• Flux calculation Method Flag (MF_i). The flux calculation method flag indicates by bit whether a given frametime was present, and whether that frametime was used in the final flux. Table 8 defines the values for this flag: value= $2^{(present\_bit-1)} + 2^{(used\_bit-1)}$

Table 8. Flux Calculation Method Flag (MF)

ft (sec)	present bit	(value)	used bit	(value)
0.6	1	(1)	2	(2)
1.2	3	(4)	4	(8)
2	5	(16)	6	(32)
12	7	(64)	8	(128)
30	9	(256)	10	(512)
100	11	(1024)	12	(2048)

For example, if 0.6 and 12 sec frametime data were present, but only the 12 sec data were used, then bits 1 and 7 will be set (fluxes present) and bit 8 will be set (12 sec used) and the MF will be $2^0 + 2^6 + 2^7 = 1 + 64 + 128 = 193$ (see Table 8). Note that, in practice, MF of 193 is rarely assigned because some detections are thrown out at the beginning of bandmerging because of sensitivity or saturation issues.

For APOGLIMPSE 12/0.6 sec frametime HDR mode, the relevant numbers work out to be

3 - short exp data used, long exp data absent
67 - short used, long present but unused
192 - long exp used, short absent
193 - long exp used, short present but unused

For the 2 second frametime data of the APOGLIMPSE survey, the method flag equals 48 (2^4 + 2^5).

4.2 APOGLIMPSE Images

The IRAC images are mosaicked using the Montage[4] package into rectangular tiles that cover the surveyed region. The units are MJy/sr and the coordinates are Galactic. The mosaic images conserve surface brightness in the original images. We provide 1.2″ pixel mosaics as well as higher resolution 0.6″ pixel mosaics. The angular sizes of the higher resolution tiles are 1.4°×0.9°, 1.1°×0.9°, 1.4°×1.1°, 1.8°×1.1°, 1.6°×0.9°, and 1.6°×1.5°. Three tiles span the latitude range of the areas. The pixel size is 0.6″ , smaller than the native IRAC pixel size of 1.2″ . World Coordinate System (WCS) keywords are standard (CTYPE, CRPIX, CRVAL, CD matrix keywords) with a Galactic projection (GLON-CAR, GLAT-CAR; Calabretta and Greisen 2002). See (§5.2) for an example of a FITS header. The mosaicked images are 32-bit IEEE floating point single-extension FITS formatted images. We also provide larger (e.g. 1.9°×2.4°, 4.5°×2.4°, 2.7°×2.7°, 2.4°×2.4°, 2.8°×2.4°, 2.5°×2.4°, 2.6°×2.4°, and 1.7°×2.9°) FITS files with a pixel size of 1.2″ , with and without background matching, for an overview look that covers the full latitude range of the APOGLIMPSE areas. For a quick-look of the mosaics, we provide 3-color jpeg files (IRAC [3.6] - blue, [4.5] - green, and WISE [12.0] - red) for each area covered by the FITS files. These are rebinned to much lower resolution to make the files small.

The background matching and gradient removal may be removing real sky variations so we provide these images *in addition* to the 1.2″ pixel images that do not have the background matching. The background matched and gradient corrected mosaics are processed using the following procedure:

For the 1.2″ pixel mosaic images, we match instrumental background variations between the 5x5 arcmin IRAC BCD frames using Montage. Instrument artifacts (see the IRAC Data Handbook) such as full array pull-up, first frame effect and frame pull-down are mostly removed from the images. We use the "level" option in the Montage mBgModel module (http://montage.ipac.caltech.edu/docs/mBgModel.html) to produce the background matched mosaics. See http://montage.ipac.caltech.edu/docs/algorithms.html#background for a discussion of the background modeling.

In the background matching process, Montage introduces unwanted large-scale gradients. Our gradient correction algorithm finds the large-scale gradients by taking the corrections table produced by Montage and creating a smoothed version to eliminate small-scale corrections. This is done by using a Radial Basis Function interpolation with a smoothing factor of 1000. We then find the difference between the corrections and the smoothed corrections, find the standard deviation of this difference, then reject all points which deviate by more than 5 sigma. A new smoothed correction map is computed and the process is repeated until no points are rejected (typically 10 iterations). Once this is complete, a final correction map is computed and removed from the image,

[4] http://montage.ipac.caltech.edu

thus undoing the large-scale gradients introduced by Montage.

5 Product Formats

5.1 Catalog and Archive

• There is a Catalog and Archive for each of the APOGLIMPSE areas (2°x 2°) except for the fields that overlap slightly and have been combined which are 2°x 4°. The combined fields are APOGLIMPSE_2N and APOGLIMPSE_3N (l = 9°to 13 °) and APOGLIMPSE_3S and APOGLIMPSE_4S (l = 344°to 348°). The Catalog and Archive files are in IPAC Table Format (http://irsa.ipac.caltech.edu/applications/DDGEN/Doc/ipac_tbl.html). Filenames are APOGLIMPSEC_l*lb*.tbl and APOGLIMPSEA_l*lb*.tbl (where *lb* is the beginning Galactic longitude of the area) for the Catalog and Archive respectively (e.g. APOGLIMPSEC_l018.tbl, APOGLIMPSEC_l028.tbl, APOGLIMPSEA_l018.tbl, APOGLIMPSEA_l028.tbl, etc.) The entries are sorted by increasing Galactic longitude within each file.

An example of a APOGLIMPSEA entry is

SSTAPOGLA G010.8583+00.0977 18091017-1929314 629521235 10.858317 0.097778 0.3 0.3
272.292412 -19.492078 0.3 0.3 0 11.887 0.021 10.848 0.022 10.393 0.021
10.103 0.033 10.175 0.035 99.999 99.999 99.999 99.999
2.803E+01 5.422E-01 4.689E+01 9.502E-01 4.642E+01 8.979E-01
2.555E+01 7.800E-01 1.529E+01 4.933E-01 -9.999E+02 -9.999E+02 -9.999E+02 -9.999E+02
9.100E-01 5.219E-02 -9.999E+02 -9.999E+02 6.105E+00 4.180E+00 -9.999E+02 -9.999E+02
51.70 49.35 51.70 32.76 31.00 -9.99 -9.99 50.1 122.0 -9.9 -9.9
5 3 0 0 5 4 0 0 29360128 29360128 29360128 512 525312 -9 -9 3 192 -9 -9

Table 9 gives all of the available fields per source. Table 10 shows how to decode the above entry into these fields. All fields associated with IRAC bands [5.8] and [8.0] have been nulled for the Warm Mission Deep GLIMPSE survey.

• Each source in both the Catalog and Archive has the entries given below.

Table 9. Fields in the Catalog and Archive

Column	Name	Description	Units	Data Type	Format	Nulls OK? or Value
1	designation	Catalog (SSTAPOGLC GLLL.llll±BB.bbbb) Archive (SSTAPOGLA GLLL.llll±BB.bbbb)	-	ASCII	A26	No
2	tmass_desig	2MASS PSC designation	-	ASCII	A16	null
3	tmass_cntr	2MASS counter (unique identification number)	-	I*4	I10	0
4	l	Galactic longitude	deg	R*8	F11.6	No
5	b	Galactic latitude	deg	R*8	F11.6	No
6	dl	Uncertainty in Gal. longitude	arcsec	R*8	F7.1	No
7	db	Uncertainty in Gal. latitude	arcsec	R*8	F7.1	No
8	ra	Right ascension (J2000)	deg	R*8	F11.6	No
9	dec	Declination (J2000)	deg	R*8	F11.6	No
10	dra	Uncertainty in right ascension	arcsec	R*8	F7.1	No
11	ddec	Uncertainty in declination	arcsec	R*8	F7.1	No
12	csf	Close source flag	-	I*2	I4	No
13–18	mag_t,$dmag_t$	Magnitudes & 1σ uncertainty in t=J,H,K_s bands	mag	R*4	6F7.3	99.999,99.999
19–26	mag_i,$dmag_i$	Magnitudes & 1σ uncertainty in IRAC band i	mag	R*4	8F7.3	99.999,99.999
27–32	F_t,dF_t	Fluxes & 1σ uncertainty in t=J,H,K_s bands	mJy	R*4	6E11.3	-999.9,-999.9
33–40	F_i,dF_i	Fluxes & 1σ uncertainty in IRAC band i	mJy	R*4	8E11.3	-999.9,-999.9
41–44	F_i_rms	RMS dev. of individual detections from F_i	mJy	R*4	4E11.3	-999.9
45–48	sky_i	Local sky bkg. for IRAC band i flux	MJy/sr	R*4	4E11.3	-999.9
49–51	SN_t	Signal/Noise for bands t=J,H,K_s	-	R*4	3F7.2	-9.99
52–55	SN_i	Signal/Noise for IRAC band i flux	-	R*4	4F7.2	-9.99
56–59	$srcdens_i$	Local source density for IRAC band i object	no./sq $'$	R*4	4F9.1	-9.9
60–63	M_i	Number of detections for IRAC band i	-	I*2	4I6	No
64–67	N_i	Number of possible detections for IRAC band i	-	I*2	4I6	No
68–70	SQF_t	Source Quality Flag for t=J,H,K_s flux	-	I*4	3I11	-9
71–74	SQF_i	Source Quality Flag for IRAC band i flux	-	I*4	4I11	-9
75–78	MF_i	Flux calc method flag for IRAC band i flux	-	I*2	4I6	-9

Table 10. Example of Catalog/Archive Entry

designation	SSTAPOGLA G010.8583+00.0977	Name
tmass_desig	18091017-1929314	2MASS designation
tmass_cntr	629521235	2MASS counter
l,b	10.858317 0.097778	Galactic Coordinates (deg)
dl,db	0.3 0.3	Uncertainty in Gal. Coordinates (arcsec)
ra,dec	272.292412 -19.492078	RA and Dec (J2000.0) (deg)
dra,ddec	0.3 0.3	Uncertainty in RA and Dec (arcsec)
csf	0	Close source flag
mag,dmag	11.887 10.848 10.393	Magnitudes (2MASS J,H,K_s) (mag)
	0.021 0.022 0.021	Uncertainties (2MASS) (mag)
mag,dmag	10.103 10.175 99.999 99.999	Magnitudes (IRAC 3.6,4.5,5.8,8.0 μm) (mag)
	0.033 0.035 99.999 99.999	Uncertainties (IRAC) (mag)
F,dF	2.803E+01 4.689E+01 4.642E+01	2MASS Fluxes (mJy)
	5.422E-01 9.502E-01 8.979E-01	Uncertainties in 2MASS fluxes (mJy)
F,dF	2.555E+01 1.529E+01 -9.999E+02 -9.999E+02	IRAC Fluxes (mJy)
	7.800E-01 4.933E-01 -9.999E+02 -9.999E+02	Uncertainties in IRAC fluxes (mJy)
F_rms	9.100E-01 5.219E-02 -9.999E+02 -9.999E+02	RMS_flux (mJy) (IRAC)
sky	6.105E+00 4.180E+00 -9.999E+02 -9.999E+02	Sky Bkg (MJy/sr) (IRAC)
SN	51.70 49.35 51.70	Signal to Noise (2MASS)
SN	32.76 31.00 -9.99 -9.99	Signal to Noise (IRAC)
srcdens	50.1 122.0 -9.9 -9.9	Local Source Density (IRAC) (#/sq arcmin)
M	5 3 0 0	Number of detections (IRAC)
N	5 4 0 0	Number of possible detections (IRAC)
SQF	29360128 29360128 29360128	Source Quality Flag (2MASS)
SQF	512 525312 -9 -9	Source Quality Flag (IRAC)
MF	3 192 -9 -9	Flux Calculation Method Flag (IRAC)

5.2 APOGLIMPSE Image Atlas

The mosaicked images for each IRAC band are standard 32-bit IEEE floating point single-extension FITS files in Galactic coordinates. Pixels that have no flux estimate have the value NaN. The FITS headers contain relevant information from both the SSC pipeline processing and the GLIMPSE processing such as IRAC frames included in the mosaicked image and coordinate information.

We provide native resolution images (1.2″ pixel mosaic FITS files) for each band, along with low resolution 3-color jpegs. Mosaics are 1.9°×2.4°, 4.5°×2.4°, 2.7°×2.7°, 2.4°×2.4°, 2.8°×2.4°, 2.5°×2.4°, 2.6°×2.4°, and 1.7°×2.9°. Filenames are APOGLM_*lcbc*_mosaic_I*ch*.fits, where *lc* and *bc* are the Galactic longitude and latitude of the center of the mosaic image, I denotes IRAC, and *ch* is the IRAC instrument channel number (1=[3.6] and 2=[4.5]). For example, APOGLM_02000+0000_mosaic_I1.fits is a 2.4°x 2.4° IRAC channel 1 [3.6] mosaic centered on l=20.00°, b=+0.00°. We provide low-resolution 3-color jpeg images for each area, combining IRAC [3.6] and [4.5] and WISE [12] to be used for quick-look purposes. The filename for this jpeg file is similar to the mosaic FITS file: e.g. APOGLM_02000+0100_mosaic_2.4x2.4.jpg. We also provide the background matched and gradient corrected 1.2″ pixel mosaics and 3-color jpegs. The background matched and gradient corrected image filenames have "corr_" pre-pended to the filename (e.g. corr_APOGLM_02000+0000_mosaic_I1.fits). This comment line is added to the FITS header for these images:

```
COMMENT Background Matched, Gradient Corrected
```

The angular sizes of the higher resolution (0.6″ pixels) tiles are 1.4°×0.9°, 1.1°×0.9°, 1.4°×1.1°, 1.8°×1.1°, 1.6°×0.9 °, and 1.6°×1.5°. Three tiles span the latitude range of the areas. There are three mosaics per Galactic longitude interval. The filenames are similar to the other FITS and jpeg images: e.g. APOGLM_02050+0000_mosaic_I2.fits, APOGLM_02050+0000.jpg.

Here is an example of the FITS header for the 4.5°x 2.4° APOGLM_01100+0000_mosaic_I1.fits:

```
--------------------------------- extension 0 ---------------------------------
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                  -32 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                13500 / length of data axis 1
NAXIS2  =                 7200 / length of data axis 2
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
TELESCOP= 'SPITZER '           / Telescope
INSTRUME= 'IRAC    '           / Instrument ID
ORIGIN  = 'UW Astronomy Dept'  / Installation where FITS file written
CREATOR = 'GLIMPSE Pipeline'   / SW that created this FITS file
CREATOR1= 'S19.2.0 '           / SSC pipeline that created the BCD
PIPEVERS= '1v04    '           / GLIMPSE pipeline version
MOSAICER= 'Montage V3.0'       / SW that originally created the Mosaic Image
FILENAME= 'APOGLM_01100+0000_mosaic_I1.fits' / Name of associated fits file
PROJECT = 'APOGLL  '           / Project ID
FILETYPE= 'mosaic  '           / Calibrated image(mosaic)/residual image(resid)
CHNLNUM =                    1 / 1 digit Instrument Channel Number
```

```
DATE    = '2018-09-28T08:25:31' / file creation date (YYYY-MM-DDThh:mm:ss UTC)
COMMENT --------------------
COMMENT Proposal Information
COMMENT --------------------
OBSRVR  = 'Robert Benjamin'    / Observer Name
OBSRVRID=                31293 / Observer ID of Principal Investigator
PROCYCLE=                   16 / Proposal Cycle
PROGID  =                13117 / Program ID
PROTITLE= 'Three Dimensional Stellar Kine' / Program Title
PROGCAT =                   30 / Program Category
COMMENT ----------------------------
COMMENT Time and Exposure Information
COMMENT ----------------------------
SAMPTIME=                  0.2 / [sec] Sample integration time
FRAMTIME=                 12.0 / [sec] Time spent integrating each BCD frame
EXPTIME =                 10.4 / [sec] Effective integration time each BCD frame
COMMENT DN per pixel=flux(photons/sec/pixel)/gain*EXPTIME
NEXPOSUR=                    3 / Typical number of exposures
COMMENT Total integration time for the mosaic = EXPTIME * NEXPOSUR
COMMENT Total DN per pixel=flux(photons/sec/pixel)/gain*EXPTIME*NEXPOSUR
AFOWLNUM=                    8 / Fowler number
COMMENT --------------------
COMMENT Pointing Information
COMMENT --------------------
CRPIX1  =           6750.5000 / Reference pixel for x-position
CRPIX2  =           3600.5000 / Reference pixel for y-position
CTYPE1  = 'GLON-CAR'           / Projection Type
CTYPE2  = 'GLAT-CAR'           / Projection Type
CRVAL1  =         11.00000000 / [Deg] Galactic Longtitude at reference pixel
CRVAL2  =          0.00000000 / [Deg] Galactic Latitude at reference pixel
EQUINOX =              2000.0 / Equinox for celestial coordinate system
DELTA-X =          4.50000000 / [Deg] size of image in axis 1
DELTA-Y =          2.40000010 / [Deg] size of image in axis 2
BORDER  =          0.00000000 / [Deg] mosaic grid border
CD1_1   =     -3.33333330E-04
CD1_2   =      0.00000000E+00
CD2_1   =      0.00000000E+00
CD2_2   =      3.33333330E-04
PIXSCAL1=               1.200 / [arcsec/pixel] pixel scale for axis 1
PIXSCAL2=               1.200 / [arcsec/pixel] pixel scale for axis 2
OLDPIXSC=               1.221 / [arcsec/pixel] pixel scale of single IRAC frame
RA      =        272.45587158 / [Deg] Right ascension at mosaic center
DEC     =        -19.41540146 / [Deg] Declination at mosaic center
COMMENT ----------------------
COMMENT Photometry Information
COMMENT ----------------------
BUNIT   = 'MJy/sr  '           / Units of image data
GAIN    =                  3.7 / e/DN conversion
```

```
JY2DN   =          2361114.250 / Average Jy to DN Conversion
ETIMEAVE=              10.4000 / [sec] Average exposure time for the BCD frames
PA_AVE  =                90.04 / [deg] Average position angle
ZODY_EST=              0.19290 / [Mjy/sr] Average ZODY_EST
ZODY_AVE=              0.15779 / [Mjy/sr] Average ZODY_EST-SKYDRKZB
COMMENT Flux conversion (FLUXCONV) for this mosaic =
COMMENT Average of FLXC from each frame*(old pixel scale/new pixel scale)**2
FLUXCONV=          0.130137980 / Average MJy/sr to DN/s Conversion
COMMENT ----------------------------
COMMENT AORKEYS/ADS Ident Information
COMMENT ----------------------------
AOR001  = '0061028096'         / AORKEYS used in this mosaic
AOR002  = '0061040896'         / AORKEYS used in this mosaic
AOR003  = '0061055232'         / AORKEYS used in this mosaic
AOR004  = '0061035520'         / AORKEYS used in this mosaic
AOR005  = '0061037568'         / AORKEYS used in this mosaic
AOR006  = '0061059840'         / AORKEYS used in this mosaic
AOR007  = '0061031424'         / AORKEYS used in this mosaic
AOR008  = '0061020416'         / AORKEYS used in this mosaic
AOR009  = '0061048320'         / AORKEYS used in this mosaic
AOR010  = '0061028608'         / AORKEYS used in this mosaic
AOR011  = '0061040384'         / AORKEYS used in this mosaic
AOR012  = '0064630528'         / AORKEYS used in this mosaic
AOR013  = '0064631552'         / AORKEYS used in this mosaic
AOR014  = '0064631808'         / AORKEYS used in this mosaic
AOR015  = '0064633088'         / AORKEYS used in this mosaic
AOR016  = '0064631040'         / AORKEYS used in this mosaic
AOR017  = '0064631296'         / AORKEYS used in this mosaic
AOR018  = '0064632064'         / AORKEYS used in this mosaic
AOR019  = '0064632576'         / AORKEYS used in this mosaic
AOR020  = '0064632832'         / AORKEYS used in this mosaic
AOR021  = '0064630272'         / AORKEYS used in this mosaic
AOR022  = '0064632320'         / AORKEYS used in this mosaic
AOR023  = '0064630784'         / AORKEYS used in this mosaic
DSID001 = 'ads/sa.spitzer#0061028096' / Data Set Identification for ADS/journals
DSID002 = 'ads/sa.spitzer#0061040896' / Data Set Identification for ADS/journals
DSID003 = 'ads/sa.spitzer#0061055232' / Data Set Identification for ADS/journals
DSID004 = 'ads/sa.spitzer#0061035520' / Data Set Identification for ADS/journals
DSID005 = 'ads/sa.spitzer#0061037568' / Data Set Identification for ADS/journals
DSID006 = 'ads/sa.spitzer#0061059840' / Data Set Identification for ADS/journals
DSID007 = 'ads/sa.spitzer#0061031424' / Data Set Identification for ADS/journals
DSID008 = 'ads/sa.spitzer#0061020416' / Data Set Identification for ADS/journals
DSID009 = 'ads/sa.spitzer#0061048320' / Data Set Identification for ADS/journals
DSID010 = 'ads/sa.spitzer#0061028608' / Data Set Identification for ADS/journals
DSID011 = 'ads/sa.spitzer#0061040384' / Data Set Identification for ADS/journals
DSID012 = 'ads/sa.spitzer#0064630528' / Data Set Identification for ADS/journals
DSID013 = 'ads/sa.spitzer#0064631552' / Data Set Identification for ADS/journals
DSID014 = 'ads/sa.spitzer#0064631808' / Data Set Identification for ADS/journals
```

```
DSID015 = 'ads/sa.spitzer#0064633088' / Data Set Identification for ADS/journals
DSID016 = 'ads/sa.spitzer#0064631040' / Data Set Identification for ADS/journals
DSID017 = 'ads/sa.spitzer#0064631296' / Data Set Identification for ADS/journals
DSID018 = 'ads/sa.spitzer#0064632064' / Data Set Identification for ADS/journals
DSID019 = 'ads/sa.spitzer#0064632576' / Data Set Identification for ADS/journals
DSID020 = 'ads/sa.spitzer#0064632832' / Data Set Identification for ADS/journals
DSID021 = 'ads/sa.spitzer#0064630272' / Data Set Identification for ADS/journals
DSID022 = 'ads/sa.spitzer#0064632320' / Data Set Identification for ADS/journals
DSID023 = 'ads/sa.spitzer#0064630784' / Data Set Identification for ADS/journals
NIMAGES =                 4044 / Number of IRAC Frames in Mosaic
```

In addition to the FITS header information given above, the associated ASCII .hdr file includes information about each IRAC frame used in the mosaic image. For example, APOGLM_01100+0000_mosaic_I1.hdr includes:

```
COMMENT ----------------------------------------
COMMENT Info on Individual Frames in Mosaic
COMMENT ----------------------------------------
IRFR0001= 'SPITZER_I1_0061028096_0407_0000_01_levbflx.fits' / IRAC frame
DOBS0001= '2016-12-15T13:56:32.097' / Date & time at frame start
MOBS0001=      57737.582031250 / MJD (days) at frame start
RACE0001=           272.375519 / [Deg] Right ascension at reference pixel
DECC0001=           -20.745358 / [Deg] Declination at reference pixel
PANG0001=                89.82 / [deg] Position angle for this image
FLXC0001=              0.12570 / Flux conversion for this image
ZODE0001=              0.19317 / [MJy/sr] ZODY_EST for this image
ZODY0001=              0.15677 / [MJy/sr] ZODY_EST-SKYDRKZB for this image
IRFR0002= 'SPITZER_I1_0061028096_0423_0000_01_levbflx.fits' / IRAC frame
DOBS0002= '2016-12-15T13:59:45.296' / Date & time at frame start
MOBS0002=      57737.582031250 / MJD (days) at frame start
RACE0002=           272.143524 / [Deg] Right ascension at reference pixel
DECC0002=           -20.746435 / [Deg] Declination at reference pixel
PANG0002=                89.90 / [deg] Position angle for this image
FLXC0002=              0.12570 / Flux conversion for this image
ZODE0002=              0.19379 / [MJy/sr] ZODY_EST for this image
ZODY0002=              0.15739 / [MJy/sr] ZODY_EST-SKYDRKZB for this image

.       Information on the IRAC frame: filename, date of observation, central
.       position, position angle, flux convert and zodiacal light for
.       frames 3 through 4042
.
IRFR4043= 'SPITZER_I1_0064632064_0039_0000_01_levbflx.fits' / IRAC frame
DOBS4043= '2017-12-28T04:08:32.962' / Date & time at frame start
MOBS4043=      58115.171875000 / MJD (days) at frame start
RACE4043=           272.487427 / [Deg] Right ascension at reference pixel
```

```
DECC4043=           -17.306927 / [Deg] Declination at reference pixel
PANG4043=                90.29 / [deg] Position angle for this image
FLXC4043=              0.12570 / Flux conversion for this image
ZODE4043=              0.18714 / [MJy/sr] ZODY_EST for this image
ZODY4043=              0.15356 / [MJy/sr] ZODY_EST-SKYDRKZB for this image
IRFR4044= 'SPITZER_I1_0064632064_0035_0000_01_levbflx.fits' / IRAC frame
DOBS4044= '2017-12-28T04:07:44.567' / Date & time at frame start
MOBS4044=      58115.171875000 / MJD (days) at frame start
RACE4044=           272.544250 / [Deg] Right ascension at reference pixel
DECC4044=           -17.307043 / [Deg] Declination at reference pixel
PANG4044=                90.27 / [deg] Position angle for this image
FLXC4044=              0.12570 / Flux conversion for this image
ZODE4044=              0.18710 / [MJy/sr] ZODY_EST for this image
ZODY4044=              0.15352 / [MJy/sr] ZODY_EST-SKYDRKZB for this image
```

6 APPENDIX A - Source Quality Flag Bit Descriptions

A.1 IRAC Source Quality Flag

Information is gathered from the SSC IRAC bad pixel mask (pmask), SSC bad data mask (dmask) and the GLIMPSE IRAC pipeline for the Source Quality Flag. Table 7 lists the bits and the origin of the flag (SSC or GLIMPSE pipeline). See ssc.spitzer.caltech.edu/irac/products/pmask.html and ssc.spitzer.caltech.edu/irac/products/bcd_dmask.html for more information about the IRAC pmask and dmask.

bit
1 poor pixels in dark current
This bit is set when a source is within 3 pixels of a pixel identified in the SSC IRAC pmask as having poor dark current response (bits 7 and 10 in the pmask).

2 flat field questionable
If a pixel is flagged in the SSC IRAC dmask as flat field applied using questionable value (bit 7) or flat field could not be applied (bit 8), a source within 3 pixels of these pixels will have this bit set.

3 latent image
This flag comes from the latent image flag (bit 5) from the dmask. The SSC pipeline predicts the positions of possible latent images due to previously observed bright sources.

8 hot, dead or otherwise unacceptable pixel
Hot, dead or unacceptable pixels are identified in the IRAC pmask as having an unacceptable response to light (bits 8, 9 and 14 in the IRAC pmask). Also considered bad pixels are ones flagged as bad or missing in bit 11 and 14 in the IRAC dmask. SQF bit 8 is set if a source is within 3 pixels of any of these bad pixels. Sources with this bit set are culled from the Catalog.

10 DAOPHOT tweak positive
11 DAOPHOT tweak negative
Bits 10 and 11 correspond to an iterative photometric step (tweaking). Photometry is initially performed by DAOPHOT/ALLSTAR using PSF fitting. This photometric step produces a list of

sources, their positions and brightnesses, as well as a residual image of those sources removed from the input image. By flattening the residual image (smoothing it and then subtracting the smoothed image from the residual image) and then performing small aperture photometry at the location of each of the extracted sources, it is possible to determine if the extracted source was over or under subtracted due to any local complex variable background or the undersampled PSF. SQF bit 10 refers to sources that were initially under-subtracted. From the aperture photometry a positive flux correction was applied to the DAOPHOT/ALLSTAR extraction value (source was brightened via aperture photometry as compared to the initial PSF fitted DAOPHOT/ALLSTAR photometry). SQF bit 11 refers to sources that were initially over-subtracted. Using aperture photometry, a negative flux correction was applied to the DAOPHOT/ALLSTAR extraction value (source was dimmed via aperture photometry as compared to the initial PSF fitted DAOPHOT/ALLSTAR photometry). Sources with both SQF bits 10 and 11 set imply 1) the source was initially under-subtracted, but the aperture photometry over- corrected and thus a second aperture correction was applied or 2) multiple observations in a band consisting of at least one observation with a positive tweak and another observation with a negative tweak.

13 confusion in in-band merge
14 confusion in cross-band merge
These bits are set during the bandmerging process. The bandmerger reports, for each source and band, the number of merge candidates it considered in each of the other bands. If the number of candidates is greater than 2, then the bandmerger had to resolve the choice based on examination of the different band-pair combinations and position (and flux in-band) χ^2 differences between candidates. If the number of candidates is greater than 1, the confusion flag is set.

15 column pulldown corrected ([3.6] and [4.5] bands)
This bit is set if the source is within 3 pixels of a column pulldown corrected pixel.

19 data predicted to saturate
This bit is set when a source is within 3 pixels of a pixel identified in the SSC IRAC dmask as being saturated (bit 10 in the dmask). GLIMPSE runs a saturated pixel predicter and sets bit 10 in the dmask. This program finds clusters of high-valued pixels. The cluster size and high pixel value are tuned so that sources above the IRAC saturation limits are flagged as saturated. Before photometry is done on an IRAC frame, these pixels are masked.

20 saturated star wing region
False sources can be extracted in the wings of saturated sources. This bit is set if the source is within a PSF-shaped region (with a 24-pixel radius) surrounding a saturated source determined from bit 10 in the dmask. See Figure 13 for an example of the shapes of the saturated star wing areas flagged by this bit. Sources with this bit set are culled from the Catalog.

21 pre-lumping in in-band merge
Sources in the same IRAC frame within a radius of 1.6″ are merged into one source (weighted mean position and flux) before bandmerging. This is potentially a case in which the source is incompletely extracted in one IRAC frame and a second source extracted on another IRAC frame. Or it could be a marginally resolvable double source. This bit is set for the band if sources have been lumped for that band.

22 post-lumping in cross-band merge
This bit is set if the source is a result of sources that were lumped in the cross-band merge step. Cross-band lumping is done with a 1.6″ radius. For example, say there are two sources within 1.6″ of each other. One source has data in bands K_s and [3.6] and the other has data in band [4.5].

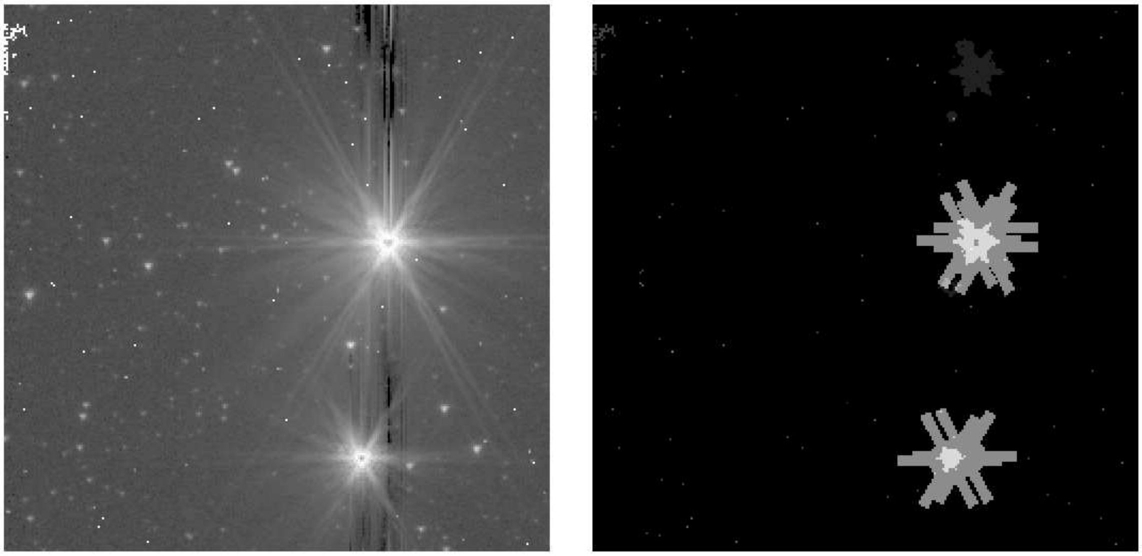

Figure 13: The [3.6] GLIMPSE360 IRAC frame (AOR 32845568, exposure 141) is on the left; the flags for that frame are shown on the right. The PSF-shaped areas around the bright sources correspond to SQF bit 20. Latent images are flagged at the top of the image, above the bright source. Various small dots are hot, dead or bad pixels (SQF bit 8). Bits in the SQF will have been set for sources within 3 pixels of any of the bad pixels.

These two sources will be lumped into one source with data in two IRAC bands.

30 within three pixels of edge of frame
Sources within three pixels of the edge of the IRAC frame are flagged since it is likely to be too close to the edge of the frame for accurate photometry to be done. Sources with this bit set are culled from the Catalog.

A.2 2MASS Source Quality Flag

For the 2MASS bands, the following contamination and confusion (cc) flags from the 2MASS All-Sky Point Source Catalog are mapped into bits 3, 4, 9 and 20 of the source quality flag. For more information about the cc flags, see
www.ipac.caltech.edu/2mass/releases/allsky/doc/sec2_2a.html#cc_flag. Users should consult the 2MASS PSC documentation for the complete information about the source, including all of their source quality flags.

bit
3 “p” persistence
Source may be contaminated by a latent image left by a nearby bright star.

4 “c” photometric confusion
Source photometry is biased by a nearby star that has contaminated the background estimation.

9 “s” electronic stripe
Source measurement may be contaminated by a stripe from a nearby bright star.

14 confusion in cross-band merge

This bit is set during the bandmerging process. The bandmerger reports, for each source and band, the number of merge candidates it considered in each of the other bands. If the number of candidates is greater than 2, then the bandmerger had to resolve the choice based on examination of the different band-pair combinations and position χ^2 differences between candidates. If the number of candidates is greater than 1, the confusion flag is set.

20 "d" diffraction spike confusion
Source may be contaminated by a diffraction spike from a nearby star.

22 post-lumping in cross-band merge
This bit is set for all bands (IRAC and 2MASS) if the source is a result of sources that were lumped in the cross-band merge step. Cross-band lumping is done with a 1.6″ radius.

23 Photometric quality flag
24 Photometric quality flag
25 Photometric quality flag

```
   2MASS           SQF bits
 "ph" Flag  =>    23, 24, 25      value
 -------------  ---------------- ----------
    X              0   0   0             0
    U              1   0   0       4194304
    F              0   1   0       8388608
    E              1   1   0      12582912
    D              0   0   1      16777216
    C              1   0   1      20971520
    B              0   1   1      25165824
    A              1   1   1      29360128

  where

 X - There is a detection at this location, but no valid brightness estimate can be
      extracted using any algorithm.

 U - Upper limit on magnitude. Source is not detected in this band or it is detected,
      but not resolved in a consistent fashion with other bands.

 F - This category includes sources where a reliable estimate of the photometric
      error could not be determined.

 E - This category includes detections where the goodness-of-fit quality of the
      profile-fit photometry was very poor, or detections where psf fit photometry
      did not converge and an aperture magnitude is reported, or detections where
      the number of frames was too small in relation to the number of frames in
      which a detection was geometrically possible.

 D - Detections in any brightness regime where valid measurements were made
      with no [jhk]_snr or [jhk]_cmsig requirement.
```

```
C - Detections in any brightness regime where valid measurements were made
     with [jhk]_snr>5 AND [jhk]_cmsig<0.21714.

B - Detections in any brightness regime where valid measurements were made
     with [jhk]_snr>7 AND [jhk]_cmsig<0.15510.

A - Detections in any brightness regime where valid measurements were made
     with [jhk]_snr>10 AND [jhk]_cmsig<0.10857.
```

B.3 Key to Bit Values

This section describes how to determine the bit values of a Source Quality Flag.

bt = bit in sqf
value = $2^{(bit-1)}$ i.e. bit 3 corresponds to 2^2=4

bit values: bt 1 => 1; 2 => 2; 3 => 4; 4 => 8; 5 => 16; 6 => 32; 7 => 64; 8 => 128 bt 9 => 256; 10 => 512; 11 => 1024; 12 => 2048; 13 => 4096; 14 => 8192; 15 => 16384; bt 16 => 32768; 17 => 65536; 18 => 131072; 19 => 262144; 20 => 524288; bt 21 => 1048576; 22 => 2097152; 23 => 4194304; 24 => 8388608; 25 => 16777216; 30 => 536870912

For example, the Source Quality Flags in the example in Table 10 are 29360128 for the 2MASS J, H and K_s bands. This translates to bits 23, 24 and 25 being set, which is the photometric quality A flag from the 2MASS PSC. IRAC [3.6] has a SQF of 512. Bit 10 was set which means tweaking was done in the source extraction. IRAC [4.5] SQF is 525312. This means bit 11 was set which means the tweaking has been done in the source extraction. Bit 20 was also set which means the source was within a saturated star wing area.

7 REFERENCES

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GLOSSARY

2MASS	Two Micron All Sky Survey
APOGEE	The Apache Point Observatory Galactic Evolution Experiment
Cygnus-X	CYGX-A Spitzer Legacy Survey of the Cygnus-X Complex
dmask	A data quality mask supplied by the SSC for the BCD
GLIMPSE	Galactic Legacy Infrared Midplane Survey Extraordinaire
APOGLC	APOGLIMPSE Point Source Catalog
APOGLA	APOGLIMPSE Point Source Archive
GQA	GLIMPSE Quality Assurance
HDR	High Dynamic Range
IPAC	Infrared Processing and Analysis Center
IRAC	*Spitzer* Infrared Array Camera
IRS	*Spitzer* Infrared Spectrometer
IRSA	InfraRed Science Archive
MF	Method Flag used to indicate exposure times included in the flux
OSV	Observing Strategy Validation
pmask	A bad pixel mask supplied by the SSC for the BCD
PSF	Point Spread Function
rmask	Outlier (radiation hit) mask
SMOG	Spitzer Mapping of the Outer Galaxy
SOM	*Spitzer* Observer's Manual
SSC	*Spitzer* Science Center
SED	Spectral energy distribution
SQF	Source Quality Flag
SST	*Spitzer* Space Telescope
WISE	Wide-field Infrared Survey Explorer