The Pan-STARRS1 Database and Data Products

H. A. Flewelling, E. A. Magnier, K. C. Chambers, J. N. Heasley, C. Holmberg, M. E. Huber, W. Sweeney, C. Z. Waters, A. Calamida, S. Casertano, X. Chen, D. Farrow, G. Hasinger, R. Henderson, K. S. Long, N. Metcalfe, G. Narayan, A. Rest, R. P. Saglia, A. Szalay, R. P. Kudritzki, P. A. Price, and B. Shiao

Institute for Astronomy, University of Hawai‘i, 2680 Woodlawn Drive, Honolulu, HI 96822, USA

Canada-France-Hawaii Telescope, 65-1238 Mamalahoa Hwy., Kamuela, HI 96743, USA

Back Yard Observatory, P.O. BOX 68856, Tucson, AZ 85737, USA

Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA

Google Inc., 1600 Amphitheatre Parkway, Mountain View, CA 94043, USA

Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraße 1, D-85748 Garching, Germany

Spire Global, Sky Park 5, 45 Finnieston Street, Glasgow, G3 8JU, UK

Department of Physics, Durham University, South Road, Durham DH1 3LE, UK

Institute for Computational Cosmology, Department of Physics, Durham University, South Road, Durham DH1 3LE, UK

Centre for Extragalactic Astronomy, Department of Physics, Durham University, South Road, Durham DH1 3LE, UK

Department of Physics and Astronomy, The Johns Hopkins University, 3400 North Charles Street, Baltimore, MD 21218, USA

Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA

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Abstract

This paper describes the organization of the database and the catalog data products from the Pan-STARRS1 3π Steradian Survey. The catalog data products are available in the form of an SQL-based relational database from MAST, the Mikulski Archive for Space Telescopes at STScI. The database is described in detail, including the construction of the database, the provenance of the data, and how the database tables are related. Examples of queries for a range of scientific goals are included.

Unified Astronomy Thesaurus concepts: Astronomy databases (83); Sky surveys (1464); Photometry (1234); Astrometry (80)

1. Introduction

For nearly 4 yr, from 2010 May through 2014 March, the 1.8 m Pan-STARRS1 telescope (PS1) was used to perform a set of astronomical surveys with wide-ranging scientific goals. The largest portion of the observing time (56%) was used for the so-called 3π Survey, covering the three-quarters of the sky north of −30° decl., easily observable by PS1 from its site on the summit of Haleakala on the Hawaiian island of Maui. The wide-field optical design of the telescope (Hodapp et al. 2004) allowed PS1 to observe most of the 3π Survey area in each of five filters (g_P1, r_P1, i_P1, z_P1, y_P1) between 10 and 15 times. Another 25% of the observing time was dedicated to the Medium-Deep (MD) Survey, in which 10 fields were repeatedly observed over the course of the 4 yr mission. The Pan-STARRS1 Gigapixel Camera (GPC1), consisting of an 8 × 8 grid of 4846 × 4868 pixel CCDs covering roughly 7 deg², has a pixel scale of 0.257. The telescope optics and the natural seeing of the site result in good image quality which is fully sampled by the GPC1 pixels: 75% of the 3π Survey images have FWHM values less than (1.5", 1.4", 1.3", 1.3", 1.2") for (g_P1, r_P1, i_P1, z_P1, y_P1), with a floor of ~0.7".

This is the sixth in a series of seven papers that describe the Pan-STARRS1 Surveys, the data processing algorithms, calibration, and the resulting data products. Chambers et al. (2016, Paper I) describe the Pan-STARRS1 Surveys, an overview of the Pan-STARRS1 System, the resulting image and catalog data products, a discussion of the overall data quality and basic characteristics, and a summary of important results. Magnier et al. (2020a, Paper II) describe how the various data processing stages of the Pan-STARRS Image Processing Pipeline (IPP) are organized and implemented. Waters et al. (2020, Paper III) describe the details of the pixel processing algorithms, including detrending, warping, and adding (to create stacked images) and subtracting (to create difference images), and the resulting image products and their properties. Magnier et al. (2020b, Paper IV) describe the details of the source detection and photometry, including point-spread-function (PSF) and extended source fitting models, and the techniques for forced photometry measurements. Magnier et al. (2020c, Paper V) describe the final calibration process and the resulting photometric and astrometric quality. This paper (Paper VI) describes the Pan-STARRS1 database, the data products, and details of their organization in the Pan-STARRS1 database. M. Huber et al. (2020, in preparation, Paper VII) will describe the MD Survey in detail, including the unique issues and data products specific to that survey.

In this article, we use the following typefaces to distinguish different concepts:

1. SMALL CAPS for the analysis stages.
2. Italics for database tables and columns.
3. Fixed-width font for program names, variables, and miscellaneous constants.

2. Background

The Pan-STARRS Project teamed with Alex Szalay’s database development group at The Johns Hopkins University (JHU) to undertake the task of providing a publicly accessible database for Pan-STARRS1 (Heasley 2008). The JHU team was the major developer of the Sloan Digital Sky Survey.
images were reprocessed from scratch using a specific implementation for internal use as well as for the public release, all of the raw data set, the wide variety of image and measurement types, and the importance of temporal information, major changes to the code base were required. Like the SDSS database, the database implementation for Pan-STARRS1 is based on the Microsoft SQL Server product line, with supporting code forked from the SDSS Catalog Archive Server Jobs System (CasJobs). Staying with SQL Server allows the use of a wealth of software developed for SDSS, including the Hierarchical Triangular Mesh tools (Szalay et al. 2007). The system developed for Pan-STARRS1 is called the Published Science Products Subsystem, or PSPS (Heasley et al. 2006).

As a widely used database engine, the Microsoft SQL Server provides a robust tool to define, build, and query the full database. The engine implements the SQL relational database language: data within different tables of the database are related to data in other tables by common fields, or indexes. In the PSPS implementation, the relationships are largely hierarchical: many measurements are linked to the images from which they came; associated measurements from the same astrophysical object are linked together to those objects. The tables use unique indexes to form these relationships, as detailed throughout this article.

The most significant challenge for the PSPS relative to the SDSS database implementation was the need to address the very large volume of Pan-STARRS1 data. The single monolithic database design of SDSS could not scale to the level needed for PS1 data. While SQL Server does not have (at present) a cluster implementation, a bespoke version can be crafted using a combination of distributed partition views and data slices (Heasley 2008). Partitioning data into smaller databases spread over multiple server machines allows the information to be presented to the users as a single, unified table.

3. Processing Versions and Data Releases

The Pan-STARRS data released to the community has been processed several times. All data is processed immediately by the data analysis system in order to discover moving and transient objects. This nightly science processing is streamlined and designed to allow fast access to the results by the Pan-STARRS1 Moving Object Processing System (MOPS; Denneau et al. 2013) and the PS1 science consortium, typically within a few hours after observation, for the discovery of moving objects, supernovae, and other time-sensitive transients. We refer to the nightly science processing as Processing Version 0 (PV0). On longer timescales, large portions of the data have been reprocessed, either for internal use or for external release. The 3π Survey data spans >4 yr of observations (2010–2014, with some observations in 2009 and 2015), a time during which the IPP was actively being developed and improved. To make a consistent set of data, both for internal use as well as for the public release, all of the raw images were reprocessed from scratch using a specific revision number of the IPP code. During the survey, the 3π Survey data were reprocessed twice for internal access by the consortium members, making use of improvements to the calibrations and the processing algorithms. These internal releases are considered PV1 and PV2. The data released to the public in DR1 and DR2 represent a third full-scale reprocessing of the data, PV3.

This paper covers multiple data releases. The first Pan-STARRS1 data release (DR1, database opened to public in 2016 December) covers the 3π STACK images and the static sky catalog. The DR1 image products are deep stacked images along with ancillary data including signal, masks, variance, and number maps. The DR1 catalog data products available from the PSPS include the PS1 static sky 3π catalog. Source properties are organized into several tables, as described in Table 1; only tables referring to the static results, without time domain information, are included in DR1.

Data Release 2 (DR2, database opened to public in 2019 January), adds more of the PS1 image products from the 3π Survey, including the single-epoch WARP images and their ancillary data, such as signal, masks, and variance maps. DR2 provides the Detection tables and Forced13 tables, containing the single-epoch source detections and the forced photometry. DR2 also contains numerous improvements to the data products in DR1, which it supersedes. Future data releases are anticipated to provide the 3π DIFF image products and catalogs and analogous data products for the MD surveys.

4. Overview of the Data Products

Public access to the Pan-STARRS data is through the web server located at https://panstarrs.stsci.edu and is hosted by the Barbara A. Mikulski Archive for Space Telescopes (MAST) at STScI. MAST provides the access point for downloading different pixel data products and their associated metadata and source catalogs. This includes FITS images, FITS and JPEG image cutouts, scriptable image access, color JPEG images, and an interactive image browser with catalog overlays through the MAST portal and the MAST PS1 image cutout server. In addition, MAST provides a simple web-based interface to access the Pan-STARRS catalog database. Full database access to the Pan-STARRS tables is available through the CasJobs interface (see description at https://mastweb.stsci.edu/ncasjobs). CasJobs emulates local free-form SQL access in a web environment and provides both synchronous and asynchronous query execution. The interface can execute complex, large queries of the PS1 (DR1/DR2) catalogs, with results saved to a private space allocated to each registered user. The Pan-STARRS catalog database accessible through CasJobs contains calibrated catalogs of photometric and astrometric parameters for single-epoch exposures, stacks, difference images, and forced photometry. The database schema for the Pan-STARRS catalog database is briefly described in Section 7 and is fully expanded in Appendix D. Examples of queries are described in Appendix A.

The Pan-STARRS1 catalog database schema is organized into four sections:

1. Fundamental Data Products. These are attributes that are calculated from either detrended but untransformed pixels or warped pixels. It should be noted that, once in the database, the instrumental fluxes and magnitudes have been subject to recalibration, as have the sky coordinates. Because of these recalibrations on the catalogs, the catalog values are to be preferred to making a new

13 In this article, we refer to groups of tables with the same base name using the file “glob” convention where, e.g., Forced refers to a collection of tables starting with Forced.
Table 1
Summary of the Different Database Tables, Their Types, and Other Comments

| PSPS Table Name                        | Table Type         | Release |
|---------------------------------------|--------------------|---------|
| Filter                                | System Metadata    | DR1     |
| FitModel                              | System Metadata    | DR1     |
| Survey                                | System Metadata    | DR1     |
| PhotoCal                              | System Metadata    | DR1     |
| StackType                             | System Metadata    | DR1     |
| DiffType                              | System Metadata    | DR1     |
| TessellationType                      | System Metadata    | DR1     |
| ImageFlags                            | System Metadata    | DR1     |
| DetectionFlags                        | System Metadata    | DR1     |
| DetectionFlags2                       | System Metadata    | DR1     |
| DetectionFlags3                       | System Metadata    | DR1     |
| ObjectInfoFlags                       | System Metadata    | DR1     |
| ObjectFilterFlags                     | System Metadata    | DR1     |
| ObjectQualityFlags                    | System Metadata    | DR1     |
| ForcedGalaxyShapeFlags                | System Metadata    | DR1     |
| ObjectThin                            | Object/Threshold   | DR1     |
| MeanObject                            | Object/Threshold   | DR1     |
| GaiaFrameCoordinate                   | Object/Threshold   | DR1 only|
| FrameMeta                             | Obs. Metadata      | DR2     |
| ImageMeta                             | Obs. Metadata      | DR1     |
| Detection                             | Detection table    | DR2     |
| ImageDefEffMeta                       | Obs. Metadata      | DR2     |
| StackMeta                             | Obs. Metadata      | DR1     |
| StackObjectThin                       | Detection table    | DR1     |
| StackObjectAttributes                 | Detection table    | DR1     |
| StackApFlx                            | Detection table    | DR1     |
| StackModelFitExp                      | Detection table    | DR1     |
| StackModelFitDeV                      | Detection table    | DR1     |
| StackModelFitSer                      | Detection table    | DR1     |
| StackApFlxExGalUnc                    | Detection table    | DR1     |
| StackApFlxExGalCon6                   | Detection table    | DR1     |
| StackApFlxExGalCon8                   | Detection table    | DR1     |
| StackPetrosian                        | Detection table    | DR1     |
| StackModelFitExp                      | Detection table    | DR1     |
| StackModelFitDeV                      | Detection table    | DR1     |
| StackModelFitSer                      | Detection table    | DR1     |
| ForcedMeanObject                      | Object/Threshold   | DR1     |
| ForcedWarpMeasurement                 | Object/Threshold   | DR2     |
| ForcedWarpLensing                     | Object/Threshold   | DR2     |
| ForcedWarpExtended                    | Object/Threshold   | DR2     |
| ForcedWarpMeasurement                 | Object/Threshold   | DR2     |
| ForcedWarpMasked                      | Detection table    | DR2     |
| ForcedWarpLensing                     | Detection table    | DR2     |
| ForcedWarpToImage                     | Detection table    | DR2     |
| Difference                             | DiffDetection      | DR3     |
| DiffDetObject                         | Object/Threshold   | DR3     |
| DiffMeta                              | Obs. Metadata      | DR3     |
| DiffDetection                         | Detection table    | DR3     |
| DiffToImage                           | Obs. Metadata      | DR3     |
| DiffDefEffMeta                        | Obs. Metadata      | DR3     |

Note. The column labeled “Release” specifies the first Data Release a specific product became available. Note that all of the DR1 tables were regenerated for DR2, in order to address minor bugs and inconsistencies discovered in DR1.

Table 2
Fundamental IPP Data Product Database Tables

| Table Class | PSPS Table Name     | Source     | Release |
|-------------|---------------------|------------|---------|
| Object      | ObjectThin          | dvo        | DR1     |
|             | MeanObject          | dvo        | DR1     |
|             | GaiaFrameCoordinate | dvo        | DR1     |
| Detection   | Detection           | dvo and sky cal cmf | DR2 |
|             | StackObjectThin     | dvo and sky cal cmf | DR1 |
|             | StackObjectAttributes| dvo and sky cal cmf | DR1 |
|             | StackApFlx          | dvo and sky cal cmf | DR1 |
|             | StackApFlxExGalUnc  | dvo and sky cal cmf | DR1 |
|             | StackApFlxExGalCon6 | dvo and sky cal cmf | DR1 |
|             | StackPetrosian      | dvo and sky cal cmf | DR1 |
|             | StackModelFitExp    | dvo and sky cal cmf | DR1 |
|             | StackModelFitDeV    | dvo and sky cal cmf | DR1 |
|             | StackModelFitSer    | dvo and sky cal cmf | DR1 |
|             | ForcMeanObject      | dvo        | DR1     |
|             | ForcWarpMeasurement | dvo and forced warp cmf | DR2 |
|             | ForcWarpLensing     | dvo and forced warp cmf | DR2 |
|             | ForcWarpExtended    | dvo and forced warp cmf | DR2 |
|             | ForcGalaxyShape     | dvo        | DR2     |
|             | ForcWarpMasked      | dvo and forced warp cmf | DR2 |
|             | Difference          | DiffDetection| dvo and diff sky cal cmf | DR3 |
|             | DiffDetObject       | dvo        | DR3     |

2. Derived Data Products. These are higher-order science products that have been calculated from the fundamental data products, such as proper motions and photometric redshifts. These data products are not yet available and will come in later data releases.

3. Observational Metadata. These metadata provide detailed information about the individual exposures (e.g., information like exposure time, filter used, etc.) or about which exposures went into an image combination (stacks and diffs), as well as information such as detection efficiencies.

4. System Metadata. These tables have fixed information about the system and the database itself, primarily descriptions of various flags and their bits, but also for other metadata such as filter information.

Various database “Views” are also constructed as an aid to the user for standard types of queries. Views act like tables and primarily consist of joins of different commonly used tables, in order to simplify queries. Views are also used to join slices of tables (sliced by area of sky) into a full sky view. For example, “Detection” is a view of 32 Detection tables, but the individual tables are hidden from the user. For more information on views, including the currently defines ones, see Table 8.

This paper covers the data products and schema for the 3π data releases, though most details also apply to the MD fields. Additional documentation is available together with the data products through MAST.

5. Flow of Data from Pipeline to the Pan-STARRS Catalog Database

This section presents a condensed version of the flow of data starting with raw image processing by the Pan-STARRS IPP
and ending with the steps used to generate the PSPS database. The description includes an overview of the various terms used to describe different data products. For the full description of these steps, see Paper II. A flowchart of the whole process is shown in Figure 1.

Exposures are first processed by the IPP, producing measurements of the sources in the individual images, stacks, and difference images. These measurements are then ingested into an instance of the "Desktop Virtual Observatory" database system (DVO, described briefly in Section 5.2 and more extensively in Paper V). The DVO database is then calibrated (Paper V). Next, the IPPToSPS combines the measurements with the calibrations and transforms them into the appropriate format for the PSPS. Data in this form are loaded into the PSPS database at the University of Hawaii’s Institute for Astronomy (IfA). The PSPS database is then copied to STScI and made available to the users.

5.1. Processing Stages

Processing with the IPP takes place in several stages. Because the organization of the PSPS database is tied to these processing stages, we describe them in some detail here. For further information, see Paper II for the overall analysis sequence, Paper III for the details in the detrending and other pixel manipulation, Paper IV for the source detection and characterization, and Paper V for the photometric and astrometric calibration.

5.1.1. Download and Registry of Images

Before processing of images can take place, they must first be transferred to the IPP cluster from the summit and registered in a metadata database to ensure that all of the >1.3 million images taken by Pan-STARRS have been properly handled. This is represented as the "image" → "ipp processing" step in Figure 1. The IPP uses an internal database to track all parts of the image processing. This database keeps basic metrics relevant to each stage, including details on what type of image was taken, when an image was processed, how long processing took, flags and other metrics on the quality, etc. This internal processing database is referenced to in this paper as the "GPC1" database.

5.1.2. Chip and Camera Stages

The next step, the WARP stage, is represented as "camera" → "stacks" in Figure 1. The WARP stage geometrically transforms the output images from the CHIP stage to a common pixel grid.
defined on a tangential R.A./decl. plane, with 0''25 pixels. The output images, called “skycells,” cover the entire sky; thus, an image from a PS1 exposure can be split and projected onto a common layout for its portion of the sky. For 3\pi, the skycell tessellation\textsuperscript{14} is called Rings.V3 and is described in detail in Paper II. This tessellation subdivides the sky into projection cell rings with centers at constant decl. For 3\pi, the skycell tessellation subdivides the sky into projection cell rings with centers at constant decl. Each projection cell is \sim4°0 \times \sim4°0, subdivided into 10 \times 10 skycells, each with 60'' of overlap on a side, yielding square image with size ranging from 6240 to 6500 pixels on a side. All image data products beyond WARP (STACKS/FORCED WARP/DIFFS/ etc.) are laid out in skycells as well.

The warp image products are available to users via MAST for the 3\pi Survey as part of DR2.

5.1.4. Stack, Staticsky, Skycal Stages

There are three stack-related stages: STACK, STATICSKY, and SKYCAL. The STACK stage generates the stacked images, STATICSKY generates the source catalogs files, while SKYCAL calibrates the source catalogs. All of the stack-related stages are represented as “stacks” in Figure 1.

STACKS are generated by adding together WARP skycells, with bad-pixel rejection and internal calibration as described in Paper III. Depending on the survey, stacks may be generated from different sets of raw exposures. For the deepest possible stacks, essentially all available exposures are combined, with only weak cuts on the data quality. Stacks may also be generated with a constraint on the image quality of the input exposures in order to yield a deep reference image with good image quality. In order to limit contamination from ongoing transient events, stacks may also be generated with constraints on the time range of the input exposures: out-of-season stacks would include only exposures not taken within a given year or period to act as a reference for transient events within that period. The different stack types are listed in the StackType table in the PSPS database. For the DR1 and DR2 3\pi databases, only the DEEP_STACK STACK type is used, i.e., all available WARP of sufficiently good quality for a given skycell and filter within the 3\pi Survey data set are used to generate the STACKS, yielding one STACK per skycell per filter. Mask images, variance images, and related pixel images are also generated for each stack.

Once each STACK image is created, source detection and characterization, including galaxy morphological analysis, are performed by the STATICSKY stage. The source analysis is run on all five filters at once. PSF photometry is forced for sources that are detected in at least two filter images on the other filter images for which the source was not detected above the 5\sigma threshold. This forced photometry is also performed for sources detected in only the y_p1 band.

Aperture photometry, for a series of circular apertures specified by SDSS (Stoughton et al. 2002), is performed on the raw stacks and also on stack images that have been convolved to a common 6 pixel FWHM, and again to a common 8 pixel FWHM. These latter seeing-matched images are only kept in memory for the analysis and are not written to disk. Up to nine of the SDSS apertures are used for this measurement: R3 (r = 1''03), R4 (r = 1''76), R5 (r = 3''00), R6 (r = 4''63), R7 (r = 7''43), R8 (r = 11''42), R9 (r = 18''20), R10 (r = 28''20), and R11 (r = 44''21). Note that the measurement is performed in apertures with the same angular diameter as used for SDSS, which necessarily results in different radii in pixels from those used by SDSS apertures (see Table 7 in Stoughton et al. 2002). For more details on the photometric analysis of the stack images, see Paper IV.

Catalog files, one per filter, are generated with sources spatially matched between filters using a 5 pixel (1''25) correlation radius. Sources matched as across filters are linked in the output catalog by the detection ID. The SKYCAL stage calibrates the STATICSKY stage relative to the reference catalog. The calibrated catalog files are later ingested into the DVO database and then into the PSPS database. Due to the overlap between skycells, sources that land in the overlaps can be reported two, three, or four times in the DVO and PSPS database. See the discussion in Section 7.4.2 regarding the “primary” and “best” stack measurements.

Stack data products are available for the 3\pi Survey as part of DR1 and DR2. Stack image products are available to users via MAST, and Stack-related tables are available in the PSPS database.

5.1.5. Forced Warp Photometry Stage

Sources that are detected in the stack images are used to measure forced photometry on each of the input warps in the FORCED WARP PHOTOMETRY stage. Two types of forced photometry analysis are performed on the WARP exposures: PSF photometry and galaxy model analysis.

In the forced warp photometry stage, the positions of sources located in the deep STACKS are used to fix the position in the warp images. The software then measures the PSF model flux at those positions on each of the individual warps. This measurement also yields the Kron and aperture fluxes for the warp image at that location. The catalogs generated by this process are ingested into the DVO database and average values are then calculated. Note that the fluxes on the warps for faint objects may be insignificant or even negative; the average values are calculated using all flux values (both positive and negative) properly weighted by the detection flux errors. Only measurements for which the warp pixels were excessively masked are rejected in this average flux calculation. The individual measurements and the averages are translated by the IPPTOPSPS stage into the ForcédWarp\textsuperscript{1} tables for the PSPS. For the 3\pi Survey, these tables are available starting with DR2.

For extended sources, galaxy models are fitted on the STACK images. These models are then used as a seed to determine galaxy models for each warp image. The position, aspect ratio, and (where appropriate) Sérsic radius are kept fixed to the values determined for the stack image. A grid of major and minor axis values is tested around the values from the stack fit for each warp image, with the galaxy model convolved with the PSF appropriate to the specific warp image. The software reports the model normalization and \chi^2 value at each grid point; these are combined together across all warp exposures and the interpolated minimum \chi^2 value is used to determine a best-fit galaxy model. Due to size constraints, only the average galaxy model results are propagated to the PSPS database. These are later ingested into the PSPS database as the ForcédGalaxy\textsuperscript{1} tables.

The extended source (galaxy) models described above are not applied to all sources. Galaxy models are only applied if the measured Kron magnitudes are brighter than the following limits for at least one filter: (g_p1, r_p1, i_p1, z_p1, y_p1) = (21.5, 21.5,
21.5, 20.5, 19.5). In addition, galaxy models and Petrosian fluxes are only measured for skycells with centers outside of a Galactic plane exclusion zone defined for the 3π Survey as

\[ |b| > b_0 + r_b e^{\frac{\pi}{l}}, \]

where \( b_0 = 20^\circ \), \( r_b = 15^\circ \), and \( \sigma_b = 50^\circ \) and \( l \), the Galactic longitude, is constructed to have a domain of \(-180^\circ \) to \(+180^\circ \). Thus, both apparently stellar and nonstellar sources outside of the dense portions of the Galactic plane and bulge have galaxy models and Petrosian fluxes measured (see full discussion in Paper IV).

### 5.1.6. Diff Stage

Difference images are generated by the IPP in order to detect transient and moving objects. Several types of difference images may be generated by the IPP depending on the type of images that are involved in the subtraction. The WARP\_WARP diffs are generated by subtracting warps from a pair of exposures, usually taken within a short period of time; these are primarily used by the nightly science processing and the MOPS analysis for inner solar system processing and the MOPS association for nonstellar sources. For transient detections from the 3π Survey data, STACK\_STACK diffs are generated by subtracting a deep reference stack from a stack of multiple exposures taken over a longer period. The STACK\_STACK diffs are used for supernova discovery in the MD survey fields with eight exposures taken in sequence and stacked to make a more sensitive single-epoch observation. The WARP\_STACK diffs were generated for the 3π Survey by combining warps from single exposures with a deep reference stack. These diffs are also used for MOPS and transient discoveries, and will be provided for the full 3π Survey as a temporal reference. There is one DIFF image for each single exposure within the 3π Survey. Finally, STACK\_WARP diffs could be made in principle but are not in practice used by the IPP.

For the difference image analysis, the input images (STACK or WARP) are convolved to have similar PSFs (Waters et al. 2020) and one subtracted from the other. Sources are detected on the difference image, basic photometry is performed on the sources, and DIFF catalog files are created. The DIFF catalog files are then ingested into the DIFF DVO and later ingested into the PSPS. The results from this stage of processing include diff catalog files, which will be available in a future release (nominally DR3). At this time, it is undecided if, as part of DR3, the complete collection of PV3 difference images will be stored at MAST or if they will be generated on demand. Within the IPP, difference images are generally stored on disk only for a short period of time (days to weeks) in order to save on storage space. When needed, historical difference images are regularly regenerated based on stored results (difference kernels and PSF models). MAST may rely on this process for DR3.

### 5.2. DVO Database Steps

The DVO (Magnier & Cuillandre 2004; Magnier et al. 2020c) is a database that tracks the measurements of astronomical sources detected in the various types of images and associates them into unique astronomical objects based on positional coincidence. This database system also tracks the metadata for each image that provided the measurements. The DVO database is loaded with a subset of photometric, astrometric, and other information from the catalog FITS files (smf/cmfs) from various IPP stages. The DVO database is then used to determine the astrometric and photometric calibrations for all survey images. These calibrations are in turn used to calculate the average properties of the astronomical objects (see Paper V).

Catalog files from several stages of IPP processing are ingested into the DVO database via the IPP program addstar. The relevant stages are CAMERA (all measurements from the individual exposures), SKYCAL (measurements from the stacks), and FORCED WARP (forced photometry and the forced galaxy model fits from the warps). Difference image catalogs are ingested into the separate diff DVO database.

Measurements from 2MASS, WISE, and Gaia are also merged into the DVO database; flags within the DVO database, and inherited by the PSPS database, note the presence of data from these surveys. Gaia DR1 (Gaia Collaboration et al. 2016) was released before the Pan-STARRS DR1 was complete, but after all of the object tables were already ingested into the PSPS database. We used the Gaia DR1 data to recalibrate the DVO object positions, which improved the astrometry significantly. Rather than regenerate the database and start over (with corrected R.A. and decl. positions), we arranged for the IPPTOPSPS system to export just the newly calibrated positions along with minimal metadata to link the new coordinates with the existing objects. See Section 5.3 for the special table that carries the Gaia DR1 calibration into the 3π Survey DR1 release. For the 3π Survey DR2, the calibration is tied directly to the Gaia DR1 astrometric system (Paper V).

The DVO database system uses a collection of binary FITS tables as the backend. These files define a spatial partition of the database, divided on lines of constant R.A. and decl. For a given file type, the database contains several thousand such files. Several categories of DVO files are used by IPPTOPSPS to populate the PSPS database. Here we give a short summary of the subset of DVO files that are most relevant for IPPTOPSPS (see Paper II for more details).

- .cpt: Object information—each .cpt table has one entry for each object in that region of the sky. It summarizes the average properties of that object as long as those properties can be derived independently of the filter used. Information such as mean R.A. and decl. is listed in these files.
- .cpl: Measurements—each .cpl table contains all of the measurement information for each object in the .cpl file. Contains measurement information for detections from the stack/sky, camera smfs, and forced warp smfs.
- .cpx: Lensing measurements—the .cpx files contain lensing parameters measured from all the forced warp cmfs.
- .cpx: Lensing Objects—the .cpx file has one entry per filter for each object in that region of the sky, same object ids as for objects in the .cpl file. It summarizes the average properties of the lensing measurements.
- .cpx: Forced Galaxy—the .cpx file has one entry per filter for each object in that region of the sky, same object IDs as for objects in the .cpl files. It summarizes the extended source galaxy shape measurements.
5.3. IppToPsps Steps

The DVO database contains the calculated astrometric and photometric calibrations and average properties of the astronomical objects but only a subset of the information recorded by the IPP in the output catalog files. It is therefore necessary, when building the PSPS database, to combine the calibrations from the DVO database with the full set of data from the individual smf and cmf files. It is also necessary to extract the average quantities from the DVO database to be uploaded to the PSPS database. The IPPTOPSPS system is responsible for both of these actions. The IPPTOPSPS system extracts the average properties from the DVO database in units of the DVO sky partition files and generates file sets called “batches” containing the information formatted according to the PSPS schema. IPPTOPSPS generates average property batches separately for measurements from individual exposures, difference exposures, and exposures measured at the FORCED WARP stage. In addition, for the 3π Survey DR1, mean property batches are generated for the astrometry tied to the Gaia DR1 catalog (Gaia Collaboration et al. 2016).

The IPPTOPSPS system also extracts calibration information and calibrated measurements for the CAMERA, STACK, FORCED WARP, and DIFFERENCE stages and combines those values with the raw measurements stored in the smf/cmf files. Batch files are generated for the CAMERA-stage data for each exposure. For data from the other three stages, batches are generated for individual sky cells. In the case of the STACK data, the batch contains data for the stack images from all five filters. For the FORCED WARP stage, the batch contains data from all warp epochs for a given sky cell.

The batches generated by the IPPTOPSPS are made available to the PSPS ingest system using an internal web-based interface called a “datastore.” The IPPTOPSPS software is written in Python/Jython, using the STILTS library (Taylor 2006) to interact with the FITS tables. IPPTOPSPS also uses an MySQL database to track the processing and for temporary scratch databases. This process also queries the IPP processing database, retrieves files from the IPP cluster, and reads data from the DVO database.

Below we provide additional details on the different batch types generated by the IPPTOPSPS system. An overview of the different batch types and associated DVO files and smf/cmf files is shown in the flowchart in Figure 2.

Init batch (IN): Defines elements of the PSPS database structure and is the first to be ingested into PSPS. It includes the system metadata tables described in Section 7.2, with flag bits listed in Appendix C.

Object batches (OB): Populate the ObjectThin and Mean-Object tables, described in more detail in Section 7.3.
batch represents individual DVO files, which are subdivided into small rectangular patches of sky. Columns are filled from the DVO database (cpt and cps files).

Detection batches (P2): Populate the Detection tables, described in more detail in Section 7.4.1. Each batch corresponds to a single exposure from Pan-STARRS1. Columns within are filled from the DVO database (cpt and cpm files) as well as the CAMERA stage catalog file (smf).

Stack batches (ST): Populate the stack tables, described in more detail in Section 7.4.2. Each batch corresponds to a skycell from the SKYCAL stage. Columns are filled from the DVO database (cpt and cpm files) as well as from the corresponding SKYCAL catalog files (cmf) for all five filters (or what is available).

Forced mean object batches (FO): Populate the ForcedMeanObject and ForcedMeanLensing tables, described in more detail in Section 7.3. Each batch contains data from individual DVO files (cpt, cps, cpy).

Forced galaxy batches (FG): Populate the ForcedGalaxy-Shape table, described in more detail in Section 7.3. Each batch contains data from individual DVO files (cpt, cps, cpg).

Forced warp batches (FW): Populate the ForcedWarp* tables, described in more detail in Section 7.4.3. Each batch corresponds to a different skycell, and contains all of the FORCED WARP catalog measurements for that skycell. Each batch contains data from individual DVO files (cpt, cps, cpx) as well as from the corresponding FORCED WARP catalog files (cmf).

Diff object batches (DO): Populate the DiffDetObject table, described in more detail in Section 7.3. Columns are filled from the DVO DIFF database (cpt and cps files).

Diff detection batches (DF): Populate the DiffDetection table, described in more detail in Section 7.4.4. Each batch corresponds to a difference image catalog file created in the DIFF stage and contains all of the skycells for a given exposure. Columns are filled from the DVO database (cpt and cpm files), and from the corresponding DIFF catalog file (cmf).

Gaia object batches (GO): Populate the GaiaFrameCoordinate table, linking the Gaia DR1 calibrated positions to the ObjectThin entries by objID. It is based on exactly the same DVO files as OB batches, has updated R.A. and decl. calibrated to Gaia, and ignores the rest of the DVO columns. These batches, and this table, are only present for DR1. For DR2, additional calibration improvements were made within the DVO database (see Paper V). The average property batches were regenerated, making the GO batch irrelevant for that release.

Within IPPTOPSPS, it is possible to verify that the expected batches were generated, and to requeue and regenerate batches that failed. Batches fail for a variety of reasons, but none of the failures are terminal. Batches can fail if any of the associated mysql databases time out or are unavailable, or if there are disk or network I/O glitches or other disk/network problems. The DVO database sets the expected number of batches to generate, and failures are investigated and retried until they are resolved. Within IPPTOPSPS, it is also possible to poll the PSPS to verify if batches have been ingested, thus closing the loop.

6. PSPS

The PSPS consists of several parts: the data transformation layer (DXLayer), the Object Database Manager (ODM), the Workflow Manager Database (WMD), and the data retrieval layer (DRL). The user accesses the data through the DRL, using either scripts, the STScI CasJobs interface, or if the user is a Pan-STARRS1 Consortium member, the Published Science Interface (PSI). The DXLayer polls the IPPTOPSPS datastores for new batches and prepares them for loading. The ODM is the software used to load, merge, copy, and publish the PSPS databases. The WMD is the database containing all the logs about the PSPS databases. The DRL is the intermediate layer between the client and the PSPS database. The PSI is the web-based interface for PS1 consortium members, for interacting with the DRL. Each of these components is described in more detail below, and a diagram of the process is shown in Figure 3.

6.1. Partitioning the PSPS

The PSPS uses Distributed Partitioned Views, a mechanism that allows tables to be partitioned into files that reside in different linked servers. For the PSPS, the largest tables are partitioned into “slices,” which divide the sky into decl. bands. The database tables exposed to the end users (e.g., Detection, ForcedWarpMeasurement, etc.) are composed of views
combining the distributed slices. This aspect of the database design is intended to be transparent to the user, but power users may find it useful to know how the slices are subdivided. The dividing decl. cuts are defined to ensure each slice contains a similar amount of data, with the constraint that no slice spans less than a full camera footprint (3°3) due to the loading implementation. Partition slices are customized for each database version (e.g., 3π DR1, DR2 versus MD). Figure 4 shows how the data is partitioned across a subset of the machines. For the 3π Survey, the PSPS database is partitioned into 32 slices. Table 3 lists the names of the slices and the decl. ranges for each slice for the 3π Survey.

6.2. Loading Data into PSPS

The process of loading data into the PSPS is split into several stages in order to manage the large data volume, to ensure data integrity, and to allow portions of the database to be exposed to internal users for testing while loading proceeds. A top-level outline of the process is as follows. First, the PSPS DXLayer retrieves the batch files, generated by the IPPTOPSPS system, from the IPP datastore interface. These batch files are loaded into an initial set of database machines (the Load/Merge Nodes; see Figure 4). As batches are loaded, they populate a temporary set of tables, which grows as more batches are added. When enough batches have been loaded, these temporary tables are merged into the corresponding tables in the first instance of the PSPS database. This initial instance, called the Cold database, naturally changes on a regular basis as more data are added. When the PSPS team is ready to expose the database to end users, the Cold database is copied to one of the two database instances exposed to end users. In this period, the database, which is the target of the copy, cannot be queried, but users may continue to query the other database while the copy proceeds. When the copy is complete, the newly copied version is “flipped” with the active query database, and a second copy is performed. Now the end users are able to query the updated database while the second copy is made. After the copies are completed, one of the two user-end databases is used for short-lived queries (the Hot database), while the other is used for long-running queries (the Warm database). Below, we discuss in more detail the PSPS components involved in various loading stages as well as those used for the user query operations.

6.3. The Data Transformation Layer (DXLayer)

The DXLayer is the first stage in the PSPS to receive data from IPPTOPSPS. This stage polls the IPP datastore interface for new batches to load and prepares them for the next step (ODM). Figure 5 shows the flowchart of the DXLayer process, and Figure 6 shows a more detailed flowchart of how batches are loaded and verified within the DXLayer and ODM. Figure 7 illustrates the merge of the batches and the flip between Warm and Cold databases, PSPS loads batches created by the IPPTOPSPS (Section 5.3). Batches contain a manifest file that describes the batch information such as type of batch, min/ max objID, MD5 checksum, and the tables to load. Batch data
are stored in FITS files, which are transformed into comma-separated value (CSV) files in the DXLayer. As noted above, the batch area cannot exceed two PSPS slices or it will fail to load. The PSPS slices are constructed so that this does not happen.

6.4. The Object Data Manager (ODM)

The ODM is the software system that oversees the steps of the loading process described above. The nodes within the ODM have naming conventions for their roles: load/merge (Im), slice (s), head (h), and admin (a). The ODM processes represent each of the steps described above: load, merge, copy, flip. All logs, processes, and requests are inserted into an administration database called the Workflow Manager Database (WMD). Databases are named by the roles defined above: Load, Cold, Warm, Hot. These databases use the MS-SQL Server engine and are divided into four volumes with 96 file partitions each. While the large data tables are distributed across multiple “slice” machines, the smaller tables (the metadata tables, ObjectThin, GaiaFrameCoordinate, and StackObjectThin) are stored on a single “head” machine for faster queries.

6.5. The Data Retrieval Layer (DRL)

The DRL is the layer between the user and the PSPS database. The DRL is responsible for management of queries that the user submits via the DRL API. The DRL is based on CasJobs (Szalay et al. 2007) and has many similar features. It primarily keeps track of all user queries and provides progress updates of those queries in a secure way. It also kills queries that use too many resources or take too long. The DRL API is accessed via the Simple Object Access Protocol (SOAP; w3.org/TR/soap), allowing users multiple ways to access the database. Before the public releases, Pan-STARRS science consortium members used the Published Science Interface (PSI, a web-based user interface) initially based at the IfA and later at STScI. For the general public, the MAST server provides access via the CasJobs interface (https://mastweb.stsci.edu/ps1casjobs/), as well as a simple object search form which implements a basic cone search (https://catalogs.mast.stsci.edu/panstarrs). It is also possible for the consortium users to query the database via SOAP calls from command line scripts.

6.6. Published Science Interface (PSI)

The PSI is the web user interface provided to the Pan-STARRS Science Consortium members. This interface provides many useful features including a query request page, information on query progress, MyDB management tools, graphing tools, access to the pixel data products, and interactive help. The query request page allows the user to easily submit queries to a variety of databases (3pi/MD/MyDB), to upload query files or to check the syntax, to name MyDB results tables, and to select the queue to submit to. The MyDB management tools allow the user to

![Figure 5. A flowchart of the DXLayer process, showing how batches are loaded into the DXLayer, verified, and submitted to the ODM. The shaded rectangles refer to different systems, and the white boxes and white cylinder refer to difference steps for the systems.](image-url)
easily select which MyDB tables to purge as well as methods to extract to CSV, FITS, or XML files to download. Some of the interactive features include an interactive schema browser, a query builder to easily create a query with multiple joins and conditions, and a flag generator to create bitmasks for the different types of flag tables.

7. Overview of the PSPS Database Schema

Table 1 lists the 51 different database tables that make up the PSPS schema. Here we give a brief overview of the tables and indexes to help aid the user in selecting the most appropriate table for queries.

The database has a unique objID for each object detected within Pan-STARRS1 data. An object that has measurable flux at a given R.A. and decl. is defined to be a source. In general, multiple detections of an object will all share the same objID, as well as multiple detections within 1″ of that object (which might not be physically associated with that object, e.g., blended sources). A detailed description of the source deblending algorithm and its properties is beyond the scope of this work (see Paper IV). This objID is the core index used to join the object and detection tables in order to select detections associated with a given object. For example, ObjectThin has the astrometric information for the objects; one would join against the Detection table, using objID, in order to get the individual photometric attributes for all the detections of that object within the single exposures (at a given R.A. and decl.).

The index objID (and diffObjID for difference tables) is derived from R.A. and decl. While it is possible to calculate the R.A. and decl. from the objID, this is not recommended. The objID value is determined when an object is initially instantiated in the DVO database and is based on the initial astrometric solutions from individual exposures and STACKS as they are ingested into the DVO database. These values are not calibrated against 2MASS or Gaia, nor are they authoritative. Because DR1 and DR2 use the same initial DVO database ingestion, the objID values are the same for the same object between the two releases. Included below is the C code for the translation between R.A. and decl. See also Figure 8.

```c
uint64_t CreatePSPSObjectID(double ra, double dec) {
    double zh = 0.0083333;
    double zid = (dec + 90.) / zh;
    // zid : 0-180 * 60 * 2 = 21600 (<15 bits)
    int izone = (int) floor(zid);
    double zresid = zid - (float) izone;
    // zresid : 0-1.0
    uint64_t part1, part2, part3;
    part1 = (uint64_t) (izone * 10000000000000LL);
    part2 = ((uint64_t) (ra + 1000000.)) * 10000;
    // part2 : 0-360 * 1e6 = 3.6e8 (<29 bits)
    part3 = (int) (zresid * 10000.0);
    // part3 : 0-10000
    // (1 bit == 30/10000") (<14 bits)
    return part1 + part2 + part3;
}
```
Example objID calculation for

R.A. = 101.287155  
DEC = -16.7164089  
ZH = 0.0083333  
ZID = (Dec + 90)/ZH = 08794.0661  
ObjID = 087941012871550661  

R.A. = 101.287155

Figure 8. Graphical description of how objID is calculated from RA and decl. It is not recommended to derive the RA and decl. from objID as this will result in an inaccurate RA and decl. ObjID is assigned when the stack/skycal cnffs are ingested into the database and are not yet calibrated against 2MASS and Gaia. OBID is primarily used for indexing the database.

7.1. The Main Categories of Tables

There are four main types of tables within the PSPS database: **Fundamental Data Product** tables can be categorized into either **Object** tables (Section 7.3) or **Detection** tables (Section 7.4). **Object** tables contain summary information for each source in the sky, including the mean photometric and astrometric information. **Detection** tables contain photometric and astrometric measurements from individual exposures (**Detection**), stacked images (**Stack** tables), warp images (**forcedWarp** tables), or difference images. The description of the **Detection** tables below is organized by these processing stages (see also Section 5.1). **Observational Metadata** tables (Section 7.4) contain information about the individual exposures and other image types and provide links to map from images to measurements. **Derived Data Products** (e.g., photo-z measurements) will be incorporated into the PSPS database in the future and are not described in this paper. **System Metadata** tables (Section 7.2) contain hardwired information about the PSPS, including tables describing flags, tessellations and other fixed system-level quantities.

7.2. System Metadata Tables

The system metadata tables primarily contain static information of flags, filters, surveys and other information that is specific to Pan-STARRS1. Several tables describe the different flag bits used to indicate data quality or to identify details of how a measurement was made. These tables are described in Section 7.2.1. The other system metadata tables are described below:

**Filter**: Provides database indexes for the optical filters used in the survey (Tonry et al. 2012). Filters (gP1, rP1, iP1, zP1, yP1) are assigned integer values from 1 to 5 (filterID).

**FitModel**: Provides database indexes for models used in fitting detections in images, both PSF-like and extended galaxy models including exponential, de Vaucouleurs (1948), and Sérsic (1963) profiles. Describes the values for column psfModelID (located in various tables).

**Survey**: Provides database indexes for the various PS1 Science Consortium Surveys. The 3π SurveyID is 0.

**PhotoCal**: Contains photometric calibration information for each filter and detector image combinations. Defines the values of photoCalID within ImageMeta, StackMeta, ForcedWarpMeta, and DiffMeta.

**StackType**: Provides database indexes for the types of stacked images constructed. For 3π, all STACKS are DEEP_STACK.

**DiffType**: Provides database indexes for the types of difference images constructed. For 3π, all DIFFS are WARP_-STACK, meaning they are constructed by subtracting warps from single exposures from the deep stacks for the corresponding part of sky.

**TessellationType**: Provides database indexes for the types of image tessellations for the sky. For 3π, this is RINGS.V3. Each MD field has its own TessellationType (MD01.V3, MD02.V3, etc.). The RINGS.V3 Tessellations are described in more detail in Magnier et al. (2020a), and the MD tessellations in M. Huber et al. (2020, in preparation).

7.2.1. Flag Tables

There are 45 flag columns within the Pan-STARRS1 database schema (e.g., Detection.infoFlag) and eight different types of flags listed below (see Table 4). These flag columns use integer values to represent, e.g., different outcomes of the detection analysis. The eight different types of flags specify the meaning of the bit values for the flag columns. This section gives a brief overview of the eight different types of flags. Table 5 lists the flag columns in each of the PSPS tables and identifies the flag type for that column. Tables D1–D8 list the bit values for each of the flag types. These tables are intended to be used as a reference to select the appropriate flag information tables.

**ObjectInfoFlags**: These flags specify characteristics of the object determined during the photometric and astrometric analysis, or by external analysis or publications. For example, several bits specify if the object has been identified as a QSO, variable, transient, or a known solar system object, if it has large proper motions, if it is extended, and the source of the average position information.

**ObjectQualityFlags**: Contains information flag values that denote if an object is real or a possible false positive. This is a subset of flags from ObjectInfoFlags, specifically the ones if the object is extended, has good measurements in individual exposures, and has good measurements in the stacks. This

| Flag Type               | Size     | See in this Paper |
|-------------------------|----------|-------------------|
| ObjectInfoFlags         | INT      | Table D1          |
| ObjectQualityFlags      | SMALLINT | Table D2          |
| ObjectFilterFlags       | INT      | Table D3          |
| ImageFlags              | INT      | Table D4          |
| ForcedGalaxyShapeFlags  | SMALLINT | Table D5          |
| Detection               | BIGINT   | Table D6          |
| Detection2              | INT      | Table D7          |
| Detection3              | INT      | Table D8          |
Table 5
Flag Columns within Pan-STARRS1

| Table Name          | Flag Column          | Size         | Flag Type          |
|---------------------|----------------------|--------------|--------------------|
| ObjectThin          | objectInfoFlag       | INT          | ObjectInfoFlags    |
| ObjectThin          | qualityFlag          | SMALLINT     | ObjectQualityFlags |
| GaiaFrameCoordinate | gaiaFlag             | INT          | ObjectInfoFlags    |
| MeanObject          | (grizy)Flags         | INT          | ObjectInfoFlags    |
| ForcedMeanObject    | (grizy)Flags         | INT          | ObjectInfoFlags    |
| DiffDetObject       | objectInfoFlag       | INT          | ObjectInfoFlags    |
| DiffDetObject       | qualityFlag          | SMALLINT     | ObjectQualityFlags |
| ImageMeta           | qaFlags              | INT          | ImageFlags         |
| ForcedGalaxyShape   | (grizy)GalFlags      | SMALLINT     | ForcedGalaxyShapeFlags |
| Detection           | infoFlag             | BIGINT       | DetectionFlags     |
| Detection           | infoFlag2            | INT          | DetectionFlags2    |
| Detection           | infoFlag3            | INT          | DetectionFlags3    |
| StackObjectThin     | (grizy)infoFlag      | BIGINT       | DetectionFlags     |
| StackObjectThin     | (grizy)infoFlag2     | INT          | DetectionFlags2    |
| StackObjectThin     | (grizy)infoFlag3     | INT          | DetectionFlags3    |
| DiffDetection       | DinfoFlag            | BIGINT       | DetectionFlags     |
| DiffDetection       | DinfoFlag2           | INT          | DetectionFlags2    |
| DiffDetection       | DinfoFlag3           | INT          | DetectionFlags3    |
| ForcedWarpMeasurement| FinfoFlag            | BIGINT       | DetectionFlags     |
| ForcedWarpMeasurement| FinfoFlag2           | INT          | DetectionFlags2    |
| ForcedWarpMeasurement| FinfoFlag3           | INT          | DetectionFlags3    |

The flags used in ObjectThin, qualityFlag and DiffDetObject.qualityFlag.

ObjectFilterFlags: These flags specify the quality of the photometric calibration for the object and are specified for each of the five filters. More detail about the meaning of these flag bits can be found in Paper V.

ImageFlags: Primarily denotes the quality of the photometric and astrometric calibration of the chip image (e.g., whether the image is bad or if there are too few measurements).

ForcedGalaxyShapeFlags: Contains information flag values that define ForcedGalaxyShape chi-squared surface fit failures.

DetectionFlags: These flag bits are generated in the pixel-level source analysis software and include information about the quality of the detection. Bits include, e.g., if the detection is blended, used for the PSF model, saturated, and many other types of defects, as well as information on types of magnitudes calculated, if it is extended, and fit information. See also Paper IV.

DetectionFlags2: Like the previous set of flags, these flags contain information about the pixel-level analysis of the detection. These bits include information specific to difference imaging, as well as quality issues such as if source is near diffraction spikes, star core, affected by the “burntool” analysis of persistence features (see Paper III), along with other analysis issues. See also Paper IV.

DetectionFlags3: These flag bits are generated by the photometric and astrometric calibration analysis. They include bits to specify, e.g., if the detection was used in the analysis of the mean astrometric or photometric properties of the object.

7.3. Object-type Tables

The object-type tables originate from the DVO database, specifically, the DVO tables that have information about objects, their mean astrometric and photometric properties, and information such as the number of detections per objects and other statistics and information. The object-type tables form the equivalent of a telephone book for all of the objects, with objID being the equivalent of the phone number or social security number. A key defining feature is that objID is unique in these object-type tables; there are no instances of two objects with the same objID in the same object-type table. If an object is not in these tables, it has not been detected in any of the stages of processing. Tables D9–D11 list the contents of the object-type tables. What follows is a description of each of the object-type tables, for DR1 and beyond.

ObjectThin: Contains the positional information for objects in a number of coordinate systems. The objects associate single-epoch detections and the stacked detections within a one arcsecond radius. The mean position from all the available single-epoch data is used as the basis for coordinates when available, or the mean position over each filter of an object in the stack when it is not. The R.A. and decl. for both the stack and single-epoch mean are provided. The number of detections in each filter from single-epoch data is listed, along with which filters the object has a stack detection (see Szalay et al. 2007). Use objID to join to most tables, uniquePspObjID to join to MeanObject. For DR1 only, the Gaia-calibrated positions were calculated after ObjectThin was populated; they are provided in GaiaFrameCoordinate. For DR2 and beyond, there is no GaiaFrameCoordinate table, as ObjectThin has been recalibrated and has the Gaia-calibrated positions.

MeanObject: Contains the mean photometric information for objects based on the single-epoch data, calculated as described in Paper V. To be included in this table, an object must be bright enough to have been detected at least once in an individual exposure. PSF, Kron (1980), and total aperture-based magnitudes and statistics are listed for all filters in a single row. The apertures are defined to match (in arcseconds) those used by SDSS (see Table 7 in Stoughton et al. 2002). Use objID to join to most tables, uniquePspObjID to join to MeanObject. Average values are determined using outlier rejection based on the iteratively reweighted least-squares technique in which measurements are averaged with weights determined by their individual errors combined with a...
are ingested into the Detection table, which also has the exposure time, etc. All of the detections measured in the image are tables from the catalog outputs of the CAMERA, STACK, FORCED PHOTOMETRY, and D2F stages of the IPP. Each of these categories of tables is described below.

Note that for these tables, if it has an objID column, objID will not necessarily be unique as each measurement of the same object on different images will have the same objID. If doing joins between tables from the same stage, use the appropriate uniquePspsStId. For example, to join between StackObjectThin and StackApFlx, use uniquePspsSTid.

7.4. Individual Exposure Detection-type Tables

The majority of the data in the database are in the form of detection-type tables. These are tables that are based on individual stages of processing from the IPP. Specifically, these are tables from the catalog outputs of the CAMERA, STACK, FORCED PHOTOMETRY, and D2F stages of the IPP. Each of these categories of tables is described below.

Images processed through the CAMERA stage of the IPP have been detrended and have had astrometry and photometry calculated. Basic information from the images are then merged into the DVO database. The core tables based on the CAMERA stage are FrameMeta, ImageMeta, Detection, and ImageDetEffMeta. The contents of these database tables are listed in Tables D12–D15. Each image ingested into the PSPS database has a unique imageID; this can be used to find out, via the FrameMeta, ImageMeta, and ImageDetEffMeta tables, information about each image such as the filter, R.A. and decl., exposure time, etc. All of the detections measured in the image are ingested into the Detection table, which also has the imageID, allowing for single detections to be traced back to the OTA on which it was imaged.

FrameMeta: Contains metadata related to an individual exposure. A Frame refers to the collection of all images obtained by the 60 OTA devices in the camera in a single exposure. The camera configuration, telescope pointing, observation time, and astrometric solution from the detector focal plane ($L$, $M$) to the sky (R.A., decl.) is provided.

ImageMeta: Contains metadata related to an individual OTA (chip) image that comprises a portion of the full exposure. The characterization of the image quality, the detrends applied, and the astrometric solution from the raw pixels ($X, Y$) to the detector focal plane ($L, M$) is provided.

Detection: Contains single-epoch photometry of individual detections from a single exposure. The identifiers connecting the detection back to the original image and to the object association are provided. PSF, aperture, and Kron (1980) photometry are included, along with sky and detector coordinate positions. Use objID to join to other tables with photometry/astrometry parameters. Note that objID is not unique.

ImageDetEffMeta: Contains the detection efficiency information for a given individual OTA image. Provides the number of recovered sources out of 500 injected fake source and statistics about the magnitudes of the recovered sources for a range of magnitude offsets.

7.4.2. Tables Based on the “Stack” Stage of IPP

There are 15 tables based on the STACK stage of processing. The contents of these database tables are listed in Tables D16–D29. Several groups of these tables share a common schema, but are based on different convolutions of the stack images or use different extended source models. The basic table is StackObjectThin, which contains the positional and photometric information for point-source photometry of stack detections. The other stack tables provide additional measurements for the objects listed in StackObjectThin. There are several stack metadata tables, they are StackMeta, StackToImage, StackToFrame, and StackDetEffMeta. They provide general information about the stack and can be used to find out the exposures used in the stack.

Joins between any of the stack tables, except for the stack meta tables, should use uniquePspsSTid.

Due to overlaps in the stack tessellations, an object may appear in multiple stack images. As neighboring stack images contain nearly the same input exposures, these measurements are not statistically independent. Only one set of such measurements should be used for valid population statistics. To aid in such analysis, we define a “primary” detection for all stack measurements (from a single filter) of the same astronomical object. The “primary” detection is that detection for which the stack pixels are closest to the center of the skycell. Because the definition is purely geometric, in theory no portion of the sky can contribute more than a single stack detection. In practice, the photometric analysis of sources will occasionally split a source into multiple detections within the image. For the primary skycells, these detections will each be identified as “primary,” though they come from the same astrophysical object. However, this is due to the analysis process, not the overlap of the stack boundaries.

Although the primary and secondary detections in general are derived from the same input pixels, differences can occur. It is possible that the primary detection of an object (for a particular filter) is actually more heavily masked than any secondary detections of the same object. Users who prefer a high-quality measurement of a particular object may choose to use these secondary measurements rather than the primary. We attempt to identify the “best” stack measurement for each filter by examining the signal-to-noise ratio of the measurements and the PSF_QF_PERFECT values, a measurement of the masked fraction for the object (see Paper IV for details of the parameter).

If the primary detection has PSF_QF_PERFECT > 0.95, then it is marked as the best. If multiple such measurements exist for the object, the highest signal-to-noise measurements are used. If not, but a secondary detection has PSF_QF_PERFECT > 0.95, then the secondary detection with the highest signal-to-noise ratio is chosen as best. If neither primary nor secondaries have PSF_QF_PERFECT > 0.95, the primary measurement with the highest PSF_QF_PERFECT is selected as the best. Finally, if no primary detection exists, the secondary with the highest PSF_QF_PERFECT is selected as the best.

Stack measurements that are the primary measurement have the STACK_PRIMARY bit set in the StackObjectThin.
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XinfoFlag3 field for the appropriate filter while stack measurements that are identified as the “best” measurement for an object within a given filter have the STACK_PHOT_SRC bit set in the same field (see Tables D8 and D17).

If all of the “best” measurements for a stack object (across all five filters) are also primary measurements, then the BEST_STACK bit is set in the ObjectThin.objInfoFlag entry for the corresponding object (see Tables D1 and D9).

Several bits in the StackObjectThin.XinfoFlag4 field for each filter may be set based on the “primary” and “best” detections (see Tables D8 and D17). If a “primary” measurement exists for a given filter, then the SECP_STACK_PRIMARY bit is set for that filter. If multiple primary stack measurements exist for a given filter, then the SECP_STACK_PRIMARY_MULTIPLE bit is also set for that filter (not set in DR1). If the “best” measurement for a filter is a significant detection (not forced from another band), then the SECP_STACK_BESTDET bit is set. If any of the “primary” measurements for a filter is a significant detection (not forced from another band), then the SECP_STACK_PRIMDET bit is set. If any stack measurements exist for a given filter, then the per-filter bit flag SECP_HAS_PSL_STACK is set.

Users should note that the fields StackObjectThin.primary-Detection and StackObjectThin.bestDetection are incorrectly set for DR1 and DR2. A coding error resulted in these bits being set based on the wrong input fields. A future update to the tables may be performed to repair these two fields.

StackObjectThin: Contains the positional and magnitude information for PSF, Kron (1980), and total aperture-based measurements of stack detections. The information for all filters are joined into a single row, with metadata indicating if this stack object represents the primary detection. In addition, a detection is flagged as “best” if it is a primary detection with a psfQF value greater than 0.98; if that condition is not met, then the primary or secondary detection with the highest psfQF value is flagged as best (see Paper V).

StackObjectAttributes: Contains the PSF, Kron (1980), and total aperture-based fluxes for all filters in a single row, along with point-source object shape parameters. Because the photometry for an object that is not detected in some filters is forced in those filters, some fluxes may have negative values. The magnitudes in StackObjectThin are derived from this table, where the flux is positive.

StackApFlx: Contains the fluxes within the SDSS R5 (r = 3″00), R6 (r = 4″63), and R7 (r = 7″43) apertures (Stoughton et al. 2002) as measured on the raw (unconvolved) stack images. Fluxes within these same apertures are also provided for images convolved to 6 sky pixels (1″5) and 8 sky pixels (2″0). See Section 5.1.4 for further information. All filters are matched into a single row. These values are measured for all objects in all stacks.

StackModelFitExp: Contains the exponential galaxy model fit parameters (see Section 5.1.5 for constraints). All filters are matched into a single row.

StackModelFitDeV: Contains the de Vaucouleurs (1948) fit parameters (see Section 5.1.5 for constraints). All filters are matched into a single row.

StackModelFitSer: Contains the Sérsic (1963) fit parameters (see Section 5.1.5 for constraints). All filters are matched into a single row.

StackApFlxExGalUnc: Contains the fluxes within the nine SDSS apertures (see Section 5.1.4) as measured on the unconvolved stacks. All filters are matched into a single row.

StackApFlxExGalCon6: Contains the fluxes within the nine SDSS aperture (see Section 5.1.4) images convolved to a target of 6 sky pixels (1″5). All filters are matched into a single row.

StackApFlxExGalCon8: Contains the fluxes within the nine SDSS aperture (see Section 5.1.4) images convolved to a target of 8 sky pixels (2″0). All filters are matched into a single row.

StackPetrosian: Contains the Petrosian (1976) magnitudes and radii (see Section 5.1.5 for constraints). All filters are matched into a single row.

StackMeta: Contains the metadata describing the stacked image produced from the combination of a set of single-epoch exposures. The nature of the stack is given by the StackTypeID. The astrometric and photometric calibration of the stacked image are listed.

StackToImage: Contains the mapping of which input images were used to construct a particular stack.

StackToFramen: Contains the mapping of input frames used to construct a particular stack along with processing statistics.

StackDetEffMeta: Contains the detection efficiency information for a given stacked image. Provides the number of recovered sources out of 500 injected sources for each magnitude bin and statistics about the magnitudes of the recovered sources for a range of magnitude offsets.

7.4.3. Tables from the “Forced Photometry” Stage of IPP

The following tables contain information related to the FORCED WARP analysis stage. Joins between ForcedWarp-Measurement, ForcedWarpMasked, ForcedWarpExtended, and ForcedWarpLensing should use uniquePspsFWid. The contents of these database tables are listed in Tables D30–D38.

ForcedMeanObject: Contains the mean of single-epoch photometric information for sources detected in the stacked data, calculated as described in Paper IV. The mean is calculated for detections associated with objects within a 1″ correlation radius. PSF, Kron (1980), and SDSS (Stoughton et al. 2002) aperture R5 (r = 3″00), R6 (r = 4″63), and R7 (r = 7″43) total aperture-based magnitudes and statistics are listed for all filters. See also Paper IV. Use objID to join to most tables, and use uniquePspsFOid to join to ForcedMean-Lensing. objID is not unique, but uniquePspsFOid is.

ForcedMeanLensing: Contains the mean Kaiser et al. (1995) lensing parameters measured from the forced photometry of objects detected in stacked images on the individual single-epoch data. Use objID to join to most tables; use uniquePspsFOid to join to ForcedMeanObject. objID is not unique, but uniquePspsFOid is.

ForcedGalaxyShape: Contains the extended source galaxy shape parameters. The positions, magnitudes, fluxes, and Sérsic indices are inherited from their parent measurement in the StackModelFit tables and are reproduced here for convenience. The major and minor axes and orientation are recalculated on a warp-by-warp basis from the best fit given these inherited properties (Sérsic 1963). Use objID to join to most tables. objID is not unique, but uniquePspsFOid is.

ForcedWarpMeta: Contains the metadata related to a sky-aligned distortion-corrected WARP image, upon which forced photometry is performed. The astrometric and photometric calibration of the WARP image are listed.
**Table 6**

Coordinate Fields in PSPS

| PSPS Table                  | Column Names         | Comments                                           |
|-----------------------------|----------------------|----------------------------------------------------|
| FrameMeta                   | raBore               | R.A./decl. of telescope boresite                  |
| ObjectThin                  | raMean               | mean R.A. and decl. from single exposure, calibrated against 2MASS |
| ObjectThin                  | decMean              | mean R.A. and decl. calculated from STACK skycells |
| Detection                   | R.A.                 | R.A. and decl. for single exposure detections      |
| StackObjectThin             | dec                  | R.A. and decl. calculated from individual STACK skycells |
| DiffDetection               | (griz)ra             | R.A. and decl. for single DIFF exposure detections |
| DiffDetObject               | R.A.                 | similar to raMean/decMean, calculated for DIFF objects |
| DetFrameCoordinate          | R.A.                 | best R.A. and decl., recalibrated to Gaia (DR1 only). |

**ForcedWarpMeasurement:** Contains single-epoch forced photometry of individual measurements for each warp image. The identifiers connecting the measurement back to the original exposure and to the object association are provided. PSF, Kron (1980), and total aperture-based fluxes are provided, along with positions in both sky and detector coordinates.

**ForcedWarpMasked:** Contains an entry for objects detected in the stacked images which were in the footprint of a single-epoch exposure, but for which there are no unmasked warp pixels at that epoch.

**ForcedWarpExtended:** Contains the single-epoch forced photometry fluxes within the SDSS R5 ($r = 3^\circ00$), R6 ($r = 4^\circ63$), and R7 ($r = 7^\circ43$) apertures (Stoughton et al. 2002) for objects detected in the stacked images.

**ForcedWarpLensing:** Contains the Kaiser et al. (1995) lensing parameters measured from the forced photometry of objects detected in stacked images on the individual single-epoch data.

**ForcedWarpToImage:** Contains the mapping of which input image comprises a particular WARP image used for forced photometry.

### 7.4.4. Tables Based on the “Diff” Stage of IPP

The tables described below relate to the difference image processing. The contents of these database tables are listed in Tables D39–D43. Each DIFF image has a unique diffImageId, and all four DIFF tables use this to join to each other.

**DiffDetObject:** Contains the positional information for difference detection objects in a number of coordinate systems. The objects associate difference detections within a $1^\circ$ radius. The number of detections in each filter is listed, along with maximum coverage fractions (see Szalay et al. 2007). Use diffObjID to join to most diff tables. diffObjID and uniquePspstoDoid are unique for DiffDetObject. Note that diffObjID and objID will be similar, but not identical, and it will not be easy to join to non-diff tables. We recommend comparing the R.A. and decl. for objects between Diff” and non-diff tables.

**DiffMeta:** Contains metadata related to a difference image constructed by subtracting a stacked image from a single-epoch image, or in the case of the MD Survey, from a nightly STACK (stack made from all exposures in a single filter in a single night). The astrometric calibration of the reference STACK is listed.

**DiffDetection:** Contains the photometry of individual detections from a difference image. The identifiers connecting the detection back to the difference image and to the object association are provided. PSF, aperture, and Kron (1980) photometry are included, along with sky and detector coordinate positions.

**DiffToImage:** Contains the mapping of which input images were used to construct a particular difference image.

**DiffDetEffMeta:** Contains the detection efficiency information for a given individual difference image. Provides the number of recovered sources out of 500 injected sources and statistics about the magnitudes of the recovered sources for a range of magnitude offsets.

### 7.5. Which R.A. and Decl. to Use?

Multiple tables contain columns that provide a measurement or representation of the R.A. and decl. This section gives information on each so that the user can choose the appropriate R.A. and decl. version to use. A summary of these tables is provided in Table 6. Generally, if the user is not interested in proper motion or moving objects, it is best to use coordinates from GaiaFrameCoordinate if using DR1, as this is the weighted mean R.A. and decl. (similar to ObjectThin), but tied to the Gaia system. This information is in a separate table and not part of ObjectThin because the mean properties were calculated and ingested into PSPS prior to Gaia’s DR1. ObjectThin’s raMean and decMean are calibrated against 2MASS and thus degraded compared to Gaia. The 2MASS reference system is consistent with the ICRS to within 15 mas, but the scatter for even bright sources is $\approx 100$ mas (Skrutskie et al. 2006).

For DR2, there is no GaiaFrameCoordinate table, as DR2’s ObjectThin table is already calibrated to Gaia. The best R.A. and decl. to use for most cases are ObjectThin’s raMean and decMean. If the proper motion is high, or the object is moving, and the user is interested in the single-epoch photometry, they should use ra and dec in the Detection table.

### 7.6. Indexes and Joins

There are multiple columns within the schema that are indexed and designed to be used to join tables together. Generally, if a column name ends in “ID,” it is designed to be joined to other tables, either to system metadata tables (examples include filterID, surveyID, ccdID) or to fundamental data tables (for example, objID, diffObjID, uniquePspstoStId). There are a few exceptions: randomID and random(stage)ID should not be used for joins, the contents of each are random numbers to aid the user in selecting repeatable random subsets of data. Also, some of the uniquePspstoXIds are only present in one table; they are used to provide unique IDs for each stage of processing but some stages (DiffDetObject, for example) only have one corresponding table and therefore nothing to join to.
Figures 9 and 10 show graphical representations of how to join various tables. On these figures, the table names are boxed, while the columns to be used to join are in ovals. For the diagram with objID in the middle, it shows that any of the boxes connected to objID can be joined to each other using objID.

All tables with photometric or astrometric information involving different sources or objects have an index, called objID. ObjID is only unique for the object type of tables, and is loosely based on R.A. and decl.; see Section 7 for more information. It is possible to use the objID to get a rough estimate of the R.A. and decl. Use ObjectThin to get the R.A. and decl. calibrated to 2MASS, and use GaiaFrameCoordinate (for DR1) or ObjectThin (for DR2) to get the R.A. and decl. calibrated to Gaia astrometry. When available and possible, if joining two tables and they both have the same column name like uniquePspsXXId, join those two tables using the uniquePspsXXId. See Table 7 to see the uniquePsps column name. UniquePspsXXId is designed to be unique; specifically for the cases when there are multiple detections that are sufficiently close by, they will have the same objID but different uniquePspsXXIds.

It is possible to join every detection, no matter what stage of processing it is from, back to the original exposure(s) and to the OTAs. Figure 10 shows how to do this. For each stage of processing, there is an associated (stage)imageID that is mapped back to the imageID via tables of the name (stage)ToImage. For example, if one wanted to find out which exposures contributed to a detection in StackObjectThin, they would join to StackToImage using the stackImageID. This allows the user to find data within the database as well as to find out the corresponding images to download from MAST.

### 7.7. NULLS as −999

The PSPS uses −999 to denote NULL values, as PSPS is based off of CasJobs, which also does not use NULL. The justification for this is explained by Szalay et al. (2002; page 7): “We also insist that all fields are non-null. These integrity constraints are invaluable tools in detecting errors during loading and they aid tools that automatically navigate the database” (see also Gray et al. 2002). Because our own database design has in its roots many of the same parts as the SDSS database, we also adopt this convention of non-null fields.

### 7.8. Tables and Views

The PSPS has defined several views to aid the user in making database queries. A view is a virtual table that is based on the results from an SQL statement and looks like a table to the user. These views are constructed to aid the user, to alleviate the need for common joins, and to produce query...
results faster than joins. Table 8 describes the views currently in PSPS.

8. The 3π Database

The 3π Survey, described in detail in Chambers et al. (2016), covers three-quarters of the sky (decl. $> -30^\circ$) in five bands $(g_{P1}, r_{P1}, i_{P1}, z_{P1}, y_{P1})$, with approximately 60 exposures per patch of sky. For various reasons, a very tiny fraction of the data does not make it into the PSPS database. Some data were intentionally skipped because of poor data quality or other
problems; some data failed to process due to glitches or software bugs, some of which may be addressed in a future reanalysis (PV4 or other). We present here the different causes (of which we are aware) for data to be skipped or missed. This section lists the numbers of exposures, skycells, or batches that were processed in each stage, including counts for what were expected and as well as counts for known faults and quality issues (see also Tables 9 and 10).

### 8.0.1. IPP Processing Stages

All of the $3\pi$ data were reprocessed in a consistent way with the same version of the IPP code, internally called Processing Version 3 (PV3) and described in Paper II.

**Raw Exposure:** A total of 388,177 raw exposures were taken between 2009 June 3 and 2015 February 25 as part of the $3\pi$ Survey. However, only 381,279 (98.2%) of these were queued for the first stage of processing, the CHIP stage. Exposures were excluded because they did not meet various requirements: they were flagged as invalid by the observers, or they failed to be processed by nightly science processing because of bad seeing, camera issues, or other observational or telescope conditions that can ruin an exposure.

**Chip Stage:** Of the 381,279 exposures queued for CHIP processing, 375,573 (98.5%) completed PV3 processing with good quality; no issues detected while detrending or finding sources and performing photometry.

**Camera Stage:** The CAMERA stage started with these 375,573 exposures, of which 374,521 (99.7%) completed processing. The other exposures failed due to insufficient stars for the astrometric analysis, failure of single chip astrometry to converge, or failure of mosaic astrometry, usually too many failed chips.

**Warp Stage:** The WARP stages started off with a larger number of exposures than expected: 379,973 instead of 374,521. This was due from some challenges in managing the remote processing on the clusters at Los Alamos National Laboratory and the University of Hawai‘i’s computer cluster (see Paper II). Data transfer failures between the remote clusters and the IPP main cluster required requeuing and rerunning the analysis for some warps in a way that resulted in temporary double counting. Of the 379,973 exposures processed, 374,339 (98.5%) are unique, and 1234 are duplicates. Of the 379,973 exposures, 379,551 (99.9%) have good quality. The WARP stage is the first stage that repartitions the exposures into the skycell tessellation, and because all later stages process on a skycell level rather than an exposure level, we note that the WARP stage yields 206,177 distinct skycells, with multiple warp skycell images from the different exposures for each skycell.

**Stack to Skycal Stages:** The STACK stage operates on 200,730 distinct skycells with up to five filter images per skycell. A total of 200,725 stack skycells have good quality. There are fewer stack skycells than the 206,177 warp skycells listed above because stacks are not generated for skycells with decl. $< -30^\circ$. Stacks generated below this decl. limit would have significantly poorer coverage and are of limited utility. A total of 200,720 distinct skycells were processed by the static sky stage, and all have good quality. The SKYCAL stage processed 200,722 skycells, of which 2 were essentially duplicate STACKS (same inputs, same skycells) and 200,684 completed with good quality.

The STACK stages have a couple of additional inconsistencies. First, of the 200,684 STACKs that completed through SKYCAL, 409 STACKs (0.2%) include duplicate exposures, i.e., the same exposure appears in a STACK twice. Second, 130 STACKs unintentionally include test exposures (short exposures, 1 s, which were mislabeled as 3 s data), which slightly degrade the stack. These artifacts were discovered during the IPPTOPSPS and PSPS phases and are thus present in the database. In addition, the two STACK duplicates mentioned above (i.e., two STACKs for the same filter and skycell) are also present in the PPS.

**Forced Warp Stage:** Forced warps are queued by skycell and filter. The 994,890 queued FORCED WARP skycell sets resulted in 19,266,450 cmf files (one per exposure per skycell) from 373,743 exposures and 199,151 distinct skycells, consistent with expectations. There are slightly fewer distinct warped skycells than the stack stages due to the varying coverage at the survey limit of $-30^\circ$: skycells with insufficient numbers of fully filled warps were not queued for forced photometry processing.

### 8.1. Building the $3\pi$ DVO Database

The $3\pi$ database was built in stages, with many checks to verify all of the data was included. Full details of the construction and final calibration are in Magnier et al. (2020c). The $3\pi$ database contains the following counts of data for various processing stages, ordered by how they were ingested into the database:

**Stack/skycal cmf:** The end product from the skycal stage produces one cmf file per stack skycell per filter. There are one to five cmfs per skycell, corresponding to different filters. All 998,101 skycal cmfs, in 200,684 distinct skycells, were successfully ingested into the DVO.

**Camera smfs:** The camera stage produces one smf file per exposure, with extensions for each of the 60 chips. Of the 374,521 available camera stage smf files, 374,446 were
ingested with no faults. The remaining 75 failed to be ingested in the DVO either due to bad data quality (poor astrometry) or in a few cases data corruption in the disk file. These smfs will not be included in the PSPS.

**Forced warp cmfs:** The forced warp photometry stage produces many cmf files: each of the exposures that are within a given sky cell will produce a cmf that is ingested into the database. There are 19,266,450 of these cmf files; they come from 373,743 exposures and are in 994,890 skycells.

**Forced warp summary cmfs:** The forced warp photometry stage also produces a summary cmf of the mean properties for a given sky cell and filter, based on the forced photometry results for all of the included exposures that are within a given sky cell. There are 994,890 of these cmfs, in 199,151 distinct skycells. There are one to five cmfs per sky cell, corresponding to different filters.

Very tiny amounts of data were not ingested due to quality issues, and there are very minor duplicate issues with processing resulting in some duplicate files being ingested. It is possible to remove those duplicates, but then the mean properties must be recalculated. There are a small number of duplicates that were discovered in IPTTOPSPS and PSPS, and it was not possible to remove and recalibrate them at this time.

### 8.1.1. Polar Astrometry Issues

After delivery of the DR2 data to STScI, internal consistency tests revealed some problems for data in the vicinity of the celestial north pole. This issue is described in some detail in Paper IV. In short, the on-the-fly astrometric calibration performed during the PV3 analysis (Section 5.1.2) relied on an astrometric reference catalog generated from the PV2 analysis of the PS1 data set, which contained some errors. In that earlier analysis, some exposures were poorly calibrated due to large rotator errors near the pole, but the failures were not recognized. These poorly calibrated images were included in the reference database, providing a set of invalid reference stars. In the PV3 analysis, exposures in the vicinity of these problem areas sometimes latch onto the invalid stars resulting in poorly calibrated images. Individual chips may have solutions with offsets of up to 2°.

These astrometry failures cause errors with the mean astrometry for objects in this region. They also result in misaligned warp images and therefore stacks with smeared or doubled stellar images. The photometry for warps and stacks are also corrupted. We identified the warps and stack sky cells affected by this issue and provide warnings to users who attempt to download these images from MAST. Stack properties from the affected images are set to NULL as these values cannot be trusted. A list of the affected sky cells is provided at MAST, and users are advised to be cautious of measurements from these regions. The problem sky cells are almost entirely north of decl. = 80°, comprising roughly 21 of the 313 square degrees in this region. A reprocessing of the polar regions north of decl. = 70° is underway and will be released to users in the future.

### 8.2. IPTTOPSPS Stage

IPTTOPSPS generates batches that includes all of the smf/cmf files categorized by stage of processing and generates batches corresponding to each DVO file. The relationship between PSPS items and the source of the data (DVO, cmf/smf files, or from the IppToPsp code) is described in Tables E1–E3. It is straightforward to verify that all the data are accounted for and have been processed through IPTTOPSPS, and easy to regenerate missing batches. This section describes the batch types and expected numbers.

**Stacks:** IPTTOPSPS is expected to generate 200,684 STACK batches. It initially created 200,681 batches for DR1, and two of the missing batches were created and added after the original DR1 date. For DR2, it generated 200,683 batches. The one missing stack batch ended up being unsuitable data quality for the database.

**ObjectThin/MeanObject:** IPTTOPSPS generated all of the expected 116,252 batches for DR1, and 111,505 for DR2. There are fewer batches for DR2 because it explicitly avoids the ragged edge of the survey and excludes those with decl. < −30°.

**GaiaFrameCoordinate:** IPTTOPSPS generated all of the expected 116,252 batches for DR1. This batch type was not relevant for DR2.

**Forced Mean Objects:** IPTTOPSPS generated all of the expected 113,665 Forced Object batches for DR1, and 113,167 batches for DR2. There are fewer of these batches than for ObjectThin because it explicitly avoids the ragged edge of the survey at decl. = −30°.

**Detection Table:** We expect 374,446 Detection batches, and we generated 374,344. The 102 missing batches were incorrectly marked as good exposures but in fact are not of sufficient quality and will not be added into the database.

### 8.3. Loading into PSPS

The PSPS loaded the tables for DR1 and DR2; however, there are a few inconsistencies discovered:

IPTTOPSPS is expected to generate 200,684 STACK batches. It initially created 200,681 batches (missing 3); of those that are expected, 1940 partially loaded, and 14 failed to load into PSPS by the DR1 deadline. These missing batches (1957) were not included in the initial DR1 release but were added over the months after the initial release. Similar gaps were present in the initial DR2 release and largely been filled in as of this time. However, users should be cautious of possible gaps in the database and consult the MAST website.

### 8.3.1. Queries to Find Holes

It is possible to use the PSPS database to verify data and to check that there are no missing data. The table GaiaFrameCoordinate is complete and has no missing data. It can be used to do quick integrity checks on other tables within PSPS. Finding missing objects from ObjectThin is straightforward:
do a **FULL OUTER JOIN** for GaiaFrameCoordinate and ObjectThin using objID. Objects with a NULL ObjectThin, batchID are missing. Missing objects from ForcedMeanObject can be found in a similar way to those in ObjectThin. Do a
FULL OUTER JOIN between GaiaFrameCoordinate and ForcedMeanObject. Objects with a NULL ForcedMeanObject.batchID are missing. Finding missing objects in StackObjectThin is trickier, because not all objects have STACK photometry. This requires a FULL OUTER JOIN on StackObjectThin to ObjectThin to GaiaFrameCoordinate. Missing STACKs will have valid ObjectThin.raStack and ObjectThin.decStack and NULL StackObjectThin.objID.

9. Conclusion

The Pan-STARRS database contains 10,723,304,629 objects. It is the largest data release from the largest digital sky survey to date, distilling the information from 1.6 PB of images and tables into a form that is accessible to the astronomical community through MAST. Nevertheless, sifting through such a large database can prove daunting, and this work is intended to describe the primary tables and quantities within the database, together with example queries. Data from Pan-STARRS have been used for myriad purposes, including detecting moving objects within the solar system (and in the case of 1I/2017 U1 (‘Oumuamua), from outside it!), the analysis of tens of thousands of high-energy transient events, mapping the 3D structure of dust within our Galaxy, and studies of the large-scale structure of our universe. Yet these only scratch the surface, and it is likely that mining the database will lead to discoveries that were missed and correlations that were overlooked. As we enter the era of multimessenger astrophysics, the Pan-STARRS data products will be essential to identifying the host galaxies and electromagnetic counterparts of events detected by gravitational wave, high-energy particle, neutrino, and radio observatories. While we have provided various tools to work with this data release, we anticipate that it will spur the development of new interfaces and ways of working with high-dimensional data sets. This work will be critical to science with future surveys such as LSST. Combining this Pan-STARRS data release with other large catalogs such as GALEX, 2MASSm and Gaia will provide a rich, high-dimensional data set that will enable new scientific studies and may yield astronomical treasures that we have not even begun to imagine.

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Facility: PS1 (GPC1).

Appendix A

Query Examples

This section shows example queries for the Pan-STARRS1 DR2 database. The progression will be from simple queries to more complicated queries. SQL has no requirements on case. We adopt the standard convention of using CAPITAL LETTERS for SQL-reserved words and functions and CamelCase for the tables and columns within the PSPS database schema. The queries given below may all be run from the CasJobs tab on the MAST website using the context “PanSTARRS1_DR2.” Note the some of the later queries rely on myDB tables generated in the earlier queries. The names for these output tables are surrounded by square brackets in the examples. These brackets are always allowed but are required if the table name includes spaces or reserved words (see https://docs.microsoft.com/en-us/sql/relational-databases/databases/databases-identifiers). Also beware that cutting and pasting in some browsers can convert the underscore characters to space.

1. Counting the number of rows in a large table.

   This is an example of a simple query; it needs to be run in the slow queue. The difference between COUNT_BIG() and COUNT() is that COUNT_BIG() returns a BIGINT, while COUNT() returns an INT. The PSPS tables are so large that COUNT(), which goes up to 2.14 billion, is too small of a number. Users should choose the method of counting rows that is appropriate for their data ranges. Unless it involves large tables and large areas of sky, COUNT() is recommended. However, if the result is too large, using COUNT() will result in an arithmetic overflow exception.

   ```sql
   SELECT COUNT_BIG(objID) FROM ObjectThin.
   ```

2. Return mean PSF magnitudes and errors for all filters (grizy) for a rectangular patch of sky.

   ```sql
   SELECT ObjectThin.objID, nDetections, raMean, decMean, gMeanPSFMag, gMeanPSFMagErr, rMeanPSFMag, rMeanPSFMagErr, iMeanPSFMag, iMeanPSFMagErr, zMeanPSFMag, zMeanPSFMagErr, yMeanPSFMag, yMeanPSFMagErr FROM ObjectThin JOIN MeanObject ON ObjectThin.objID = MeanObject.objID WHERE raMean > 100.0 AND raMean < 100.1 AND decMean > 0.0 AND decMean < 0.1.
   ```


3. Make a simple text histogram of ObjectThin.nDetections for a rectangular patch of sky. It is possible to save queries into your own personal MyDB as well as to make queries on your MyDB. Do the query from above, but save it to your MyDB as “MyDBtest.” Run the following query on your MyDB (MyDB context) to make a histogram of nDetections.

```sql
SELECT nDetections, COUNT(nDetections) FROM MyDBtest GROUP BY nDetections ORDER BY nDetections;
```

The results are ordered by nDetections, and it is apparent that most of the objects have zero to two detections. The nDetections column refers to the number of times something is detected from the individual exposures. Objects that have zero detections are so faint that they are not visible in the individual exposures but are detected in the stacks. Objects with one to two (or a few) detections might be spurious detections, moving objects, or faint objects. If the user is interested in objects that are more likely to be well measured in several epochs and also of astrophysical nature, it is best to add a restriction on nDetections. If the user is interested in the static sky and in STACK photometry, it is best to do a JOIN on StackObjectThin. See the next two queries for examples of each of those types of queries.

4. Select mean PSF magnitudes and errors for filters griyz, and for a rectangular patch of sky, with a restriction of >10 nDetections. This is an example of a query to get mean PSF magnitudes and errors for all filters in a rectangular patch of sky, for objects with >10 nDetections. The reason we chose 10 detections is somewhat arbitrary and can be adjusted, but is used primarily to cut out objects for which there are only a few detections. Objects with very few detections might not be astrophysical or they might be too faint to be seen multiple times.

```sql
SELECT ObjectThin.objID, raMean, decMean,
   gMeanPSFMag, gMeanPSFMagErr,
   rMeanPSFMag, rMeanPSFMagErr,
   iMeanPSFMag, iMeanPSFMagErr,
   zMeanPSFMag, zMeanPSFMagErr,
   yMeanPSFMag, yMeanPSFMagErr
FROM ObjectThin
INNER JOIN MeanObject ON objectThin.
   objID = MeanObject.objID
WHERE nDetections > 10
  AND raMean > 100.0
  AND raMean < 100.1
  AND decMean > 0.0
  AND decMean < 0.1;
```

This returns 748 objects, a significant reduction from the 3867 returned in query # 2.

5. Select STACK PSF magnitudes for all filters for a rectangular patch of sky.

This is an example of a query to get STACK PSF magnitudes for the same rectangular patch of sky. No restrictions on nDetections are necessary; the expectation is that sources on STACKS are more likely to be astrophysical.

```sql
SELECT ObjectThin.objID, raStack,
   decStack,
   gPSFMag, gPSFMagErr,
   rPSFMag, rPSFMagErr,
   iPSFMag, iPSFMagErr,
   zPSFMag, zPSFMagErr,
   yPSFMag, yPSFMagErr
FROM ObjectThin
INNER JOIN StackObjectThin ON ObjectThin.
   objID = StackObjectThin.objID
WHERE raStack > 100.0
  AND raStack < 100.1
  AND decStack > 0.0
  AND decStack < 0.1;
```

This returns 1806 objects.

6. An example of finding rows with NULL values, using TOP to limit results. The PSPS uses −999 to denote NULL values. The following query returns some objects that are detected in single exposures but not in the stacks. The numbers are limited by TOP to return the first 10 rows.

```sql
SELECT TOP 10
   ObjectThin.objID, raMean, decMean,
   nDetections, ng, nr, ni, nz, ny,
   imeanpsfmag
FROM ObjectThin
INNER JOIN MeanObject on objectThin.
   objID = MeanObject.objID
WHERE raStack = -999;
```

7. Basic search using BETWEEN to limit ranges.

Similar to query # 5, except uses BETWEEN to limit R.A. and decl. ranges as well as iPSFMag ranges.

```sql
SELECT ObjectThin.objID, raStack,
   decStack,
   gPSFMag, gPSFMagErr,
   rPSFMag, rPSFMagErr,
   iPSFMag, iPSFMagErr,
   zPSFMag, zPSFMagErr,
   yPSFMag, yPSFMagErr
FROM ObjectThin
INNER JOIN StackObjectThin ON ObjectThin.
   objID = StackObjectThin.objID
WHERE raMean BETWEEN 100.0 AND 100.1
  AND decMean BETWEEN 0.0 AND 0.1
  AND iPSFMag BETWEEN 18.0 AND 21.0;
```

8. Using built-in functions to do a box search.

ObjectThin contains Hierarchical triangular mesh information, making it possible to use the built-in function dbo.fGetObjFromRectEq(minra, mindec, maxra, maxdec) to do a rectangular search. Tables that have htm, cx, cy, cz can use this built-in function.

```sql
SELECT o.objID, o.raMean, o.decMean
FROM ObjectThin o, dbo.fGetObjFromRectEq(minra, mindec, maxra, maxdec)
WHERE o.objID = r.objID;
```

9. Using built-in functions to do a cone search. ObjectThin contains Hierarchical triangular mesh information, making it possible to use the built-in function dbo.fGetNearbyObjEq(ra, dec, conезise[arcmin]) to do a radial search for objects near a given ra and dec (cone search). Tables that have htm, cx, cy, cz can use this built-in function. The query below returns the objects.
within 0.2 of the coordinate 56.85, 24.12. Note that only one of these objects was detected in a g-band image and thus has a valid value for the g-mean-magnitude.

SELECT o.objID, raMean, decMean, gMeanPSFMag, gMeanPSFMagErr
FROM ObjectThin AS o
JOIN MeanObject AS m ON o.objID = m.objID
JOIN dbo.fGetNearbyObjEq(56.85, 24.12, 0.2) AS n
ON o.objID = n.objID.

10. **Conic search of high-fidelity stellar-like objects.** We want to get all objects with R degrees of a given position that are high-fidelity stellar-like objects. We get all objects within 0.2 of R.A. = 334.0 and decl. = 0.0 which have mean magnitudes in griz (i.e., at least one detection in each band that can be used for the mean mag). In addition, we require QfPerfect > 0.85 in all bands. We select stars with a small (<0.05) difference between Kron and PSF magnitudes.

SELECT o.objID, o.raMean, o.decMean, o.raMeanErr, o.decMeanErr, o.qualityFlag, o.gMeanPSFMag, o.gMeanPSFMagErr, o.rMeanPSFMag, o.rMeanPSFMagErr, o.iMeanPSFMag, o.iMeanPSFMagErr, o.zMeanPSFMag, o.zMeanPSFMagErr, o.yMeanPSFMag, o.yMeanPSFMagErr, o.rQfPerfect, o.iQfPerfect, o.zQfPerfect, o.yQfPerfect, o.qualityFlag, o.objInfoFlag, o.raMeanErr, o.decMeanErr, o.quality-

12. **Find the objID of a single object.** Star CSS J030521.9 +013231 (Catalina Sky Survey), 584630948352256 (GAIA) is an RR Lyrae with period = 0.55547 days and coordinates R.A. = 46.341468915923 and decl. = 1.54199810825252 (ref. GAIA DR2, 2018yCat.1345....0G). In the following, we obtain the PSF and aperture photometry light curves, both forced and unforced, for this star. (See Figure 11.)

First, we generate a MyDB table containing the Gaia information for this source by running the following query against the Gaia DR2 database at MAST:

SELECT source_id AS ID_GAIA, ra AS RA_GAIA, dec AS DEC_GAIA, phot_g_mean_mag AS Gmag INTO mydb.[RRL_584630948352256] FROM gaia source WHERE source_id = 584630948352256

Now we run the following query to extract the Pan-STARRS DR2 information:

SELECT d.ID_GAIA, d.RA_GAIA as GAIARA, d.DEC_GAIA as GAIADEC, d.Gmag, o.objID, o.raMean, o.decMean, o.raMeanErr, o.decMeanErr, o.qualityFlag, o.gMeanPSFMag, o.gMeanPSFMagErr, o.rMeanPSFMag, o.rMeanPSFMagErr, o.iMeanPSFMag, o.iMeanPSFMagErr, o.zMeanPSFMag, o.zMeanPSFMagErr, o.yMeanPSFMag, o.yMeanPSFMagErr, o.rMeanKronMag, o.rMeanKronMagErr, o.nDetections, o.ng,
13. Obtain the lightcurve for a given object (Detections). The query above gives an objID of 109850463414820867 for that RR Lyrae star. Knowing the objID, it is possible to query to get the lightcurve.

SELECT o.ID, o.GAIARA, o.GAIA-Dec, o.Gmag, o.objID, o.raMean, o.dec-Mean, d.detectID, d.obstime, d.exptime, d.airmass, d.psfFlux, d.psfFluxErr, d.psfQf, d.psfQfPerfect, d.psfLikelihood, d.psfChisq, d.extNSigma, dzp, d.apFlux, d.apFluxErr, d.imageID, d.filterID, d.sky, d.skyerr, d.infoFlag, d.infoFlag2, d.infoFlag3, o.qualityFlag, o.gMeanPSFMag, o.rMeanPSFMag, o.iMeanPSFMag, o.zMeanPSFMag, o.rMeanPSFMagErr, o.iMeanPSFMagErr, o.zMeanPSFMagErr, o.gMeanCPSFMag, o.rMeanCPSFMag, o.iMeanCPSFMag, o.zMeanCPSFMag, o.gMeanCPSFMagErr, o.rMeanCPSFMagErr, o.iMeanCPSFMagErr, o.zMeanCPSFMagErr, o.qualityFlag, o.gMeanPSFMag, o.rMeanPSFMag, o.iMeanPSFMag, o.zMeanPSFMag, o.gMeanPSFMagErr, o.rMeanPSFMagErr, o.iMeanPSFMagErr, o.zMeanPSFMagErr, o.detection, o.ng, o.nr, o.ni, o.nz, o.ny, o.rFlags, o.iFlags, o.zFlags, o.rQfPerfect, o.iQfPerfect, o.zQfPerfect, o.rFlags2, o.iFlags2, o.zFlags2, o.rQfPerfect2, o.iQfPerfect2, o.zQfPerfect2, o.flags2, o.flag2Flag, o.flag2Flag2, o.flag2Flag3, o.qualityFlag2, o.gMeanPSFMag2, o.rMeanPSFMag2, o.iMeanPSFMag2, o.zMeanPSFMag2, o.gMeanCPSFMag2, o.rMeanCPSFMag2, o.iMeanCPSFMag2, o.zMeanCPSFMag2, o.gMeanCPSFMag2Err, o.rMeanCPSFMag2Err, o.iMeanCPSFMag2Err, o.zMeanCPSFMag2Err, o.qualityFlag22, o.gMeanPSFMag22, o.rMeanPSFMag22, o.iMeanPSFMag22, o.zMeanPSFMag22, o.gMeanCPSFMag22, o.rMeanCPSFMag22, o.iMeanCPSFMag22, o.zMeanCPSFMag22, o.gMeanCPSFMag22Err, o.rMeanCPSFMag22Err, o.iMeanCPSFMag22Err, o.zMeanCPSFMag22Err, o.qualityFlag222, o.gMeanPSFMag222, o.rMeanPSFMag222, o.iMeanPSFMag222, o.zMeanPSFMag222, o.gMeanCPSFMag222, o.rMeanCPSFMag222, o.iMeanCPSFMag222, o.zMeanCPSFMag222, o.gMeanCPSFMag222Err, o.rMeanCPSFMag222Err, o.iMeanCPSFMag222Err, o.zMeanCPSFMag222Err FROM mydb.[RRL_584630948352256_PS1] o JOIN ForcedWarpMeasurement fwm ON fwm.objID = o.objID.

Figure 11. A key feature of this data release is the inclusion of the individual detections, allowing time-resolved studies, illustrated by the r-band phase curve of one of the PS1 RR Lyrae. The IPP aperture and PSF fluxes are in good agreement, and either can be used for studies of the hundreds of thousands of variable and transient sources within PS1. Users are encouraged to check the provided flags for various bits documented in this work, as these may indicate suboptimal photometry. We highlight two such measurements in red. Uncertainties are typically smaller than the marker size.

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Appendix B
Abbreviations and Acronyms

3pi or 3π: Three Pi Survey. This survey covers 3π steradians of the sky (three-quarters of the sky), everything with decl. greater than −30°.

DR1: Data Release 1. Covers the 3π data release for ObjectThin, MeanObject, Stack*, ForcedMean*, and related metadata tables. Covers the static sky.

DR2: Data Release 2. 3π data release of time domain tables, including Detection, ForcedWarp*, Diff*, and related metadata.

DVO: Desktop Virtual Observatory—written by Eugene Manger, IPP uses this to store and manipulate catalog data.

GPC1: Gigapixel Camera 1. This is the name of the camera that is part of the Pan-STARRS1 telescope. 1.4 gigapixels and sees 7 deg² per exposure. It is made up of 60 OTA, each with 64 cells per OTA.

IPP: Image Processing Pipeline. Code developed to process and manage all aspects of Pan-STARRS1 processing, starting from downloading the images to the summit to generating data in the final database schema form.

MD: Short for Medium-Deep fields. A set of 10 fields, each of which is 7 deg², observed at a high cadence, primarily to be used for searches for transient objects. These will be released at a later time.

MOPS: Short for Moving Object Processing System. The Pan-STARRS subsystem responsible for linking detections from the IPP into discoveries of asteroids or other solar system objects.

OTA: Orthogonal transfer array, the name of the devices that make up the GPC1 camera.

PSI: Science interface. The interface used by consortium members to access earlier versions of the data.

PSPS: Published Science Products Subsystem—the Pan-STARRS1 databases.

PV3: Processing Version 3, refers to the processing/code iteration; this is the processing version of the first public Pan-STARRS1 data release (covers DR1–DR2).

Appendix C
Flag Tables

There are eight different classes of Flag tables for the database schema. This section lists the different flags as well as their descriptions. See Section 7.2.1 for more details on flags and bitmasks, and Appendix A for some example queries.

Appendix D
Schema

In this section, we present the contents of all DR2 tables, along with the expected DIFF tables for DR3. These listings were automatically generated from the XML code used to define the PSPS tables, with light editing to clean up the formatting for some of the units and equations.
### Table D1
**ObjectInfoFlags**

| Name             | Hexadecimal | Value | Description rerence |
|------------------|-------------|-------|---------------------|
| DEFAULT          | 0x00000000  | 0     | Initial value; resets all bits. |
| FEW              | 0x00000001  | 1     | Used within relphot; skip star. |
| POOR             | 0x00000002  | 2     | Used within relphot; skip star. |
| ICRF_QSO         | 0x00000004  | 4     | Object IDed with known ICRF quasar (may have ICRF position measurement) |
| HERN_QSO_P60     | 0x00000008  | 8     | Identified as a likely QSO (Hernitschek et al. 2016); P_QSO ≥ 0.60 |
| HERN_QSO_P05     | 0x00000010  | 16    | Identified as a possible QSO (Hernitschek et al. 2016), P_QSO ≥ 0.05 |
| HERN_RRL_P60     | 0x00000020  | 32    | Identified as a likely RR Lyra (Hernitschek et al. 2016), P_RRLyra ≥ 0.60 |
| HERN_RRL_P05     | 0x00000040  | 64    | Identified as a possible RR Lyra (Hernitschek et al. 2016), P_RRLyra ≥ 0.05 |
| HERN_VARIABLE    | 0x00000080  | 128   | Identified as a variable based on ChiSq? (Hernitschek et al. 2016) |
| TRANSIENT        | 0x00000100  | 256   | Identified as a nonperiodic (stationary) transient |
| HAS_SOLSYS_DET   | 0x00000200  | 512   | At least one detection identified with a known solar system object (asteroid or other) |
| MOST_SOLSYS_DET  | 0x00000400  | 1024  | Most detections identified with a known solar system object (asteroid or other) |
| LARGE_PM         | 0x00000800  | 2048  | Star with large proper motion |
| RAW_AVE          | 0x00001000  | 4096  | Simple weighted average position was used (no IRLS fitting) |
| FIT_AVE          | 0x00002000  | 8192  | Average position was fitted |
| FIT_PM           | 0x00004000  | 16384 | Proper motion model was fitted |
| FIT_PAR          | 0x00008000  | 32768 | Parallax model was fitted |
| USE_AVE          | 0x00010000  | 65536 | Average position used (not PM or PAR) |
| USE_PM           | 0x00020000  | 131072| Proper motion used (not AVE or PAR) |
| USE_PAR          | 0x00040000  | 262144| Parallax used (not AVE or PM) |
| NO_MEAN_ASTROM   | 0x00080000  | 524288| Mean astrometry could not be measured |
| STACK_FOR_MEAN   | 0x01000000  | 1048576| Stack position used for mean astrometry |
| MEAN_FOR_STACK   | 0x02000000  | 2097152| Mean astrometry used for STACK position |
| BAD_PM           | 0x04000000  | 4194304| Failure to measure proper motion model |
| EXT              | 0x08000000  | 8388608| Extended in our data (eg; PS) |
| EXT_ALT          | 0x10000000  | 16777216| Extended in external data (eg, 2MASS) |
| GOOD             | 0x02000000  | 33554432| Good-quality measurement in our data (eg., PS) |
| GOOD_ALT         | 0x04000000  | 67108864| Good-quality measurement in external data (eg., 2MASS) |
| GOOD_STACK       | 0x08000000  | 134217728| Good-quality object in the STACK (>1 good stack measurement) |
| BEST_STACK       | 0x10000000  | 268435456| The primary STACK measurements are the best measurements |
| SUSPECT_STACK    | 0x20000000  | 536870912| Suspect object in the STACK (no more than one good measurement, two or more suspect or good stack measurement) |
| BAD_STACK        | 0x40000000  | 1073741824| Poor-quality STACK object (no more than one good or suspect measurement) |

### Table D2
**ObjectQualityFlags**

| Name             | Hexadecimal | Value | Description rerence |
|------------------|-------------|-------|---------------------|
| DEFAULT          | 0x00000000  | 0     | Initial value; resets all bits. |
| QF_OBJ_EXT       | 0x00000001  | 1     | Extended in our data (eg., PS). |
| QF_OBJ_EXT_ALT   | 0x00000002  | 2     | Extended in external data (eg, 2MASS). |
| QF_OBJ_GOOD      | 0x00000004  | 4     | Good-quality measurement in our data (eg., PS). |
| QF_OBJ_GOOD_ALT  | 0x00000008  | 8     | Good-quality measurement in external data (eg., 2MASS). |
| QF_OBJ_GOOD_STACK| 0x00000010  | 16    | Good-quality object in the STACK (>1 good stack measurement). |
| QF_OBJ_BEST_STACK| 0x00000020  | 32    | The primary stack measurements are the best measurements. |
| QF_OBJ_SUSPECT_STACK| 0x00000040    | 64    | Suspect object in the STACK (no more than one good measurement, two or more suspect or good stack measurement). |
| QF_OBJ_BAD_STACK | 0x00000080  | 128   | Poor-quality STACK object (no more than one good or suspect measurement). |
### Table D3
ObjectFilterFlags

| Name               | Hexadecimal | Value | Description                                                                 |
|--------------------|-------------|-------|-----------------------------------------------------------------------------|
| DEFAULT            | 0x00000000  | 0     | Initial value; resets all bits.                                             |
| SECF_STAR_FEW      | 0x00000001  | 1     | Used within relphot: skip star.                                             |
| SECF_STAR_POOR     | 0x00000002  | 2     | Used within relphot: skip star.                                             |
| SECF_USE_SYNTH     | 0x00000004  | 4     | Synthetic photometry used in average measurement.                           |
| SECF_USE_UBERCAL   | 0x00000008  | 8     | Ubercal photometry used in average measurement.                             |
| SECF_HAS_PS1       | 0x00000010  | 16    | PS1 photometry used in average measurement.                                 |
| SECF_HAS_PS1_STACK | 0x00000020  | 32    | PS1 STACK photometry exists.                                                |
| SECF_HAS_TYCHO     | 0x00000040  | 64    | Tycho photometry used for synthetic magnitudes.                             |
| SECF_FIX_SYNTH     | 0x00000080  | 128   | Synthetic magnitudes repaired with zero-point map.                          |
| SECF_RANK_0        | 0x00000100  | 256   | Average magnitude calculated in zeroth pass.                               |
| SECF_RANK_1        | 0x00000200  | 512   | Average magnitude calculated in first pass.                                |
| SECF_RANK_2        | 0x00000400  | 1024  | Average magnitude calculated in second pass.                               |
| SECF_RANK_3        | 0x00000800  | 2048  | Average magnitude calculated in third pass.                                |
| SECF_RANK_4        | 0x00001000  | 4096  | Average magnitude calculated in fourth pass.                               |
| SECF_STACK_PRIMARY | 0x00004000  | 16384 | PS1 STACK photometry comes from primary skycell.                           |
| SECF_STACK_BESTDET | 0x00008000  | 32768 | PS1 STACK best measurement is a detection (not forced).                    |
| SECF_STACK_PRIMDET | 0x00100000  | 65536 | PS1 stack primary measurement is a detection (not forced).                 |
| SECF_STACK_PRIMARY_MULTIPLE | 0x00200000 | 131072 | PS1 stack object has multiple primary measurements (DR2).                |
| SECF_HAS_SDSS      | 0x00100000  | 1048576 | This photocode has SDSS photometry.                                      |
| SECF_HAS_HSC       | 0x00200000  | 2097152 | This photocode has HSC photometry.                                       |
| SECF_HAS_CFH       | 0x00400000  | 4194304 | This photocode has CFH photometry (mostly megacam).                        |
| SECF_HAS_DES       | 0x00800000  | 8388608 | This photocode has DES photometry.                                        |
| SECF_OBJ_EXT       | 0x01000000  | 16777216 | Extended in this band.                                                  |

### Table D4
ImageFlags

| Name                | Hexadecimal | Value | Description                                                                 |
|---------------------|-------------|-------|-----------------------------------------------------------------------------|
| NEW                 | 0x00000000  | 0     | No relphot/relastro attempted.                                              |
| PHOTOM_NOCAL        | 0x00000001  | 1     | Used within relphot to mean “do not apply fit.”                            |
| PHOTOM_POOR         | 0x00000002  | 2     | Relphot says image is bad (dMcal > limit).                                 |
| PHOTOM_SKIP         | 0x00000004  | 4     | External information image has bad photometry.                             |
| PHOTOM_FEW          | 0x00000008  | 8     | Currently too few measurements for good value for photometry.              |
| ASTROM_NOCAL        | 0x00000010  | 16    | User-set value used within relastro: ignore.                               |
| ASTROM_POOR         | 0x00000020  | 32    | Relastro says image is bad (dR, dD > limit).                               |
| ASTROM_FAIL         | 0x00000040  | 64    | Relastro fit diverged, fit not applied.                                    |
| ASTROM_SKIP         | 0x00000080  | 128   | External information image has bad astrometry.                             |
| ASTROM_FEW          | 0x00000100  | 256   | Currently too few measurements for good value for astrometry.              |
| PHOTOM_UBERCAL      | 0x00000200  | 512   | Externally supplied photometry zero point from ubercal analysis.            |
| ASTROM_GMM          | 0x00000400  | 1024  | Image was fitted to positions corrected by the galaxy motion model.        |

### Table D5
ForcedGalaxyShapeFlags

| Name                | Hexadecimal | Value | Description                                                                 |
|---------------------|-------------|-------|-----------------------------------------------------------------------------|
| NO_ERROR            | 0x00000000  | 0     | No error condition raised.                                                  |
| FAIL_FIT            | 0x00000001  | 1     | Fit failed to converge or was degenerate                                    |
| TOO_FEW             | 0x00000002  | 2     | Not enough points to fit the model                                          |
| OUT_OF_RANGE        | 0x00000004  | 4     | Fit minimum too far outside data range                                       |
| BAD_ERROR           | 0x00000008  | 8     | Invalid size error (nan or inf)                                             |
### Table D6
DetectionFlags

| Name                | Hexadecimal | Value | Description                                                                 |
|---------------------|-------------|-------|-----------------------------------------------------------------------------|
| DEFAULT             | 0x00000000  | 0     | Initial value; resets all bits.                                             |
| PSFMODEL            | 0x00000001  | 1     | Source fitted with a PSF model (linear or nonlinear).                       |
| EXTMODEL            | 0x00000002  | 2     | Source fitted with an extended source model.                                |
| FITTED              | 0x00000004  | 4     | Source fitted with a nonlinear model (PSF or EXT; good or bad).             |
| FAIL                | 0x00000008  | 8     | Fit (nonlinear) failed (nonconverge; off edge; run to zero).                |
| POOR                | 0x00000100  | 16    | Fit succeeds, but low signal-to-noise ratio, high-Chisq, or large (for PSF—drop?). |
| PAIR                | 0x00000200  | 32    | Source fitted with a double PSF.                                            |
| PSFSTAR             | 0x00000400  | 64    | Source used to define PSF model.                                            |
| SATSTAR             | 0x00000800  | 128   | Source model peak is above saturation.                                      |
| BLEND               | 0x00001000  | 256   | Source is a blend with other sources.                                       |
| EXTERNAL            | 0x00002000  | 512   | Source based on supplied input position.                                     |
| BADPSF              | 0x00004000  | 1024  | Failed to get good estimate of object’s PSF.                                |
| DEFECT              | 0x00008000  | 2048  | Source is thought to be a defect.                                           |
| SATURATED           | 0x00010000  | 4096  | Source is thought to be saturated pixels (bleed trail).                      |
| CR_LIMIT            | 0x00020000  | 8192  | Source has crNsigma above limit.                                            |
| EXT_LIMIT           | 0x00040000  | 16384 | Source has extNsigma above limit.                                           |
| MOMENTS.FAILURE     | 0x00080000  | 32768 | Could not measure the moments.                                              |
| SKY_FAILURE         | 0x00100000  | 65536 | Could not measure the local sky.                                            |
| SKYVAR_FAILURE      | 0x00200000  | 131072| Could not measure the local sky variance.                                    |
| BELOW_MOMENTS_SN    | 0x00400000  | 262144| Moments not measured due to low signal-to-noise ratio.                      |
| UNDEF_1             | 0x00800000  | 524288| Unused bit value.                                                           |
| BIG_RADIUS          | 0x01000000  | 1048576| Poor moments for small radius; try large radius.                             |
| AP_MAGS             | 0x02000000  | 2097152| Source has an aperture magnitude.                                           |
| BLEND_FIT           | 0x04000000  | 4194304| Source was fitted as a blend.                                                |
| EXTENDED_FIT        | 0x08000000  | 8388608| Full extended fit was used.                                                  |
| EXTENDED_STATS      | 0x0a000000  | 16777216| Extended aperture stats calculated.                                         |
| LINEAR_FIT          | 0x0a020000  | 3355432| Source fitted with the linear fit.                                           |
| NONLINEAR_FIT       | 0x0b000000  | 67108864| Source fitted with the nonlinear fit.                                       |
| RADIAL_FLUX         | 0x0d000000  | 134217728| Radial flux measurements calculated.                                        |
| SIZE_SKIPPED        | 0x10000000  | 268435456| Size could not be determined.                                               |
| PEAK_ON_SPIKE       | 0x20000000  | 536870912| Peak lands on diffraction spike.                                             |
| PEAK_ON_GHOST       | 0x2a000000  | 1073741824| Peak lands on ghost or glint.                                                |
| PEAK_OFF_CHIP       | 0x80000000  | 2147483648| Peak lands off edge of chip.                                                 |

### Table D7
DetectionFlags2

| Name                | Hexadecimal | Value | Description                                                                 |
|---------------------|-------------|-------|-----------------------------------------------------------------------------|
| DEFAULT             | 0x00000000  | 0     | Initial value; resets all bits.                                             |
| DIFF_WITH_Single    | 0x00000001  | 1     | Difference source matched to a single positive detection.                  |
| DIFF_WITH_DOUBLE    | 0x00000002  | 2     | Difference source matched to positive detections in both images.           |
| MATCHED             | 0x00000004  | 4     | Source generated based on another image (forced photometry at source location). |
| ON_SPIKE            | 0x00000008  | 8     | More than 25% of (PSF-weighted) pixels land on a diffraction spike.        |
| ON_STARCORE         | 0x00000010  | 16    | More than 25% of (PSF-weighted) pixels land on star core.                   |
| ON_BURNTOOL         | 0x00000020  | 32    | More than 25% of (PSF-weighted) pixels land on burntool.                    |
| ON_CONVPOOR         | 0x00000040  | 64    | More than 25% of (PSF-weighted) pixels land on convpoor.                    |
| PASS1_SRC           | 0x00000080  | 128   | Source detected in first pass analysis.                                     |
| HAS_BRIGHTER_NEIGHBOR| 0x00000100  | 256   | Peak is not the brightest in its footprint.                                |
| BRIGHT_NEIGHBOR_1   | 0x00000200  | 512   | Flux_negative/(r^2 flux_positive) > 1.                                     |
| BRIGHT_NEIGHBOR_10  | 0x00000400  | 1024  | Flux_negative/(r^2 flux_positive) > 10.                                    |
| DIFF_SELF_MATCH     | 0x00000800  | 2048  | Positive detection match is probably this source.                          |
| SATSTAR_PROFILE     | 0x00001000  | 4096  | Saturated source is modeled with a radial profile.                          |
| ECONTOUR_FEW_PTS    | 0x00002000  | 8192  | Too few points to measure the elliptical contour.                           |
| RADBIN_NAN_CENTER   | 0x00004000  | 16384 | Radial bins failed with too many NaN center bin.                            |
| PETRO_NAN_CENTER    | 0x00008000  | 32768 | Petrosian (1976) radial bins failed with too many NaN center bin.           |
| PETRO_NO_PROFILE    | 0x00010000  | 65536 | Petrosian (1976) not built because radial bins missing.                     |
| PETRO_INSIG_RATIO   | 0x00020000  | 131072| Insignificant measurement of Petrosian (1976) ratio.                        |
| PETRO_RATIO_ZEROBIN | 0x00040000  | 262144| Petrosian (1976) ratio in the zeroth bin (likely bad).                      |
| EXT_FITS_RUN        | 0x00080000  | 524288| Attempted to run extended fits on this source.                              |
| EXT_FITS_FAIL       | 0x00100000  | 1048576| At least one of the model fits failed.                                      |
| EXT_FITS_RETRY      | 0x00200000  | 2097152| One of the model fits was retried with new window.                          |
| EXT_FITS_NONE       | 0x00400000  | 4194304| All of the model fits failed.                                               |
## Table D8
DetectionFlags3

| Name              | Hexadecimal | Value | Description                                           |
|-------------------|-------------|-------|-------------------------------------------------------|
| DEFAULT           | 0x00000000  | 0     | Initial value; resets all bits.                       |
| NOCAL             | 0x00000001  | 1     | Detection ignored for this analysis (photocode; time range)—internal only. |
| POOR_PHOTO        | 0x00000002  | 2     | Detection is photometry outlier.                     |
| AREA              | 0x00000004  | 4     | Detection was ignored for photometry measurement.    |
| POOR_ASTROM       | 0x00000008  | 8     | Detection near image edge.                            |
| SKIP_ASTROM       | 0x00000020  | 32    | Detection was ignored for astrometry measurement.    |
| USED_OBJ          | 0x00000040  | 64    | Detection was used during update objects             |
| USED_CHIP         | 0x00000080  | 128   | Detection was used during update chips to measure astrometry with IRLS fit. |
| BLEND_MEAS        | 0x00000100  | 256   | Detection is within radius of multiple objects.      |
| BLEND_OBJ         | 0x00000200  | 512   | Multiple detections within radius of object.         |
| WARP_USED         | 0x00000400  | 1024  | Measurement used to find mean WARP photometry.       |
| UNMASKED_ASTRO    | 0x00000800  | 2048  | Detection was unmasked in update chips to determine astrometry parameter errors. |
| BLEND_MEAS_X      | 0x00001000  | 4096  | Detection is within radius of multiple objects across catalogs. |
| ARTIFACT          | 0x00002000  | 8192  | Detection is thought to be nonastronomical.          |
| SYNTH_MAG         | 0x00004000  | 16384 | Magnitude is synthetic.                               |
| PHOTOM_OBERCAL    | 0x00008000  | 32768 | Externally supplied zero point from ubercal analysis. |
| STACK_PRIMARY     | 0x00010000  | 65536 | This STACK measurement is in the primary sky cell.   |
| STACK_PHOT_SRC    | 0x00020000  | 131072| This measurement supplied the STACK photometry.       |
| ICRF_QSO          | 0x00040000  | 262144| This measurement is an ICRF reference position.       |
| IMAGE_EPOCH       | 0x00080000  | 524288| This measurement is registered to the image epoch    |
|                   |             |       | (not tied to the reference catalog epoch).            |
| PHOTOM_PSF        | 0x01000000  | 1048576| This measurement is used for the mean PSF magnitude.  |
| PHOTOM_APER       | 0x02000000  | 2097152| This measurement is used for the mean aperture magnitude. |
| PHOTOM_KRON       | 0x04000000  | 4194304| This measurement is used for the mean Kron (1980) magnitude. |
| MASKED_PSF        | 0x01000000  | 16777216| This measurement is masked based on IRLS weights for the mean PSF magnitude. |
| MASKED_APER       | 0x02000000  | 33554432| This measurement is masked based on IRLS weights for the mean aperture magnitude. |
| MASKED_KRON       | 0x04000000  | 67108864| This measurement is masked based on IRLS weights for the mean Kron (1980) magnitude. |
| OBJECT_HAS_2MASS  | 0x10000000  | 268435456| This measurement comes from an object with 2MASS data. |
| OBJECT_HAS_GAIA   | 0x20000000  | 536870912| This measurement comes from an object with Gaia data. |
| OBJECT_HAS_TYCHO  | 0x40000000  | 1073741824| This measurement comes from an object with Tycho data. |
D.2. Single Exposure Detection Tables

Table D9
ObjectThin: Contains the Positional Information for Objects in a Number of Coordinate Systems

| Column Name            | Units     | Data Type | Default | Description                                                                 |
|------------------------|-----------|-----------|---------|-----------------------------------------------------------------------------|
| objName                | VARCHAR   | REAL      | NA      | IAU name for this object.                                                   |
| objNameHMS             | VARCHAR   | REAL      | NA      | Alternate sexigesimal name for this object (DR2 only).                      |
| objPSOName             | VARCHAR   | REAL      | NA      | Alternate Pan-STARRS name for this object (DR1 only).                        |
| objAltName1            | VARCHAR   | REAL      | NA      | Alternate name for this object.                                             |
| objAltName2            | VARCHAR   | REAL      | NA      | Alternate name for this object.                                             |
| objAltName3            | VARCHAR   | REAL      | NA      | Alternate name for this object.                                             |
| objPopularName         | VARCHAR   | REAL      | NA      | Well-known name for this object.                                            |
| objID                  | BIGINT    | REAL      | NA      | Unique object identifier.                                                  |
| uniquePspsOBid         | BIGINT    | REAL      | NA      | Unique internal PSPS object identifier.                                     |
| ippObjID               | BIGINT    | REAL      | NA      | IPP internal object identifier.                                             |
| surveyID               | TINYINT   | REAL      | NA      | Survey identifier. Details in the Survey table.                             |
| htmlID                 | BIGINT    | REAL      | NA      | Hierarchical triangular mesh (Szalay et al. 2007) index.                    |
| zoneID                 | INT       | REAL      | NA      | Local zone index, found by dividing the sky into bands of decl. 1/2 arcminute in height: zoneID = floor((90+decl()./0.0083333). |
| tessID                 | TINYINT   | REAL      | 0       | Tessellation identifier. Details in the TessellationType table.             |
| projectionID           | SMALLINT  | REAL      | -1      | Projection cell identifier.                                                |
| skyCellID              | TINYINT   | REAL      | 255     | SkyCell region identifier.                                                  |
| randomID               | FLOAT     | REAL      | NA      | Random value drawn from the interval between zero and one.                  |
| batchID                | BIGINT    | REAL      | NA      | Internal database batch identifier.                                         |
| dvoRegionID            | INT       | REAL      | -1      | Internal DVO region identifier.                                            |
| processingVersion      | TINYINT   | REAL      | NA      | Data release version.                                                      |
| objInfoFlag            | INT       | REAL      | 0       | Information flag bitmask indicating details of the photometry. Values listed in ObjectInfoFlags. |
| raStackFlag            | TINYINT   | REAL      | 0       | Subset of objInfoFlag denoting whether this object is real or a likely false positive. Values listed in ObjectQualityFlags. |
| raStack                | degrees   | REAL      | -999    | Right ascension from STACK detections, weighted mean value across filters, in equinox J2000. See StackObjectThin for STACK epoch information. |
| decStack               | degrees   | REAL      | -999    | Decl. from STACK detections, weighted mean value across filters, in equinox J2000. See StackObjectThin for STACK epoch information. |
| raStackErr             | arcsec    | REAL      | -999    | Right ascension standard deviation from STACK detections.                   |
| decStackErr            | arcsec    | REAL      | -999    | Decl. standard deviation from STACK detections.                            |
| raMean                 | degrees   | REAL      | -999    | Right ascension from single-epoch detections (weighted mean) in equinox J2000 at the mean epoch given by epochMean. |
| decMean                | degrees   | REAL      | -999    | Decl. from single-epoch detections (weighted mean) in equinox J2000 at the mean epoch given by epochMean. |
| raMeanErr              | arcsec    | REAL      | -999    | Right ascension standard deviation from single-epoch detections.            |
| decMeanErr             | arcsec    | REAL      | -999    | Decl. standard deviation from single-epoch detections.                      |
| epochMean              | days      | REAL      | -999    | Modified Julian Date of the mean epoch corresponding to raMean, decMean (equinox J2000). |
| posMeanChisq           | REAL      | REAL      | -999    | Reduced chi-squared value of mean position.                                |
| cx                     | FLOAT     | REAL      | NA      | Cartesian x on a unit sphere.                                              |
| cy                     | FLOAT     | REAL      | NA      | Cartesian y on a unit sphere.                                              |
| cz                     | FLOAT     | REAL      | NA      | Cartesian z on a unit sphere.                                              |
| lambda                 | degrees   | REAL      | -999    | Ecliptic longitude.                                                       |
| beta                   | degrees   | REAL      | -999    | Ecliptic latitude.                                                        |
| l                      | degrees   | REAL      | -999    | Galactic longitude.                                                       |
| b                      | degrees   | REAL      | -999    | Galactic latitude.                                                        |
| nStackObjectRows       | SMALLINT  | REAL      | -999    | No. of independent StackObjectThin rows associated with this object.       |
| nStackDetections       | SMALLINT  | REAL      | -999    | Number of STACK detections.                                               |
| nDetections            | SMALLINT  | REAL      | -999    | Number of single-epoch detections in all filters.                         |
| ng                     | SMALLINT  | REAL      | -999    | Number of single-epoch detections in the g filter.                         |
| nr                     | SMALLINT  | REAL      | -999    | Number of single-epoch detections in the r filter.                         |
| ni                     | SMALLINT  | REAL      | -999    | Number of single-epoch detections in the i filter.                         |
| nz                     | SMALLINT  | REAL      | -999    | Number of single-epoch detections in the z filter.                         |
| ny                     | SMALLINT  | REAL      | -999    | Number of single-epoch detections in the y filter.                         |

Note. The objects associate single-epoch detections and the stacked detections within a 1° radius. The mean position from the single-epoch data is used as the basis for coordinates when available, or the position of an object in the STACK when it is not. The R.A. and decl. for both the STACK and single-epoch mean are provided. The number of detections in each filter from single-epoch data is listed, along with which filters the object has a STACK detection (Szalay et al. 2007).
### Table D10
MeanObject: Contains the Mean Photometric Information for Objects Based on the Single-epoch Data, Calculated as Described in Magnier et al. (2013)

| Column Name       | Units | Data Type | Default | Description                                                                 |
|-------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID             | …     | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspsOBid    | …     | BIGINT    | NA      | Unique internal PSPS object identifier.                                    |
| gQfPerfect        | …     | REAL      | −999    | Maximum PSF-weighted fraction of pixels totally unmasked from g-filter detections. |
| gMeanPSFMag       | AB    | REAL      | −999    | Mean PSF magnitude from g-filter detections.                               |
| gMeanPSFMagErr    | AB    | REAL      | −999    | Error in mean PSF magnitude from g-filter detections.                      |
| gMeanPSFMagStd    | AB    | REAL      | −999    | Standard deviation of PSF magnitudes from g-filter detections.              |
| gMeanKronMag      | AB    | REAL      | −999    | Mean Kron (1980) magnitude from g-filter detections.                       |
| gMeanKronMagErr   | AB    | REAL      | −999    | Error in mean Kron (1980) magnitude from g-filter detections.              |
| gMeanKronMagNpt   | …     | SMALLINT  | −999    | Number of measurements included in mean Kron (1980) magnitude from g-filter detections. |
| gMeanApMag        | AB    | REAL      | −999    | Mean aperture magnitude from g-filter detections.                          |
| gMeanApMagErr     | AB    | REAL      | −999    | Error in mean aperture magnitude from g-filter detections.                |
| gMeanApMagStd     | AB    | REAL      | −999    | Standard deviation of aperture magnitudes from g-filter detections.        |
| gMeanApMagNpt     | …     | SMALLINT  | −999    | Number of measurements included in the mean aperture magnitude from g-filter detections. |
| gFlags            | …     | INT       | 0       | Information flag bitmask for mean object from g-filter detections.         |
| rQfPerfect        | …     |           |         | Same entries repeated for the r, i, z, and y filters                       |
| yFlags            | …     |           |         |                                                                             |

**Note.** To be included in this table, an object must be bright enough to have been detected at least once in an individual exposure. PSF, Kron (1980), and aperture magnitudes and statistics are listed for all filters.

### Table D11
GaiaFrameCoordinate: PSPS Objects Calibrated Against Gaia Astrometry

| Column Name       | Units | Data Type | Default | Description                                                                 |
|-------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID             | …     | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspsGOid    | …     | BIGINT    | NA      | Unique internal PSPS object identifier.                                    |
| ippObjID          | …     | BIGINT    | NA      | IPP internal object identifier.                                            |
| batchID           | …     | BIGINT    | NA      | Internal database batch identifier.                                        |
| gaiaFlag          | …     | INT       |         | Information flag bitmask.                                                  |
| ra                | degrees | FLOAT    | −999    | Right ascension from single-epoch detections (weighted mean) in equinox J2000 at the mean epoch given by epochMean and calibrated against Gaia. |
| dec               | degrees | FLOAT    | −999    | Decl. from single-epoch detections (weighted mean) in equinox J2000 at the mean epoch given by epochMean and calibrated against Gaia. |
| raErr             | arcsec | REAL      | −999    | Right ascension standard deviation from single-epoch detections.            |
| decErr            | arcsec | REAL      | −999    | Decl. standard deviation from single-epoch detections.                     |
### Table D12
FrameMeta: Contains Metadata Related to an Individual Exposure

| Column Name     | Units     | Data Type      | Default | Description                                                                 |
|-----------------|-----------|----------------|---------|-----------------------------------------------------------------------------|
| frameID         |           | INT            | NA      | Unique frame/exposure identifier.                                           |
| frameName       |           | VARCHAR(32)    | NA      | Frame/exposure name provided by the camera software.                       |
| surveyID        |           | TINYINT        | NA      | Survey identifier. Details in the Survey table.                             |
| filterID        |           | TINYINT        | NA      | Filter identifier. Details in the Filter table.                             |
| ippCamID        |           | INT            | NA      | IPP camRun identifier.                                                      |
| ippWarpID       |           | INT            | NA      | IPP warpRun identifier.                                                     |
| cameraID        |           | SMALLINT       | NA      | Camera identifier. Details in the CameraConfig table.                       |
| cameraConfigID  |           | SMALLINT       | NA      | Camera configuration identifier. Details in the CameraConfig table.          |
| telescopeID     |           | SMALLINT       | NA      | Telescope identifier.                                                       |
| analysisVer     |           | VARCHAR(100)   |         | IPP software analysis release version.                                      |
| md5sum          |           | VARCHAR(100)   |         | IPP MD5 Checksum.                                                           |
| nOTA            |           | SMALLINT       | −999    | Number of valid OTA images in this frame/exposure.                         |
| photoScat       | magnitudes| REAL           | −999    | Photometric scatter relative to reference catalog across the full FOV.      |
| nPhotoRef       |           | INT            | −999    | Number of photometric reference sources.                                   |
| expStart        | days      | FLOAT          | −999    | Modified Julian Date at the start of the exposure.                         |
| expTime         | seconds   | REAL           | −999    | Exposure time of the frame/exposure. Necessary for converting listed fluxes|
| airmass         |           | REAL           | 0       | Airmass at midpoint of the exposure. Necessary for converting listed fluxes|
| raBore          | degrees   | FLOAT          | −999    | Right ascension of telescope boresight.                                    |
| decBore         | degrees   | FLOAT          | −999    | Decl. of telescope boresight.                                              |
| ctype1          |           | VARCHAR(100)   |         | Name of astrometric projection in R.A.                                      |
| ctype2          |           | VARCHAR(100)   |         | Name of astrometric projection in decl.                                    |
| crval1          | degrees   | FLOAT          | −999    | Right ascension corresponding to reference pixel.                          |
| crval2          | degrees   | FLOAT          | −999    | Decl. corresponding to reference pixel.                                    |
| crpix1          | pixels    | FLOAT          | −999    | Reference pixel for R.A.                                                    |
| crpix2          | pixels    | FLOAT          | −999    | Reference pixel for decl.                                                  |
| cdelt1          | degrees/pixel | FLOAT       | −999    | Pixel scale in R.A.                                                        |
| cdelt2          | degrees/pixel | FLOAT       | −999    | Pixel scale in decl.                                                       |
| pc001001        |           | FLOAT          | −999    | Linear transformation matrix element between focal plane pixel L and R.A.   |
| pc001002        |           | FLOAT          | −999    | Linear transformation matrix element between focal plane pixel M and R.A.   |
| pc002001        |           | FLOAT          | −999    | Linear transformation matrix element between focal plane pixel L and decl.  |
| pc002002        |           | FLOAT          | −999    | Linear transformation matrix element between focal plane pixel M and decl.  |
| polyOrder       |           | TINYINT        | 255     | Polynomial order of astrometric fit between detector focal plane and sky.  |
| pca1x3y0        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^3 y^0)\) for R.A.|
| pca1x2y1        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^2 y^1)\) for R.A.|
| pca1x1y2        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^1 y^2)\) for R.A.|
| pca1x0y3        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^0 y^3)\) for R.A.|
| pca1x2y0        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^2 y^0)\) for R.A.|
| pca1x1y1        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^1 y^1)\) for R.A.|
| pca1x0y2        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^0 y^2)\) for R.A.|
| pca2x3y0        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^2 y^0)\) for decl.|
| pca2x2y1        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^2 y^1)\) for decl.|
| pca2x1y2        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^1 y^2)\) for decl.|
| pca2x0y3        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^0 y^3)\) for decl.|
| pca2x2y0        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^2 y^0)\) for decl.|
| pca2x1y1        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^1 y^1)\) for decl.|
| pca2x0y2        |           | FLOAT          | −999    | Polynomial coefficient for the astrometric fit component \((x^0 y^2)\) for decl.|
| batchID         |           | BIGINT         | NA      | Internal database batch identifier.                                        |
| processingVersion |       | TINYINT        | NA      | Data release version.                                                      |

**Note.** A “Frame” refers to the collection of all images obtained by the 60 OTA devices in the camera in a single exposure. The camera configuration, telescope pointing, observation time, and astrometric solution from the detector focal plane \((L, M)\) to the sky \((\text{R.A.}, \text{decl.})\) are provided.
Table D13

| Column Name       | Units          | Data Type   | Default | Description                                                                 |
|-------------------|----------------|-------------|---------|-----------------------------------------------------------------------------|
| imageID           |                | BIGINT      | NA      | Unique image identifier. Constructed as (100 × frameID + ccdID).             |
| frameID           |                | INT         | NA      | Unique frame/exposure identifier.                                            |
| ccdID             |                | SMALLINT    | NA      | OTA identifier based on location in the focal plane, specific to an individual device. |
| photoCalID        |                | INT         | NA      | Photometric calibration identifier. Details in the PhotoCal table.            |
| filterID          |                | TINYINT     | NA      | Filter identifier. Details in the Filter table.                             |
| bias              | adu            | REAL        | −999    | OTA bias level.                                                             |
| biasScat          | adu            | REAL        | −999    | Scatter in bias level.                                                      |
| sky               | Jy arcsec⁻²    | REAL        | −999    | Mean sky brightness.                                                        |
| skyScat           | Jy arcsec⁻²    | REAL        | −999    | Scatter in mean sky brightness.                                             |
| nDetect           |                | INT         | −999    | Number of detections in this image.                                         |
| detectionThreshold| magnitudes     | REAL        | −999    | Reference magnitude for detection efficiency calculation.                   |
| astroScat         | arcseconds     | REAL        | −999    | Measurement of the calibration (not astrometric error) defined to be the sum in quadrature of the standard deviations in the X and Y directions. |
| photoScat         | magnitudes     | REAL        | −999    | Photometric scatter relative to reference catalog.                          |
| nAstroRef         |                | INT         | −999    | Number of astrometric reference sources.                                    |
| nPhotoRef         |                | INT         | −999    | Number of photometric reference sources.                                    |
| recalAstroScatX   | arcseconds     | REAL        | −999    | Measurement of the recalibration (not astrometric error) in the X direction. |
| recalAstroScatY   | arcseconds     | REAL        | −999    | Measurement of the recalibration (not astrometric error) in the Y direction. |
| recalNAAstroStars | INT            | REAL        | −999    | Number of astrometric reference sources used in recalibration.              |
| recalphotoScat    | magnitudes     | REAL        | −999    | Photometric scatter relative to reference catalog.                          |
| nAxis1            | pixels         | SMALLINT    | −999    | Image dimension in x.                                                       |
| nAxis2            | pixels         | SMALLINT    | −999    | Image dimension in y.                                                       |
| psfModelID        |                | INT         | −999    | PSF model identifier.                                                       |
| psFWHM            | arcseconds     | REAL        | −999    | Mean PSF FWHM at image center.                                               |
| psFWHMAcc         | arcseconds     | REAL        | −999    | PSF major axis FWHM at image center.                                         |
| psFWHMMinor       | arcseconds     | REAL        | −999    | PSF minor axis FWHM at image center.                                         |
| psrTheta          | degrees        | REAL        | −999    | PSF major axis orientation at image center.                                 |
| momentMajor       | arcseconds     | REAL        | −999    | PSF major axis second moment.                                               |
| momentMinor       | arcseconds     | REAL        | −999    | PSF minor axis second moment.                                               |
| momentM2C         | arcsec²        | REAL        | −999    | Moment $M2C = M_{xx} - M_{yy}$.                                              |
| momentM2S         | arcsec²        | REAL        | −999    | Moment $M2S = 2M_{xy}$.                                                     |
| momentM3          | arcsec²        | REAL        | −999    | Trefolq second moment $= \sqrt{(M_{xxx} - 3M_{xyy})^2 + (3M_{xyy} - M_{yyy})^2}$. |
| momentM4          | arcsec²        | REAL        | −999    | Quadrupole second moment $= \sqrt{(M_{xxx} - 6M_{xyy} + M_{yyy})^2 + (4M_{xyy} - 4M_{yyy})^2}$. |
| apResid           | magnitudes     | REAL        | −999    | Residual of aperture corrections.                                           |
| dapResid          | magnitudes     | REAL        | −999    | Scatter of aperture corrections.                                            |
| detectorID        |                | VARCHAR     | (100)   | Identifier for each individual OTA detector device.                         |
| qaFlags           |                | BIGINT      | −999    | Q/A flags for this image. Values listed in ImageFlags.                      |
| detrend1          |                | VARCHAR     | (100)   | Identifier for detrend image 1, the static mask.                            |
| detrend2          |                | VARCHAR     | (100)   | Identifier for detrend image 2, the dark model.                             |
| detrend3          |                | VARCHAR     | (100)   | Identifier for detrend image 3, the flat.                                   |
| detrend4          |                | VARCHAR     | (100)   | Identifier for detrend image 4, the fringe.                                 |
| detrend5          |                | VARCHAR     | (100)   | Identifier for detrend image 5, the noise map.                              |
| detrend6          |                | VARCHAR     | (100)   | Identifier for detrend image 6, the nonlinearity correction.                |
| detrend7          |                | VARCHAR     | (100)   | Identifier for detrend image 7, the video dark model.                       |
| detrend8          |                | VARCHAR     | (100)   | Identifier for detrend image 8.                                             |
| photoZero         | magnitudes     | REAL        | −999    | Locally derived photometric zero point for this image.                      |
| ctype1            |                | VARCHAR     | (100)   | Name of astrometric projection in focal plane L.                            |
| ctype2            |                | VARCHAR     | (100)   | Name of astrometric projection in focal plane M.                            |
| crval1            | focal plane pixels | FLOAT     | −999    | Focal plane L corresponding to reference pixel.                            |
| crval2            | focal plane pixels | FLOAT     | −999    | Focal plane M corresponding to reference pixel.                            |
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Table D13
(Continued)

| Column Name | Units | Data Type | Default | Description |
|-------------|-------|-----------|---------|-------------|
| crpix1      | raw pixels | FLOAT | −999    | Reference pixel for focal plane L. |
| crpix2      | raw pixels | FLOAT | −999    | Reference pixel for focal plane M. |
| cdel1       | focal plane pixels/ raw pixel | FLOAT | −999    | Pixel scale in focal plane x. |
| cdel2       | focal plane pixels/ raw pixel | FLOAT | −999    | Pixel scale in focal plane y. |
| pc001001    | ... | FLOAT | −999    | Linear transformation matrix element between image pixel x and focal plane pixel L. |
| pc001002    | ... | FLOAT | −999    | Linear transformation matrix element between image pixel y and focal plane pixel L. |
| pc002001    | ... | FLOAT | −999    | Linear transformation matrix element between image pixel x and focal plane pixel M. |
| pc002002    | ... | FLOAT | −999    | Linear transformation matrix element between image pixel y and focal plane pixel M. |
| polyOrder   | ... | TINYINT | 255     | Polynomial order of astrometric fit between the image pixels and the detector focal plane. |
| pca1x3y0    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^3, y^0)\) for focal plane L. |
| pca1x2y1    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^2, y^1)\) for focal plane L. |
| pca1x1y2    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^1, y^2)\) for focal plane L. |
| pca1x0y3    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^0, y^3)\) for focal plane L. |
| pca1x2y0    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^2, y^0)\) for focal plane L. |
| pca1x1y1    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^1, y^1)\) for focal plane L. |
| pca1x0y2    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^0, y^2)\) for focal plane L. |
| pca2x3y0    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^3, y^0)\) for focal plane M. |
| pca2x2y1    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^2, y^1)\) for focal plane M. |
| pca2x1y2    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^1, y^2)\) for focal plane M. |
| pca2x0y3    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^0, y^3)\) for focal plane M. |
| pca2x2y0    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^2, y^0)\) for focal plane M. |
| pca2x1y1    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^1, y^1)\) for focal plane M. |
| pca2x0y2    | ... | FLOAT | −999    | Polynomial coefficient for the astrometric fit component \((x^0, y^2)\) for focal plane M. |
| processingVersion | ... | TINYINT | NA      | Data release version. |

Note. The characterization of the image quality, the detrends applied, and the astrometric solution from the raw pixels \((X, Y)\) to the detector focal plane \((L, M)\) are provided.
### Table D14
Detection: Contains Single-epoch Photometry of Individual Detections from a Single Exposure

| Column Name | Units | Data Type | Default | Description |
|-------------|-------|-----------|---------|-------------|
| objID       | ...   | BIGINT    | NA      | Unique object identifier. |
| uniquePsp2id| ...   | BIGINT    | NA      | Unique internal PSPS detection identifier. |
| detectID    | ...   | BIGINT    | NA      | Unique detection identifier. |
| ippObjID    | ...   | BIGINT    | NA      | IPP internal object identifier. |
| ippDetectID | ...   | BIGINT    | NA      | IPP internal detection identifier. |
| filterID    | ...   | TINYINT   | NA      | Filter identifier. Details in the Filter table. |
| surveyID    | ...   | TINYINT   | NA      | Survey identifier. Details in the Survey table. |
| imageID     | ...   | BIGINT    | NA      | Unique image identifier. Constructed as (100 × frameID + ccdID). |
| randomDetID | ...   | FLOAT     | NA      | Random value drawn from the interval between zero and one. |
| dvoRegionID | ...   | INT       | –1      | Internal DVO region identifier. |
| obsTime     | days  | FLOAT     | –999    | Modified Julian Date at the midpoint of the observation. |
| xPos        | raw pixels | REAL   | –999    | PSF x-center location. |
| yPos        | raw pixels | REAL   | –999    | PSF y-center location. |
| xPosErr     | raw pixels | REAL   | –999    | Error in the PSF x-center location. |
| yPosErr     | raw pixels | REAL   | –999    | Error in the PSF y-center location. |
| pltScale    | arcseconds/pixel | REAL | –999 | Local plate scale at this location. |
| posAngle    | degrees  | FLOAT    | –999    | Position angle (sky-to-chip) at this location. |
| ra          | degrees  | FLOAT    | –999    | Right ascension. |
| dec         | degrees  | FLOAT    | –999    | Declination. |
| raErr       | arcseconds | REAL   | –999    | Right ascension error. |
| decErr      | arcseconds | REAL   | –999    | Declination error. |
| extNSigma   |        | REAL     | 0       | An extendedness measure based on the deviation between PSF and Kron model. |
| zp          | magnitudes | REAL   | 0       | Photometric zero point. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| telluricExt | magnitudes | REAL   | NA      | Estimated Telluric extinction due to nonphotometric observing conditions. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| expTime     | seconds  | REAL     | –999    | Exposure time of the frame/exposure. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| airMass     |        | REAL     | 0       | Airmass at midpoint of the exposure. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| psIFlux     | Jy      | REAL     | –999    | Flux from PSF fit. |
| psIFluxErr  | Jy      | REAL     | –999    | Error on flux from PSF fit. |
| psMajorFWHM | arcsec | REAL     | –999    | PSF major axis FWHM. |
| psMinorFWHM | arcsec | REAL     | –999    | PSF minor axis FWHM. |
| psTheta     | degrees | REAL     | –999    | PSF major axis orientation. |
| psCore      |        | REAL     | –999    | PSF core parameter k, where $F = F_0/(1 + kr^2 + r^{3.33})$. |
| psQF        |        | REAL     | –999    | PSF coverage factor. |
| psQFPerfect |        | REAL     | –999    | PSF weighted fraction of pixels totally unmasked. |
| psChiSq     |        | REAL     | –999    | Reduced chi-squared value of the PSF model fit. |
| psFLikelihood|        | REAL     | –999    | Likelihood that this detection is best fit by a PSF. |
| momentXX    | arcsec^2 | REAL   | –999    | Second moment $M_{xx}$. |
| momentXY    | arcsec^2 | REAL   | –999    | Second moment $M_{xy}$. |
| momentYY    | arcsec^2 | REAL   | –999    | Second moment $M_{yy}$. |
| momentR1    | arcsec  | REAL     | –999    | First radial moment. |
| momentRH    | arcsec^0.5 | REAL  | –999    | Half-radial moment ($r^{0.5}$ weighting). |
| momentM3C   | arcsec^2 | REAL     | –999    | Cosine of trefoil second moment term: $r^2 \cos(3\theta) = M_{xxx} - 3M_{xyy}$. |
| momentM3S   | arcsec^2 | REAL     | –999    | Sine of trefoil second moment: $r^2 \sin(3\theta) = 3M_{xxy} - M_{yyy}$. |
| momentM4C   | arcsec^2 | REAL     | –999    | Cosine of quadrupole second moment: $r^2 \cos(4\theta) = M_{xxxx} - 6M_{xxyy} + M_{yyy}$. |
| momentM4S   | arcsec^2 | REAL     | –999    | Sine of quadrupole second moment: $r^2 \sin(4\theta) = 4M_{xxyy} - 4M_{yy}$. |
| apFlux      | Jy      | REAL     | –999    | Flux in seeing-dependent aperture. |
| apFluxErr   | Jy      | REAL     | –999    | Error on flux in seeing-dependent aperture. |
| apFillF     |        | REAL     | –999    | Aperture fill factor. |
| apRadius    | arcsec | REAL     | –999    | Aperture radius. |
| kronFlux    | Jy      | REAL     | –999    | Kron (1980) flux. |
| kronFluxErr | Jy      | REAL     | –999    | Error on Kron (1980) flux. |
| kronRad     | arcsec | REAL     | –999    | Kron (1980) radius. |
| sky         | Jy arcsec^-2 | REAL  | –999    | Background sky level. |
| skyErr      | Jy arcsec^-2 | REAL  | –999    | Error in background sky level. |
| infoFlag    |        | BIGINT   | 0       | Information flag bitmask indicating details of the photometry. Values listed in DetectionFlags. |
| infoFlag2   |        | INT      | 0       | Information flag bitmask indicating details of the photometry. Values listed in DetectionFlags2. |
Table D14 (Continued)

| Column Name   | Units | Data Type | Default | Description                                                                 |
|---------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| infoFlag3     | ⋯     | INT       | 0       | Information flag bitmask indicating details of the photometry. Values listed in DetectionFlags3. |
| processingVersion | ⋯   | TINYINT   | NA      | Data release version.                                                       |

**Note.** The identifiers connecting the detection back to the original image and to the object association are provided. PSF, aperture, and Kron (1980) photometry are included, along with sky and detector coordinate positions.

Table D15

ImageDetEffMeta: Contains the Detection Efficiency Information for a Given Individual OTA Image

| Column Name   | Units      | Data Type | Default | Description                                                                 |
|---------------|------------|-----------|---------|-----------------------------------------------------------------------------|
| imageID       | ⋯          | BIGINT    | NA      | Unique image identifier. Constructed as (100 × frameID + ccdID).             |
| frameID       | ⋯          | INT       | NA      | Unique frame/exposure identifier.                                           |
| magref        | magnitudes | REAL      | NA      | Detection efficiency reference magnitude.                                   |
| nInjected     | ⋯          | INT       | NA      | Number of fake sources injected in each magnitude bin.                      |
| offset01      | magnitudes | REAL      | NA      | Detection efficiency magnitude offset for bin 1.                            |
| counts01      |           | REAL      | NA      | Detection efficiency count of recovered sources in bin 1.                   |
| diffMean01    | magnitudes | REAL      | NA      | Detection efficiency mean magnitude difference in bin 1.                    |
| diffStdev01   | magnitudes | REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 1.   |
| errMean01     | magnitudes | REAL      | NA      | Detection efficiency mean magnitude error in bin 1.                         |
| counts02      |           | REAL      | NA      | Detection efficiency count of recovered sources in bin 2.                   |
| diffMean02    | magnitudes | REAL      | NA      | Detection efficiency mean magnitude difference in bin 2.                    |
| diffStdev02   | magnitudes | REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 2.   |
| errMean02     | magnitudes | REAL      | NA      | Detection efficiency mean magnitude error in bin 2.                         |
| offset03      | magnitudes | REAL      | NA      | Detection efficiency magnitude offset for bin 3.                            |
| counts03      |           | REAL      | NA      | Detection efficiency count of recovered sources in bin 3.                   |
| diffMean03    | magnitudes | REAL      | NA      | Detection efficiency mean magnitude difference in bin 3.                    |
| diffStdev03   | magnitudes | REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 3.   |
| errMean03     | magnitudes | REAL      | NA      | Detection efficiency mean magnitude error in bin 3.                         |
| ...           |           | REAL      | NA      | Detection efficiency magnitude offset for bin 13.                           |
| offset13      | magnitudes | REAL      | NA      | Detection efficiency magnitude offset for bin 13.                           |
| counts13      |           | REAL      | NA      | Detection efficiency count of recovered sources in bin 13.                  |
| diffMean13    | magnitudes | REAL      | NA      | Detection efficiency mean magnitude difference in bin 13.                   |
| diffStdev13   | magnitudes | REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 13.  |
| errMean13     | magnitudes | REAL      | NA      | Detection efficiency mean magnitude error in bin 13.                         |

**Note.** Provides the number of recovered sources out of 500 injected fake sources and statistics about the magnitudes of the recovered sources for a range of magnitude offsets.
D.3. Stack Tables

StackMeta: Contains the Metadata Describing the Stacked Image Produced from the Combination of a Set of Single-epoch Exposures

| Column Name        | Units | Data Type     | Default | Description                                                                 |
|--------------------|-------|---------------|---------|-----------------------------------------------------------------------------|
| stackImageID       |       | BIGINT        | NA      | Unique STACK identifier.                                                    |
| batchID            |       | BIGINT        | NA      | Internal database batch identifier.                                         |
| surveyID           |       | TINYINT       | NA      | Survey identifier. Details in the Survey table.                             |
| filterID           |       | TINYINT       | NA      | Filter identifier. Details in the Filter table.                             |
| stackTypeID        |       | TINYINT       | 0       | Stack-type identifier. Details in the StackType table.                      |
| tessID             |       | TINYINT       | 0       | Tessellation identifier. Details in the TessellationType table.             |
| projectionID       |       | SMALLINT      | −1      | Projection cell identifier.                                                |
| skyCellID          |       | TINYINT       | 255     | Sky cell region identifier.                                                |
| photoCalID         |       | INT           | NA      | Photometric calibration identifier. Details in the PhotoCal table.           |
| analysisVer        |       | VARCHAR(100) |         | IPP software analysis release version.                                      |
| md5sum             |       | TINYINT       |         | IPP MD5 Checksum.                                                          |
| expTime            |       | REAL          | −999    | Exposure time of the stack. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| nP2Images          |       | SMALLINT      | −999    | Number of input exposures/faces contributing to this stack.                |
| detectionThreshold |       | REAL          | −999    | Reference magnitude for detection efficiency calculation.                  |
| astroScat          |       | REAL          | −999    | Measurement of the calibration (not astrometric error) defined to be the sum in quadrature of the standard deviations in the X and Y directions. |
| photoScat          |       | REAL          | −999    | Photometric scatter relative to the reference catalog.                     |
| nAstroRef          |       | INT           | −999    | Number of astrometric reference sources.                                   |
| nPhotoRef          |       | INT           | −999    | Number of photometric reference sources.                                   |
| recalAstroScatX    | arcsec| REAL          | −999    | Measurement of the recalibration (not astrometric error) in the X direction.|
| recalAstroScatY    | arcsec| REAL          | −999    | Measurement of the recalibration (not astrometric error) in the Y direction.|
| recalNAstroStars   |       | INT           | −999    | Number of astrometric reference sources used in recalibration.             |
| recalphotoScat     |       | REAL          | −999    | Photometric scatter relative to reference catalog.                         |
| recalNPhotoStars   |       | INT           | −999    | Number of astrometric reference sources used in recalibration.             |
| psfModelID         |       | INT           | −999    | PSF model identifier.                                                       |
| psfFWHM            | arcsec| REAL          | −999    | Mean PSF FWHM at image center.                                              |
| psfWidMajor        | arcsec| REAL          | −999    | PSF major axis FWHM at image center.                                        |
| psfWidMinor        | arcsec| REAL          | −999    | PSF minor axis FWHM at image center.                                        |
| psfTheta           | degrees| REAL         | −999    | PSF major axis orientation at image center.                                 |
| photoZero          |        | REAL          | −999    | Locally derived photometric zero point for this stack.                     |
| photoZeroAperture  |        | REAL          | −999    | Locally derived photometric zero point for this stack (aperture-like measurements only; DR2). |
| ctype1             |       | VARCHAR(100) |         | Name of astrometric projection in R.A.                                     |
| ctype2             |       | VARCHAR(100) |         | Name of astrometric projection in decl.                                    |
| crval1             | degrees| FLOAT        | −999    | R.A. corresponding to reference pixel.                                     |
| crval2             | degrees| FLOAT        | −999    | Decl. corresponding to reference pixel.                                    |
| crpix1             | sky pixels| FLOAT | −999    | Reference pixel for R.A.                                                   |
| crpix2             | sky pixels| FLOAT | −999    | Reference pixel for decl.                                                  |
| cdel1              | degrees/pixel | FLOAT | −999    | Pixel scale in R.A.                                                       |
| cdel2              | degrees/pixel | FLOAT | −999    | Pixel scale in decl.                                                      |
| pc001001           |       | FLOAT         | −999    | Linear transformation matrix element between image pixel x and R.A.         |
| pc001002           |       | FLOAT         | −999    | Linear transformation matrix element between image pixel y and R.A.         |
| pc002001           |       | FLOAT         | −999    | Linear transformation matrix element between image pixel x and decl.       |
| pc002002           |       | FLOAT         | −999    | Linear transformation matrix element between image pixel y and decl.       |
| processingVersion  |       | TINYINT       | NA      | Data release version.                                                      |

Note. The nature of the STACK is given by the StackTypeID. The astrometric and photometric calibration of the stacked image are listed.
Table D17
StackObjectThin: Contains the Positional and Photometric Information for Point-source Photometry of STACK Detections

| Column Name   | Units    | Data Type | Default | Description                                                                 |
|---------------|----------|-----------|---------|-----------------------------------------------------------------------------|
| objID         |          | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspSStid|          | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                      |
| rippObjID     |          | BIGINT    | NA      | IPP internal object identifier.                                             |
| tessID        |          | TINYINT   | 0       | Tessellation identifier. Details in the TessellationType table.             |
| projectionID  |          | SMALLINT  | −1      | Projection cell identifier.                                                |
| skyCellID     |          | TINYINT   | 255     | SkyCell region identifier.                                                 |
| tessID        |          | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| primaryDetection |       | TINYINT   | 255     | Identifies if this row is the primary STACK detection (incorrectly set in DR1 and DR2). |
| bestDetection |          | TINYINT   | 255     | Identifies if this row is the best detection (incorrectly set in DR1 and DR2).|
| dvoRegionID   |          | INT       | −1      | Internal DVO region identifier.                                            |
| processingVersion |     | TINYINT   | NA      | Data release version.                                                      |
| gippDetectID  |          | BIGINT    | NA      | IPP internal detection identifier.                                          |
| gstackDetectID|          | BIGINT    | NA      | Unique STACK detection identifier.                                         |
| gstackImageID |          | BIGINT    | NA      | Unique STACK identifier for g-filter detection.                            |
| gra           |          | degrees   | FLOAT   | Right ascension from g-filter STACK detection.                             |
| gdec          |          | degrees   | FLOAT   | Decl. from g-filter STACK detection.                                       |
| graErr        |          | arcseconds| REAL    | Right ascension error from g-filter STACK detection.                       |
| gdecErr       |          | arcsec    | REAL    | Decl. error from g-filter STACK detection.                                 |
| gEpoch        |          | days      | FLOAT   | Modified Julian Date of the mean epoch of images contributing to the g-band STACK (equinox J2000). |
| gPSFMag       |          | AB        | REAL    | PSF magnitude from the g-filter STACK detection.                           |
| gPSFMagErr    |          | AB        | REAL    | Error in the PSF magnitude from the g-filter STACK detection.              |
| gApMag        |          | AB        | REAL    | Aperture magnitude from the g-filter STACK detection.                      |
| gApMagErr     |          | AB        | REAL    | Error in the aperture magnitude from the g-filter STACK detection.        |
| gKronMag      |          | AB        | REAL    | Kron (1980) magnitude from the g-filter STACK detection.                   |
| gKronMagErr   |          | AB        | REAL    | Error in the Kron (1980) magnitude from the g-filter STACK detection.      |
| ginfoFlag     |          | BIGINT    | 0       | Information flag bitmask indicating details of the g-filter STACK photometry. Values listed in DetectionFlags. |
| ginfoFlag2    |          | INT       | 0       | Information flag bitmask indicating details of the g-filter STACK photometry. Values listed in DetectionFlags2. |
| ginfoFlag3    |          | INT       | 0       | Information flag bitmask indicating details of the g-filter STACK photometry. Values listed in DetectionFlags3. |
| ginfoFlag4    |          | INT       | 0       | Information flag bitmask indicating details of the g-filter STACK photometry. Values listed in ObjectFilterFlags. (DR2) |
| gframes       |          | INT       | −999    | Number of input frames/exposures contributing to the g-filter STACK detection. |

Note. The information for all filters are joined into a single row, with metadata indicating if this STACK object represents the primary detection. Due to overlaps in the STACK tessellations, an object may appear in multiple STACK images. The primary detection is the unique detection from the STACK image that provides the best coverage with minimal projection stretching. All other detections of the object in that filter are secondary, regardless of their properties. The detection flagged as best is the primary detection if that detection has a psfQf value greater than 0.98; if that is not met, then any of the primary or secondary detections with the highest psfQf value is flagged as best.
Table D18
StackObjectAttributes: Contains the PSF, Kron (1980), and Aperture Fluxes for All Filters in a Single Row, along with Point-source Object Shape Parameters

| Column Name       | Units  | Data Type | Default | Description                                                                 |
|-------------------|--------|-----------|---------|-----------------------------------------------------------------------------|
| objID             | ...    | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspsSTid    | ...    | BIGINT    | NA      | Unique internal PSFS STACK identifier.                                      |
| ippObjID          | ...    | BIGINT    | NA      | IPP internal object identifier.                                             |
| randomStackObjID  | ...    | FLOAT     | NA      | Random value drawn from the interval between zero and one.                  |
| primaryDetection  | ...    | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                      |
| bestDetection     | ...    | TINYINT   | 255     | Identifies if this row is the best detection.                               |
| gippDetectID      | ...    | BIGINT    | NA      | Unique STACK detection identifier.                                          |
| gstackDetectID    | ...    | BIGINT    | NA      | Unique STACK detection identifier.                                          |
| gstackImageID     | ...    | BIGINT    | NA      | Unique STACK identifier for g-filter detection.                             |
| gxPos             | sky pixels | REAL    | −999   | PSF x-center location from g-filter STACK detection.                        |
| gyPos             | sky pixels | REAL    | −999   | PSF y-center location from g-filter STACK detection.                        |
| gxPosErr          | sky pixels | REAL    | −999   | Error in PSF x-center location from g-filter STACK detection.               |
| gyPosErr          | sky pixels | REAL    | −999   | Error in PSF y-center location from g-filter STACK detection.               |
| gpsFLmajorFWHM    | arcseconds | REAL    | −999   | PSF major axis FWHM from g-filter STACK detection.                           |
| gpsFLminorFWHM    | arcseconds | REAL    | −999   | PSF minor axis FWHM from g-filter STACK detection.                           |
| gpsiTheta         | degrees  | REAL     | −999   | PSF major axis orientation from g-filter STACK detection.                   |
| gskFLcore         | ...     | REAL     | −999   | PSF core parameter \( k \) from g-filter STACK detection, where \( F = FO/(1 + kr^2 + r^4) \). |
| gpsiLikelihood    | ...     | REAL     | −999   | Likelihood that this g-filter STACK detection is best fit by a PSF.          |
| gpsFQf            | ...     | REAL     | −999   | PSF coverage factor for g-filter STACK detection.                           |
| gpsFQfPerfect     | ...     | REAL     | −999   | PSF-weighted fraction of pixels totally unmasked for g-filter STACK detection. |
| gskFLchiSqr       | ...     | REAL     | −999   | Reduced chi-squared value of the PSF model fit for g-filter STACK detection. |
| gmomentXX         | arcsec^2 | REAL    | −999   | Second moment \( M_x \) for the g-filter STACK detection.                   |
| gmomentXY         | arcsec^2 | REAL    | −999   | Second moment \( M_y \) for the g-filter STACK detection.                   |
| gmomentYY         | arcsec^2 | REAL    | −999   | Second moment \( M_y \) for the g-filter STACK detection.                   |
| gmomentR1         | arcseconds | REAL    | −999   | First radial moment for the g-filter STACK detection.                       |
| gmomentRH         | arcsec^0.5 | REAL    | −999   | Half-radial moment \((r^2 + \rho^2)^{1/2}\) weighting for the g-filter STACK detection. |
| gPSFFlux          | Jansky  | REAL     | −999   | PSF flux from the g-filter STACK detection.                                 |
| gPSFFluxErr       | Jansky  | REAL     | −999   | Error in PSF flux from the g-filter STACK detection.                        |
| gApFlux           | Jansky  | REAL     | −999   | Aperture flux from the g-filter STACK detection.                            |
| gApFluxErr        | Jansky  | REAL     | −999   | Error in aperture flux from the g-filter STACK detection.                   |
| gApFillFac        | ...     | REAL     | −999   | Aperture fill factor from the g-filter STACK detection.                     |
| gApRadius         | arcseconds | REAL    | −999   | Aperture radius for the g-filter STACK detection.                           |
| gKronFlux         | Jansky  | REAL     | −999   | Kron (1980) flux from g-filter STACK detection.                             |
| gKronFluxErr      | Jansky  | REAL     | −999   | Error in Kron (1980) flux from the g-filter STACK detection.                 |
| gKronRad          | arcseconds | REAL    | −999   | Kron (1980) radius from g-filter STACK detection.                           |
| gexpTime          | seconds | REAL     | −999   | Exposure time of the g-filter stack. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| gExtNSigma        | ...     | REAL     | −999   | An extendedness measure for the g-filter STACK detection based on the deviation between the PSF and Kron (1980) magnitudes, normalized by the PSF magnitude uncertainty. |
| gsky              | Jy arcsec^{-2} | REAL    | −999   | Residual background sky level at the g-filter STACK detection.               |
| gskyErr           | Jy arcsec^{-2} | REAL    | −999   | Error in the residual background sky level at the g-filter STACK detection.  |
| gApPER            | magnitudes | REAL    | 0      | Photometric zero point for the g-filter stack. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| gPlateScale       | arcsec/pixel | REAL    | 0      | Local plate scale for the g-filter stack.                                   |
| rippDetectID      | ...     | BIGINT    | NA      | Same entries repeated for the r, i, z, and y filters                       |
| yPlateScale       | ...     | BIGINT    | NA      | Same entries repeated for the r, i, z, and y filters                       |

Note. See StackObjectThin table for discussion of primary, secondary, and best detections.
### Table D19

StackApFlx: Contains the Unconvolved Fluxes within the SDSS R5 ($r = 3'r0$), R6 ($r = 4'r63$), and R7 ($r = 7'r43$) Apertures (Stoughton et al. 2002)

| Column Name       | Units   | Data Type | Default | Description                                                                 |
|-------------------|---------|-----------|---------|-----------------------------------------------------------------------------|
| objID             |         | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspsStid    |         | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                     |
| ippsObjID         |         | BIGINT    | NA      | IPP internal object identifier.                                            |
| randomStackObjID  |         | FLOAT     | NA      | Randomly drawn from the interval between zero and one.                     |
| primaryDetection  |         | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                     |
| bestDetection     |         | TINYINT   | 255     | Identifies if this row is the best detection.                              |
| gstackDetectID    |         | BIGINT    | NA      | Unique STACK detection identifier.                                         |
| gstackImageID     |         | BIGINT    | NA      | Unique STACK identifier for g-filter detection.                            |
| gippsDetectID     |         | BIGINT    | NA      | IPP internal detection identifier.                                          |
| gflxR5            | Jy      | REAL      | −999    | Flux from g-filter detection within an aperture of radius $r = 3'r0$.       |
| gflxR5Err         | Jy      | REAL      | −999    | Error in the flux from the g-filter detection within an aperture of radius $r = 3'r0$. |
| gflxR5Std         | Jy      | REAL      | −999    | Standard deviation of the g-filter flux within an aperture of radius $r = 3'r0$. |
| gflxR5Fill        |         | REAL      | −999    | Aperture fill factor for the g-filter detection within an aperture of radius $r = 3'r0$. |
| gflxR6            | Jy      | REAL      | −999    | Flux from the g-filter detection within an aperture of radius $r = 4'63$.    |
| gflxR6Err         | Jy      | REAL      | −999    | Error in the flux from the g-filter detection within an aperture of radius $r = 4'63$. |
| gflxR6Std         | Jy      | REAL      | −999    | Standard deviation of the g-filter flux within an aperture of radius $r = 4'63$. |
| gflxR6Fill        |         | REAL      | −999    | Aperture fill factor for the g-filter detection within an aperture of radius $r = 4'63$. |
| gflxR7            | Jy      | REAL      | −999    | Flux from the g-filter detection within an aperture of radius $r = 7'43$.    |
| gflxR7Err         | Jy      | REAL      | −999    | Error in the flux from the g-filter detection within an aperture of radius $r = 7'43$. |
| gflxR7Std         | Jy      | REAL      | −999    | Standard deviation of the g-filter flux within an aperture of radius $r = 7'43$. |
| gflxR7Fill        |         | REAL      | −999    | Aperture fill factor for the g-filter detection within an aperture of radius $r = 7'43$. |
| gc6flxR5          | Jy      | REAL      | −999    | Flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 3'r0$. |
| gc6flxR5Err       | Jy      | REAL      | −999    | Error in the flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 3'r0$. |
| gc6flxR5Std       | Jy      | REAL      | −999    | Standard deviation of the flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 3'r0$. |
| gc6flxR5Fill      |         | REAL      | −999    | Aperture fill factor for the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 3'r0$. |
| gc6flxR6          | Jy      | REAL      | −999    | Flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 4'63$. |
| gc6flxR6Err       | Jy      | REAL      | −999    | Error in the flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 4'63$. |
| gc6flxR6Std       | Jy      | REAL      | −999    | Standard deviation of the flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 4'63$. |
| gc6flxR6Fill      |         | REAL      | −999    | Aperture fill factor for the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 4'63$. |
| gc6flxR7          | Jy      | REAL      | −999    | Flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 7'43$. |
| gc6flxR7Err       | Jy      | REAL      | −999    | Error in the flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 7'43$. |
| gc6flxR7Std       | Jy      | REAL      | −999    | Standard deviation of the flux from the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 7'43$. |
| gc6flxR7Fill      |         | REAL      | −999    | Aperture fill factor for the g-filter detection convolved to a target of 6 sky pixels ($1'5$) within an aperture of radius $r = 7'43$. |
| gc8flxR5          | Jy      | REAL      | −999    | Flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 3'r0$. |
| gc8flxR5Err       | Jy      | REAL      | −999    | Error in the flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 3'r0$. |
| gc8flxR5Std       | Jy      | REAL      | −999    | Standard deviation of the flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 3'r0$. |
| gc8flxR5Fill      |         | REAL      | −999    | Aperture fill factor for the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 3'r0$. |
| gc8flxR6          | Jy      | REAL      | −999    | Flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 4'63$. |
| gc8flxR6Err       | Jy      | REAL      | −999    | Error in the flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 4'63$. |
| gc8flxR6Std       | Jy      | REAL      | −999    | Standard deviation of the flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 4'63$. |
| gc8flxR6Fill      |         | REAL      | −999    | Aperture fill factor for the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 4'63$. |
| gc8flxR7          | Jy      | REAL      | −999    | Flux from the g-filter detection convolved to a target of 8 sky pixels ($2'0$) within an aperture of radius $r = 7'43$. |
| Column Name   | Units | Data Type | Default | Description                                                                                   |
|--------------|-------|-----------|---------|------------------------------------------------------------------------------------------------|
| gc8flR7Err   | Jy    | REAL      | −999    | Error in the flux from the g-filter detection convolved to a target 8 sky pixels (2°0) within an aperture of radius r = 7′43. |
| gc8flR7Std  | Jy    | REAL      | −999    | Standard deviation of the flux from the g-filter detection convolved to a target of 8 sky pixels (2°0) within an aperture of radius r = 7′43. |
| gc8flR7Fill | ...   | REAL      | −999    | Aperture fill factor for the g-filter detection convolved to a target of 8 sky pixels (2°0) within an aperture of radius r = 7′43. |
| rstackDetectID |       |           |         |                                                                                               |
| yc8flR7Fill |       |           |         | Same entries repeated for the r, i, z, and y filters                                           |

Note. Convoluted fluxes within these same apertures are also provided for images convolved to 6 sky pixels (1′5) and 8 sky pixels (2′0). All filters are matched into a single row. See the StackObjectThin table for a discussion of the primary, secondary, and best detections.

| Column Name   | Units | Data Type | Default | Description                                                                                   |
|--------------|-------|-----------|---------|------------------------------------------------------------------------------------------------|
| objID        | ...   | BIGINT    | NA      | Unique object identifier.                                                                      |
| uniquePspSSTid | ...   | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                                         |
| ippObjID     | ...   | BIGINT    | NA      | IPP internal object identifier.                                                                |
| randomStackObjID | ...   | FLOAT     | NA      | Random value drawn from the interval between zero and one.                                     |
| primaryDetection | ...   | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                                          |
| bestDetection | ...   | TINYINT   | 255     | Identifies if this row is the best detection.                                                   |
| gippDetectID | ...   | BIGINT    | NA      | IPP internal detection identifier.                                                             |
| gstackDetectID | ...   | BIGINT    | NA      | Unique STACK detection identifier.                                                              |
| gstackImageID | ...   | BIGINT    | NA      | Unique STACK identifier for the g-filter detection.                                             |
| gExpRadius   | arcsec | REAL      | −999    | Exponential fit radius for the g-filter STACK detection.                                         |
| gExpRadiusErr | arcsec | REAL      | −999    | Error in exponential fit radius for the g-filter STACK detection.                               |
| gExpMag      | AB     | REAL      | −999    | Exponential fit magnitude for the g-filter STACK detection.                                     |
| gExpMagErr   | AB     | REAL      | −999    | Error in exponential fit magnitude for the g-filter STACK detection.                            |
| gExpAb       | ...    | REAL      | −999    | Exponential fit axis ratio for the g-filter STACK detection.                                    |
| gExpAbErr    | ...    | REAL      | −999    | Error in exponential fit axis ratio for the g-filter STACK detection.                           |
| gExpPhi      | degrees | REAL      | −999    | Major axis position angle, phi, of exponential fit for the g-filter STACK detection.            |
| gExpPhiErr   | degrees | REAL      | −999    | Error in major axis position angle of exponential fit for the g-filter STACK detection.         |
| gExpRa       | degrees | FLOAT     | −999    | Right ascension of exponential fit center for the g-filter STACK detection.                     |
| gExpDec      | degrees | FLOAT     | −999    | Decl. of the exponential fit center for the g-filter STACK detection.                           |
| gExpRaErr    | arcsec | REAL      | −999    | Error in the R.A. of the exponential fit center for the g-filter STACK detection.               |
| gExpDecErr   | arcsec | REAL      | −999    | Error in decl. of the exponential fit center for the g-filter STACK detection.                  |
| gExpChisq    | ...    | REAL      | −999    | Exponential fit reduced chi squared for the g-filter STACK detection.                           |
| rippDetectID | ...    | REAL      | −999    |                                                                                               |
| yExpChisq    |       |           |         | Same entries repeated for the r, i, z, and y filters                                           |

Note. See the StackObjectThin table for a discussion of the primary, secondary, and best detections.
### Table D21
StackModelFitDeV: Contains the de Vaucouleurs (1948) Fit Parameters to Extended Sources

| Column Name      | Units       | Data Type | Default | Description                                                                                   |
|------------------|-------------|-----------|---------|-----------------------------------------------------------------------------------------------|
| objID            | ...         | BIGINT    | NA      | Unique object identifier.                                                                      |
| uniquePspsSTid   | ...         | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                                          |
| ippObjID         | ...         | BIGINT    | NA      | IPP internal object identifier.                                                                 |
| randomStackObjID | ...         | FLOAT     | NA      | Random value drawn from the interval between zero and one.                                     |
| primaryDetection | TINYINT     | 255       |         | Identifies if this row is the primary STACK detection.                                         |
| bestDetection    | TINYINT     | 255       |         | Identifies if this row is the best detection.                                                   |
| gippDetectID     | ...         | BIGINT    | NA      | IPP internal detection identifier.                                                              |
| gstackDetectID   | ...         | BIGINT    | NA      | Unique STACK detection identifier.                                                               |
| gstackImageID    | ...         | BIGINT    | NA      | Unique STACK identifier for g-filter detection.                                                 |
| gDeVRadius       | arcsec      | REAL      | −999    | de Vaucouleurs (1948) fit radius for the g-filter STACK detection.                               |
| gDeVRadiusErr    | arcsec      | REAL      | −999    | Error in the de Vaucouleurs (1948) fit radius for the g-filter STACK detection.                 |
| gDeVMag          | AB          | REAL      | −999    | de Vaucouleurs (1948) fit magnitude for the g-filter STACK detection.                           |
| gDeVMagErr       | AB          | REAL      | −999    | Error in the de Vaucouleurs (1948) fit magnitude for the g-filter STACK detection.              |
| gDeVAb           | ...         | REAL      | −999    | de Vaucouleurs (1948) fit axis ratio for the g-filter STACK detection.                          |
| gDeVAbErr        | ...         | REAL      | −999    | Error in de Vaucouleurs (1948) fit axis ratio for g-filter STACK detection.                     |
| gDeVPhi          | degrees     | REAL      | −999    | Major axis position angle, phi, of the de Vaucouleurs (1948) fit for the g-filter STACK detection. |
| gDeVPhiErr       | degrees     | REAL      | −999    | Error in the major axis position angle of the de Vaucouleurs (1948) fit for the g-filter STACK detection. |
| gDeVRa           | degrees     | FLOAT     | −999    | Right ascension of the de Vaucouleurs (1948) fit center for the g-filter STACK detection.       |
| gDeVDec          | degrees     | FLOAT     | −999    | Decl. of the de Vaucouleurs (1948) fit center for the g-filter STACK detection.                 |
| gDeVRaErr        | arcsec      | REAL      | −999    | Error in the R.A. of the de Vaucouleurs (1948) fit center for the g-filter STACK detection.     |
| gDeVDecErr       | arcsec      | REAL      | −999    | Error in the decl. of the de Vaucouleurs (1948) fit center for the g-filter STACK detection.    |
| gDeVChisq        | ...         | REAL      | −999    | de Vaucouleurs (1948) fit reduced chi squared for the g-filter STACK detection.                 |
| rippDetectID     | ...         | BIGINT    | NA      | Same entries repeated for the r, i, z, and y filters                                           |

**Note.** See the StackObjectThin table for a discussion of the primary, secondary, and best detections.
| Column Name          | Units | Data Type | Default | Description                                                                 |
|---------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID               |       | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspSttid      |       | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                     |
| ippObjID            |       | BIGINT    | NA      | IPP internal object identifier.                                            |
| randomStackObjID    |       | FLOAT     | NA      | Random value drawn from the interval between zero and one.                  |
| primaryDetection    |       | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                      |
| bestDetection       |       | TINYINT   | 255     | Identifies if this row is the best detection.                              |
| gippDetectionID     |       | BIGINT    | NA      | IPP internal detection identifier.                                         |
| gstackDetectionID   |       | BIGINT    | NA      | Unique STACK detection identifier.                                         |
| gstackImageID       |       | BIGINT    | NA      | Unique STACK identifier for the g-filter detection.                         |
| gSerRadius          | arcsec| REAL      | −999    | Sérsic (1963) fit radius for the g-filter STACK detection.                  |
| gSerRadiusErr       | arcsec| REAL      | −999    | Error in the Sérsic (1963) fit radius for the g-filter STACK detection.     |
| gSerMag             | AB    | REAL      | −999    | Sérsic (1963) fit magnitude for the g-filter STACK detection.               |
| gSerMagErr          |       | REAL      | −999    | Error in the Sérsic (1963) fit magnitude for the g-filter STACK detection.  |
| gSerAb              |       | REAL      | −999    | Sérsic (1963) fit axis ratio for the g-filter STACK detection.              |
| gSerAbErr           |       | REAL      | −999    | Error in the Sérsic (1963) fit axis ratio for the g-filter STACK detection. |
| gSerNu              |       | REAL      | −999    | Sérsic (1963) fit index for the g-filter STACK detection.                   |
| gSerNuErr           |       | REAL      | −999    | Error in the Sérsic (1963) fit index for the g-filter STACK detection.      |
| gSerPhi             | degrees| REAL     | −999    | Major axis position angle, phi, of the Sérsic (1963) fit for the g-filter STACK detection. |
| gSerPhiErr          | degrees| REAL     | −999    | Error in the major axis position angle of Sérsic (1963) fit for the g-filter STACK detection. |
| gSerRa              | degrees| FLOAT    | −999    | Right ascension of the Sérsic (1963) fit center for the g-filter STACK detection. |
| gSerDec             | degrees| FLOAT    | −999    | Decl. of the Sérsic (1963) fit center for g-filter STACK detection.         |
| gSerDecErr          | arcsec| REAL      | −999    | Error in the R.A. of the Sérsic (1963) fit center for the g-filter STACK detection. |
| gSerChisq           |       | REAL      | −999    | Sérsic (1963) fit reduced chi squared for the g-filter STACK detection.     |
| rippDetectID        |       |           |         | Same entries repeated for the r, i, z, and y filters                        |
| ySerChisq           |       |           |         |                                                                               |

**Note.** See the `StackObjectThin` table for a discussion of the primary, secondary, and best detections (Sérsic 1963).
Table D23
StackApFlxExGalUnc: Contains the Unconvolved Fluxes within the SDSS R3 (r = 1.003), R4 (r = 1.076), R5 (r = 3.000), R6 (r = 4.063), R7 (r = 7.043), R8 (r = 11.042), R9 (r = 18.020), R10 (r = 28.020), and R11 (r = 44.021) Apertures (Stoughton et al. 2002) for Extended Sources

| Column Name                      | Units   | Data Type | Default | Description                                                      |
|----------------------------------|---------|-----------|---------|------------------------------------------------------------------|
| objID                            | BIGINT  | NA        |         | Unique object identifier.                                        |
| uniquePspSTid                    | BIGINT  | NA        |         | Unique internal PSPS STACK identifier.                            |
| ippObjID                         | BIGINT  | NA        |         | IPP internal object identifier.                                  |
| randomStackObjID                 | FLOAT   | NA        |         | Random value drawn from the interval between zero and one.        |
| primaryDetection                 | TINYINT | 255       |         | Identifies if this row is the primary STACK detection.           |
| bestDetection                   | TINYINT | 255       |         | Identifies if this row is the best detection.                    |
| gippDetectID                     | BIGINT  | NA        |         | IPP internal detection identifier.                               |
| gstackDetectID                   | BIGINT  | NA        |         | Unique STACK detection identifier.                               |
| gstackImageID                    | BIGINT  | NA        |         | Unique STACK identifier for the g-filter detection.              |
| gfluxR3                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 1.003. |
| gfluxR3Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 1.003. |
| gfluxR3Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 1.003. |
| gfluxR4                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 1.076. |
| gfluxR4Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 1.076. |
| gfluxR4Std                       | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 1.076. |
| gfluxR4Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 1.076. |
| gfluxR5                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 3.000. |
| gfluxR5Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 3.000. |
| gfluxR5Std                       | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 3.000. |
| gfluxR5Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 3.000. |
| gfluxR6                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 4.063. |
| gfluxR6Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 4.063. |
| gfluxR6Std                       | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 4.063. |
| gfluxR6Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 4.063. |
| gfluxR7                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 7.043. |
| gfluxR7Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 7.043. |
| gfluxR7Std                       | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 7.043. |
| gfluxR7Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 7.043. |
| gfluxR8                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 11.042. |
| gfluxR8Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 11.042. |
| gfluxR8Std                       | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 11.042. |
| gfluxR8Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 11.042. |
| gfluxR9                          | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 18.020. |
| gfluxR9Err                       | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 18.020. |
| gfluxR9Std                       | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 18.020. |
| gfluxR9Fill                      | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 18.020. |
| gfluxR10                         | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 28.020. |
| gfluxR10Err                      | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 28.020. |
| gfluxR10Std                      | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 28.020. |
| gfluxR10Fill                     | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 28.020. |
| gfluxR11                         | Jy      | REAL      | -999    | Flux from the g-filter detection within an aperture of radius r = 44.021. |
| gfluxR11Err                      | Jy      | REAL      | -999    | Error in the flux from the g-filter detection within an aperture of radius r = 44.021. |
| gfluxR11Std                      | Jy      | REAL      | -999    | Standard deviation of the flux from the g-filter detection within an aperture of radius r = 44.021. |
| gfluxR11Fill                     | REAL    | -999      |         | Aperture fill factor for the g-filter detection within an aperture of radius r = 44.021. |
|rippDetectID                     |         |           |         | Same entries repeated for the r, i, z, and y filters              |
|yfluxR11Fill                      |         |           |         |                                                                 |

**Note.** These measurements are only provided for objects in the extragalactic sky, i.e., they are not provided for objects in the Galactic plane because they are not useful in crowded areas. See the StackObjectThin table for a discussion of the primary, secondary, and best detections.
Table D24
StackApFlxExGalCon6: Contains the Fluxes within the SDSS R3 ($r = 1^{\circ}03$), R4 ($r = 1^{\circ}76$), R5 ($r = 3^{\circ}00$), R6 ($r = 4^{\circ}63$), R7 ($r = 7^{\circ}43$), R8 ($r = 11^{\circ}42$), R9 ($r = 15^{\circ}20$), R10 ($r = 28^{\circ}20$), and R11 ($r = 44^{\circ}21$) Apertures (Stoughton et al. 2002) for Extended Sources after the Images Have Been Convolved to a Target of 6 Sky Pixels ($1^{\circ}5$)

| Column Name                  | Units | Data Type | Default | Description                                                                                                                                 |
|------------------------------|-------|-----------|---------|------------------------------------------------------------------------------------------------------------------------------------------|
| objID                        |       | BIGINT    | NA      | Unique object identifier.                                                                                                                  |
| uniquePspStid                |       | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                                                                                    |
| ippObjID                     |       | BIGINT    | NA      | IPP internal object identifier.                                                                                                           |
| randomStackObjID             |       | FLOAT     | NA      | Random value drawn from the interval between zero and one.                                                                               |
| primaryDetection             |       | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                                                                                    |
| bestDetection                |       | TINYINT   | 255     | Identifies if this row is the best detection.                                                                                              |
| gippDetectID                 |       | BIGINT    | NA      | IPP internal detection identifier.                                                                                                         |
| gstackDetectID               |       | BIGINT    | NA      | Unique STACK detection identifier.                                                                                                         |
| gstackImageID                |       | BIGINT    | NA      | Unique STACK identifier for the g-filter detection.                                                                                       |
| gc6flxR3                     | Jy    | REAL      | -999    | Flux from the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 1^{\circ}03$.         |
| gc6flxR3Err                  | Jy    | REAL      | -999    | Error in the flux from the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 1^{\circ}03$. |
| gc6flxR3Std                  | Jy    | REAL      | -999    | Standard deviation of the flux from the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 1^{\circ}03$. |
| gc6flxR3Fill                 |       | REAL      | -999    | Aperture fill factor for the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 1^{\circ}03$. |
| gc6flxR11                    | Jy    | REAL      | -999    | Flux from the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 28^{\circ}21$.          |
| gc6flxR11Err                 | Jy    | REAL      | -999    | Error in the flux from the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 28^{\circ}21$. |
| gc6flxR11Std                 | Jy    | REAL      | -999    | Standard deviation of the flux from the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 28^{\circ}21$. |
| gc6flxR11Fill                |       | REAL      | -999    | Aperture fill factor for the g-filter detection convolved to a target of 6 sky pixels ($1^{\circ}5$) within an aperture of radius $r = 28^{\circ}21$. |
| rippDetectID                 |       |           |         | Same entries repeated for r, i, z, and y filters                                                                                           |
| ye6flxR11Fill                |       |           |         |                                                                                                                                           |

Note. These measurements are only provided for objects in the extragalactic sky, i.e., they are not provided for objects in the Galactic plane because they are not useful in crowded areas. See the StackObjectThin table for a discussion of primary, secondary, and best detections.
Table D25
StackApFlxExGalCon8: Contains the Fluxes within the SDSS R3 (r = 1\".05), R4 (r = 1\".76), R5 (r = 3\".00), R6 (r = 4\".63), R7 (r = 7\".43), R8 (r = 11\".42), R9 (r = 18\".20), R10 (r = 28\".20), and R11 (r = 44\".21) Apertures (Stoughton et al. 2002) for Extended Sources after the Images Have Been Convolved to a Target of 8 Sky Pixels (2\".0)

| Column Name           | Units | Data Type | Default | Description                                                                 |
|-----------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID                 | ...   | BIGINT    | NA      | Unique object identifier.                                                  |
| uniquePspSTid         | ...   | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                     |
| ippObjID              | ...   | BIGINT    | NA      | IPP internal object identifier.                                            |
| randomStackObjID      | ...   | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| primaryDetection      | ...   | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                     |
| bestDetection         | ...   | TINYINT   | 255     | Identifies if this row is the best detection.                              |
| gippDetectID          | ...   | BIGINT    | NA      | IPP internal detection identifier.                                         |
| gstackDetectID        | ...   | BIGINT    | NA      | Unique STACK detection identifier.                                         |
| gstackImageID         | ...   | BIGINT    | NA      | Unique STACK identifier for the g-filter detection.                        |
| gc8flxR3              | Jy    | REAL      | -999    | Flux from the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 1\".03. |
| gc8flxR3Err           | Jy    | REAL      | -999    | Error in the flux from the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 1\".03. |
| gc8flxR3Std           | Jy    | REAL      | -999    | Standard deviation of the flux from the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 1\".03. |
| gc8flxR3Fill          | ...   | REAL      | -999    | Aperture fill factor for the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 1\".03. |
| ...                   |       |           |         | gc8flxR3 ... gc8flxR3Fill columns repeated for R4 (r = 1\".76).              |
| ...                   |       |           |         | repeated for R5 (r = 3\".00).                                              |
| ...                   |       |           |         | repeated for R6 (r = 4\".63).                                              |
| ...                   |       |           |         | repeated for R7 (r = 7\".43).                                              |
| ...                   |       |           |         | repeated for R8 (r = 11\".42).                                             |
| ...                   |       |           |         | repeated for R9 (r = 18\".20).                                             |
| gc8flxR3             | Jy    | REAL      | -999    | Flux from the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 44\".21. |
| gc8flxR11Err          | Jy    | REAL      | -999    | Error in the flux from the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 44\".21. |
| gc8flxR11Std          | Jy    | REAL      | -999    | Standard deviation of the flux from the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 44\".21. |
| gc8flxR11Fill         | ...   | REAL      | -999    | Aperture fill factor for the g-filter detection convolved to a target of 8 sky pixels (2\".0) within an aperture of radius r = 44\".21. |
| rippDetectID          |       |           |         | Same entries repeated for the r, i, z, and y filters                       |

Note. These measurements are only provided for objects in the extragalactic sky, i.e., they are not provided for objects in the Galactic plane because they are not useful in crowded areas. See the StackObjectThin table for a discussion of the primary, secondary, and best detections.
Table D26  
StackPetrosian: Contains the Petrosian (1976) Magnitudes and Radii for Extended Sources

| Column Name     | Units | Data Type | Default | Description                                                                 |
|-----------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID           |       | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspsSTid  |       | BIGINT    | NA      | Unique internal PSPS STACK identifier.                                      |
| ippObjID        |       | BIGINT    | NA      | IPP internal object identifier.                                             |
| randomStackObjID|       | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| primaryDetection|       | TINYINT   | 255     | Identifies if this row is the primary STACK detection.                     |
| bestDetection   |       | TINYINT   | 255     | Identifies if this row is the best detection.                              |
| gippDetectID    |       | BIGINT    | NA      | IPP internal detection identifier.                                         |
| gstackDetectID  |       | BIGINT    | NA      | Unique STACK detection identifier.                                         |
| gstackImageID   |       | BIGINT    | NA      | Unique STACK identifier for the g-filter STACK detection.                  |
| gpetRadius     | arcsec| REAL      | −999    | Petrosian (1976) fit radius for the g-filter STACK detection.              |
| gpetRadiusErr  | arcsec| REAL      | −999    | Error in the Petrosian (1976) fit radius for the g-filter STACK detection. |
| gpetMag        | AB    | REAL      | −999    | Petrosian (1976) magnitude from the g-filter STACK detection.              |
| gpetMagErr     | AB    | REAL      | −999    | Error in the Petrosian (1976) magnitude from the g-filter STACK detection. |
| gpetR50        | arcsec| REAL      | −999    | Petrosian (1976) fit radius for the g-filter STACK detection at 50% light  |
| gpetR50Err     | arcsec| REAL      | −999    | Error in the Petrosian (1976) fit radius for the g-filter STACK detection at 50% light |
| gpetR90        | arcsec| REAL      | −999    | Petrosian (1976) fit radius for the g-filter STACK detection at 90% light  |
| gpetR90Err     | arcsec| REAL      | −999    | Error in the Petrosian (1976) fit radius for the g-filter STACK detection at 90% light |
| gpetCf         | REAL  |           | −999    | Petrosian (1976) fit coverage factor for the g-filter STACK detection.    |

... Same entries repeated for the r, i, z, and y filters.

Note. See the StackObjectThin table for a discussion of the primary, secondary, and best detections.

Table D27  
StackToImage: Contains the Mapping of Which Input Images Were Used to Construct a Particular Stack

| Column Name   | Units | Data Type | Default | Description                                                                 |
|---------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| stackImageID  |       | BIGINT    | NA      | Unique STACK identifier.                                                   |
| imageID       |       | BIGINT    | NA      | Unique image identifier. Constructed as (100 × frameID + ccdID).            |

Table D28  
StackToFrame: Contains the Mapping of Input Frames Used to Construct a Particular STACK along with Processing Statistics

| Column Name    | Units     | Data Type | Default | Description                                                                 |
|----------------|-----------|-----------|---------|-----------------------------------------------------------------------------|
| stackImageID   | ...       | BIGINT    | NA      | Unique STACK identifier.                                                   |
| frameID        | ...       | INT       | NA      | Unique frame/exposure identifier.                                          |
| scaleFactor    | ...       | REAL      | 0       | Normalization factor applied to input image before stacking.               |
| zp             | magnitudes| REAL      | 0       | Photometric zero point. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| expTime        | seconds   | REAL      | −999    | Exposure time of the frame/exposure. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| airMass        | ...       | REAL      | 0       | Airmass at midpoint of the exposure. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| Column Name    | Units | Data Type | Default | Description                                                                 |
|---------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| stackImageID  | ...   | BIGINT    | NA      | Unique stack identifier.                                                    |
| magref        | magnitudes | REAL     | NA      | Detection efficiency reference magnitude.                                   |
| nInjected     | ...   | INT       | NA      | Number of fake sources injected in each magnitude bin.                     |
| offset01      | magnitudes | REAL     | NA      | Detection efficiency magnitude offset for bin 1.                           |
| counts01      | ...   | REAL      | NA      | Detection efficiency count of recovered sources in bin 1.                  |
| diffMean01    | magnitudes | REAL     | NA      | Detection efficiency mean magnitude difference in bin 1.                   |
| diffStdev01   | magnitudes | REAL     | NA      | Detection efficiency standard deviation of magnitude differences in bin 1.  |
| errMean01     | magnitudes | REAL     | NA      | Detection efficiency mean magnitude error in bin 1.                        |
| offset02      | magnitudes | REAL     | NA      | Detection efficiency magnitude offset for bin 2.                           |
| counts02      | ...   | REAL      | NA      | Detection efficiency count of recovered sources in bin 2.                  |
| diffMean02    | magnitudes | REAL     | NA      | Detection efficiency mean magnitude difference in bin 2.                   |
| diffStdev02   | magnitudes | REAL     | NA      | Detection efficiency standard deviation of magnitude differences in bin 2.  |
| errMean02     | magnitudes | REAL     | NA      | Detection efficiency mean magnitude error in bin 2.                        |
| offset03      | magnitudes | REAL     | NA      | Detection efficiency magnitude offset for bin 3.                           |
| counts03      | ...   | REAL      | NA      | Detection efficiency count of recovered sources in bin 3.                  |
| diffMean03    | magnitudes | REAL     | NA      | Detection efficiency mean magnitude difference in bin 3.                   |
| diffStdev03   | magnitudes | REAL     | NA      | Detection efficiency standard deviation of magnitude differences in bin 3.  |
| errMean03     | magnitudes | REAL     | NA      | Detection efficiency mean magnitude error in bin 3.                        |
| ...           |       |           |         |                                                                             |
| offset13      | magnitudes | REAL     | NA      | Detection efficiency magnitude offset for bin 13.                          |
| counts13      | ...   | REAL      | NA      | Detection efficiency count of recovered sources in bin 13.                 |
| diffMean13    | magnitudes | REAL     | NA      | Detection efficiency mean magnitude difference in bin 13.                  |
| diffStdev13   | magnitudes | REAL     | NA      | Detection efficiency standard deviation of magnitude differences in bin 13. |
| errMean13     | magnitudes | REAL     | NA      | Detection efficiency mean magnitude error in bin 13.                       |

**Note.** Provides the number of recovered sources out of 500 injected sources for each magnitude bin and statistics about the magnitudes of the recovered sources for a range of magnitude offsets.
### D.4. Forced Warp Tables

Table D30

ForcedMeanObject: Contains the Mean of Single-epoch Photometric Information for Sources Detected in the Stacked Data, Calculated as Described in Magnier et al. (2013)

| Column Name             | Units | Data Type | Default | Description                                                                 |
|-------------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID                   | ...   | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspFoId           | ...   | BIGINT    | NA      | Unique internal PSPS forced object identifier.                              |
| ippObjID                | ...   | BIGINT    | NA      | IPP internal object identifier.                                             |
| randomForcedObjID       | ...   | FLOAT     | NA      | Random value drawn from the interval between zero and one.                  |
| nDetections             | ...   | SMALLINT  | –999    | Number of single-epoch detections in all filters.                          |
| batchID                 | ...   | BIGINT    | NA      | Internal database batch identifier.                                         |
| processingVersion       | ...   | TINYINT   | NA      | Data release version.                                                       |
| gnTotal                 | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the g filter.                   |
| gnIncPSFFlux            | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the PSF flux mean in the g filter. |
| gnIncKronFlux           | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the Kron (1980) flux mean in the g filter. |
| gnIncApFlux             | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the aperture flux mean in the g filter. |
| gnIncR5                 | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the R5 (r = 3.900) aperture flux mean in the g filter. |
| gnIncR6                 | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the R6 (r = 4.963) aperture flux mean in the g filter. |
| gnIncR7                 | ...   | SMALLINT  | –999    | Number of forced single-epoch detections in the R7 (r = 7.43) aperture flux mean in the g filter. |
| gFPSFFlux               | Jy    | REAL      | –999    | Mean PSF flux from forced single-epoch g-filter detections.                 |
| gFPSFFluxErr            | Jy    | REAL      | –999    | Error in the mean PSF flux from forced single-epoch g-filter detections.    |
| gFPSFFluxStd            | Jy    | REAL      | –999    | Standard deviation of PSF fluxes from forced single-epoch g-filter detections. |
| gFPSFMag                | AB    | REAL      | –999    | Magnitude from mean PSF flux from forced single-epoch g-filter detections.  |
| gFPSFMagErr             | AB    | REAL      | –999    | Error in magnitude from the mean PSF flux from forced single-epoch g-filter detections. |
| g FKronFlux             | Jy    | REAL      | –999    | Mean Kron (1980) flux from forced single-epoch g-filter detections.         |
| gFKronFluxErr           | Jy    | REAL      | –999    | Error in mean Kron (1980) flux from forced single-epoch g-filter detections. |
| gFKronFluxStd           | Jy    | REAL      | –999    | Standard deviation of Kron (1980) fluxes from forced single-epoch g-filter detections. |
| gFKronMag               | AB    | REAL      | –999    | Magnitude from the mean Kron (1980) flux from forced single-epoch g-filter detections. |
| gFKronMagErr            | AB    | REAL      | –999    | Error in magnitude from the mean Kron (1980) flux from forced single-epoch g-filter detections. |
| gFApFlux                | Jy    | REAL      | –999    | Mean aperture flux from forced single-epoch g-filter detections.            |
| gFApFluxErr             | Jy    | REAL      | –999    | Error in the mean aperture flux from forced single-epoch g-filter detections. |
| gFApFluxStd             | Jy    | REAL      | –999    | Standard deviation of aperture fluxes from forced single-epoch g-filter detections. |
| gFApMag                 | AB    | REAL      | –999    | Magnitude from the mean aperture flux from forced single-epoch g-filter detections. |
| gFApMagErr              | AB    | REAL      | –999    | Error in magnitude from the mean aperture flux from forced single-epoch g-filter detections. |
| gFmeanFlxR5             | Jy    | REAL      | –999    | Mean flux from forced single-epoch g-filter detections within an aperture of radius r = 3.00. |
| gFmeanFlxR5Err          | Jy    | REAL      | –999    | Error in mean flux from forced single-epoch g-filter detections within an aperture of radius r = 3.00. |
| gFmeanFlxR5Std          | Jy    | REAL      | –999    | Standard deviation of forced single-epoch g-filter detection fluxes within an aperture of radius r = 3.00. |
| gFmeanFlxR5Fill         | ...   | REAL      | –999    | Aperture fill factor for forced single-epoch g-filter detections within an aperture of radius r = 3.00. |
| gFmeanMagR5             | AB    | REAL      | –999    | Magnitude from the mean flux from forced single-epoch g-filter detections within an aperture of radius r = 3.00. |
| gFmeanMagR5Err          | AB    | REAL      | –999    | Error in magnitude from the mean flux from forced single-epoch g-filter detections within an aperture of radius r = 3.00. |
| gFmeanFlxR6             | Jy    | REAL      | –999    | Mean flux from the forced single-epoch g-filter detections within an aperture of radius r = 4.63. |
| gFmeanFlxR6Err          | Jy    | REAL      | –999    | Error in the mean flux from forced single-epoch g-filter detections within an aperture of radius r = 4.63. |
| gFmeanFlxR6Std          | Jy    | REAL      | –999    | Standard deviation of forced single-epoch g-filter detection fluxes within an aperture of radius r = 4.63. |
| gFmeanFlxR6Fill         | ...   | REAL      | –999    | Aperture fill factor for forced single-epoch g-filter detections within an aperture of radius r = 4.63. |
| gFmeanMagR6             | AB    | REAL      | –999    | Magnitude from the mean flux from forced single-epoch g-filter detections within an aperture of radius r = 4.63. |
| gFmeanMagR6Err          | AB    | REAL      | –999    | Error in the magnitude from the mean flux from forced single-epoch g-filter detections within an aperture of radius r = 4.63. |
| gFmeanFlxR7             | Jy    | REAL      | –999    | Mean flux from forced single-epoch g-filter detections within an aperture of radius r = 7.43. |
| gFmeanFlxR7Err          | Jy    | REAL      | –999    | Error in the mean flux from forced single-epoch g-filter detections within an aperture of radius r = 7.43. |
| gFmeanFlxR7Std          | Jy    | REAL      | –999    | Standard deviation of forced single-epoch g-filter detections within an aperture of radius r = 7.43. |
Table D30
(Continued)

| Column Name                  | Units | Data Type | Default | Description                                                                 |
|------------------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| gMeanfMagR7Fill              | ...   | REAL      | -999    | Aperture fill factor for forced single-epoch g-filter detections within an apertures radius $r = 7''43$. |
| gMeanMagR7                  | AB    | REAL      | -999    | Magnitude from the mean flux from forced single-epoch g-filter detections within an aperture radius $r = 7''43$. |
| gMeanMagR7Err               | AB    | REAL      | -999    | Error in the magnitude from the mean flux from forced single-epoch g-filter detections within an aperture radius $r = 7''43$. |
| gFlags                      | ...   | INT       | 0       | Information flag bitmask indicating details of the photometry from forced single-epoch g-filter detections. Values listed in ObjectInfoFlags. |
| gE1                          | ...   | REAL      | -999    | Kaiser et al. (1995) polarization parameter $e_1 = (M_{xx} - M_{y})/(M_{xx} + M_{y})$ from forced single-epoch g-filter detections. |
| gE2                          | ...   | REAL      | -999    | Kaiser et al. (1995) polarization parameter $e_2 = (2M_{y})/(M_{xx} + M_{y})$ from forced single-epoch g-filter detections. |
| nTotal                      |       |           |         | Same entries repeated for the $r$, $i$, $z$, and $y$ filters                  |
| ye2                         |       |           |         |                                                                             |

Note. The mean is calculated for detections associated into objects within a 1" correlation radius. PSF, Kron (1980), and SDSS aperture R5 ($r = 3''00$), R6 ($r = 4''63$), and R7 ($r = 7''43$) aperture (Stoughton et al. 2002) magnitudes and statistics are listed for all filters. See also Kaiser et al. (1995).

Table D31
ForcedMeanLensing: Contains the Mean Kaiser et al. (1995, K95) Lensing Parameters Measured from the Forced Photometry of Objects Detected in Stacked Images on the Individual Single-epoch Data

| Column Name                  | Units | Data Type | Default | Description                                                                 |
|------------------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID                        | ...   | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspSFoid               | ...   | BIGINT    | NA      | Unique internal PPS forced object identifier.                               |
| ippObjID                     | ...   | BIGINT    | NA      | IPP internal object identifier.                                             |
| randomForcedObjID            | ...   | FLOAT     | NA      | Random value drawn from the interval between zero and one.                  |
| nDetections                  | ...   | SMALLINT  | -999    | Number of single-epoch detections in all filters.                           |
| batchID                      | ...   | BIGINT    | NA      | Internal database batch identifier.                                         |
| processingVersion            | ...   | TINYINT   | NA      | Data release version.                                                       |
| gLensObjSmearX11             | arcsec | REAL      | -999    | K95 Equation (A11) smear polarizability X11 term from forced g-filter detections. |
| gLensObjSmearX12             | arcsec | REAL      | -999    | K95 Equation (A11) smear polarizability X12 term from forced g-filter detections. |
| gLensObjSmearX22             | arcsec | REAL      | -999    | K95 Equation (A11) smear polarizability X22 term from forced g-filter detections. |
| gLensObjSmearE1              | arcsec | REAL      | -999    | K95 Equation (A12) smear polarizability e1 term from forced g-filter detections. |
| gLensObjSmearE2              | arcsec | REAL      | -999    | K95 Equation (A12) smear polarizability e2 term from forced g-filter detections. |
| gLensObjShearX11             |       | REAL      | -999    | K95 Equation (B11) shear polarizability X11 term from forced g-filter detections. |
| gLensObjShearX12             |       | REAL      | -999    | K95 Equation (B11) shear polarizability X12 term from forced g-filter detections. |
| gLensObjShearX22             |       | REAL      | -999    | K95 Equation (B11) shear polarizability X22 term from forced g-filter detections. |
| gLensObjShearE1              |       | REAL      | -999    | K95 Equation (B12) shear polarizability e1 term from forced g-filter detections. |
| gLensObjShearE2              |       | REAL      | -999    | K95 Equation (B12) shear polarizability e2 term from forced g-filter detections. |
| gLensPSFSmearX11             | arcsec | REAL      | -999    | K95 Equation (A11) smear polarizability X11 term from the PSF model for forced g-filter detections. |
| gLensPSFSmearX12             | arcsec | REAL      | -999    | K95 Equation (A11) smear polarizability X12 term from the PSF model for forced g-filter detections. |
| gLensPSFSmearX22             | arcsec | REAL      | -999    | K95 Equation (A11) smear polarizability X22 term from the PSF model for forced g-filter detections. |
| gLensPSFSmearE1              | arcsec | REAL      | -999    | K95 Equation (A12) smear polarizability e1 term from the PSF model for forced g-filter detections. |
| gLensPSFSmearE2              | arcsec | REAL      | -999    | K95 Equation (A12) smear polarizability e2 term from the PSF model for forced g-filter detections. |
| gLensPSFShearX11             |       | REAL      | -999    | K95 Equation (B11) shear polarizability X11 term from the PSF model for forced g-filter detections. |
| gLensPSFShearX12             |       | REAL      | -999    | K95 Equation (B11) shear polarizability X12 term from the PSF model for forced g-filter detections. |
| gLensPSFShearX22             |       | REAL      | -999    | K95 Equation (B11) shear polarizability X22 term from the PSF model for forced g-filter detections. |
| gLensPSFShearE1              |       | REAL      | -999    | K95 Equation (B12) shear polarizability e1 term from the PSF model for forced g-filter detections. |
| gLensPSFShearE2              |       | REAL      | -999    | K95 Equation (B12) shear polarizability e2 term from the PSF model for forced g-filter detections. |
| rlenObjShearX11              |       | REAL      | -999    | K95 Equation (B12) shear polarizability e2 term from the PSF model for forced g-filter detections. |
| ylenPSFShearE2               |       |           |         | Same entries repeated for the $r$, $i$, $z$, and $y$ filters                  |
Table D32

ForcedWarpMeta: Contains the Metadata Related to a Sky-aligned Distortion-corrected WARP Image, Upon Which Forced Photometry Is Performed

| Column Name      | Units | Data Type    | Default | Description                                                                 |
|------------------|-------|--------------|---------|------------------------------------------------------------------------------|
| forcedWarpID     |       | BIGINT       | NA      | Unique forced WARP identifier.                                               |
| batchID          |       | BIGINT       | NA      | Internal database batch identifier.                                          |
| surveyID         |       | TINYINT      | NA      | Survey identifier. Details in the Survey table.                              |
| filterID         |       | TINYINT      | NA      | Filter identifier. Details in the Filter table.                              |
| frameID          |       | INT          | NA      | Frame/exposure identifier of the Frame associated with this warp.           |
| ippSkycalID      |       | INT          | NA      | IPP skycal identifier for the run that generated the positions for forced photometry. |
| stackMetaID      |       | INT          | NA      | Identifier for the STACK that yielded the positions for forced photometry. |
| tessID           |       | TINYINT      | 0       | Tessellation identifier. Details in the TessellationType table.              |
| projectionID     |       | SMALLINT     | −1      | Projection cell identifier.                                                  |
| skyCellID        |       | TINYINT      | 255     | Skycell region identifier.                                                   |
| photoCalID       |       | INT          | NA      | Photometric calibration identifier. Details in the PhotoCal table.           |
| analysisVer      |       | VARCHAR(100)|         | IPP software analysis release version.                                       |
| md5sum           |       | VARCHAR(100)|         | IPP MD5 Checksum.                                                           |
| expTime          | seconds | REAL        | −999    | Exposure time of the source frame/exposure for this WARP image. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| recalAstroScatX  | arcsec| REAL        | −999    | Measurement of the recalibration (not astrometric error) in the X direction. |
| recalAstroScatY  | arcsec| REAL        | −999    | Measurement of the recalibration (not astrometric error) in the Y direction. |
| recalNAstroStars |      | INT         | −999    | Number of astrometric reference sources used in recalibration.              |
| recalphotoScat   | magnitudes | REAL    | −999    | Photometric scatter relative to reference catalog.                           |
| recalNPhotoStars |      | INT         | −999    | Number of astrometric reference sources used in recalibration.              |
| psfModelID       |       | INT         | −999    | PSF model identifier.                                                       |
| psfFWHM          | arcsec| REAL        | −999    | Mean PSF FWHM at image center.                                               |
| psfWidMajor      | arcsec| REAL        | −999    | PSF major axis FWHM at image center.                                         |
| psfWidMinor      | arcsec| REAL        | −999    | PSF minor axis FWHM at image center.                                         |
| psfTheta         | degrees| REAL        | −999    | PSF major axis orientation at image center.                                  |
| photoZero        | magnitudes | REAL    | −999    | Locally derived photometric zero point for this WARP image.                 |
| ctype1           |       | VARCHAR(100)|         | Name of astrometric projection in R.A.                                      |
| ctype2           |       | VARCHAR(100)|         | Name of astrometric projection in decl.                                     |
| crval1           | degrees| FLOAT       | −999    | Right ascension corresponding to reference pixel.                           |
| crval2           | degrees| FLOAT       | −999    | Decl. corresponding to reference pixel.                                     |
| crpix1           | sky pixels | FLOAT   | −999    | Reference pixel for R.A.                                                    |
| crpix2           | sky pixels | FLOAT   | −999    | Reference pixel for decl.                                                   |
| cdelt1           | degrees/pixel | FLOAT | −999    | Pixel scale in R.A.                                                        |
| cdelt2           | degrees/pixel | FLOAT | −999    | Pixel scale in decl.                                                       |
| pc001001         |       | FLOAT       | −999    | Linear transformation matrix element between image pixel x and R.A.          |
| pc001002         |       | FLOAT       | −999    | Linear transformation matrix element between image pixel y and R.A.          |
| pc002001         |       | FLOAT       | −999    | Linear transformation matrix element between image pixel x and decl.         |
| pc002002         |       | FLOAT       | −999    | Linear transformation matrix element between image pixel y and decl.         |
| processingVersion|       | TINYINT     | NA      | Data release version.                                                      |

Note: The astrometric and photometric calibrations of the WARP image are listed.
| Column Name                | Units   | Data Type  | Default | Description                                                                 |
|---------------------------|---------|------------|---------|-----------------------------------------------------------------------------|
| objID                     | ...     | BIGINT     | NA      | Unique object identifier.                                                   |
| uniquePspsFWid            | ...     | BIGINT     | NA      | Unique internal PSPS forced WARP identifier.                               |
| detectID                  | ...     | BIGINT     | NA      | Unique detection identifier.                                               |
| ippObjectID               | ...     | BIGINT     | NA      | IPP internal object identifier.                                            |
| ippDetectID               | ...     | BIGINT     | NA      | IPP internal detection identifier.                                         |
| filterID                  | ...     | TINYINT    | NA      | Filter identifier. Details in the Filter table.                             |
| surveyID                  | ...     | TINYINT    | NA      | Survey identifier. Details in the Survey table.                            |
| forcedSummaryID           | ...     | BIGINT     | NA      | Unique forced WARP summary identifier.                                     |
| forcedWarpID              | ...     | BIGINT     | NA      | Unique forced WARP identifier.                                             |
| randomWarpID              | ...     | FLOAT      | NA      | Random value drawn from the interval between zero and one.                 |
| tessID                    | ...     | TINYINT    | 0       | Tessellation identifier. Details in the TessellationType table.            |
| projectionID              | ...     | SMALLINT   | −1      | Projection cell identifier.                                                |
| skyCellID                 | ...     | TINYINT    | 255     | Skycell region identifier.                                                 |
| dvoRegionID               | ...     | INT        | −1      | Internal DVO region identifier.                                            |
| obsTime                   | days    | FLOAT      | −999    | Modified Julian Date at the midpoint of the observation.                  |
| zp                        | magnitudes | REAL      | 0       | Photometric zero point. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| telluricExt               | magnitudes | REAL      | NA      | Estimated telluric extinction due to nonphotometric observing conditions. |
| expTime                   | seconds | REAL       | −999    | Exposure time of the frame/exposure. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| airMass                   | ...     | REAL       | 0       | Airmass at midpoint of the exposure. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| FpsfFlux                   | Jy      | REAL       | −999    | PSF flux.                                                                  |
| FpsfFluxErr                | Jy      | REAL       | −999    | Error in PSF flux.                                                        |
| xPosChip                  | raw pixels | REAL     | −999    | PSF x position in original chip pixels.                                    |
| yPosChip                  | raw pixels | REAL     | −999    | PSF y position in original chip pixels.                                    |
| FcdID                     | ...     | SMALLINT   | −999    | OTA identifier of original chip (see ImageMeta).                           |
| FpsfMajorFWHM             | arcsec  | REAL       | −999    | PSF major axis FWHM.                                                      |
| FpsfMinorFWHM             | arcsec  | REAL       | −999    | PSF minor axis FWHM.                                                      |
| FpsfTheta                 | degrees | REAL       | −999    | PSF major axis orientation.                                                |
| FpsfCore                  | ...     | REAL       | −999    | PSF core parameter k, where $F = F_0/(1 + kr^2 + r^{3.33})$.                |
| FpsfQF                    | ...     | REAL       | −999    | PSF coverage factor.                                                       |
| FpsfQFPerfect             | ...     | REAL       | −999    | PSF weighted fraction of pixels totally unmasked.                         |
| FpsfChiSq                 | ...     | REAL       | −999    | Reduced chi-squared value of the PSF model fit.                           |
| FmomentXX                 | arcsec$^2$ | REAL     | −999    | Second moment $M_{xx}$                                                    |
| FmomentXY                 | arcsec$^2$ | REAL     | −999    | Second moment $M_{xy}$.                                                    |
| FmomentYY                 | arcsec$^2$ | REAL     | −999    | Second moment $M_{yy}$.                                                    |
| FmomentR1                 | arcsec  | REAL       | −999    | First radial moment.                                                      |
| FmomentM3C                | arcsec$^2$ | REAL     | −999    | Half-radial moment ($0.5$ weighting).                                      |
| FmomentM3S                | arcsec$^2$ | REAL     | −999    | Cosine of trefoil second moment term: $r^2 \cos(3\theta) = M_{xx} - 3M_{xy}$. |
| FmomentM4C                | arcsec$^2$ | REAL     | −999    | Sine of trefoil second moment: $r^2 \sin(3\theta) = 3M_{xy} - M_{yy}$.     |
| FmomentM4S                | arcsec$^2$ | REAL     | −999    | Cosine of quadrupole second moment: $r^2 \cos(4\theta) = M_{xx} - 6M_{xy} + M_{yy}$. |
| FapFlux                   | Jy      | REAL       | −999    | Aperture flux.                                                            |
| FapFluxErr                | Jy      | REAL       | −999    | Error in aperture flux.                                                   |
| FapFillF                  | ...     | REAL       | −999    | Aperture fill factor.                                                     |
| FapRadius                 | arcsec  | REAL       | −999    | Aperture radius for forced WARP detection.                                 |
| FkronFlux                 | Jy      | REAL       | −999    | Kron (1980) flux.                                                         |
| FkronFluxErr              | Jy      | REAL       | −999    | Error in Kron (1980) flux.                                                 |
| FkronRad                  | arcsec  | REAL       | −999    | Kron (1980) radius.                                                       |
| Fsksy                     | Jy arcsec$^{-2}$ | REAL     | −999    | Background sky level.                                                     |
| FsksyErr                  | Jy arcsec$^{-2}$ | REAL     | −999    | Error in background sky level.                                             |
| FinfoFlag                 | ...     | BIGINT     | 0       | Information flag bitmask indicating details of the photometry. Values listed in DetectionFlags. |
| FinfoFlag2                | ...     | INT        | 0       | Information flag bitmask indicating details of the photometry. Values listed in DetectionFlags2. |
| FinfoFlag3                | ...     | INT        | 0       | Information flag bitmask indicating details of the photometry. Values listed in DetectionFlags3. |
| processingVersion         | ...     | TINYINT    | NA      | Data release version.                                                     |

**Note.** The identifiers connecting the measurement back to the original image and to the object association are provided. PSF, aperture, and Kron (1980) photometry are included, along with sky and detector coordinate positions.
### Table D34
ForcedWarpedMasked: Contains an Entry for Objects Detected in the Stacked Images Which Were in the Footprint of a Single-epoch Exposure, but for Which There Are No Unmasked Pixels at that Epoch

| Column Name       | Units | Data Type | Default | Description                                                                 |
|-------------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID             |       | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspFWid     |       | BIGINT    | NA      | Unique internal PPS forced WARP identifier.                                 |
| ippObjID          |       | BIGINT    | NA      | IPP internal object identifier.                                             |
| ippDetectID       |       | BIGINT    | NA      | IPP internal detection identifier.                                          |
| filterID          |       | TINYINT   | NA      | Filter identifier. Details in the Filter table.                             |
| surveyID          |       | TINYINT   | NA      | Survey identifier. Details in the Survey table.                             |
| forcedSummaryID   |       | BIGINT    | NA      | Forced WARP summary meta identifier.                                        |
| forcedWarpID      |       | BIGINT    | NA      | Unique forced WARP identifier.                                             |
| randomWarpID      |       | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| tessID            |       | TINYINT   | 0       | Tessellation identifier. Details in the TessellationType table.             |
| projectionID      |       | SMALLINT  | −1      | Projection cell identifier.                                                |
| skyCellID         |       | REAL      | −999    | Skycell region identifier.                                                 |
| dvoRegionID       |       | REAL      | −999    | Internal DVO region identifier.                                            |
| obsTime           | days  | FLOAT     | −999    | Modified Julian Date at the midpoint of the observation.                   |

### Table D35
ForcedWarpedExtended: Contains the Single-epoch Forced Photometry Fluxes within the SDSS R5 (r = 3"00), R6 (r = 4"63), and R7 (r = 7"43) Apertures (Stoughton et al. 2002) for Objects Detected in the Stacked Images

| Column Name       | Units    | Data Type | Default | Description                                                                 |
|-------------------|----------|-----------|---------|-----------------------------------------------------------------------------|
| objID             |          | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspFWid     |          | BIGINT    | NA      | Unique internal PPS forced WARP identifier.                                 |
| detectID          |          | BIGINT    | NA      | Unique detection identifier.                                                |
| ippObjID          |          | BIGINT    | NA      | IPP internal object identifier.                                             |
| ippDetectID       |          | BIGINT    | NA      | IPP internal detection identifier.                                          |
| filterID          |          | TINYINT   | NA      | Filter identifier. Details in the Filter table.                             |
| surveyID          |          | TINYINT   | NA      | Survey identifier. Details in the Survey table.                             |
| forcedWarpID      |          | BIGINT    | NA      | Unique forced WARP identifier.                                             |
| randomWarpID      |          | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| tessID            |          | TINYINT   | 0       | Tessellation identifier. Details in the TessellationType table.             |
| projectionID      |          | SMALLINT  | −1      | Projection cell identifier.                                                |
| skyCellID         |          | SMALLINT  | 255     | Skycell region identifier.                                                 |
| dvoRegionID       |          | INT       | −1      | Internal DVO region identifier.                                            |
| obsTime           | days     | FLOAT     | −999    | Modified Julian Date at the midpoint of the observation.                   |
| fRX5              |          | Jy        | REAL    | −999 | Flux from forced photometry measurement within an aperture of radius \( r = 3"00 \). |
| fRX5Err           |          | Jy        | REAL    | −999 | Error in flux from forced photometry measurement within an aperture of radius \( r = 3"00 \). |
| fRX5Std           |          | Jy        | REAL    | −999 | Standard deviation of flux from forced photometry measurement within an aperture of radius \( r = 3"00 \). |
| fRX5Fill          |          | REAL      | −999    | Aperture fill factor for forced photometry measurement within an aperture of radius \( r = 3"00 \). |
| fRX6              |          | Jy        | REAL    | −999 | Flux from forced photometry measurement within an aperture of radius \( r = 4"63 \). |
| fRX6Err           |          | Jy        | REAL    | −999 | Error in flux from forced photometry measurement within an aperture of radius \( r = 4"63 \). |
| fRX6Std           |          | Jy        | REAL    | −999 | Standard deviation of flux from forced photometry measurement within an aperture of radius \( r = 4"63 \). |
| fRX6Fill          |          | REAL      | −999    | Aperture fill factor for forced photometry measurement within an aperture of radius \( r = 4"63 \). |
| fRX7              |          | Jy        | REAL    | −999 | Flux from forced photometry measurement within an aperture of radius \( r = 7"43 \). |
| fRX7Err           |          | Jy        | REAL    | −999 | Error in flux from forced photometry measurement within an aperture of radius \( r = 7"43 \). |
| fRX7Std           |          | Jy        | REAL    | −999 | Standard deviation of flux from forced photometry measurement within an aperture of radius \( r = 7"43 \). |
| fRX7Fill          |          | REAL      | −999    | Aperture fill factor for forced photometry measurement within an aperture of radius \( r = 7"43 \). |
Table D36
ForcedWarpLensing: Contains the Kaiser et al. (1995, K95) Lensing Parameters Measured from the Forced Photometry of Objects Detected in Stacked Images on the Individual Single-epoch Data

| Column Name   | Units   | Data Type | Default | Description                                                                 |
|---------------|---------|-----------|---------|-----------------------------------------------------------------------------|
| objID         |         | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspFWid |         | BIGINT    | NA      | Unique internal PSPS forced WARP identifier.                                |
| detectID      |         | BIGINT    | NA      | Unique detection identifier.                                               |
| ippObjID      |         | BIGINT    | NA      | IPP internal object identifier.                                            |
| ippDetectID   |         | BIGINT    | NA      | IPP internal detection identifier.                                         |
| filterID      |         | TINYINT   | NA      | Filter identifier. Details in the Filter table.                            |
| surveyID      |         | TINYINT   | NA      | Survey identifier. Details in the Survey table.                            |
| forcedWarpID  |         | BIGINT    | NA      | Unique forced WARP identifier.                                             |
| randomWarpID  |         | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| tessID        |         | TINYINT   | 0       | Tessellation identifier. Details in the TessellationType table.            |
| projectionID  |         | SMALLINT  | −1      | Projection cell identifier.                                               |
| skyCellID     |         | TINYINT   | 255     | Skycell region identifier.                                                |
| dvoRegionID   |         | INT       | −1      | Internal DVO region identifier.                                           |
| obsTime       | days    | FLOAT     | −999    | Modified Julian Date at the midpoint of the observation.                  |
| lensObjSmearX11 | arcsec⁻² | REAL      | −999 K95 Equation (A11) smear polarizability X11 term from forced photometry. |
| lensObjSmearX12 | arcsec⁻² | REAL      | −999 K95 Equation (A11) smear polarizability X12 term from forced photometry. |
| lensObjSmearX22 | arcsec⁻² | REAL      | −999 K95 Equation (A11) smear polarizability X22 term from forced photometry. |
| lensObjShearX11 | arcsec⁻² | REAL      | −999 K95 Equation (A12) shear polarizability e1 term from forced photometry. |
| lensObjShearX12 | arcsec⁻² | REAL      | −999 K95 Equation (A12) shear polarizability e2 term from forced photometry. |
| lensObjShearX22 | arcsec⁻² | REAL      | −999 K95 Equation (B11) shear polarizability X11 term from forced photometry. |
| lensObjShearX11 |         | REAL      | −999 K95 Equation (B12) shear polarizability e1 term from forced photometry. |
| lensObjShearX12 |         | REAL      | −999 K95 Equation (B12) shear polarizability e2 term from forced photometry. |
| lensObjShearX22 |         | REAL      | −999 K95 Equation (B11) shear polarizability X12 term from forced photometry. |
| lensPSFSmearX11 | arcsec⁻² | REAL      | −999 K95 Equation (A11) smear polarizability X11 term from PSF model for forced photometry. |
| lensPSFSmearX12 | arcsec⁻² | REAL      | −999 K95 Equation (A11) smear polarizability X12 term from PSF model for forced photometry. |
| lensPSFSmearX22 | arcsec⁻² | REAL      | −999 K95 Equation (A11) smear polarizability X22 term from PSF model for forced photometry. |
| lensPSFShearX11 | arcsec⁻² | REAL      | −999 K95 Equation (A12) shear polarizability e1 term from PSF model for forced photometry. |
| lensPSFShearX12 | arcsec⁻² | REAL      | −999 K95 Equation (A12) shear polarizability e2 term from PSF model for forced photometry. |
| lensPSFShearX22 | arcsec⁻² | REAL      | −999 K95 Equation (B11) shear polarizability X11 term from PSF model for forced photometry. |
| lensPSFShearX11 |         | REAL      | −999 K95 Equation (B12) shear polarizability e1 term from PSF model for forced photometry. |
| lensPSFShearX12 |         | REAL      | −999 K95 Equation (B12) shear polarizability e2 term from PSF model for forced photometry. |
| lensPSFShearX22 |         | REAL      | −999 K95 Equation (B11) shear polarizability X12 term from PSF model for forced photometry. |
| psfE1         |         | REAL      | −999 K95 polarization parameter e1 = (M_{psf} - M_{psf})/(M_{psf} + M_{psf}) from forced photometry. |
| psfE2         |         | REAL      | −999 K95 polarization parameter e2 = (2M_{psf})/(M_{psf} + M_{psf}) from forced photometry. |

Table D37
ForcedWarpToImage: Contains the Mapping of Which Input Image Comprises a Particular WARP Image Used for Forced Photometry

| Column Name    | Units | Data Type | Default | Description                                                                 |
|----------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| forcedWarpID   |       | BIGINT    | NA      | Unique forced WARP identifier.                                             |
| imageID        |       | BIGINT    | NA      | Unique image identifier. Constructed as (100 × frameID + ccdID).            |
Table D38
ForcedGalaxyShape: Contains the Extended Source Galaxy Shape Parameters

| Column Name     | Units | Data Type | Default | Description                                                                 |
|-----------------|-------|-----------|---------|-----------------------------------------------------------------------------|
| objID           | ...   | BIGINT    | NA      | Unique object identifier.                                                   |
| uniquePspSFGid  | ...   | BIGINT    | NA      | Unique internal PSPS forced galaxy identifier.                             |
| ippObjID        | ...   | BIGINT    | NA      | IPP internal object identifier.                                            |
| surveyID        | ...   | TINYINT   | NA      | Survey identifier. Details in the Survey table.                            |
| randomForcedID  | ...   | FLOAT     | NA      | Random value drawn from the interval between zero and one.                 |
| galModelType    | ...   | TINYINT   | −999    | Galaxy model identifier.                                                   |
| nFilter         | ...   | TINYINT   | −999    | Number of filters with valid model measurements.                           |
| gippDetectID    | ...   | BIGINT    | NA      | IPP internal detection identifier.                                         |
| gstackImageID   | ...   | BIGINT    | NA      | Unique STACK identifier for the g-filter STACK that was the original detection source. |
| gGalMajor       | arcsec| REAL      | −999    | Galaxy major axis for the g-filter measurement.                            |
| gGalMajorErr    | arcsec| REAL      | −999    | Error in the galaxy major axis for the g-filter measurement.               |
| gGalMinor       | arcsec| REAL      | −999    | Galaxy minor axis for the g-filter measurement.                            |
| gGalMinorErr    | arcsec| REAL      | −999    | Error in the galaxy minor axis for the g-filter measurement.               |
| gGalMag         | AB    | REAL      | −999    | Galaxy fit magnitude for the g-filter measurement.                         |
| gGalMagErr      | AB    | REAL      | −999    | Error in the galaxy fit magnitude for the g-filter measurement.            |
| gGalPhi         | degrees| REAL    | −999    | Major axis position angle of the model fit for the g-filter measurement.  |
| gGalIndex       | ...   | REAL      | −999    | Sérsic index of the model fit for the g-filter measurement.                |
| gGalChisq       | ...   | SMALLINT  | −999    | Analysis flags for the galaxy model chi-square fit (g-filter measurement, values defined in ForcedGalaxyShapeFlags). |
| rippDetectID    | ...   | REAL      | −999    | Reduced chi-squared value for the g-filter measurement.                    |

Note. All filters are matched into a single row. The positions, magnitudes, fluxes, and Sérsic indices are inherited from their parent measurement in the StackModelFit tables and are reproduced here for convenience. The major and minor axes and orientation are recalculated on a warp-by-warp basis from the best fit given these inherited properties (Sérsic 1963).
### Table D39

DiffDetObject: Contains the Positional Information for Difference Detection Objects in a Number of Coordinate Systems

| Column Name                  | Units | Data Type     | Default | Description                                           |
|------------------------------|-------|---------------|---------|-------------------------------------------------------|
| diffObjName                  |       | VARCHAR(32)  | NA      | IAU name for this object.                              |
| diffObjPSOname               |       | VARCHAR(32)  | NA      | Alternate Pan-STARRS name for this object.             |
| diffObjAltName1              |       | VARCHAR(32)  |         | Alternate name for this object.                        |
| diffObjAltName2              |       | VARCHAR(32)  |         | Alternate name for this object.                        |
| diffObjAltName3              |       | VARCHAR(32)  |         | Alternate name for this object.                        |
| diffObjPopularName           |       | VARCHAR(140) |         | Well-known name for this object.                       |
| diffObjID                    |       | BIGINT        | NA      | Unique difference object identifier.                  |
| uniquePspSDOid               |       | BIGINT        | NA      | Unique internal PSPS difference object identifier.    |
| ippObjID                     |       | BIGINT        | NA      | IPP internal object identifier.                        |
| surveyID                     |       | TINYINT       | NA      | Survey identifier. Details in the Survey table.       |
| htmID                        |       | BIGINT        | NA      | Hierarchical triangular mesh (Szalay et al. 2007) index. |
| zoneID                       |       | INT           | NA      | Local zone index, found by dividing the sky into bands of decl. |
| randomDiffObjID              |       | FLOAT         | NA      | Random value drawn from the interval between zero and one. |
| batchID                      |       | BIGINT        | NA      | Internal database batch identifier.                   |
| dvoRegionID                  |       | INT           | -1      | Internal DVO region identifier.                       |
| objInfoFlag                  |       | INT           | 0       | Information flag bitmask indicating details of the photometry. Values listed in ObjectInfoFlags. |
| qualityFlag                  |       | TINYINT       | 0       | Subset of objInfoFlag denoting whether this object is real or a likely false positive. Values listed in ObjectQualityFlags. |
| ra                           | degrees | FLOAT     | -999    | Right ascension mean.                                 |
| dec                          | degrees | FLOAT     | -999    | Decl. mean.                                           |
| cx                           |         | FLOAT        | NA      | Cartesian x on a unit sphere.                         |
| cy                           |         | FLOAT        | NA      | Cartesian y on a unit sphere.                         |
| cz                           |         | FLOAT        | NA      | Cartesian z on a unit sphere.                         |
| lambda                       | degrees | FLOAT        | -999    | Ecliptic longitude.                                   |
| beta                         | degrees | FLOAT        | -999    | Ecliptic latitude.                                    |
| l                            | degrees | FLOAT        | -999    | Galactic longitude.                                   |
| b                            | degrees | FLOAT        | -999    | Galactic latitude.                                    |
| gQfPerfect                   |         | REAL         | -999    | Maximum PSF weighted fraction of pixels totally unmasked from g-filter detections. |
| rQfPerfect                   |         | REAL         | -999    | Maximum PSF weighted fraction of pixels totally unmasked from r-filter detections. |
| iQfPerfect                   |         | REAL         | -999    | Maximum PSF weighted fraction of pixels totally unmasked from i-filter detections. |
| zQfPerfect                   |         | REAL         | -999    | Maximum PSF weighted fraction of pixels totally unmasked from z-filter detections. |
| yQfPerfect                   |         | REAL         | -999    | Maximum PSF weighted fraction of pixels totally unmasked from y-filter detections. |
| processingVersion            |       | TINYINT      | NA      | Data release version.                                 |
| nDetections                  |       | SMALLINT     | -999    | Number of difference detections in all filters.       |
| ng                           |       | SMALLINT     | -999    | Number of difference detections in the g filter.      |
| nr                           |       | SMALLINT     | -999    | Number of difference detections in the r filter.      |
| ni                           |       | SMALLINT     | -999    | Number of difference detections in the i filter.      |
| nz                           |       | SMALLINT     | -999    | Number of difference detections in the z filter.      |
| ny                           |       | SMALLINT     | -999    | Number of difference detections in the y filter.      |

**Note.** The objects associate difference detections within a 1° radius. The number of detections in each filter from is listed, along with maximum coverage fractions (see Szalay et al. 2007).
Table D40
DiffMeta: Contains Metadata Related to a Difference Image Constructed by Subtracting a Stacked Image from a Single-epoch Image, or In the Case of the MD Survey, from a Nightly STACK (Stack Made from All Exposures in a Single Filter in a Single Night)

| Column Name  | Units | Data Type         | Default | Description                                                                 |
|-------------|-------|-------------------|---------|-----------------------------------------------------------------------------|
| diffImageID |       | BIGINT            | NA      | Unique difference identifier.                                               |
| batchID     |       | BIGINT            | NA      | Internal database batch identifier.                                        |
| surveyID    |       | TINYINT           | NA      | Survey identifier. Details in the Survey table.                            |
| filterID    |       | TINYINT           | NA      | Filter identifier. Details in the Filter table.                            |
| diffTypeID  |       | TINYINT           | 0       | Difference type identifier. Details in the DiffType table.                 |
| frameID     |       | INT               | NA      | Frame/exposure identifier for the positive image in warp-stack difference images. |
| posImageID  |       | BIGINT            | NA      | Image identifier for the positive image.                                   |
| negImageID  |       | BIGINT            | NA      | Image identifier for the negative image.                                   |
| ippDiffID   |       | BIGINT            | NA      | IPP diffRun identifier.                                                    |
| tessID      |       | TINYINT           | 0       | Tessellation identifier. Details in the TessellationType table.            |
| projectionID|       | SMALLINT          | −1      | Projection cell identifier.                                               |
| skyCellID   |       | TINYINT           | 255     | Skycell region identifier.                                                |
| photoCalID  |       | INT               | NA      | Photometric calibration identifier. Details in the PhotoCal table.         |
| analysisVer |       | VARCHAR(100)      |         | IPP software analysis release version.                                     |
| md5sum      |       | VARCHAR(100)      |         | IPP MD5 Checksum.                                                          |
| detectionThreshold magnitudes |       | REAL             | −999    | Reference magnitude for detection efficiency calculation.                  |
| expTime seconds |     | REAL             | −999    | Exposure time of positive image. Necessary for converting listed fluxes and magnitudes back to measured ADU counts. |
| psmModelID  |       | INT               | −999    | PSF model identifier.                                                      |
| psmFWHM arcsec |     | REAL             | −999    | Mean PSF FWHM at image center.                                             |
| psmWidMajor arcsec |   | REAL             | −999    | PSF major axis FWHM at image center.                                       |
| psmWidMinor arcsec |   | REAL             | −999    | PSF minor axis FWHM at image center.                                       |
| psmTheta degrees |    | REAL             | −999    | PSF major axis orientation at image center.                               |
| kernel      |       | VARCHAR(100)      |         | Subtraction kernel.                                                        |
| mode        |       | TINYINT           | 0       | Subtraction mode for which input to convolve.                             |
| numStamps   |       | INT               | −999    | Number of stamps.                                                          |
| stampDevMean |      | REAL             | −999    | Mean stamp deviation.                                                     |
| stampDevRMS |       | REAL              | −999    | rms stamp deviation.                                                      |
| normalization |     | REAL             | −999    | Normalization.                                                             |
| convolveMax |       | REAL              | −999    | Maximum convolution fraction.                                              |
| deconvolveMax |     | REAL             | −999    | Maximum deconvolution fraction.                                            |
| ctype1      |       | VARCHAR(100)      |         | Name of astrometric projection in R.A.                                    |
| ctype2      |       | VARCHAR(100)      |         | Name of astrometric projection in decl.                                   |
| crval1 degrees |     | FLOAT            | −999    | Right ascension corresponding to reference pixel.                          |
| crval2 degrees |     | FLOAT            | −999    | decl. corresponding to reference pixel.                                   |
| crpix1 sky pixels |   | FLOAT            | −999    | Reference pixel for R.A.                                                  |
| crpix2 sky pixels |   | FLOAT            | −999    | Reference pixel for decl.                                                 |
| cdelt1 degrees/pixel | | FLOAT         | −999    | Pixel scale in R.A.                                                       |
| cdelt2 degrees/pixel |   | FLOAT            | −999    | Pixel scale in decl.                                                      |
| pc001001    |       | FLOAT             | −999    | Linear transformation matrix element between image pixel x and R.A.        |
| pc001002    |       | FLOAT             | −999    | Linear transformation matrix element between image pixel y and R.A.        |
| pc002001    |       | FLOAT             | −999    | Linear transformation matrix element between image pixel x and decl.       |
| pc002002    |       | FLOAT             | −999    | Linear transformation matrix element between image pixel y and decl.       |
| processingVersion |   | TINYINT          | NA      | Data release version.                                                     |

Note. The astrometric calibration of the reference STACK is listed.
Table D41

DiffDetection: Contains the Photometry of Individual Detections from a Difference Image

| Column Name         | Units         | Data Type | Default | Description                                                                 |
|---------------------|---------------|-----------|---------|-----------------------------------------------------------------------------|
| diffObjID           |               | BIGINT    | NA      | Unique difference object identifier.                                       |
| uniquePspsDFid      |               | BIGINT    | NA      | Unique internal PSPS difference detection identifier.                       |
| diffDetID           |               | BIGINT    | NA      | Unique difference detection identifier.                                     |
| diffImageID         |               | BIGINT    | NA      | Difference detection meta identifier.                                       |
| ippObjID            |               | BIGINT    | NA      | IPP internal object identifier.                                             |
| ippDetectID         |               | BIGINT    | NA      | IPP internal detection identifier.                                          |
| fromPosImage        |               | TINYINT   | NA      | Detection is from positive image (if 1) or negative image (if 0).            |
| filterID            |               | TINYINT   | NA      | Filter identifier. Details in the Filter table.                             |
| surveyID            |               | TINYINT   | NA      | Survey identifier. Details in the Survey table.                             |
| randomDiffID        |               | FLOAT     | NA      | Random value drawn from the interval between zero and one.                  |
| tessID              |               | SMALLINT  | −1      | Tessellation identifier. Details in the TessellationType table.             |
| projectionID        |               | SMALLINT  | −1      | Projection cell identifier.                                                 |
| skyCellID           |               | TINYINT   | 255     | Skycell region identifier.                                                  |
| dvoRegionID         |               | INT       | −1      | Internal DVO region identifier.                                             |
| obsTime             | days          | FLOAT     | −999    | Modified Julian Date at the midpoint of the observation.                   |
| xPos                | sky pixels    | REAL      | −999    | PSF x-center location.                                                      |
| yPos                | sky pixels    | REAL      | −999    | PSF y-center location.                                                      |
| xPosErr             | sky pixels    | REAL      | −999    | Error in PSF x-center location.                                             |
| yPosErr             | sky pixels    | REAL      | −999    | Error in PSF y-center location.                                             |
| phScale             | arcsec/pixel  | REAL      | −999    | Local plate scale at this location.                                         |
| posAngle            | degrees       | REAL      | −999    | Position angle (sky-to-chip) at this location.                              |
| ra                  | degrees       | FLOAT     | −999    | Right ascension.                                                            |
| dec                 | degrees       | FLOAT     | −999    | Declination.                                                               |
| raErr               | arcsec        | REAL      | −999    | Right ascension error.                                                      |
| decErr              | arcsec        | REAL      | −999    | Decl. error.                                                               |
| zp                  | magnitudes    | REAL      | 0       | Photometric zero point for converting fluxes and magnitudes to measured ADU.|
| telluricExt         | magnitudes    | REAL      | NA      | Estimated telluric extinction due to nonphotometric observing conditions.   |
| expTime             | seconds       | REAL      | −999    | Exposure time of the positive single-epoch image.                          |
| airMass             |               | REAL      | 0       | Airmass at the midpoint of the exposure to convert fluxes and magnitudes to measured ADU. |
| DpsfFlux            | Jy            | REAL      | −999    | Flux from PSF fit.                                                          |
| DpsfFluxErr         | Jy            | REAL      | −999    | Error in PSF flux.                                                          |
| xPosChip            | raw pixels    | REAL      | −999    | PSF x position in original chip pixels.                                    |
| yPosChip            | raw pixels    | REAL      | −999    | PSF y position in original chip pixels.                                    |
| ccdID               |               | SMALLINT  | −999    | OTA identifier of original chip (see ImageMeta).                            |
| DpsfMajorFWHM       | arcsec        | REAL      | −999    | PSF major axis FWHM.                                                        |
| DpsfMinorFWHM       | arcsec        | REAL      | −999    | PSF minor axis FWHM.                                                        |
| DpsfTheta           | degrees       | REAL      | −999    | PSF major axis orientation.                                                |
| DpsfCore            |               | REAL      | −999    | PSF core parameter k, where $F = F_0 / (1 + kr^2 + r^{3.33})$.              |
| DpsfQI              |               | REAL      | −999    | PSF coverage factor.                                                        |
| DpsfQIPerfect       |               | REAL      | −999    | PSF-weighted fraction of pixels totally unmasked.                          |
| DpsfChSi            |               | REAL      | −999    | Reduced chi-squared value of the PSF model fit.                            |
| DpsfLikelihood      |               | REAL      | −999    | Likelihood that this detection is best fit by a PSF.                        |
| DmomentXX           | arcsec²       | REAL      | −999    | Second moment $M_{XX}$.                                                     |
| DmomentXY           | arcsec²       | REAL      | −999    | Second moment $M_{XY}$.                                                     |
| DmomentYY           | arcsec²       | REAL      | −999    | Second moment $M_{YY}$.                                                     |
| DmomentR1           | arcsec        | REAL      | −999    | First radial moment.                                                       |
| DmomentRH           | arcsec²       | REAL      | −999    | Half-radial moment ($r^{0.5}$ weighting).                                   |
| DapFlux             | Jy            | REAL      | −999    | Aperture flux.                                                             |
| DapFluxErr          | Jy            | REAL      | −999    | Error in aperture flux.                                                     |
| DapFillF            |               | REAL      | −999    | Aperture fill factor.                                                       |
| DkronFlux           | Jy            | REAL      | −999    | Kron (1980) flux.                                                           |
| DkronFluxErr        | Jy            | REAL      | −999    | Error in Kron (1980) flux.                                                  |
| DkronRad            | arcsec        | REAL      | −999    | Kron (1980) radius.                                                        |
| diffINPos           | sky pixels    | INT       | −999    | Number of difference pixels within the aperture that are positive.         |
| diffFPosRatio       |               | REAL      | −999    | Ratio of the sum of positive flux pixel values to the sum of the absolute value of all unmasked pixels within the aperture. |
| diffINPosRatio      |               | REAL      | −999    | Ratio of the number of positive flux pixels to the number of unmasked pixels within the aperture. |
| diffINPosMask       |               | REAL      | −999    | Ratio of the number of positive flux pixels to the number of positive or masked pixels within the aperture. |
| diffINPosAll        |               | REAL      | −999    | Ratio of the number of positive flux pixels to the total number of all pixels within the aperture. |
| diffPosDist         | sky pixels    | REAL      | −999    | Distance to matching source in positive image.                             |
Table D41
(Continued)

| Column Name   | Units     | Data Type | Default | Description                              |
|---------------|-----------|-----------|---------|------------------------------------------|
| diffNegDist   | sky pixels| REAL      | −999    | Distance to matching source in negative image. |
| diffPosSN     | ...       | REAL      | −999    | Signal to noise of matching source in positive image. |
| diffNegSN     | ...       | REAL      | −999    | Signal to noise of matching source in negative image. |
| Dsky          | Jy arcsec^{-2} | REAL    | −999    | Background sky level.                      |
| DskyErr       | Jy arcsec^{-2} | REAL    | −999    | Error in background sky level.            |
| DinfoFlag     | BIGINT    | 0        |         | Information flag bitmask indicating details of the photometry. see DetectionFlags. |
| DinfoFlag2    | INT       | 0        |         | Information flag bitmask indicating details of the photometry. See DetectionFlags2. |
| DinfoFlag3    | INT       | 0        |         | Information flag bitmask indicating details of the photometry. See DetectionFlags3. |
| processingVersion   | TINYINT | NA       |         | Data release version.                      |

Note. The identifiers connecting the detection back to the difference image and to the object association are provided. PSF, aperture, and Kron (1980) photometry are included, along with sky and detector coordinate positions.

Table D42
DiffToImage: Contains the Mapping of Which Input Images Were Used to Construct a Particular Difference Image

| Column Name   | Units     | Data Type | Default | Description                              |
|---------------|-----------|-----------|---------|------------------------------------------|
| diffImageID   | ...       | BIGINT    | NA      | Unique difference identifier.            |
| imageID       | ...       | BIGINT    | NA      | Unique image identifier. Constructed as (100 × frameID + ccdID). |

Table D43
DiffDetEffMeta: Contains the Detection Efficiency Information for a Given Individual Difference Image

| Column Name   | Units     | Data Type | Default | Description                              |
|---------------|-----------|-----------|---------|------------------------------------------|
| diffImageID   | ...       | BIGINT    | NA      | Unique difference image identifier.      |
| magref        | magnitudes| REAL      | NA      | Detection efficiency reference magnitude. |
| nInjected     | ...       | INT       | NA      | Number of fake sources injected in each magnitude bin. |
| offset01      | magnitudes| REAL      | NA      | Detection efficiency count of recovered sources in bin 1. |
| counts01      | ...       | REAL      | NA      | Detection efficiency mean magnitude difference in bin 1. |
| diffMean01    | magnitudes| REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 1. |
| errMean01     | magnitudes| REAL      | NA      | Detection efficiency mean magnitude error in bin 1. |
| offset02      | magnitudes| REAL      | NA      | Detection efficiency count of recovered sources in bin 2. |
| counts02      | ...       | REAL      | NA      | Detection efficiency mean magnitude difference in bin 2. |
| diffMean02    | magnitudes| REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 2. |
| errMean02     | magnitudes| REAL      | NA      | Detection efficiency mean magnitude error in bin 2. |
| offset03      | magnitudes| REAL      | NA      | Detection efficiency count of recovered sources in bin 3. |
| counts03      | ...       | REAL      | NA      | Detection efficiency mean magnitude difference in bin 3. |
| diffMean03    | magnitudes| REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 3. |
| errMean03     | magnitudes| REAL      | NA      | Detection efficiency mean magnitude error in bin 3. |
| offset13      | magnitudes| REAL      | NA      | Detection efficiency count of recovered sources in bin 13. |
| counts13      | ...       | REAL      | NA      | Detection efficiency mean magnitude difference in bin 13. |
| diffMean13    | magnitudes| REAL      | NA      | Detection efficiency standard deviation of magnitude differences in bin 13. |
| diffStdev13   | magnitudes| REAL      | NA      | Detection efficiency mean magnitude error in bin 13. |
| errMean13     | magnitudes| REAL      | NA      | Detection efficiency mean magnitude error in bin 13. |

Note. Provides the number of recovered sources out of 500 injected sources and statistics about the magnitudes of the recovered sources for a range of magnitude offsets.
Appendix E
IppToPsps Translation Tables

The tables in this section describe the relationship between fields in the PSPS database and their immediate source. In some cases, the values are calculated by the IPP processing and extracted by the IPPTOPSPS system from the output catalog files (e.g., the cmf or smf files). In other cases, the values are calculated within the DVO system during the construction of that database or during the calibration. Some values are calculated directly by the PSPS ingest software from other information (e.g., the \( cx, cy, cz \) coordinate system for objects).

| Table E1 |
|----------|
| **ObjectThin** | This Describes the Sources for Each of the Columns within ippdbtableObjectThin as Well as the Formula to Generate the Data within the Column, If It Is Not Just Copying Directly | |
| **Column Name** | **Source** | **Notes** |
| objName | DVO cpt IAUNAME /IPPTOPSPS | |
| objPSOName | DVO cpt PSO_NAME | |
| objAltName1 | not set | |
| objAltName2 | not set | |
| objAltName3 | not set | |
| objPopularName | not set | |
| objID | DVO cpt EXT_ID | |
| uniquePspsOBid | IPPTOPSPS | uniquePspsOBid = (batchID \( \times 1000000000 \) + row number) |
| ippObjID | DVO cpt OBJ_ID and CAT_ID | OBJ_ID + (CAT_ID \( \ll 32 \)) |
| surveyID | IPPTOPSPS | set to 0 for 3\( \pi \) |
| htmID | PSPS | calculated and filled in PSPS (Szalay et al. 2007) |
| zoneID | PSPS | calculated and filled in PSPS |
| tessID | DVO cpt TESS_ID | |
| projectionID | DVO cpt PROJECTION_ID | |
| skyCellID | DVO cpt SKYCELL_ID | |
| randomID | IPPTOPSPS | random is seeded with RAND(batchID) |
| batchID | IPPTOPSPS | sequentially increases as batches are made |
| dvoRegionID | DVO cpt CAT_ID | |
| processingVersion | IPPTOPSPS | set to 3 for this data release, for PV3 |
| objInfoFlag | DVO cpt FLAGS | |
| qualityFlag | DVO cpt FLAGS | FLAGS \( \geq 23 \) & 0xFF |
| raStack | DVO cpt RA_STK | |
| decStack | DVO cpt DEC_STK | |
| raStackErr | DVO cpt RA_STK_ERR | |
| decStackErr | DVO cpt DEC_STK_ERR | |
| raMean | DVO cpt RA_MEAN | |
| decMean | DVO cpt DEC_MEAN | |
| raMeanErr | DVO cpt RA_ERR | |
| decMeanErr | DVO cpt DEC_ERR | |
| epochMean | DVO cpt EPOCH_MEAN | |
| posMeanChisq | DVO cpt CHISQ_POS | |
| cx | PSPS | set to 0 initially; calculated and filled by PSPS |
| cy | PSPS | set to 0 initially; calculated and filled by PSPS |
| cz | PSPS | set to 0 initially; calculated and filled by PSPS |
| lambda | PSPS set to 0; calculated and filled by PSPS | |
| beta | PSPS set to 0; calculated and filled by PSPS | |
| l | PSPS | set to 0; calculated and filled by PSPS |
| b | PSPS | set to 0; calculated and filled by PSPS |
| nStackObjectRows | IPPTOPSPS | set to \(-999\) for \(3\pi\) |
| nStackDetections | DVO cpt NSTACK_DET | sum of NSTACK_DET for all 5 filters |
| nDetections | IPPTOPSPS | sum of non-null ng + nr + ni + nz + ny |
| ng | DVO cpt NCODE | |
| nr | DVO cpt NCODE | |
| ni | DVO cpt NCODE | |
| nz | DVO cpt NCODE | |
| ny | DVO cpt NCODE | |

**Note.** For this table, DVO cpt NAME shows that this comes from the cpt files in the DVO database and has a column of NAME. The sources for this table include the DVO cpt files, IPPTOPSPS, PSPS, as well as a few columns that are not currently being used.
### Table E2
MeanObject: This Describes the Sources for Each of the Columns within MeanObject as Well as the Formula to Generate the Data within the Column, If It Is Not Just Copying Directly

| Column Name     | Source                            | Notes                                                                                                                                 |
|-----------------|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| objID           | IPPTOPSPSobjectThin.objID         |                                                                                                                                         |
| uniquePspsOBid  | IPPTOPSPSobjectThin.              | uniquePspsOBid                                                                                                                                 |
| gQfPerfect      | DVO cps                           | PSF_QF_PERF_MAX                                                                                                                       |
| gMeanPSFMag     | DVO cps                           | MAG                                                                                                                                   |
| gMeanPSFMagErr  | DVO cps                           | MAG_ERR                                                                                                                              |
| gMeanPSFMagStd  | DVO cps                           | MAG_STDEV                                                                                                                            |
| gMeanPSFMagNpt  | DVO cps                           | NUSED                                                                                                                                |
| gMeanPSFMagMin  | DVO cps                           | MAG_MIN                                                                                                                              |
| gMeanPSFMagMax  | DVO cps                           | MAG_MAX                                                                                                                              |
| gMeanKronMag    | DVO cps                           | MAG_KRON                                                                                                                             |
| gMeanKronMagErr | DVO cps                           | MAG_KRON_ERR                                                                            |
| gMeanKronMagStd | DVO cps                           | MAG_KRON_STDEV                                                                           |
| gMeanKronMagNpt | DVO cps                           | NUSED_KRON                                                                            |
| gMeanApMag      | DVO cps                           | MAG_AP                                                                                                                                |
| gMeanApMagErr   | DVO cps                           | MAG_AP_ERR                                                                             |
| gMeanApMagStd   | DVO cps                           | MAG_AP_STDEV                                                                            |
| gMeanApMagNpt   | DVO cps                           | NUSED_AP                                                                                                                             |
| fFlags          | DVO cps                           | FLAGS                                                                                                                                 |
| rQfPerfect      | DVO cps                           |                                                                                                                                         |
| ...             |                                   | Same entries repeated for the r, i, z, and y filters                                                                                   |
| yFlags          |                                   |                                                                                                                                         |

**Note.** For this table, DVO cps NAME shows that this comes from the cps files in the DVO database and has a column of NAME. The sources for this table include the DVO cps files and IPPTOPSPS.

### Table E3
StackObjectThin: This Describes the Sources for Each of the Columns within StackObjectThin as Well as the Formula to Generate the Data within the Column, If It Is Not Just Copying Directly

| Column Name     | Source                            | Notes                                                                                                                                 |
|-----------------|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| objID           | DVO cpt                           | average.extID                                                                                                                                 |
| uniquePspsSTid  | IPPTOPSPS                         | (batchID + 1000000000) + row number                                                                                                 |
| ippObjID        | DVO cpm                           | OBJ_ID + (CAT_ID << 32)                                                                                                               |
| surveyID        | IPPTOPSPS                         | set to 0 for 3π                                                                                                                       |
| tessID          | cmf file                          | from header: TESS_ID                                                                                                                  |
| projectionID    | cmf file                          | from header, first 4 numbers in SKYCELL                                                                                               |
| skyCellID       | cmf file                          | from header, last 4 numbers in SKYCELL                                                                                               |
| randomStackObjID| ipptopsps                         | random number generated in ipptopsps, seeded with batch_id                                                                          |
| primaryDetection| DVO cpm                           | (dvo.measure.flags & 0x10000) >> 16                                                                                                   |
| bestDetection   | DVO cpm                           | (dvo.average.objflags & 0x8000) >> 15                                                                                                 |
| dvoRegionID     | DVO cpm                           | dvo.measure.catID                                                                                                                     |
| processingVersion| ipptopsps                        | set to 3 for this data release, for PV3                                                                                               |
| gippDetectID    | DVO cpm                           | dvo.measure.detID                                                                                                                     |
| gstackDetectID  | DVO cpm                           | dvo.measure.extID                                                                                                                     |
| gstackImageID   | gpcl database                     | internal stack ID for this stack                                                                                                      |
| gra             | DVO cpm                           | dvo.average.ra                                                                                                                       |
| gdec            | DVO cpm                           | dvo.average.dec                                                                                                                       |
| graErr          | cmf file                          | X_PSF3JG * PLTSCALE                                                                                                                   |
| gdecErr         | cmf file                          | Y_PSF3JG * PLTSCALE                                                                                                                   |
| gEpoch          | cmf file                          | from header, MID-OBS                                                                                                                  |
| gPSFMag         | DVO cpm                           | dvo.measure.FluxPSF (converted to mag using the zero point)                                                                         |
| gPSFMagErr      | DVO cpm                           | dvo.measure.dFluxPSF (converted to mag error)                                                                                            |
| gApMag          | DVO cpm                           | dvo.measure.FluxAp (converted to mag using the zero point)                                                                         |
| gApMagErr       | DVO cpm                           | dvo.measure.dFluxAp (converted to mag error)                                                                                            |
| gKronMag        | DVO cpm                           | dvo.measure.FluxKron (converted to mag using the zero point)                                                                         |
| gKronMagErr     | DVO cpm                           | dvo.measure.dFluxKron (converted to mag error)                                                                                         |
| ginfoFlag       | cmf file                          | FLAGS                                                                                                                                 |
| ginfoFlag2      | cmf file                          | FLAGS2                                                                                                                                |
| ginfoFlag3      | DVO cpm                           | measure.dbFlags                                                                                                                       |
| gFrames         | cmf file, header                  | N_FRAMES                                                                                                                              |
| rippDetectID    |                                   |                                                                                                                                         |
| ...             |                                   | same entries repeated for r, i, z, and y filters                                                                                       |
| ynFrames        |                                   |                                                                                                                                         |

**Note.** For this table, DVO cps NAME shows that this comes from the cps files in the DVO database and has a column of NAME. The sources for this table include the DVO cps files and IPPTOPSPS.
ORCID iDs

H. A. Flewelling @ https://orcid.org/0000-0002-1050-4056
E. A. Magnier @ https://orcid.org/0000-0002-7965-2815
K. C. Chambers @ https://orcid.org/0000-0001-6965-7789
M. E. Huber @ https://orcid.org/0000-0003-1059-9603
C. Z. Waters @ https://orcid.org/0000-0003-1989-4879
A. Calamida @ https://orcid.org/0000-0002-0882-7702
G. Hasinger @ https://orcid.org/0000-0002-0797-0646
K. S. Long @ https://orcid.org/0000-0002-7965-2815
G. Narayan @ https://orcid.org/0000-0001-6022-0484
N. Metcalfe @ https://orcid.org/0000-0001-9034-4402
K. W. Hodapp @ https://orcid.org/0000-0003-0786-2140
R. P. Saglia @ https://orcid.org/0000-0003-0378-7032
R. White @ https://orcid.org/0000-0002-9194-2807
P. W. Draper @ https://orcid.org/0000-0002-7204-9802
K. W. Hodapp @ https://orcid.org/0000-0003-0786-2140
R. J. Wainscoat @ https://orcid.org/0000-0002-1341-0952
M. Postman @ https://orcid.org/0000-0002-9365-7989

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