

U N I V E R S I T Y O F H A W A I ' I A T M Ā N O A

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Pan-STARRS Project Management System

**Pan-STARRS PS1 Image Processing Pipeline–Published
Science Products Subsystem
Interface Control Document
(PS1 IPP-PSPS ICD)**

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1 Scope

1.1 Identification

This document is the Interface Control Document (ICD) for the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) Image Processing Pipeline (IPP) and Published Science Product Subsystem (PSPS) for the operational prototype referred to as Pan-STARRS-1 (PS1). This document is a system-level controlled specification in the official Pan-STARRS engineering specification tree.

1.2 System Overview

Project Sponsor	AFRL, United States Air Force
Acquirer	University of Hawaii Institute for Astronomy
User	Astronomical community
Developer	University of Hawaii Institute for Astronomy, participating institutions, and associated subcontractors

The Institute for Astronomy (IfA) at the University of Hawaii (UH) is developing a large optical synoptic survey telescope system, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). The Pan-STARRS PS1 Science Goals Statement (SGS, PSDC-230-001) describes several concepts of interest, including: science goals; priorities; top-level concept of operations, with associated operational requirements; and principal system performance factors, with associated system performance requirements.

Pan-STARRS consists of six subsystems: TEL - An array of four 1.8m telescopes, each with a 7 deg² field of view. CAM - 1 Giga Pixel CCD cameras, one per telescope, with low noise and rapid read-out. OTIS - The Observatory, Telescope, and Instrument Software control system. IPP - The Image Processing Pipeline, a raw data to science data converter which produces both cumulative sky images and difference images from which transient, moving, and variable objects can be detected. MOPS - Moving Object Processing Software - a preferred science client which obtains raw data from the IPP and publishes derived object and attributed object data to the PSPS. PSPS - The Published Science Products System which is the data archive and software that provides access of published data to the astronomy community.

PS1, the single telescope operational prototype, is being developed as a risk mitigation step prior to construction of PS4, the complete four-telescope system. This document defines the interface architecture, protocols, messages, and data exchange between the PS1 IPP and PSPS subsystems for the prototype effort.

1.3 Document Overview

This document defines the implementation details for the interface between the PS1 IPP and PSPS subsystems in conformance with the interface requirements specified in the PS1 IPP-PSPS Interface Requirements Specification (IRS, PSDC- 930- 006).

2 Referenced Documents

The subsections that follow identify documents, either generated by U.S. federal government agencies, or developed under the Pan-STARRS project, consulted during the production of this specification.

2.1 Government Documents

Table 2.1 presents documents applicable to the contents of this specification that were generated by U.S. government agencies.

Table 2.1 U.S. Government Documents

Document ID	Document Title
F29601-02-1-0268	Air Force Research Laboratory Grant/Cooperative Agreement Award for "Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)", dated September 23, 2002.

2.2 Non-Government Documents

Table 2.2 presents documents applicable to the contents of this specification that were previously generated by the Pan-STARRS project.

Table 2.2 Non-Government Documents

Document ID	Document Title
PSDC-230-001	Pan-STARRS PS1 Science Goals Statement
PSDC-230-002	Pan-STARRS PS1 System/Subsystem Specification
PSDC-430-005	Pan-STARRS PS1 IPP Software Requirements Specification
PSDC-430-011	Pan-STARRS PS1 IPP System/Subsystem Design Description
PSDC- 930- 006	Pan-STARRS PS1 IPP-PSPS Interface Requirements Specification
PSDC-630-001	Pan-STARRS PS1 PSPS Software Requirements Specification
PSDC-630-SSDD	Pan-STARRS PS1 PSPS System/Subsystem Design Description
FITS Standard, Version 2.1	Definition of the Flexible Image Transport System (FITS), April 7, 2005
FITS Checksum Proposal	FITS Checksum Proposal, May 23, 2003.

3 Interface Design

The IPP produces multiple science data products that are made available to the public via the PSPS. The Pan-STARRS design concept defines the interface between the IPP and the PSPS subsystems (i.e., the IPP - PSPS Interface) as a unidirectional exchange of data from the IPP to the PSPS, and further restricts the PSPS from issuing commands to the IPP or any other Pan-STARRS subsystem (reference SCD, Section 10.3.4). The interface is further constrained by the IPP design decision to transfer science data products in the form of files compliant with the Flexible Image Transport System (FITS) data format (reference IPP SSDD, Section 9.2.3). This document identifies the protocol and data formats needed to define the IPP - PSPS Interface within these design constraints.

3.1 Physical Connectivity and Interface Protocols

Selection of hardware to provide connectivity between the IPP and PSPS is **TBD**, making selection of interconnection protocols other than the application layer protocol (i.e., transfer of science data via FITS files) **TBD**.

3.2 Data Transfer Protocol

As described in the IPP-PSPS IRS, the PS1 observations are scheduled on (roughly) monthly cycles. During a cycle, the IPP processes telescope data into products, such as object detections, that the IPP publishes to the PSPS. The PSPS caches each full cycle of data so that it may optimize its correlation of the detections to achieve requisite performance specifications. The objective is for the PSPS to keep up with the IPP publication rate, so that updates to the PSPS data stores are made available to end users at a predictable period after observation.

3.2.1 The Initialization Job

The "initialization job" is a one-time transfer of predefined catalog objects derived from PS1 observations. The IPP will transfer the initialization job piecewise as a series of "batches" of data to the PSPS. A "batch" is a compressed archive file containing the IPP data products as a set of FITS files and a batch manifest file. A batch manifest is a file that contains the filename and content identification for every FITS file sent in a batch; the batch manifest permits the PSPS to verify proper receipt of published IPP data products,. Figure 3.1 depicts the Initialization Job transfer process.

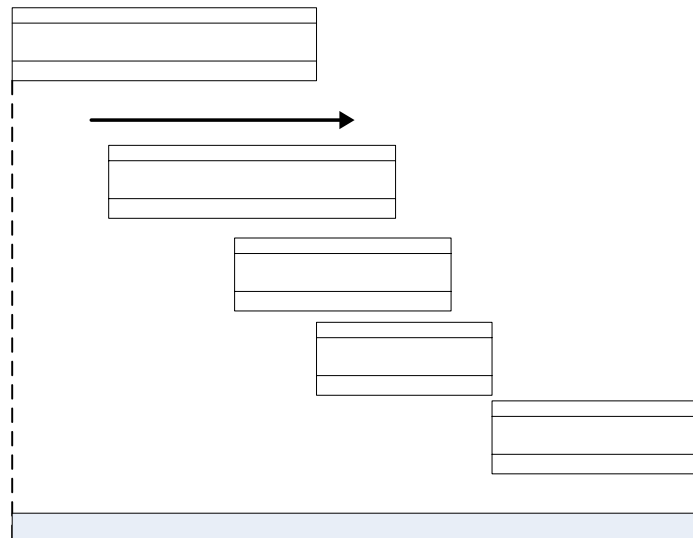


Figure 3.1 Initialization Job Transfer Process

When the IPP transfers the catalog batch to the PSPS, the PSPS performs a four stage Batch Verification process, as depicted in Figure 3.3. This verification process is identical to the verification process used for The Publication Cycle, and is completely described in Section 3.2.2. The transfer of the predefined object catalog must complete successfully before the publication cycles can commence. In addition, transfer of the predefined object catalog cannot be repeated once the publication cycles begin.

3.2.2 The Publication Cycle

Figure 3.2 depicts the publication cycle as a pipelined set of staged processes: The IPP product generation process, the Data Transfer process, the PSPS Batch Verification process, the PSPS Ingest Preparation Process, and the PSPS Ingest & Publication processes. The science data published by the IPP in a cycle is labeled a "job". During the Transfer process, the IPP transfers each job piecewise as a series of "batches" of data to the PSPS. A "batch" is a compressed archive file containing the IPP products as a set of FITS files and a batch manifest file. A batch manifest is a file that contains the filename and content identification for every FITS file sent in a batch; the batch manifest permits the PSPS to verify proper receipt of published IPP data products, per requirement.

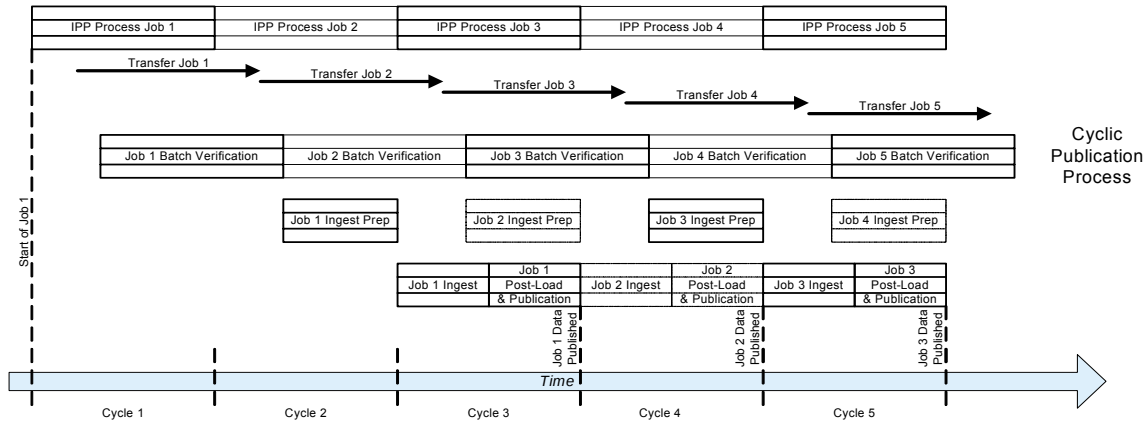


Figure 3.2 Cyclic Publication Process

When the IPP transfers a batch to the PSPS, the PSPS performs a four stage Batch Verification process, as depicted in Figure 3.3. First, the PSPS verifies that the FITS files included in the batch match the batch manifest. If not, the PSPS transmits a Batch Manifest Error Notification, and then awaits correction and retransmission of the batch. Second, the PSPS verifies the integrity of the FITS files by checking each file's checksum. If any of the files were corrupted during transfer, the PSPS transmits a Batch Corruption Error Notification, and then awaits retransmission of the batch; otherwise, the PSPS transmits a Batch Received Notification. Note that the PSPS sends this notification within **TBD** seconds of the batch file arrival, per IRS requirement 3.4.1. Third, the PSPS verifies that the contents of the FITS files match the manifest description. If any mismatches are identified, the PSPS transmits a Batch Content Error Notification, and then awaits correction and retransmission of the batch. Finally, the PSPS performs a detailed verification of every datum in each FITS file. If the file contents are found to be incomplete, inconsistent, or any datum is out of its defined range, then the PSPS transmits a Batch Verification Error Notification, and then awaits correction and retransmission of the batch.

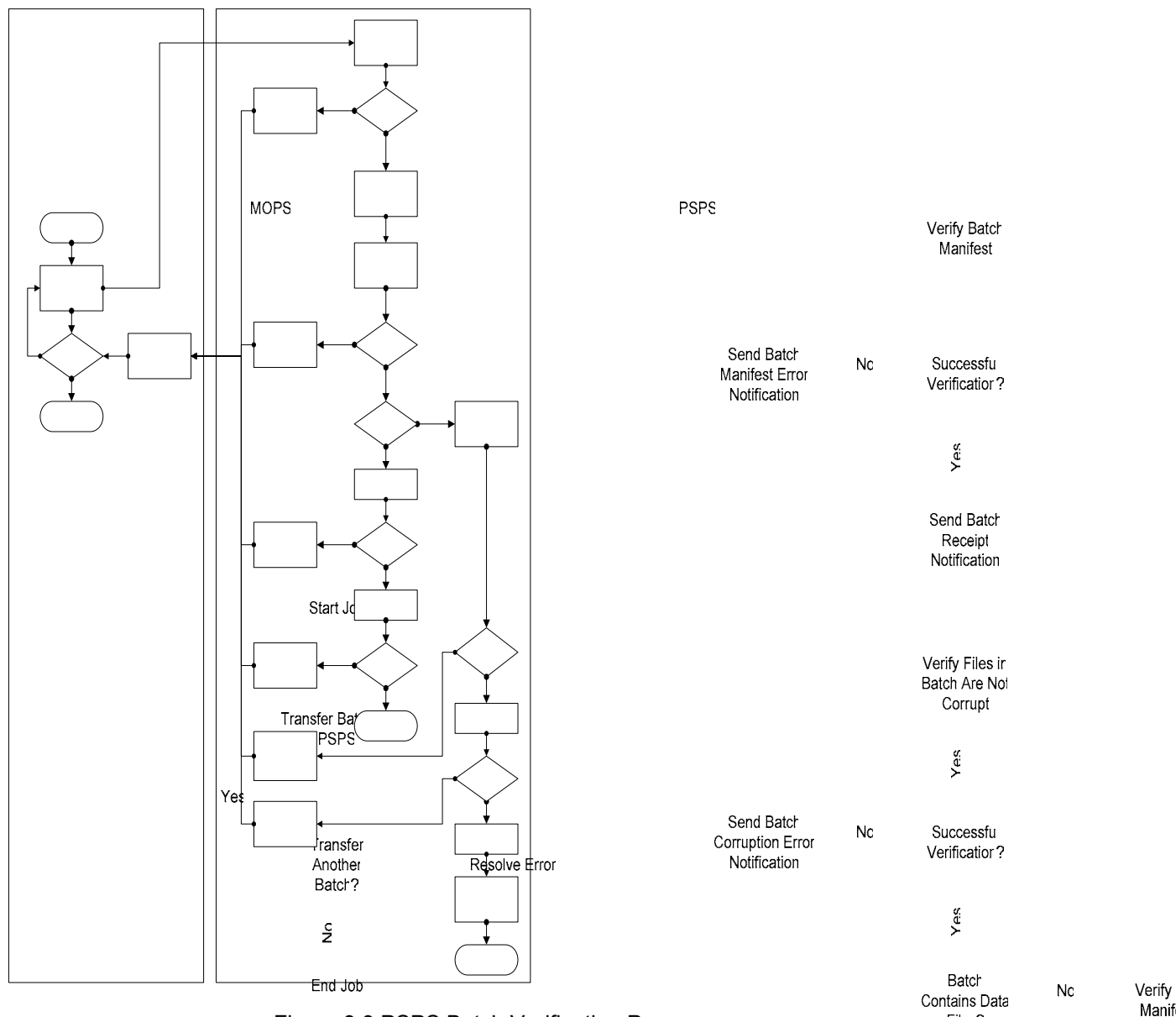


Figure 3.3 PSPS Batch Verification Process

The PSPS reports all errors found at each stage of the batch verification process in an attempt to minimize multiple retransmission of the same batch. For example, during the data content verification stage, the PSPS will report all data content errors found within all FITS files comprising the batch in a single Batch Data Verification Error Notification.

Once the IPP has finished transferring a job, it transmits the job manifest. A job manifest is a file that identifies every batch comprising a job. If the PSPS detects a discrepancy between the batches it has received and the job manifest, it transmits a Job Manifest Error Notification to the IPP, and then awaits correction and retransmittal of the job manifest. Correction may include transfer of new batches or replacement of previously transmitted batches, but a new job manifest will always be transmitted.

Once the job manifest is successfully verified, the PSPS prepares the job for ingest by performing full verification of all science data from the job. The PSPS will send a Job Verification Error Notification to the IPP if it detects data that is combinationally inconsistent and would cause

errors with PSPS correlation or attribute derivation. The PSPS performs full verification across all science data from the job, and sends a compilation of the verification errors in one notification. Job ingest will not occur until the IPP transmits corrective data, as required, and resends the job manifest.

The PSPS considers the job to be successfully transferred when job ingest preparation is successfully completed. At this point, the PSPS has one month, by requirement, to correlate the detections reported by the IPP into astronomical objects, calculate object properties derivable from the detections, and publish the updated database. Derivable object properties will include statistical properties (mean magnitudes, median magnitudes, minimum magnitudes, maximum magnitudes), proper motions (for stars), and photometric redshifts (extragalactic sources). Once the PSPS has successfully completed ingest, the PSPS will send a Job Publication Notification to the IPP. Otherwise, if the ingest fails, the PSPS will send a Job Ingest Failure Notification.

3.2.3 A Broken Publication Cycle

The cyclic publication process shown in Figure 3.2 works because the IPP Process, Transfer process, PSPS Batch Verification process, PSPS Ingest Preparation Process, and PSPS Ingest & Publication processes are each designed to complete one cycle prior to beginning the next. This means that the maximum length of time that any of these processes may take is one cycle (i.e., one month). Figure 3.3 demonstrates this relationship by showing what happens to the successful publication process (top portion of Figure 3.3) if an error is detected in the Ingest Preparation process for Job 2 that causes the Job 2 Transfer and Batch Verification processes to exceed one month to correct (bottom portion of Figure 3.3).

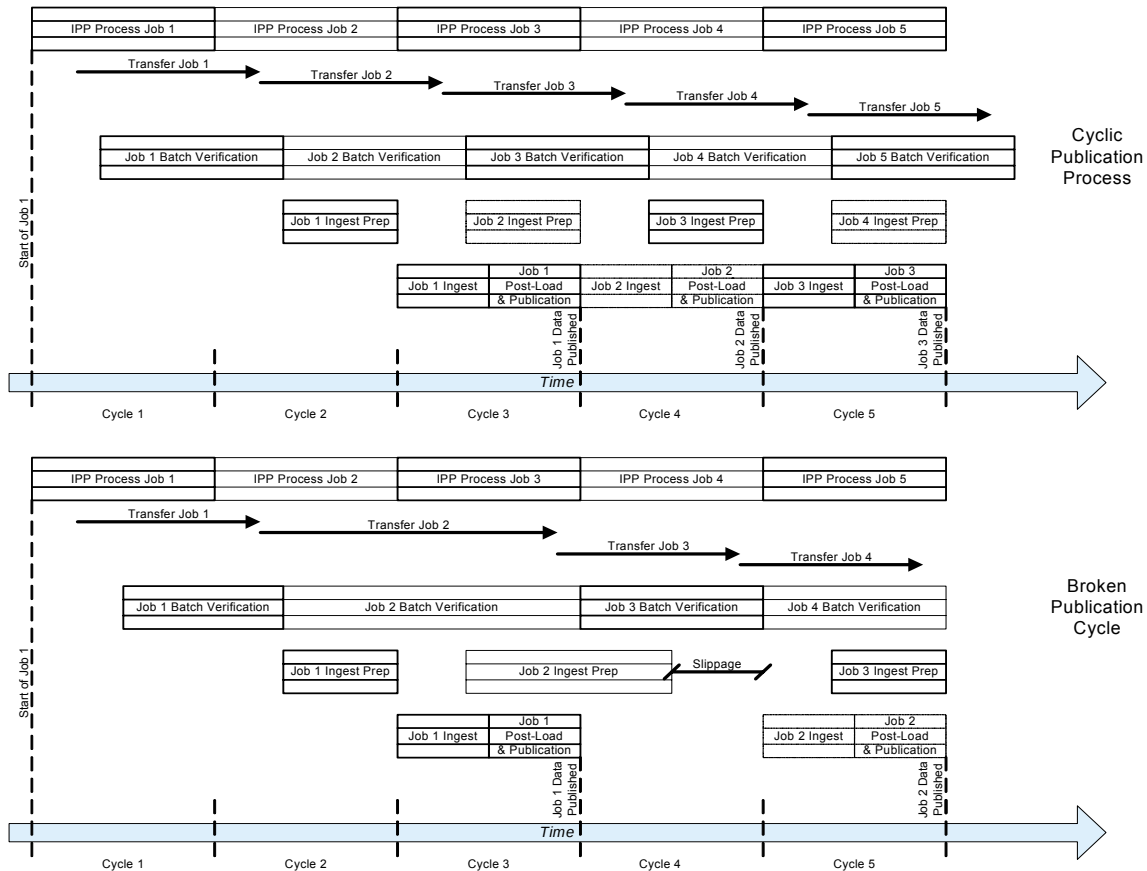


Figure 3.2 Broken Publication Cycle

In this error scenario, the Job 2 Ingest Preparation process detects a verification error and sends the IPP a Job Verification Error Notification with details about the error. Correction of the error requires retransmittal of sufficient Job 2 batches, reverification of the batches, and reverification of the job that the Job 2 Ingest process cannot start on schedule. The gross effect of this error is that the publication schedule is broken.

The bottom portion of Figure 3.3 shows one way to deal with a broken cycle: Defer the publication process by introducing "slippage" into the ingest process so that publication resumes on schedule after a one cycle break. The net effect is that users can continue to expect updates at the same periodicity, but an additional cycle has been added to the publication latency.

3.2.4 Resynchronization After A Broken Cycle

Figure 3.4 shows an alternate solution that may be feasible to resynchronize the publication process. This solution is based on two critical assumptions: 1. The PSPS enters **abnormal** mode when data to be processed exceeds normal bounds; and, 2. PSPS timing and processing requirements are not applicable when the PSPS is operating in an **abnormal** mode. The justification for these two assumptions is such: The PSPS is optimized to meet data size and process performance requirements to keep pace with the IPP product publication cycle; when the data to be processed exceeds normal bounds -- e.g., more than one job per cycle -- then the PSPS must be re-optimized to meet new processing limits.

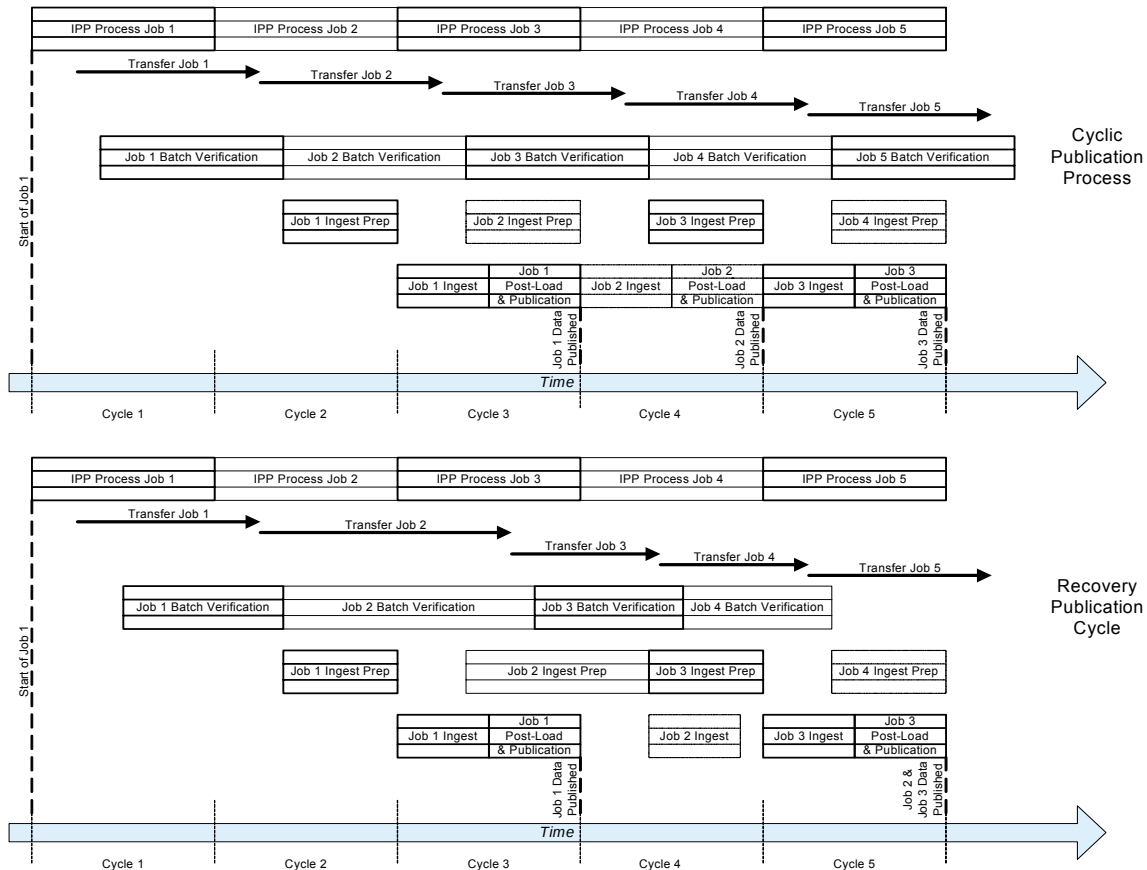


Figure 3.3 Recovery & Resynchronization Publication Cycle

Evaluating the processes in Figure 3.2 (as duplicated at the top of Figure 3.4), it is certainly possible that the transfer of data from the IPP to the PSPS can take less than one cycle to

accomplish. This assertion is demonstrated by the shorter transfer times for jobs 3 and 4 in the Recovery Publication Cycle of Figure 3.4. However, the PSPS is able to cache only one job at once. This means the PSPS must "work off" one job at a time; i.e., the PSPS will not accept data from more than one job at a time. Moreover, the jobs must be chronologically increasing; that is, job 2 must be transferred before job 3. Note that the PSPS will send the Batch Refused Error Notification in this circumstance, or whenever the PSPS is unable to accept data from the IPP.

The time needed to verify additional batches of data will certainly increase linearly as the number of batches transmitted increases linearly. This is why the time allocated to batch verification always matches the job transfer time in Figure 3.4.

Ingest preparation is likely to take less time than allocated. Considering that ingest cannot occur until ingest preparation is complete, then the logical question is: why allocate so much time to ingest preparation? Under the current publication cycle, the publication latency -- i.e., the time from observation to science data availability to an end user -- is capped at three months. Compressing the ingest preparation time could decrease the publication latency by several weeks (ideally, up to 4 weeks assuming instantaneous transmission and verification). The answer is: the more time allocated to the verification process, the more likely the publication of science data will stay on schedule. As the ingest publication process time allocation is decreased, the risk that the need for retransmission and reverification of data will cause a publication delay increases, resulting in the need for the PSPS to run in an abnormal mode.

The PSPS ingest process is designed, by requirement, to ingest data at twice the normal processing load. This requirement is meant to smooth out variances in the amount of data contained in each job. It is possible, but by no means assured, that this spare processing power may help recover time needed to resynchronize the publication cycle.

Deferring the post-load and publication processes for a cycle is likely to save sufficient time to help resynchronize a broken publication cycle. Recall that post load processes involve deriving object properties to reflect new detection information. The time needed to update object properties is expected to depend on the number of objects, not the number of detections per object. This means that considerable time savings may be achieved by deferring these calculations to be performed on detections from two jobs rather than one. During the normal publication cycle, the PSPS has some latitude to defer post load processes to stay on the publication schedule. Table 3.7 in the IRS defines the allowable job cycle lags for each of the PSPS post-load attribute calculations. Recall that the job cycle lag may exceed these numbers when the PSPS is running in an abnormal mode.

Figure 3.4 identifies the "cost" of this publication resynchronization process as the deferred publication of science data from the problematic job cycle until the following job cycle. This cost is much preferred over the additional latency cost introduced in Section 3.2.2. This recovery scenario also highlights the requirement for stringent data validation by the IPP and data verification by the PSPS: it is clear from Figure 3.4 that backing out a "bad" job of data could require months of non-publication to resynchronize the publication cycle.

3.2.5 Authentication

Data transfer between the IPP and the PSPS is assumed to occur in a trusted environment. No authentication measures are specified.

3.3 Notification Formats

The Pan-STARRS conceptual design identifies the IPP-PSPS interface as a simple "push" of science data, as it is generated by the IPP, to the PSPS subsystem. The main advantage of this

design is its ease of implementation. The negotiation between the two systems to accomplish the data transfer can be implemented by well known and supported communication layer protocols (e.g., FTP, TCP, IP). The main disadvantage of this design is the inability of the destination system to respond to error conditions not detected by these communication protocols. For example, a successfully transferred file may be in a format which is unrecognizable by the destination system. To address this disadvantage, the PSPS plans to supplement the IPP - PSPS interface with event notifications. The PSPS is designed to notify PSPS administrators of priority events related to data ingest via email; this design is easily extended to notify registered IPP administrators of priority events relating to IPP - PSPS Interface errors. This process assigns the IPP and PSPS administrators the responsibility for working together to identify and resolve the root causes of IPP - PSPS Interface errors. The following notifications are defined in the remainder of this section:

- Batch Manifest Error
- Batch Corruption Error
- Batch Recieved
- Batch Refused Error
- Batch Content Error
- Batch Verification Error
- Job Manifest Error
- Job Verification Error
- Job Verification Successful
- Job Ingest Failure
- Job Publication

Error notifications shall report the job identifier (JOBID) and batch identifier (BATCHID) in accordance with the file naming convection as described in section 3.4.1.

3.3.1 Batch Manifest Error

A Batch Manifest Error Notification is sent as a priority email when a batch manifest identifies FITS files which are not present in the batch, or vice versa. Upon identifying this error, the PSPS will halt further verification phases for the batch, i.e., the PSPS will not process partially correct batches. The IPP administrators are to correct the discrepancy and retransmit both the batch and the batch manifest.

Subject: IPP-PSPS NOTIFICATION 3.3.1 Batch Manifest Error [JOBID/BATCHID]

PSPS failed to process job ID JOBID batch BATCHID due to a batch manifest error. Batch BATCHID must be resubmitted. Further information:

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

Discrepancy: [describe here]

3.3.2 Batch Corruption Error

A Batch Corruption Error Notification is sent as a priority email when one or more of the FITS files contained in a batch become corrupted during transfer. Upon identifying this error, the PSPS will halt further verification phases for the batch, i.e., the PSPS will not process partially correct

Subject: IPP-PSPS NOTIFICATION 3.3.2 Batch Corruption Error [JOBID/ BATCHID]

PSPS failed to process job ID JOBID batch BATCHID due to a batch corruption error. Batch BATCHID must be resubmitted. Further information:

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

Filename: [offending filename in batch]

Discrepancy: [describe in detail here –report both expected and received checksums]

3.3.3 Batch Received

A Batch Received Notification is sent as an email when a batch has been received without file corruption. No action is required upon receipt of this email by IPP administrators.

Subject: IPP-PSPS NOTIFICATION 3.3.3: Batch Successful [JOBID/BATCHID]

Job JOBID Batch BATCHID was received successfully.

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

3.3.4 Batch Refused Error

A Batch Refused Notification is sent as a priority email when the PSPS is unable to accept data from the IPP. This notification is sent if the PSPS is caching data from a preceding job; e.g., the PSPS is caching job 4, and the batch is for job 5. Alternatively, the notification is sent whenever the PSPS is non-operational, or is unable to ingest data from the IPP. The PSPS administrators are responsible for communicating with the IPP administrators to resolve this error.

Subject: IPP-PSPS NOTIFICATION 3.3.4 Batch Refused Error [JOBID/BATCHID]

PSPS was unable to accept job ID JOBID batch BATCHID. Batch BATCHID must be resubmitted. Further information:

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

Reason: [describe by batch refused]

3.3.5 Batch Content Error

A Batch Content Error Notification is sent as a priority email when the contents of a FITS file contained in a batch does not match the contents described in the batch manifest. Upon identifying this error, the PSPS will halt further verification phases for the batch, i.e., the PSPS will not process partially correct batches. The IPP administrators are to correct the discrepancy and retransmit both the batch and the batch manifest.

Subject: IPP-PSPS NOTIFICATION 3.3.5 Batch Content Error [JOBID/BATCHID]

PSPS failed to process job ID JOBID batch BATCHID due to a batch content error. Batch BATCHID must be resubmitted. Further information:

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

Filename: [offending filename in batch]

Line Number: [offending line number, or "N/A"]

Discrepancy: [list offending line here]

Other: [as necessary to describe the error]

3.3.6 Batch Verification Error

A Batch Verification Error Notification is sent as a priority email when the science data from a FITS file contained in a batch fails data verification. For example, this error would be sent for omitted mandatory attributes, out of range attributes, etc. The PSPS performs full verification on every FITS file in the batch, and sends a compilation of the verification errors in one notification. The IPP administrators are to correct all discrepancies and retransmit both the batch and the batch manifest.

Subject: IPP-PSPS NOTIFICATION 3.3.6 Batch Verification Error [JOBID/ BATCHID]

PSPS failed to process job ID JOBID batch BATCHID due to a batch verification error. Batch BATCHID must be resubmitted. Further information:

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

Filename: [offending filename in batch]

psdc-940-006-01

11

Line Number: [offending line number, or "N/A"]

Discrepancy: [describe in detail here -- list object ID, error]

3.3.7 Job Manifest Error

A Job Manifest Error Notification is sent as a priority email when a job manifest identifies batches which have not been received by the PSPS. Alternatively, this notification is sent as a priority email when the PSPS has received batches which are not identified in the job manifest. The PSPS may continue to perform batch verification, but job verification cannot proceed until the job manifest matches the batches received by the PSPS. The IPP and PSPS administrators are to work together to correct the discrepancy and retransmit the job manifest.

Subject: IPP-PSPS NOTIFICATION 3.3.7 Job Manifest Error [JOBID]

PSPS failed to process job ID JOBID due to a job manifest error. Job JOBID must be resubmitted. Further information:

Job ID: JOBID

Reporting Hostname:

Discrepancy: [describe here]

3.3.8 Job Verification Error

A Job Verification Error Notification is sent as a priority email when the science data from a job fails data verification. This notification will be sent when data obtained from different batches is combinationally inconsistent and would cause errors with PSPS correlation or attribute derivation. The PSPS performs full verification across all science data from the job, and sends a compilation of the verification errors in one notification. The IPP and PSPS administrators are to work together to correct the discrepancy/discrepancies. It is important to note that failure to resolve job verification errors within the allotted time frame will delay job publication by at least one cycle.

Subject: IPP-PSPS NOTIFICATION 3.3.8 Job Verification Error [JOBID/BATCHID]

PSPS failed to process job ID JOBID due to a job verification error with batch BATCHID. Job JOBID must be resubmitted. Further information:

Job ID: JOBID

Batch ID: BATCHID

Reporting Hostname:

Filename: [offending filename in batch]

Line Number: [offending line number, or "N/A"]

Discrepancy: [describe in detail here -- list object ID, error]

3.3.9 Job Verification Successful

A Job Verification Successful Notification is sent as an email when the science data from a job is successfully verified by the PSPS. Note that this does not mean that the science data is available for query, since further processing will be required by PSPS. No action is required upon receipt of this email by IPP administrators.

Subject: IPP-PSPS NOTIFICATION 3.3.9: Job Verification Successful [JOBID]

Job JOBID was verified successfully.

Job ID: JOBID

Reporting Hostname:

3.3.10 Job Ingest Failure

A Job Ingest Failure notification is sent as a priority email when the science data from a job is successfully verified, but the PSPS is unable to ingest the job. The IPP and PSPS administrators are to work together to correct identified discrepancy/discrepancies. Note that this failure will likely delay job publication by at least one cycle.

Subject: IPP-PSPS NOTIFICATION 3.3.10 Job Manifest Error [JOBID]

PSPS failed to process job ID JOBID due to a job ingest error. Job JOBID must be resubmitted. Further information:

Job ID: JOBID

Reporting Hostname:

Discrepancy: [describe here]

3.3.11 Job Publication

A Job Publication Notification is sent as an email when the science data from a job is available for query. No action is required upon receipt of this email by IPP administrators.

Subject: IPP-PSPS NOTIFICATION 3.3.11 Job Publication [JOBID]

Job JOBID was published successfully.

Job ID: JOBID

Reporting Hostname:

3.4 Batch Files

Both the IPP and the PSPS are designed to run on Linux platforms. Common Linux utilities, tar and gzip, will be used to group and compress FITS files, respectively, into an archive file. Each archive file is the basis for a "batch" transfer.

Providing batch data in one compressed archive file may result in a very large file which increases the probability of corruption, and can make the file awkward to process. So:

Derived Requirement 3.3.1: The maximum size of a batch file shall not exceed 100 gigabytes ([TBR](#)).

3.4.1 Batch File Naming Convention

Batch files must be uniquely named within a job to facilitate verification of the job manifest. It is also preferable to relate the batch to a job. A batch file must be named using the following case-sensitive naming convention:

JOBID_BATCHID.EXT

Where:

"JOBID" is the literal 'J' followed by a sequence number identifying the job to which the batch belongs; e.g, "J1" for the first job.

"BATCHID" is the literal 'B' followed by a sequence number uniquely identifying the batch, given the context of the JOBID; i.e., the BATCHID is initialized to 1 for every job; and,

"EXT" is the literal "tar.gz".

For example, the first batch file for the first job should have the filename J1_B1.jar.gz

3.5 Manifest Files

Batch and job manifest files are used to support the science data transfer verification requirements of the IRS. Both are simple XML files. The batch manifest file is transmitted jointly with the FITS files within the compressed file that forms the batch. The job manifest file is transmitted as the final batch by the IPP after transmitting all other batches in the job.

3.5.1 Batch Manifest

Batch manifest files shall follow the structure illustrated in this sample dtd file:

```
<!ELEMENT manifest (file+)>
<!-- Manifest attributes.
      type: Type of manifest (job or batch).
      name: Name of batch (or job) (Match filename w/o extension).
      timestamp: Formatted as YYYY-MM-DD@HH:mm:ssZ -->
<!ATTLIST manifest
      type (batch | job) #REQUIRED
      name CDATA #REQUIRED
      timestamp CDATA #REQUIRED
>
<!ELEMENT file EMPTY>
<!-- File attributes: Note that these should reference the file after
it
has
      been extracted from the tar.gz batch file.
      name: Filename of file within batch (relative to the manifest
```

```
location).
    bytes: Size of file
    md5: MD5 checksum of file -->
<!ATTLIST file
    name CDATA #REQUIRED
    bytes CDATA #REQUIRED
    md5 CDATA #REQUIRED
>
```

3.5.1.1 Batch Manifest File Structure

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE manifest SYSTEM "psps-manifest.dtd">
<manifest type="batch" name="IPP1_B1" timestamp="2006-07-
06@08:26:00GMT">
    <file name="P2_F0001_a.fits" bytes="xyz" md5="xxxxxxx"/>
    <file name="P2_F0001_b.fits" bytes="xyz" md5="xxxxxxx"/>
    <file name="P4S_F0001.fits" bytes="xyz" md5="xxxxxxx"/>
    <file name="P4D_F0001.fits" bytes="xyz" md5="xxxxxxx"/>
    <file name="P4Dlow_F0001.fits" bytes="xyz" md5="xxxxxxx"/>
    <file name="ORB.txt" bytes="xyz" md5="xxxxxxx"/>
</manifest>
```

3.5.1.2 Batch Manifest File Naming Convention

Since every batch contains only one batch manifest, and the batch manifest is contained within a compressed file, all batch files have the same case-sensitive filename:

BatchManifest.xml

3.5.2 Job Manifest

3.5.2.1 Job Manifest File Structure

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE manifest SYSTEM "psps-manifest.dtd">
<manifest type="job" name="JobManifest_1" timestamp="2006-07-
06@10:26:00GMT">
    <file name="IPP1_B1.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B2.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B3.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B4.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B5.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B6.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B7.tar.gz" bytes="xyz" md5="xxxxxxx"/>
    <file name="IPP1_B8.tar.gz" bytes="xyz" md5="xxxxxxx"/>
</manifest>
```

Note that the job manifest will be transmitted as the final batch of the job. This means that it will exist within a normal batch file as defined in 3.3 above. The batch manifest for that batch will identify the single job manifest file as the payload for that batch.

3.5.2.2 Job Manifest File Naming Convention

Since the job manifest file is transmitted independently from other files, the filename should indicate the identity of the job. Assuming every job is sequentially numbered, the job manifest shall have the following case-sensitive naming convention:

JobManifest_n.xml

Where:

"JobManifest_" is a literal value;

"n" is a sequence number with a value between the ranges of 1 and **TBD**, inclusive; and,

"xml" is a literal value.

3.6 FITS Files

This section establishes rules for the naming and construction of FITS files containing IPP products to be published to the PSPS. FITS files are organized in partitions named Header Data Units (HDU). A HDU is a unit of 23040 bits (or 36 "Cards" at 80 bytes each = 2880 bytes) comprised of a header or data; the header is metadata that describes the astronomy data. The HDU containing the metadata or header information must be an integer multiple of 2880 bytes. If the header contains fewer than 36 cards, the record is padded (usually with blanks) to produce a length of 2880 bytes. The data records follow those of the header. Similarly, if the last data record is less than 2880 bytes, it is padded to the proper length. A FITS file must contain a primary HDU, and may contain any number of conforming extensions. The primary HDU was originally designed to describe a digital image. Later extensions were added to support description of other astronomy data. Currently, the three standard conforming extensions are used to describe ASCII data in table form, binary data in table form, and additional images.

The IPP operates on a sequence of exposures in a four phase pipelined process, and publishes multiple products to the PSPS at the conclusion of the second and fourth phases. These products include digitized images, objects detected from the images, and metadata such as exposure characteristics and processing information.

The IPP is expected to provide object detections as a binary FITS table, and metadata as either an ASCII or binary table as specified below. Unfortunately, these characterizations are insufficient to describe the published science data to the level of detail needed for ingest by the PSPS. So, the purpose of the remainder of this section is to describe the IPP science data products in terms of FITS file naming, organization, and HDUs with sufficient detail to permit design of the PSPS ingest processes.

3.6.1 Checksums

When the IPP sends a FITS file to the PSPS, the file may become corrupt during transfer. The FITS checksum proposal provides some assurance that a FITS file has not been corrupted. Every HDU in the FITS file will include the CHECKSUM and DATASUM cards (reference Section 3.3.4). The CHECKSUM is an unsigned integer value which forces the 32-bit 1's complement checksum accumulated over the entire FITS HDU to equal negative zero. The DATASUM is an unsigned integer value of the 32-bit 1's complement checksum of all the data records of the HDU. Refer to Appendix A of the FITS Checksum Proposal for implementation information.

3.6.2 Initialization Phase Products

The predefined catalog of objects is expected to be transferred to the PSPS once during the Initialization job prior to the start of the publication cycle. The following products apply only to the IPP catalog of predefined objects. For all other IPP products, please refer to Section 3.6.3.

Predefined Object Catalogs in FITS files consisting of:

- A primary HDU (§ 3.6.6.1)
- An extension with an HDU describing the table of predefined objects provided by the IPP (IPP-PSPS IRS Table 3.1, § 3.6.6.1.1)
- Binary data records of the data described in the table header.

At the PSPS initialization, in addition to the predefined object catalog, the IPP will transfer to the PSPS certain metadata that are required to validate the ingest of the various IPP data products. These metadata may be considered to be “system metadata” in that they reflect quantities or relationships that change slowly with time. The initialization metadata include the description of Sky Cells (IPP-PSPS IRS Table 3.2), the PS1 Camera Configuration description (IPP-PSPS IRS Table 3.3), Photometry Transformation Metadata (IPP-PSPS IRS Table 3.8), Sky Cell Image Version Information (IPP-PSPS IRS Table 3.11), the description of Alternate Fitting Models used in Phase 2 reductions (IPP-PSPS IRS Table 3.12), the List of PS1 Survey Programs (IPP-PSPS IRS Table 3.13), and a table describing the Photo-Z recipes (IPP-PSPS IRS Table 3.14)

These files will include:

A Sky Cell definition consisting of a FITS file (§ 3.6.6.2) with

- A primary HDU
- A FITS extension with an HDU describing the format of the FITS table containing the cell number and a description of its spatial extent (IPP-PSPS Table 3.2).
- A set of binary data records defining the sky cells and their boundaries.

A Camera Configuration definition consisting of a FITS file (§ 3.6.6.3) with

- A primary HDU
- A FITS extension with an HDU describing the format of the data file that maps focal plane local, CCD device number, the associated electronics, and date(s) for which the configuration is valid (IPP-PSPS IRS Table 3.3).
- An ASCII data record set containing the table entries.

The Photometry Transformation Definition consisting of a FITS file (§ 3.6.6.4) containing

- A primary HDU
- A FITS extension with HDU containing the information specified in IPP-PSPS IRS Table 3.8 as a FITS table structure.
- A set of ASCII records with the table entries.

The Alternate Source Fitting Models Description consisting of a FITS file (§ 3.6.6.5) with
psdc-940-006-01

- A primary HDU
- A FITS extension with an HDU defining the FITS table describing the alternate fitting models used on P2 image data when the PSF fit is insufficient to describe a source (IPP-PSPS IRS Table 3.12)
- An ASCII table with the model identifier, description, and parameter definitions

The Survey Program List consisting of a FITS file (§ 3.6.6.6) with

- A primary HDU
- A FITS extension with an HDU defining the table of survey indices and descriptions (IPP-PSPS IRS Table 3.13)
- An ASCII table with the description of each survey.

A Table of Photometric Redshift Recipes containing a FITS file (§ 3.6.6.7) with

- A primary HDU
- A FITS extension with an HDU defining the format of the table of recipes
- An ASCII table with the photometric redshift recipe descriptions

3.6.3 IPP Products

IPP products are expected to be transferred to the PSPS shortly after the products are generated. The IPP will publish to the PSPS both detections of astronomical sources from the PS1 image data as well as updates to the system metadata (e.g., camera configuration information) that provide the scientific provenance of the catalogs generated by the IPP. For the source detections, this suggests a natural grouping of IPP products by exposure. This grouping works for P2, P4 Σ , and P4 Δ exposures, but fails when describing cumulative sky products that are a product of multiple exposures. Instead, the IPP products are grouped by "frame". A frame is defined to contain IPP products describing an area of sky. With this definition, a frame is equivalent to the IPP products generated on an exposure by the P2, P4 Σ , and P4 Δ processes, and can be defined by the IPP for cumulative sky products. With this definition, a FITS file containing catalog information may contain 1 (**TBR**) of the following products:

1) A P2 frame data set consisting of a FITS file containing:

- A primary HDU with the frame descriptor metadata for the P2 exposure (IPP-PSPS IRS Table 3.7, § 3.6.6.8)
- For each detector in the focal plane, a FITS extension consisting of:
 - An HDU of image metadata (§ 3.6.6.9) containing: photometric calibration metadata for the individual CCD sensor (IPP-PSPS IRS Table 3.9)
 - astrometric calibration metadata for the individual CCD sensor (IPP-PSPS IRS Table 3.9)
 - the spatial coverage metadata for the individual CCD sensor (IPP-PSPS IRS Table 3.9)
- A FITS table (§ 3.6.6.10) containing the PSF fits to detections consisting of

- HDU cards describing the source catalog column entries (IPP-PSPS IRS Table 3.4)
- The binary data records of the source catalog of P2 detections (IPP-PSPS IRS Table 3.4)
- A FITS table (§ 3.6.6.11) containing the alternate model fits to detections consisting of
 - HDU cards describing the source catalog column entries (IPP-PSPS IRS Table 3.5)
 - The binary data records of the source catalog of P2 detections (IPP-PSPS IRS Table 3.5)

3) An image stack, or high significance frame FITS detection file consisting of:

- A primary HDU (§ 3.6.6.12) identifying the number of sky cells in the data set.
- For each sky cell in the data set, a FITS extension consisting of
 - An HDU containing the Image Stack/Difference frame metadata (IPP-PSPS IRS Table 3.10, § 3.6.6.13.1)
 - A FITS extension for a table containing:
 - HDU cards describing an ASCII table (§ 3.6.6.13.2) containing the names of the P2 images that contributed to this image combination.
 - The ASCII entries for the table.
 - A FITS extension with a table consisting of PSF fits to the detections with HDU cards describing the source catalog column entries (IPP-PSPS IRS Table 3.4, identical in format to § 3.6.6.10)
 - HDU cards describing the source catalog column entries (IPP-PSPS IRS Table 3.4)
 - The binary data records for the source catalog of Image Stack/Cumulative Sky detections (IPP-PSPS IRS Table 3.4)
 - A FITS extension with a table consisting of fits to extended sources (§ 3.6.6.13.13) in the detections with HDU cards describing the source catalog column entries (IPP-PSPS IRS Tables 3.6)
 - HDU cards describing the source catalog column entries (IPP-PSPS IRS Table 3.6)
 - The binary data records for the source catalog column entries (IPP-PSPS IRS Table 3.6)

4) A difference frame for detections with significance less than 5σ consisting of a FITS file with

- A primary HDU identifying the number of cells covered by the difference image set.
- For each sky cell in this data set, a FITS extension consisting of
 - An HDU containing the difference image metadata (IPP-PSPS IRS Table 3.10)
 - A FITS extension for a table containing:
 - HDU cards describing an ASCII table containing the names of the P2 images that contributed to this image combination.
 - The ASCII entries for the table.
 - A FITS extension for a table containing PSF fits to the detections consisting of
 - HDU cards describing the source catalog entries (IPP-PSPS IRS Table 3.4)

- The binary data records for the source catalog of P4 Δ detections IPP-PSPS IRS Table 3.4)
- A FITS extension for a table listing the P2 files that contributed to this cell.

Note that each difference image exposure will always result in two FITS files: The normal difference frame detection file and the low-significance detection file. Each of these files will be associated with the same difference frame, and will duplicate the metadata for that frame. In the case of the low significance detections, the PSPS will store the entire FITS table as a blob.

The metadata for the difference image detections and image stack data files are identical in format. The difference image data sets will identify in the metadata for each cell the identifier for the sky cell or other image subtracted from the P4 Σ to produce the difference frame.

The IPP shall inform the PSPS of the system configuration information needed to ascertain the scientific provenance of the catalogs it publishes. These metadata shall be provided to the PSPS at the time the system is initialized with the IPP's catalog of initial objects. They will be updated with time as they change as FITS files transmitted as part of a processing job. The update files will have the same format structure as those files used to publish these data at the PSPS initialization phase.

3.6.4 FITS File Naming Convention

FITS files must be uniquely named within a batch to facilitate verification of the batch manifest. Naming the FITS file after a uniquely generated frame identifier has the obvious benefit of permitting verification that the file name matches the frame descriptor metadata, and therefore matches the file contents. In addition, defining a unique frame identifier permits the PSPS to relate detections to their originating frame. Given the design that the frame descriptor metadata includes a unique frame identifier, the FITS file name shall have the following case-sensitive naming convention:

FTYPE_FRAMEID[_ALPHA].EXT

Where:

"FTYPE" is an enumeration for the frame types including the values:

- 'P2' for a P2 frame
- 'P4S' for a P4 Δ frame
- 'P4D' for a P4 Δ frame
- 'P4Dlow' for detections with significance less than 5σ for a P4 Δ frame
- 'IS' for an image stack frame
- 'CS' for a cumulative sky frame
- 'INIT' for initialization predefined object catalog frame

"FRAMEID" is the unique alphanumeric frame identifier;¹

"EXT" is the literal "fits";

'_' is the literal underline character; and,

¹ "FRAMEID" is an arbitrary sequence number for the initialization job.

"ALPHA" is a lowercase alphabetic character (i.e., 'a', 'b', 'c', 'd', etc.) used in alphabetic order when the frame data exceeds the maximum FITS file size and must be provided in multiple files. The brackets indicate this is an optional member of the file name. Alternatively, if everything fit in the file without exceeding the maximum file limit, the file would be named "P2_THISFRAMEID.fits".

Note that the two P4 Δ detection FITS files associated with each P4 Δ image must always be sent in the same batch file, and will use the same FRAMEID in their filenames.

Providing frame data in one FITS file may result in a very large file which increases the probability of corruption, and can make the file awkward to process. So:

Derived Requirement 3.6.3.1: The maximum size of a FITS file shall not exceed 2 gigabytes ([TBR](#)).

The file naming convention for metadata information is essentially identical to that used for the transfer of catalog data. The FITS file name shall have the following case-sensitive naming convention:

FTYPE_FRAMEID[_ALPHA].EXT

Where:

"FTYPE" is an enumeration for the frame types including the values:

- 'SKYCELL' for Sky Cell metadata definitions
- 'CAMERA' for Camera Configuration definitions
- 'PHOTRANS' for Photometry Transformation definitions
- 'SKYIMGVER' for Sky Cell Image versioning information
- 'ALTMOD' for definitions of alternatives to PSF fitting models
- 'SURVEY' definitions of observing survey programs
- 'PHOTOZ' for the description of photometric redshift recipes

"FRAMEID" is the unique alphanumeric frame identifier;

"EXT" is the literal "fits";

'_' is the literal underline character; and,

"ALPHA" is a lowercase alphabetic character (i.e., 'a', 'b', 'c', 'd', etc.) used in alphabetic order when the frame data exceeds the maximum FITS file size and must be provided in multiple files. The brackets indicate this is an optional member of the file name. Alternatively, if everything fit in the file without exceeding the maximum file limit, the file would be named "P2_THISFRAMEID.fits".

3.6.5 FITS Cards

Card usage in a FITS HUD is defined in the FITS Standard (Version 2.1). The glossary of card definitions used to describe the IPP products published to the PSPS is provided in Appendix A.

3.6.6 FITS Header Data Units (HDU)

The header of an HDU defines the structure of the data portion of the FITS file. This section describes the HDUs for each IPP science data product. As previously noted, if the header is shorter than an integer multiple of 2880 bytes, it must be padded to the correct length before the data records start.

The IPP headers will employ four types of FITS HDUs. The primary (i.e. first) HDU of a data file will have SIMPLE = T. The subsequent HDUs will be extensions with XTENSION = 'IMAGE' (for metadata information with no associated data), 'TABLE' (defining ASCII tables), and 'BINTABLE' (defining tables with binary data).

3.6.6.1 Predefined Object Catalog HDU

The predefined objects from the IPP will be transferred in FITS files that require a primary HDU and an extension HDU describing the FITS table. These are illustrated here.

```
SIMPLE = T / FITS STANDARD
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
COMMENT
COMMENT Predefined Objects from IPP for ODM Initialization
COMMENT
CHECKSUM= / Checksum for this header
END
```

3.6.6.1.1 Predefined Objects Table Description

```
XTENSION= 'BINTABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = 192 /
NAXIS2 = NNNNNNNN /
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 46 /
EXTNAME = 'PREDEFINED_OBJECTS' /
COMMENT
COMMENT This file includes objects that have been associated
COMMENT by the IPP and are being used to initialize the PSPS
COMMENT ODM.
COMMENT
TTYPE1 = 'IPP_OBJ_ID' / IPP object identification index
TUNIT1 = ' /
TFORM1 = 'J /
TTYPE2 = 'RA' / RA
TUNIT2 = 'DEGREES' /
TFORM2 = 'D' /
TTYPE3 = 'DEC' / DEC
TUNIT3 = 'DEGREES' /
TFORM3 = 'D' /
TTYPE4 = 'RA_SIG' / Sigma of RA
TUNIT4 = 'ARCSECONDS' /
```

TFORM4	=	'E	' /
TTYPE5	=	'DEC_SIG	' / Sigma of DEC
TUNIT5	=	'ARCSECONDS	' /
TFORM5	=	'E	' /
TTYPE5	=	'FYEAR	' / Fractional year of epoch
TUNIT5	=	'YEARS	' /
TFORM5	=	'E	' /
TTYPE6	=	'MU_RA	' / Mu in RA
TUNIT6	=	'MAS/YR	' /
TFORM6	=	'E	' /
TTYPE7	=	'MU_DEC	' / Mu in DEC
TUNIT7	=	'MAS/YR	' /
TFORM7	=	'E	' /
TTYPE8	=	'MU_RA_ERR	' / error of Mu in RA
TUNIT8	=	'MAS/YR	' /
TFORM8	=	'E	' /
TTYPE9	=	'MU_DEC_ERR	' / error of mu in DEC
TUNIT9	=	'MAS/YR	' /
TFORM9	=	'E	' /
TTYPE10	=	'MU_TOT	' / Total proper motion
TUNIT10	=	'MAS/YR	' /
TFORM10	=	'E	' /
TTYPE11	=	'MU_TOT_ERR	' / Error of total proper motion
TUNIT11	=	'MAS/YR	' /
TFORM11	=	'E	' /
TTYPE12	=	'PAR_FACT_RA	' / Parallax factor in RA
TUNIT12	=	'MAS	' /
TFORM12	=	'E	' /
TTYPE13	=	'PAR_FACT_DEC	' / Parallax factor in DEC
TUNIT13	=	'MAS	' /
TFORM13	=	'E	' /
TTYPE14	=	'PARALLAX_RA	' / Parallax in RA
TUNIT14	=	'MAS	' /
TFORM14	=	'E	' /
TTYPE15	=	'PARALLAX_RA_ERR	' / Error of Parallax in RA
TUNIT15	=	'MAS	' /
TFORM15	=	'E	' /
TTYPE16	=	'PARALLAX_DEC	' / Parallax in DEC
TUNIT16	=	'MAS	' /
TFORM16	=	'E	' /
TTYPE17	=	'PARALLAX_DEC_ERR	' / Error of Parallax in DEC
TUNIT17	=	'MAS	' /
TFORM17	=	'E	' /
TTYPE18	=	'PARALLAX_TOT	' / Total parallax
TUNIT18	=	'MAS	' /
TFORM18	=	'E	' /
TTYPE19	=	'PARALLAX_TOT_ERR	' / Error of Total Parallax
TUNIT19	=	'MAS	' /
TFORM19	=	'E	' /
TTYPE20	=	'PZRA	' / Projected tan(zenith dist) in RA
TUNIT20	=	'	' /
TFORM20	=	'E	' /
TTYPE21	=	'PZDEC	' / Projected tan(zenith dist) in DEC
TUNIT21	=	'	' /
TFORM21	=	'E	' /
TTYPE22	=	'REFRA	' / Amplitude of refractive term in RA
TUNIT22	=	'	' /

```

TFORM22 = 'E' /
TTYPER23 = 'REFRA_ERR' / Error in REFRA
TUNIT23 = ' /
TFORM23 = 'E' /
TTYPER24 = 'REFDEC' / Amplitude of refractive term in DEC
TUNIT24 = ' /
TFORM24 = 'E' /
TTYPER25 = 'REFDEC_ERR' / Error of REFDEC
TUNIT25 = ' /
TFORM25 = 'E' /
TTYPER26 = 'RMS_RA' / RMS of astrometric solution in RA
TUNIT26 = 'MAS' /
TFORM26 = 'E' /
TTYPER27 = 'RMS_DEC' / RMS of astrometric solution in DEC
TUNIT27 = 'MAS' /
TFORM27 = 'E' /
TTYPER28 = 'WIGGLE' / Flag for/ Index of astrometric orbit
TUNIT28 = 'J' /
TFORM28 = 'E' /
TTYPER29 = 'G_MAG' / g magnitude
TUNIT29 = 'MAG' /
TFORM29 = 'E' /
TTYPER30 = 'G_MAG_SIG' / Sigma of g magnitude
TUNIT30 = 'MAG' /
TFORM30 = 'E' /
TTYPER30 = 'G_N_OBS' / Number of g observations
TUNIT30 = ' /
TFORM30 = 'J' /
TTYPER31 = 'R_MAG' / r magnitude
TUNIT31 = 'MAG' /
TFORM31 = 'E' /
TTYPER32 = 'R_MAG_SIG' / Sigma of r magnitude
TUNIT32 = 'MAG' /
TFORM32 = 'E' /
TTYPER33 = 'R_N_OBS' / Number of r observations
TUNIT33 = ' /
TFORM33 = 'J' /
TTYPER34 = 'I_MAG' / i magnitude
TUNIT34 = 'MAG' /
TFORM34 = 'E' /
TTYPER35 = 'I_MAG_SIG' / Sigma of i magnitude
TUNIT35 = 'MAG' /
TFORM35 = 'E' /
TTYPER36 = 'I_N_OBS' / Number of i observations
TUNIT36 = ' /
TFORM36 = 'J' /
TTYPER37 = 'Y_MAG' / y magnitude
TUNIT37 = 'MAG' /
TFORM37 = 'E' /
TTYPER38 = 'Y_MAG_SIG' / Sigma of y magnitude
TUNIT38 = 'MAG' /
TFORM38 = 'E' /
TTYPER39 = 'Y_N_OBS' / Number of y observations
TUNIT39 = ' /
TFORM39 = 'J' /
TTYPER40 = 'Z_MAG' / z magnitude
TUNIT40 = 'MAG' /

```

```

TFORM40 = 'E' /
TTYPE41 = 'Z_MAG_SIG' / Sigma of z magnitude
TUNIT41 = 'MAG' /
TFORM41 = 'E' /
TTYPE42 = 'Z_N_OBS' / Number of z observations
TUNIT42 = ' ' /
TFORM42 = 'J' /
TTYPE43 = 'W_MAG' / w magnitude
TUNIT43 = 'MAG' /
TFORM43 = 'E' /
TTYPE44 = 'W_MAG_SIG' / Sigma of w magnitude
TUNIT44 = 'MAG' /
TFORM45 = 'E' /
TTYPE46 = 'W_N_OBS' / Number of w observations
TUNIT46 = ' ' /
TFORM46 = 'J' /
CHECKSUM= / header checksum
DATASUM = / datafile checksum
END

```

3.6.6.2 Sky Cell Definition Metadata HDU

The following illustrates the primary and table extension HDU for a file that would describe the sky cell definitions.

```

SIMPLE = T / FITS STANDARD
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
COMMENT
COMMENT Sky Cell Definition Metadata
COMMENT
CHECKSUM= / Checksum for this header
END

```

3.6.6.2.1 Table of Defined Sky Cells

```

XTENSION= 'BINTABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = 68 /
NAXIS2 = NNNNNNNN /
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 9 /
EXTNAME = 'SKY_CELL_TABLE' /
COMMENT
COMMENT This file defines the regions on the sky covered by
COMMENT each sky cell used by the IPP. For this sample, it
COMMENT is assumed each cell is a quadralateral defined by
COMMENT 4 vertices on the sky.
COMMENT

```

```

TTYPE1 = 'ID' / Sky cell identifier
TUNIT1 = ' ' /
TFORM1 = 'J' /
TTYPE2 = 'RA1' / RA of 1st cell vertex.
TUNIT2 = 'DEGREES' /
TFORM2 = 'D' /
TTYPE3 = 'DEC1' / DEC of 1st cell vertex.
TUNIT3 = 'DEGREES' /
TFORM3 = 'D' /
TTYPE4 = 'RA2' / RA of 2nd cell vertex.
TUNIT4 = 'DEGREES' /
TFORM4 = 'D' /
TTYPE5 = 'DEC2' / DEC of 2nd cell vertex.
TUNIT5 = 'DEGREES' /
TFORM5 = 'D' /
TTYPE6 = 'RA3' / RA of 3rd cell vertex.
TUNIT6 = 'DEGREES' /
TFORM6 = 'D' /
TTYPE7 = 'DEC3' / DEC of 3rd cell vertex.
TUNIT7 = 'DEGREES' /
TFORM7 = 'D' /
TTYPE8 = 'RA4' / RA of 4th cell vertex.
TUNIT8 = 'DEGREES' /
TFORM8 = 'D' /
TTYPE9 = 'DEC4' / DEC of 4th cell vertex.
TUNIT9 = 'DEGREES' /
TFORM9 = 'D' /
CHECKSUM= / Checksum for this header
DATASUM = / Checksum for table data
END

```

3.6.6.3 Camera Configuration Metadata HDU

The following illustrates the primary and table extension HDU for a file that would describe the camera configuration information.

```

SIMPLE = T / FITS STANDARD
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
CAMERAID= N / Numerical ID for this camera
COMMENT
COMMENT Camera configuration Metadata
COMMENT
CHECKSUM= / Checksum for this header
END

```

3.6.6.3.1 Table of Camera Properties

```

XTENSION= 'TABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = 10 /
NAXIS2 = 2 /

```

```

PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 3 /
EXTNAME = 'CAMERA_CONFIG' /
EXTVER = 1 /
EXTLEVEL= 1 /
COMMENT
COMMENT This table identifies the various camera
COMMENT configurations of the Pan-STARRS system
COMMENT
TBCOL1 = 1 /
TFORM1 = 'I2' /
TTYPE1 = 'CLASSID' / Focal Plane Location ID
TBCOL2 = 3 /
TFORM2 = 'I4' /
TTYPE2 = 'DETECTOR_ID_NUM' / Numerical ID of CCD
TBCOL3 = 7 /
TFORM3 = 'I4' /
TTYPE3 = 'ELECTRONICS_ID_NUM' / Numerical ID of Electronics
CHECKSUM= / Checksum for this header
DATASUM = / Checksum for tabular data
END

```

3.6.6.4 Photometry Transformation Metadata HDU

The following illustrates the primary and table extension HDU for a file that would describe the photometric transformation metadata.

```

SIMPLE = T / FITS STANDARD
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
COMMENT
COMMENT Photometric Calibration Metadata
COMMENT
CHECKSUM= / Checksum for this header
END

```

3.6.6.4.1 Table of Photometric Transformations

```

XTENSION= 'TABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = 66 /
NAXIS2 = NNNN /
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 9 /
EXTNAME = 'PHOTOMETRIC CALIB' /
EXTVER = 1 /
EXTLEVEL= 1 /
COMMENT
COMMENT This table identifies the photometric calibration
COMMENT information used to convert instrumental to

```

```

COMMENT    calibrated magnitudes
COMMENT
TBCOL1    =                1 /
TFORM1    = 'A20            ' /
TTYPER1    = 'PHOTOCODE_NAME' / Unique photometry reduction ID
TBCOL2    =                21 /
TFORM2    = 'I5             ' /
TTYPER2    = 'PHOTOCODE_ID  ' / Numerical code for this name
TBCOL3    =                26 /
TFORM3    = 'F7.4           ' /
TTYPER3    = 'NOMINAL_ZERO_PT' / Nominal zero point
TBCOL4    =                33 /
TFORM4    = 'F7.4           ' /
TTYPER4    = 'COLOR_TERM    ' / Color term
TBCOL5    =                40 /
TFORM5    = 'F7.2           ' /
TTYPER5    = 'COLORXAIRMASS_TERM' / Color dependent extinction term
TBCOL6    =                47 /
TFORM6    = 'I2             ' /
TTYPER6    = 'PHOTCODE_COLOR_1' / Photometry code for Color 1
TBCOL7    =                49 /
TFORM7    = 'I2             ' /
TTYPER7    = 'PHOTCODE_COLOR_2' / Photometry code for Color 2
TBCOL8    =                51 /
TFORM8    = 'A8             ' /
TTYPER8    = 'START_DATE    ' / Starting date for this transformation
TBCOL9    =                59 /
TFORM8    = 'A8             ' /
TTYPER8    = 'END_DATE      ' / Ending date for this transformation
CHECKSUM=                / Checksum for this header
DATASUM =                / Checksum for table data
END

```

3.6.6.5 Alternate Source Fitting Models HDU

The following illustrates the primary and table extension HDU for a file that would describe the definitions of alternate fitting models.

```

SIMPLE    =                T / FITS STANDARD
BITPIX    =                8 / FITS BITS/PIXEL
NAXIS     =                0 / NUMBER OF AXES
EXTEND    =                T /
DATE      = 'DD/MM/YY'      / Date file created
COMMENT
COMMENT    Metadata describing alternate fit methods
COMMENT
CHECKSUM=                / Checksum for this header
END

```

3.6.6.5.1 Table of Alternate Source Models Definitions

```

XTENSION= 'TABLE          ' /
BITPIX   =                8 /
NAXIS    =                2 /

```

```

NAXIS1 = 122 /
NAXIS2 = NN /
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 7 /
EXTNAME = 'ALT_PSF_METHODS' /
EXTVER = 1 /
EXTLEVEL= 1 /
COMMENT
COMMENT This table identifies the alternative fits to simple
COMMENT PSF fitting used for P2, P4S, and P4D data
COMMENT
TBCOL1 = 1 /
TFORM1 = 'I2' /
TTYPER1 = 'METHOD_ID' / Method number
TBCOL2 = 3 /
TFORM2 = '20A' /
TTYPER2 = 'METHOD_NAME' / Method name
TBCOL3 = 23 /
TFORM3 = '20A' /
TTYPER3 = 'PARAM_1_DESCRIPTION' / Parameter 1 description
TBCOL4 = 43 /
TFORM4 = '20A' /
TTYPER4 = 'PARAM_2_DESCRIPTION' / Parameter 2 description
TBCOL5 = 63 /
TFORM5 = '20A' /
TTYPER5 = 'PARAM_3_DESCRIPTION' / Parameter 3 description
TBCOL6 = 83 /
TFORM6 = '20A' /
TTYPER6 = 'PARAM_4_DESCRIPTION' / Parameter 4 description
TBCOL7 = 103 /
TFORM7 = '20A' /
TTYPER7 = 'PARAM_5_DESCRIPTION' / Parameter 5 description
CHECKSUM= / Checksum for this header
DATASUM = / Checksum for table data
END

```

3.6.6.6 Survey Program Metadata HDU

The following illustrates the primary and table extension HDU for a file that would describe the PS1 observing programs.

```

SIMPLE = T / FITS STANDARD
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
COMMENT
COMMENT Pan-STARRS Survey Definition Metadata
COMMENT
CHECKSUM= / Checksum for this header
END

```

3.6.6.6.1 Table of Survey Programs

```

XTENSION= 'TABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = 80 /
NAXIS2 = 3 /
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 2 /
EXTNAME = 'SURVEY_PROGRAMS' /
EXTVER = 1 /
EXTLEVEL= 1 /
COMMENT
COMMENT This table identifies the various surveys
COMMENT conducted with the Pan-STARRS system
COMMENT
TBCOL1 = 1 /
TFORM1 = 'I2' /
TTYPE1 = 'SURVEY_ID' / Recipe number
TBCOL2 = 3 /
TFORM2 = '78A' /
TTYPE2 = 'SURVEY_DESCRIPTION' / Recipe name/description
CHECKSUM= / Checksum for this header
DATASUM = / Checksum for tabular data
END

```

3.6.6.7 Photo-Z Recipe Metadata HDU

The following illustrates the primary and table extension HDU for a file that would describe the recipes used to compute photometric redshifts.

```

SIMPLE = T / FITS STANDARD
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
COMMENT
COMMENT Photometric Redshift Definition Metadata
COMMENT
CHECKSUM= / Checksum for this header
END

```

3.6.6.7.1 Table of Photo-Z definitions

```

XTENSION= 'TABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = 80 /
NAXIS2 = 3 /
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 2 /
EXTNAME = 'PHOTO_Z_RECIPES' /
EXTVER = 1 /
EXTLEVEL= 1 /
COMMENT

```

```

COMMENT  This table identifies the recipes used in the PSPS
COMMENT  to compute photometric redshifts
COMMENT
TBCOL1   =                1 /
TFORM1   = 'I2             ' /
TTYPER1   = 'RECIPE_ID     ' / Recipe number
TBCOL2   =                3 /
TFORM2   = '78A            ' /
TTYPER2   = 'RECIPE_DESCRIPTION' / Recipe name/description
CHECKSUM=                    / Checksum for this header
DATASUM  =                    / Checksum for table data
END

```

3.6.6.8 P2 Frame Descriptor HDU

The detections for each P2 observation will contain a primary HDU that describes the metadata for the entire FITS file. The following is an example of such a primary HDU

```

SIMPLE   =                T / FITS STANDARD
BITPIX   =                0 / FITS BITS/PIXEL
NAXIS    =                0 / NUMBER OF AXES
EXTEND   =                T /
DATE     = 'DD/MM/YY'      / Date file created
COMMENT
COMMENT  P2 Frame Metadata HDU
COMMENT
EXTNAME  = 'P2 FRAME METADATA ' /
TELESCOP= 'PS1             ' / Telescope name
TELNUM   =                1 / Telescope number
CAMERA   = 'GPC1           ' / Camera name
CAMERAID=                1 / Camera number
SURVEY   =                N / Survey number
EXP_ID   =                N / Exposure identifier
ANALVER  =                XXX / Analysis version number
P1RECIP  =                YYY / Phase 1 recipe
P2RECIP  =                ZZZ / Phase 2 recipe
P3RECIP  =                AAA / Phase 3 recipe
NFILES   =                60 / Number of associated CCD files
CERROR   =                xxx.yyy / Scatter in astrometry solution (MAS)
PHOT_CS  =                aa.bbbb / Scatter in photometric solution (mag)
MJDATE   =                XXXXX.YYYYYYY / MJD at start of exposure
EXPTIME  =                TTT.SS / Exposure time (seconds)
FILTER   = 'r.12345        ' / Filter identification string
FILTERID=                2 / Filter holder position
AIRMASS  =                xx.yyy / Airmass at start of exposure
RA       =                aaa.bbbbbb / Telescope boresight in RA (degrees)
DEC      =                ccc.ddddd / Telescope boresight in DEC (degrees)
CHECKSUM=                    / Checksum for this header]
END

```

3.6.6.9 P2 Image Metadata

Each P2 data file will have a separate extension to describe the metadata for each of the CCDs in the PS1 camera. The following is an example of such a header.

```

XTENSION= 'IMAGE' /
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
COMMENT
COMMENT Combination (P4S, P4D, Image Stack/ Cumulative Sky) Image
COMMENT Metadata HDU
COMMENT
EXTNAME = 'P2 IMAGE METADATA '
EXP_ID = / Exposure ID
CLASSID = / Class ID = focal plane location
DETECTID= / Numerical ID of detector
NX = CCCC / Number of columns on the detector
NY = RRRR / Number of rows on the detector
COMMENT
COMMENT Astrometric Solution (up to linear terms)
COMMENT
NASTRO = NNNN / Number of astrometry stars
CERROR = XXX.YYY / Scatter in astrometry solution (MAS)
CTYPE1 = 'RA--TAN' / WCS Coordinate type
CTYPE2 = 'DEC--TAN' / WCS Coordinate type
CRVAL1 = 321.30941666667 / WCS Ref value (RA in decimal degrees)
CRVAL2 = -5.1685277777778 / WCS Ref value (DEC in decimal degrees)
CRPIX1 = -1051.17692913657 / WCS Coordinate reference pixel
CRPIX2 = 2033.40939404705 / WCS Coordinate reference pixel
CD1_1 = 1.13378419402790E-4 / WCS Coordinate scale matrix
CD1_2 = 8.93919113249280E-8 / WCS Coordinate scale matrix
CD2_1 = -5.4105516940550E-7 / WCS Coordinate scale matrix
CD2_2 = -1.1365323690945E-4 / WCS Coordinate scale matrix
COMMENT
COMMENT Higher order terms in astrometric solution
COMMENT
POLYORD = 3 / Polynomial Order
PCA1X3Y0= / WCS, Axis 1, coefficient of X^3
PCA1X2Y1= / WCS, Axis 1, coefficient of X^2 * Y
PCA1X1Y2= / WCS, Axis 1, coefficient of X * Y^2
PCA1X0Y3= / WCS, Axis 1, coefficient of Y^3
PCA1X2Y0= / WCS, Axis 1, coefficient of X^2
PCA1X1Y1= / WCS, Axis 1, coefficient of X * Y
PCA1X0Y2= / WCS, Axis 1, coefficient of Y^2
PCA1X3Y0= / WCS, Axis 2, coefficient of X^3
PCA1X2Y1= / WCS, Axis 2, coefficient of X^2 * Y
PCA1X1Y2= / WCS, Axis 2, coefficient of X * Y^2
PCA1X0Y3= / WCS, Axis 2, coefficient of Y^3
PCA1X2Y0= / WCS, Axis 2, coefficient of X^2
PCA1X1Y1= / WCS, Axis 2, coefficient of X * Y
PCA1X0Y2= / WCS, Axis 2, coefficient of Y^2
COMMENT
COMMENT PSF Description Parameters
COMMENT
PSFMODE = / PSF Model number
PSFFWHM = / PSF Full width Half Max (pixels)
PSFWMAJ = / PSF Width on major axis (pixels)
PSFWMIN = / PSF Width on minor axis (pixels)
PSFTHETA= / PSF Orientation angle (degrees)
PSF_EX1 = / PSF Extra parameter #1

```

```

PSF_EX2 =                / PSF Extra parameter #2
COMMENT
COMMENT Photometry Calibration information
COMMENT
COMMENT Formula for Photometry, based on keywords given in this
header:
COMMENT m = -2.5*log(DN) + 2.5*log(EXPTIME)
COMMENT M = m + PHOT_C + PHOT_K*(AIRMASS - 1) + PHOT_X*(PHOT_C1 -
PHOT_C2)
COMMENT
PHOTOCID=                / Numerical code for reduction code
PHOT_C =                25.7150 / zero point - measured for camera run
PHOT_CS =                0.0048 / zero point - scatter
PHOT_NS =                19 / zero point - N stars

PHOT_C0 =                25.7430 / zero point - nominal
PHOT_X =                0.0830 / zero point - color term
PHOT_K =               -0.0400 / zero point - airmass term
PHOT_C1 = 'i_SDSS        ' / zero point - color 1
PHOT_C2 = 'r_SDSS        ' / zero point - color 2
COMMENT
COMMENT Some statistics on this image
COMMENT
NDETECT =                / Number of detections
MAGSAT =                / Magnitude at which sources saturate
MAGCOMP =                / Magnitude where frame is 95% complete
SKYVAL =                / Median sky value on detector
SKYVAR =                / Variance of sky values
BIASVAL =                / Mean bias level of frame
BIASVAR =                / Variance of bias values
COMMENT
COMMENT Images used to process this exposure
COMMENT
DETREND1= '              ' /
DETREND2= '              ' /
DETREND3= '              ' /
DETREND4= '              ' /
DETREND5= '              ' /
DETREND6= '              ' /
DETREND7= '              ' /
DETREND8= '              ' /
COMMENT
COMMENT Quality Assurance Flags from IPP
COMMENT
QAFLAGS = '              ' / IP QA flags
CHECKSUM=                / Checksum for this header
END

```

3.6.6.9.1 Image Bitmap Mask

```

XTENSION= 'IMAGE'
BITPIX =                8 / 8 bit-byte pixels
NAXIS =                2 / 2-dimensional image
NAXIS1 =               4800 / x dimension
NAXIS2 =               4800 / y dimension

```

```

EXTNAME = 'BAD PIXEL MASK      '
COMMENT
COMMENT  OTA/Image cell mask. One 8 bit-byte per pixel in the image.
COMMENT  If the pixel byte != 0 then it is masked for some reason.
COMMENT
DATE-OBS= '15/05/1995'          / local date of observation [DD/MM/YYYY]
CHECKSUM=                        / mask checksum
DATASUM =                       / checksum for mask image
END

```

3.6.6.10 PSF Fit Detection Catalog HDU

The detections derived from PSF fitting are transmitted as binary FITS table extensions. This header format is used for both P2 and combination image PSF fitting. The following illustrates the header for such a table.

```

XTENSION= 'BINTABLE           ' /
BITPIX   =                      8 /
NAXIS    =                      2 /
NAXIS1   =          NNNNNNNNNN / Number of objects in the table
NAXIS2   =          112 / Number of bytes per row
PCOUNT   =                      0 /
GCOUNT   =                      1 /
TFIELDS  =          26 /
EXTNAME  = 'PSF_FIT_PARAMS    ' /
COMMENT
COMMENT  This HDU applies to all detections that have been analyzed
COMMENT  with the IPP PSF fitting procedure. Note that the IPP_IDET
COMMENT  must be unique within a file so as to allow matching up
COMMENT  sources between the PSF matching and either the alternative
COMMENT  PSF fits for P2, P4S, and P4D detections or the extended
COMMENT  source fits to the Image Stack/Cumulative Sky detections.
COMMENT
TTYPE1   = 'IPP_DET_ID        ' / IPP detection identifier
TUNIT1   = '                  ' /
TFORM1   = 'J                 ' /
TTYPE2   = 'IPP_OBJ_ID        ' / IPP object identifier
TUNIT2   = '                  ' /
TFORM2   = 'J                 ' /
TTYPE3   = 'X_PSF              ' / PSF x coordinate
TUNIT3   = 'PIXELS             ' /
TFORM3   = 'E                 ' /
TTYPE4   = 'Y_PSF              ' / PSF y coordinate
TUNIT4   = 'PIXELS             ' /
TFORM4   = 'E                 ' /
TTYPE5   = 'X_PSF_SIG          ' / Sigma in PSF x coordinate
TUNIT5   = 'PIXELS             ' /
TFORM5   = 'E                 ' /
TTYPE6   = 'Y_PSF_SIG          ' / Sigma in PSF y coordinate
TUNIT6   = 'PIXELS             ' /
TFORM6   = 'E                 ' /
TTYPE7   = 'RA_PSF             ' / RA from PSF fit
TUNIT7   = 'DECIMAL DEGREES    ' /
TFORM7   = 'D                 ' /
TTYPE8   = 'DEC_PSF            ' / DEC from PSF fit
TUNIT8   = 'DECIMAL DEGREES    ' /

```

```

TFORM8  = 'D' /
TTYPER9 = 'RA_PSF_SIG' / Sigma of PSF fit RA
TUNIT9  = 'ARCSECONDS' /
TFORM9  = 'E' /
TTYPER10 = 'DEC_PSF_SIG' / Sigma of PSF fit DEC
TUNIT10 = 'ARCSECONDS' /
TFORM10 = 'E' /
TTYPER11 = 'PSF_INST_MAG' / PSF fit instrumental magnitude
TUNIT11 = 'MAG' /
TFORM11 = 'E' /
TTYPER12 = 'PSF_INST_MAG_SIG' / Sigma of PSF instrumental magnitude
TUNIT12 = 'MAG' /
TFORM12 = 'E' /
TTYPER13 = 'PEAK_FLUX_AS_MAG' / Peak flux expressed as magnitude
TUNIT13 = 'MAG' /
TFORM13 = 'E' /
TTYPER14 = 'SKY' / Sky level
TUNIT14 = 'ADU' /
TFORM14 = 'E' /
TTYPER15 = 'SKY_SIGMA' / Sigma of sky level
TUNIT15 = 'ADU' /
TFORM15 = 'E' /
TTYPER16 = 'STAR_GALAXY_SEP' / Star-Galaxy separator
TUNIT16 = ' ' /
TFORM16 = 'E' /
TTYPER17 = 'PSF_WIDTH_MAJOR' / PSF width on major axis
TUNIT17 = 'ARCSECONDS' /
TFORM17 = 'E' /
TTYPER18 = 'PSF_WIDTH_MINOR' / PSF width on minor axis
TUNIT18 = 'ARCSECONDS' /
TFORM18 = 'E' /
TTYPER19 = 'PSF_THETA' / PSF orientation angle
TUNIT19 = 'DEGREES' /
TFORM19 = 'E' /
TTYPER20 = 'PSF_LF' / PSF likelihood factor
TUNIT20 = ' ' /
TFORM20 = 'E' /
TTYPER21 = 'PSF_CF' / PSF coverage factor
TUNIT21 = ' ' /
TFORM21 = 'E' /
TTYPER22 = 'CAL_PSF_MAG' / Calibrated magnitude
TUNIT22 = 'MAG' /
TFORM22 = 'E' /
TTYPER23 = 'CAL_PSF_MAG_SIG' / Sigma of calibrated magnitude
TUNIT23 = 'MAG' /
TFORM23 = 'E' /
TTYPER24 = 'CAL_STD_COLOR' / Color used in calibration
TUNIT24 = 'MAG' /
TFORM24 = 'E' /
TTYPER25 = 'FUNNY_FLAG' / Funny source flag
TUNIT25 = ' ' /
TFORM25 = 'I' /
TTYPER26 = 'N_FRAMES' / Number of frames overlapping source
TUNIT26 = ' ' /
TFORM26 = 'I' /
CHECKSUM= / Header checksum
DATASUM = / Data section checksum

```

END

3.6.6.11 Alternate Model Fit Detection Catalog HDU

When the IPP transfers descriptions of detections based upon an alternate model fit, the following header illustrates the contents of such a FITS binary table.

```
XTENSION= 'BINTABLE' /
BITPIX = 8 /
NAXIS = 2 /
NAXIS1 = NNNNNNNNNN / Number of objects in the table
NAXIS2 = 118 / Number of bytes per row
PCOUNT = 0 /
GCOUNT = 1 /
TFIELDS = 27 /
EXTNAME = 'ALT_FIT_PARAMS' /
COMMENT
COMMENT This HDU applies to all detections that have been analyzed
COMMENT with the IPP alternative PSF fitting procedure.
COMMENT Note that the IPP_IDET must be unique within a file so as
COMMENT to allow matching up sources between the PSF matching and
COMMENT either the alternative PSF fits for P2, P4S, and P4D
COMMENT detections or the extended source fits to the
COMMENT Image Stack/Cumulative Sky detections.
COMMENT
TTYPE1 = 'IPP_IDET' / IPP detection identifier index
TUNIT1 = ' ' /
TFORM1 = 'J' /
TTYPE2 = 'ALT_MODEL_ID' / Alternate ALT fit model index
TUNIT2 = ' ' /
TFORM2 = 'I' /
TTYPE6 = 'RA_ALT' / RA from ALT fit
TUNIT6 = 'DECIMAL DEGREES' /
TFORM6 = 'D' /
TTYPE7 = 'DEC_ALT' / DEC from ALT fit
TUNIT7 = 'DECIMAL DEGREES' /
TFORM7 = 'D' /
TTYPE8 = 'RA_ALT_SIG' / Sigma of ALT fit RA
TUNIT8 = 'ARCSECONDS' /
TFORM8 = 'E' /
TTYPE9 = 'DEC_ALT_SIG' / Sigma of ALT fit DEC
TUNIT9 = 'ARCSECONDS' /
TFORM9 = 'E' /
TTYPE20 = 'ALT_QF' / ALT coverage/quality factor
TUNIT20 = ' ' /
TFORM20 = 'E' /
TTYPE21 = 'CAL_ALT_MAG' / Calibrated ALT magnitude
TUNIT21 = 'MAG' /
TFORM21 = 'E' /
TTYPE23 = 'ALT_PARM_1' / ALT model parameter 1
TUNIT23 = ' ' /
TFORM23 = 'E' /
TTYPE24 = 'ALT_PARM_2' / ALT model parameter 2
TUNIT24 = ' ' /
TFORM24 = 'E' /
```

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```

TTYTYPE25 = 'ALT_PARM_3      ' / ALT model parameter 3
TUNIT25 = '                  ' /
TFORM25 = 'E                ' /
TTYTYPE26 = 'ALT_PARM_4      ' / ALT model parameter 4
TUNIT26 = '                  ' /
TFORM26 = 'E                ' /
TTYTYPE27 = 'ALT_PARM_5      ' / ALT model parameter 5
TUNIT27 = '                  ' /
TFORM27 = 'E                ' /
CHECKSUM= / Header checksum
DATASUM = / Data section checksum
END

```

3.6.6.12 Combination Image Metadata HDU

The following format is used for the P4 Σ , P4 Δ , and image stack detection catalogs. In the following, in the top level HDU, NCELLS indicates how many cells are being reported in the file. SKYCELL is the index of the sky cell for which a particular set of detections have been measured. The REFID parameter designates the identifier for a particular reference set of measurements (e.g., a cumulative sky image) for that cell upon which the analysis of astrometry and photometry in that cell in a given filter is based. STACKID is the identifier for the processed results being reported in this particular set of data. If the detections are of the P4 Δ variety, SUBTRID is the identifier of the image which is subtracted from STACKID to produce the difference image for which the detections are being reported. In the case of P4 Σ or image stacks, the SUBTRID should be set to a blank string (indicating no image was subtracted).

Following the calibration metadata, an extension with a FITS table listing the P2 images that contributed to these data is present.

```

SIMPLE = T /
BITPIX = 8 / FITS BITS/PIXEL
NAXIS = 0 / NUMBER OF AXES
EXTEND = T /
DATE = 'DD/MM/YY' / Date file created
NCELLS = NNN / Number of sky cell extensions
CHECKSUM= / Checksum for this header
END

XTENSION= 'IMAGE' /
BITPIX = 8 /
NAXIS = 0 /
COMMENT
COMMENT Calibration information for this sky cell
COMMENT
EXTNAME = 'STACK IMAGE METADATA'
SKYCELL = / Sky Cell ID number
REFID = / Reference Sky Cell ID number
SUBTRID = / ID of Sky Cell Image subtracted
FILTER = / Filter
STACKID = / ID for this image stack
NP2IMGS = / Number of P2 images contributing
ANALVER = / Software Analysis Version
COMMENT
COMMENT Astrometric Solution (up to linear terms)

```

```

COMMENT
NASTRO  =          NNNN / Number of astrometry stars
CERROR  =          XXX.YYY / Scatter in astrometry solution (MAS)
CTYPE1  = 'RA---TAN' / WCS Coordinate type
CTYPE2  = 'DEC--TAN' / WCS Coordinate type
CRVAL1  =      321.30941666667 / WCS Ref value (RA in decimal degrees)
CRVAL2  =     -5.1685277777778 / WCS Ref value (DEC in decimal degrees)
CRPIX1  =    -1051.17692913657 / WCS Coordinate reference pixel
CRPIX2  =     2033.40939404705 / WCS Coordinate reference pixel
CD1_1   =    1.13378419402790E-4 / WCS Coordinate scale matrix
CD1_2   =    8.93919113249280E-8 / WCS Coordinate scale matrix
CD2_1   =   -5.4105516940550E-7 / WCS Coordinate scale matrix
CD2_2   =   -1.1365323690945E-4 / WCS Coordinate scale matrix
COMMENT
COMMENT  Higher order terms in astrometric solution
COMMENT
POLYORD  =          3 / Polynomial Order
PCA1X3Y0=          / WCS, Axis 1, coefficient of X^3
PCA1X2Y1=          / WCS, Axis 1, coefficient of X^2 * Y
PCA1X1Y2=          / WCS, Axis 1, coefficient of X * Y^2
PCA1X0Y3=          / WCS, Axis 1, coefficient of Y^3
PCA1X2Y0=          / WCS, Axis 1, coefficient of X^2
PCA1X1Y1=          / WCS, Axis 1, coefficient of X * Y
PCA1X0Y2=          / WCS, Axis 1, coefficient of Y^2
PCA1X3Y0=          / WCS, Axis 2, coefficient of X^3
PCA1X2Y1=          / WCS, Axis 2, coefficient of X^2 * Y
PCA1X1Y2=          / WCS, Axis 2, coefficient of X * Y^2
PCA1X0Y3=          / WCS, Axis 2, coefficient of Y^3
PCA1X2Y0=          / WCS, Axis 2, coefficient of X^2
PCA1X1Y1=          / WCS, Axis 2, coefficient of X * Y
PCA1X0Y2=          / WCS, Axis 2, coefficient of Y^2
COMMENT
COMMENT  PSF Description Parameters
COMMENT
PSFMODE  =          / PSF Model number
PSFFWHM  =          / PSF Full width Half Max (pixels)
PSFWMJ  =          / PSF Width on major axis (pixels)
PSFWMIN  =          / PSF Width on minor axis (pixels)
PSFTHETA=          / PSF Orientation angle (degrees)
PSF_EX1  =          / PSF Extra parameter #1
PSF_EX2  =          / PSF Extra parameter #2
COMMENT
COMMENT  Photometry Calibration information
COMMENT
COMMENT  Formula for Photometry, based on keywords given in this
header:
COMMENT  m = -2.5*log(DN) + 2.5*log(EXPTIME)
COMMENT  M = m + PHOT_C + PHOT_K*(AIRMASS - 1) + PHOT_X*(PHOT_C1 -
PHOT_C2)
COMMENT
PHOTOCID=          / Numerical code for reduction code
PHOT_C   =      25.7150 / zero point - measured for camera run
PHOT_CS  =       0.0048 / zero point - scatter
PHOT_NS  =       19 / zero point - N stars
PHOT_C0  =      25.7430 / zero point - nominal
PHOT_X   =       0.0830 / zero point - color term
PHOT_K   =      -0.0400 / zero point - airmass term

```

```

PHOT_C1 = 'i_SDSS          ' / zero point - color 1
PHOT_C2 = 'r_SDSS          ' / zero point - color 2
COMMENT
COMMENT  Some statistics on this image
COMMENT
NDETECT =                   / Number of detections
MAGSAT  =                   / Magnitude at which sources saturate
MAGCOMP =                   / Magnitude for which frame is 95%
complete
SKYVAL  =                   / Median sky value on detector
SKYVAR  =                   / Variance of sky values
BIASVAL =                   / Mean bias level of frame
BIASVAR =                   / Variance of bias values
COMMENT
COMMENT  P2 images used to generate this image stack
COMMENT
COMMENT
COMMENT  Quality Assurance Flags from IPP
COMMENT
QAFLAGS = '                  ' / IP QA flags
CHECKSUM=                   / header checksum
END

XTESNION= 'TABLE            '
BITPIX  =                   8 /
NAXIS   =                   2 /
NAXIS1  =                   20 /
NAXIS2  =                   NNN / Number of P2 Images (= NP2IMGS)
PCOUNT  =                   0 /
GCOUNT  =                   1 /
TFIELDS =                   1 /
EXTNAME = 'P2-FRAMES-USED   ' /
EXTVER  =                   1 /
EXTLEVEL=                   1 /
COMMENT
COMMENT  This table identifies the various P2
COMMENT  frames that contributed to this processed image
COMMENT
TBCOL1  =                   1 /
TFORM1  = 'A20              ' /
TTYPE1  = 'P2 NAME          ' /
CHECKSUM=                   / Checksum for this header
DATASUM =                   / Checksum for tabular data
END

```

3.6.6.13 Extended Source Fit Detection Catalog HDU

Detections in the cumulative sky (or image stacks) describing extended sources are sent from the IPP in a binary FITS table extension. The following illustrates the header for such a table.

```

XTENSION= 'BINTABLE        ' /
BITPIX  =                   8 /
NAXIS   =                   2 /
NAXIS1  =                   NNNNNNNNNN / Number of objects in the table
NAXIS2  =                   448 / Number of bytes per row

```

```

PCOUNT   =                               0 /
GCOUNT   =                               1 /
TFIELDS  =                             112 /
EXTNAME  = 'EXTENDED_SRC_PARMS' /
COMMENT
COMMENT   This HDU applies to all detections that have been analyzed
COMMENT   with the IPP extended source fitting procedure.
COMMENT   Note that the IPP_IDET must be unique within a file so as
COMMENT   to allow matching up sources between the PSF matching and
COMMENT   either the alternative PSF fits for P2, P4S, and P4D
COMMENT   detections or the extended source fits to the
COMMENT   Image Stack/Cumulative Sky detections.
COMMENT
TTYPE1   = 'IPP_IDET'                    ' / IPP detection identifier index
TUNIT1   = '                             ' /
TFORM1   = 'J                           ' /
TTYPE2   = 'PET_R'                       ' / Petrosian radius
TUNIT2   = 'ARCSECONDS'                  ' /
TFORM2   = 'E                           ' /
TTYPE3   = 'PET_MAG'                     ' / Petrosian magnitude
TUNIT3   = 'MAG'                         ' /
TFORM3   = 'E                           ' /
TTYPE4   = 'PET_R50'                     ' / Petrosian radius for 50% light
TUNIT4   = 'ARCSECONDS'                  ' /
TFORM4   = 'E                           ' /
TTYPE4   = 'PET_R90'                     ' / Petrosian radius for 90% light
TUNIT4   = 'ARCSECONDS'                  ' /
TFORM4   = 'E                           ' /
TTYPE6   = 'RA_PET'                      ' / RA from Petrosian fit
TUNIT6   = 'DECIMAL DEGREES'             ' /
TFORM6   = 'D                           ' /
TTYPE7   = 'DEC_PET'                     ' / DEC from Petrosian fit
TUNIT7   = 'DECIMAL DEGREES'             ' /
TFORM7   = 'D                           ' /
TTYPE8   = 'RA_PET_SIG'                  ' / Sigma of Petrosian fit RA
TUNIT8   = 'ARCSECONDS'                  ' /
TFORM8   = 'E                           ' /
TTYPE9   = 'DEC_PET_SIG'                 ' / Sigma of Petrosian fit DEC
TUNIT9   = 'ARCSECONDS'                  ' /
TFORM9   = 'E                           ' /
TTYPE10  = 'PET_QF'                      ' / Petrosian coverage/quality factor
TUNIT10  = '                             ' /
TFORM10  = 'E                           ' /
TTYPE11  = 'DEV_R'                       ' / deVaucouleurs radius
TUNIT11  = 'ARCSECONDS'                  ' /
TFORM11  = 'E                           ' /
TTYPE12  = 'MAG_DEV'                     ' / deVaucouleurs magnitude
TUNIT12  = 'MAG'                         ' /
TFORM12  = 'E                           ' /
TTYPE13  = 'MAG_DEV_SIG'                 ' / Sigma of deVaucouleurs magnitude
TUNIT13  = 'MAG'                         ' /
TFORM13  = 'E                           ' /
TTYPE14  = 'DEV_AB'                      ' / deVaucouleurs axis ratio
TUNIT14  = '                             ' /
TFORM14  = 'E                           ' /
TTYPE15  = 'DEV_PHI'                     ' / deVaucouleurs orientation angle
TUNIT15  = 'DEGREES'                    ' /

```

```

TFORM15 = 'E' /
TTYPER16 = 'RA_DEV' / RA from deVaucouleurs fit
TUNIT16 = 'DECIMAL DEGREES' /
TFORM16 = 'D' /
TTYPER17 = 'DEC_DEV' / DEC from deVaucouleurs fit
TUNIT17 = 'DECIMAL DEGREES' /
TFORM17 = 'D' /
TTYPER18 = 'RA_DEV_SIG' / Sigma of deVaucouleurs fit RA
TUNIT18 = 'ARCSECONDS' /
TFORM18 = 'E' /
TTYPER19 = 'DEC_DEV_SIG' / Sigma of deVaucouleurs fit DEC
TUNIT19 = 'ARCSECONDS' /
TFORM19 = 'E' /
TTYPER20 = 'DEV_QF' / deVaucouleurs coverage/quality factor
TUNIT20 = ' ' /
TFORM20 = 'E' /
TTYPER21 = 'EXP_R' / Exponential fit model radius
TUNIT21 = 'ARCSECONDS' /
TFORM21 = 'E' /
TTYPER22 = 'MAG_EXP' / Exponential fit model magnitude
TUNIT22 = 'MAG' /
TFORM22 = 'E' /
TTYPER23 = 'MAG__EXP_SIG' / Sigma of Exponential fit model
magnitude
TUNIT23 = 'MAG' /
TFORM23 = 'E' /
TTYPER24 = 'EXP_AB' / Exponential fit model axis ratio
TUNIT24 = ' ' /
TFORM24 = 'E' /
TTYPER25 = 'EXP_PHI' / Exponential fit orientation angle
TUNIT25 = 'DEGREES' /
TFORM25 = 'E' /
TTYPER26 = 'RA_EXP' / RA from Exponential model fit
TUNIT26 = 'DECIMAL DEGREES' /
TFORM26 = 'D' /
TTYPER27 = 'DEC_EXP' / DEC from Exponential model fit
TUNIT27 = 'DECIMAL DEGREES' /
TFORM27 = 'D' /
TTYPER28 = 'RA_EXP_SIG' / Sigma of Exponential model fit RA
TUNIT28 = 'ARCSECONDS' /
TFORM28 = 'E' /
TTYPER29 = 'DEC_EXP_SIG' / Sigma of Exponential model fit DEC
TUNIT29 = 'ARCSECONDS' /
TFORM29 = 'E' /
TTYPER30 = 'EXP_QF' / Exponential fit coverage/quality factor
TUNIT30 = ' ' /
TFORM30 = 'E' /
TTYPER31 = 'SER_R' / Sersic fit model radius
TUNIT31 = 'ARCSECONDS' /
TFORM31 = 'E' /
TTYPER32 = 'MAG_SER' / Sersic fit model magnitude
TUNIT32 = 'MAG' /
TFORM32 = 'E' /
TTYPER33 = 'MAG_SER_SIG' / Sigma of Sersic fit model magnitude
TUNIT33 = 'MAG' /
TFORM33 = 'E' /
TTYPER34 = 'SER_AB' / Sersic fit model axis ratio

```

```

TUNIT34 = ' ' /
TFORM34 = 'E ' /
TTYPER35 = 'SER_PHI ' / Exponential fit orientation angle
TUNIT35 = 'DEGREES ' /
TFORM35 = 'E ' /
TTYPER36 = 'SER_NU ' / Sersic fit index nu
TUNIT36 = ' ' /
TFORM36 = 'E ' /
TTYPER16 = 'RA_SER ' / RA from Sersic fit
TUNIT16 = 'DECIMAL DEGREES ' /
TFORM16 = 'D ' /
TTYPER37 = 'DEC_SER ' / DEC from Sersic fit
TUNIT37 = 'DECIMAL DEGREES ' /
TFORM37 = 'D ' /
TTYPER38 = 'RA_SER_SIG ' / Sigma of Sersic fit RA
TUNIT38 = 'ARCSECONDS ' /
TFORM38 = 'E ' /
TTYPER39 = 'DEC_SER_SIG ' / Sigma of Sersic fit DEC
TUNIT39 = 'ARCSECONDS ' /
TFORM39 = 'E ' /
TTYPER40 = 'SER_QF ' / Sersic fit coverage/quality factor
TUNIT40 = ' ' /
TFORM40 = 'E ' /
TTYPER41 = 'PCS_R ' / PSF Convolved Sersic fit model radius
TUNIT41 = 'ARCSECONDS ' /
TFORM41 = 'E ' /
TTYPER42 = 'MAG_PSC ' / PSF Convolved Sersic fit model
magnitude
TUNIT42 = 'MAG ' /
TFORM42 = 'E ' /
TTYPER43 = 'MAG_PSC_SIG ' / Sigma of PSF Convolved Sersic fit model
magnitude
TUNIT43 = 'MAG ' /
TFORM43 = 'E ' /
TTYPER44 = 'PCS_AB ' / PSF Convolved Sersic fit model axis
ratio
TUNIT44 = ' ' /
TFORM45 = 'E ' /
TTYPER46 = 'PCS_PHI ' / Exponential fit orientation angle
TUNIT46 = 'DEGREES ' /
TFORM46 = 'E ' /
TTYPER47 = 'PCS_NU ' / PSF Convolved Sersic fit index nu
TUNIT47 = ' ' /
TFORM47 = 'E ' /
TTYPER48 = 'RA_PSC ' / RA from PSF Convolved Sersic fit
TUNIT48 = 'DECIMAL DEGREES ' /
TFORM48 = 'D ' /
TTYPER49 = 'DEC_PSC ' / DEC from PSF Convolved Sersic fit
TUNIT49 = 'DECIMAL DEGREES ' /
TFORM49 = 'D ' /
TTYPER50 = 'RA_PSC_SIG ' / Sigma of PSF Convolved Sersic fit RA
TUNIT50 = 'ARCSECONDS ' /
TFORM50 = 'E ' /
TTYPER51 = 'DEC_PSC_SIG ' / Sigma of PSF Convolved Sersic fit DEC
TUNIT51 = 'ARCSECONDS ' /
TFORM51 = 'E ' /

```

```

TTYPE52 = 'PCS_QF          ' / PSF Convolved Sersic coverage/quality
factor
TUNIT52 = '                ' /
TFORM52 = 'E              ' /
TTYPE53 = 'WL_SIGMA       ' / Weak lensing sigma
TUNIT53 = '                ' /
TFORM53 = 'E              ' /
TTYPE54 = 'EPS_1          ' / Weak lensing eps(1)
TUNIT54 = '                ' /
TFORM54 = 'E              ' /
TTYPE55 = 'EPS_2          ' / Weak lensing eps(2)
TUNIT55 = '                ' /
TFORM55 = 'E              ' /
TTYPE56 = 'P_SM_1_1       ' / Weak lensing P_SM(1,1)
TUNIT56 = '                ' /
TFORM56 = 'E              ' /
TTYPE57 = 'P_SM_1_2       ' / Weak lensing P_SM(1,2)
TUNIT57 = '                ' /
TFORM57 = 'E              ' /
TTYPE58 = 'P_SM_2_1       ' / Weak lensing P_SM(2,1)
TUNIT58 = '                ' /
TFORM58 = 'E              ' /
TTYPE59 = 'P_SM_2_2       ' / Weak lensing P_SM(2,2)
TUNIT59 = '                ' /
TFORM59 = 'E              ' /
TTYPE60 = 'P_SH_1_1       ' / Weak lensing P_SH(1,1)
TUNIT60 = '                ' /
TFORM60 = 'E              ' /
TTYPE61 = 'P_SH_1_2       ' / Weak lensing P_SH(1,2)
TUNIT61 = '                ' /
TFORM61 = 'E              ' /
TTYPE62 = 'P_SH_2_1       ' / Weak lensing P_SH(2,1)
TUNIT62 = '                ' /
TFORM62 = 'E              ' /
TTYPE63 = 'P_SH_2_2       ' / Weak lensing P_SH(2,2)
TUNIT63 = '                ' /
TFORM63 = 'E              ' /
TTYPE64 = 'SB_R_1         ' / Surface brightness inside R #1
TUNIT64 = 'MAG            ' /
TFORM64 = 'E              ' /
TTYPE65 = 'SB_R_1_ERR     ' / Estimated error of SB inside R #1
TUNIT65 = 'MAG            ' /
TFORM65 = 'E              ' /
TTYPE66 = 'SB_R_1_VAR     ' / Estimated variance of SB inside R #1
TUNIT66 = 'MAG            ' /
TFORM66 = 'E              ' /
TTYPE67 = 'SB_R_2         ' / Surface brightness inside R #2
TUNIT67 = 'MAG            ' /
TFORM67 = 'E              ' /
TTYPE68 = 'SB_R_2_ERR     ' / Estimated error of SB inside R #2
TUNIT68 = 'MAG            ' /
TFORM68 = 'E              ' /
TTYPE69 = 'SB_R_2_VAR     ' / Estimated variance of SB inside R #2
TUNIT69 = 'MAG            ' /
TFORM69 = 'E              ' /
TTYPE70 = 'SB_R_3         ' / Surface brightness inside R #3
TUNIT70 = 'MAG            ' /

```

```

TFORM70 = 'E' /
TTYPE71 = 'SB_R_3_ERR' / Estimated error of SB inside R #3
TUNIT71 = 'MAG' /
TFORM71 = 'E' /
TTYPE72 = 'SB_R_3_VAR' / Estimated variance of SB inside R #3
TUNIT72 = 'MAG' /
TFORM72 = 'E' /
TTYPE73 = 'SB_R_4' / Surface brightness inside R #4
TUNIT73 = 'MAG' /
TFORM73 = 'E' /
TTYPE74 = 'SB_R_4_ERR' / Estimated error of SB inside R #4
TUNIT74 = 'MAG' /
TFORM74 = 'E' /
TTYPE75 = 'SB_R_4_VAR' / Estimated variance of SB inside R #4
TUNIT75 = 'MAG' /
TFORM75 = 'E' /
TTYPE76 = 'SB_R_5' / Surface brightness inside R #5
TUNIT76 = 'MAG' /
TFORM76 = 'E' /
TTYPE77 = 'SB_R_5_ERR' / Estimated error of SB inside R #5
TUNIT77 = 'MAG' /
TFORM77 = 'E' /
TTYPE78 = 'SB_R_5_VAR' / Estimated variance of SB inside R #5
TUNIT78 = 'MAG' /
TFORM78 = 'E' /
TTYPE79 = 'SB_R_6' / Surface brightness inside R #6
TUNIT79 = 'MAG' /
TFORM79 = 'E' /
TTYPE80 = 'SB_R_6_ERR' / Estimated error of SB inside R #6
TUNIT80 = 'MAG' /
TFORM80 = 'E' /
TTYPE81 = 'SB_R_5_VAR' / Estimated variance of SB inside R #6
TUNIT81 = 'MAG' /
TFORM81 = 'E' /
TTYPE82 = 'SB_R_7' / Surface brightness inside R #7
TUNIT82 = 'MAG' /
TFORM82 = 'E' /
TTYPE83 = 'SB_R_7_ERR' / Estimated error of SB inside R #7
TUNIT83 = 'MAG' /
TFORM83 = 'E' /
TTYPE84 = 'SB_R_7_VAR' / Estimated variance of SB inside R #7
TUNIT84 = 'MAG' /
TFORM84 = 'E' /
TTYPE85 = 'SB_R_8' / Surface brightness inside R #8
TUNIT85 = 'MAG' /
TFORM85 = 'E' /
TTYPE86 = 'SB_R_8_ERR' / Estimated error of SB inside R #8
TUNIT86 = 'MAG' /
TFORM86 = 'E' /
TTYPE87 = 'SB_R_8_VAR' / Estimated variance of SB inside R #8
TUNIT87 = 'MAG' /
TFORM87 = 'E' /
TTYPE88 = 'SB_R_9' / Surface brightness inside R #9
TUNIT88 = 'MAG' /
TFORM88 = 'E' /
TTYPE89 = 'SB_R_9_ERR' / Estimated error of SB inside R #9
TUNIT89 = 'MAG' /

```

```

TFORM89 = 'E' /
TTYPER90 = 'SB_R_9_VAR' / Estimated variance of SB inside R #9
TUNIT90 = 'MAG' /
TFORM90 = 'E' /
TTYPER91 = 'SB_R_10' / Surface brightness inside R #10
TUNIT91 = 'MAG' /
TFORM91 = 'E' /
TTYPER92 = 'SB_R_10_ERR' / Estimated error of SB inside R #10
TUNIT92 = 'MAG' /
TFORM92 = 'E' /
TTYPER93 = 'SB_R_10_VAR' / Estimated variance of SB inside R #10
TUNIT93 = 'MAG' /
TFORM93 = 'E' /
TTYPER94 = 'SB_R_11' / Surface brightness inside R #11
TUNIT94 = 'MAG' /
TFORM94 = 'E' /
TTYPER95 = 'SB_R_11_ERR' / Estimated error of SB inside R #11
TUNIT95 = 'MAG' /
TFORM95 = 'E' /
TTYPER96 = 'SB_R_11_VAR' / Estimated variance of SB inside R #11
TUNIT96 = 'MAG' /
TFORM96 = 'E' /
TTYPER97 = 'SB_R_12' / Surface brightness inside R #12
TUNIT97 = 'MAG' /
TFORM97 = 'E' /
TTYPER98 = 'SB_R_12_ERR' / Estimated error of SB inside R #12
TUNIT98 = 'MAG' /
TFORM98 = 'E' /
TTYPER99 = 'SB_R_12_VAR' / Estimated variance of SB inside R #12
TUNIT99 = 'MAG' /
TFORM99 = 'E' /
TTYPER100 = 'SB_R_13' / Surface brightness inside R #13
TUNIT100 = 'MAG' /
TFORM100 = 'E' /
TTYPER101 = 'SB_R_13_ERR' / Estimated error of SB inside R #13
TUNIT101 = 'MAG' /
TFORM101 = 'E' /
TTYPER102 = 'SB_R_13_VAR' / Estimated variance of SB inside R #13
TUNIT102 = 'MAG' /
TFORM102 = 'E' /
TTYPER103 = 'SB_R_14' / Surface brightness inside R #14
TUNIT103 = 'MAG' /
TFORM103 = 'E' /
TTYPER104 = 'SB_R_14_ERR' / Estimated error of SB inside R #14
TUNIT104 = 'MAG' /
TFORM104 = 'E' /
TTYPER105 = 'SB_R_14_VAR' / Estimated variance of SB inside R #14
TUNIT105 = 'MAG' /
TFORM105 = 'E' /
TTYPER106 = 'SB_R_15' / Surface brightness inside R #15
TUNIT106 = 'MAG' /
TFORM106 = 'E' /
TTYPER107 = 'SB_R_15_ERR' / Estimated error of SB inside R #15
TUNIT107 = 'MAG' /
TFORM107 = 'E' /
TTYPER108 = 'SB_R_15_VAR' / Estimated variance of SB inside R #15
TUNIT108 = 'MAG' /
TFORM108 = 'E' /
TTYPER109 = 'SB_R_15_VAR' / Estimated variance of SB inside R #15
TUNIT109 = 'MAG' /

```

```

TFORM109= 'E           ' /
TTYPER110= 'LOG_A      ' / Log of asymmetry parameter
TUNIT110= '           ' /
TFORM110= 'E           ' /
TTYPER111= 'LOG_C      ' / Log of concentration parameter
TUNIT111= '           ' /
TFORM111= 'E           ' /
TTYPER112= 'INCL       ' / Inclination
TUNIT112= '           ' /
TFORM112= 'E           ' /
CHECKSUM=           / Header checksum
DATASUM =           / Data checksum
END

```

4 Requirements Traceability

Table 4-1 IPP - PSPS Interface Requirements Allocation

Requirement	Description	Specification	Section
3.1.1	The IPP shall publish to the PSPS a predefined catalog of objects derived from PS1 observations.	IPP-PSPS IRS	3.2.1, 3.6.2
3.1.2	The catalog of predefined objects published by the IPP shall include the attributes listed in Table 3.1 of the IPP-PSPS IRS.	IPP-PSPS IRS	3.2.1, 3.6.2, 3.6.5
3.1.3	The IPP shall publish to the PSPS at the same time as the catalog of predefined objects a table describing the position and extent of the sky cells mapped onto the celestial sphere	IPP-PSPS IRS	3.2.1, 3.6.2
3.1.4	The properties of the sky cells shall be as described in Table 3.2 of the IPP-PSPS IRS	IPP-PSPS IRS	3.2.1, 3.6.2
3.1.5r	The IPP shall publish to the PSPS at the same time as the catalog of predefined objects a table describing the configuration of the PS1 camera	IPP-PSPS IRS	3.2.1, 3.6.2
3.1.6	The camera configuration table shall include the attributes as listed in Table 3.3 of the IPP-PSPS IRS	IPP-PSPS IRS	3.2.1, 2.6.2
3.1.7	The IPP shall publish to the PSPS catalogs of detections for P2, P4 Σ , and P4 Δ frames that have been processed by the IPP.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6

Requirement	Description	Specification	Section
3.1.8	The IPP shall publish to the PSPS catalogs of the detections and descriptive parameters for sources found in Cumulative Sky images.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6
3.1.9	The IPP detection/source catalogs shall contain the attributes derived from PSF fitting to sources listed in Tables 3.4 of the IPP-PSPS IRS.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6
3.1.10	The detection catalogs for the P2, P4 Σ , and P4 Δ sources shall contain additional attributes as listed in Table 3.5 of the IPP-PSPS IRS when the IPP determines that the PSF fit alone does not adequately describe the source.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6
3.1.11	The IPP detection catalogs for sources measured in Image Stacks or the Cumulative Sky shall contain the attributes as listed in Table 3.6 of the IPP-PSPS IRS	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6
3.1.12	The IPP shall publish to the PSPS frame descriptor metadata for P2 exposures as listed in Table 3.7.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.5
3.1.13	The IPP shall publish to the PSPS metadata describing the photometric calibration of the catalog tables as listed in Table 3.8.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6
3.1.14	The IPP shall publish to the PSPS metadata describing the spatial coverage, photometric and astrometric calibrations of the source images for the catalogs as listed in Tables 3.2, and 3.11.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6
3.1.15	The IPP shall publish to the PSPS metadata describing the photometric and astrometric calibration of the cumulative sky catalogs as listed in Table 3.10.	IPP-PSPS IRS	3.2.2, 3.6.3, 3.6.5, 3.6.6

Requirement	Description	Specification	Section
3.1.16	The IPP shall publish to the PSPS metadata describing the sky cell images as described in Table 3.11 of the IPP-PSPS IRS	IPP-PSPS IRS	
3.1.17	The IPP shall publish to the PSPS metadata describing the alternative fitting models to PSF fits for P2, P4 Σ , and P4 Δ catalogs as described in Table 3.12 of the IPP-PSPS IRS.	IPP-PSPS-IRS	
3.1.18	The IPP shall ;publish to the PSPS a list of survey programs run by the observatory as described in Table 3.13 of the IPP-PSPS IRS.	IPP-PSPS-IRS	
3.1.19	The IPP shall publish to the PSPS a list of recipes used to compute photometric redshifts as listed in Table 3.14 of the IPP-PSPS IRS	IPP-PSPS-IRS	
3.1.20	The IPP shall update the metadata in Tables 3.2, 3.3, 3.8, 3.11, 3.12, 3.13, and 3.14 prior to transferring to the PSPS any detection records that use the updated metadata.	IPP-PSPS-IRS	
3.2.1	The PSPS shall initialize the ODM with the predefined objects published by the IPP.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.2	The PSPS shall publish the detections obtained from the IPP in a searchable database.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.3	The PSPS shall correlate into objects the detections from the IPP.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.4	The PSPS shall establish a common numbering scheme for all objects derived from the IPP detections.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.5	The PSPS shall publish all objects determined from the IPP detections in a searchable database.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD

Requirement	Description	Specification	Section
3.2.6	The PSPS object records shall support the attributes identified in Table 3.7.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.7	The PSPS object records shall incorporate any attributes of the source found in the cumulative sky detections of that object.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.8	The PSPS shall derive from the detection records for objects associated from the P2 and P4 Σ images the mean celestial positions (for mean epoch and equinox J2000), their variances, mean proper motions and their variances for all stellar sources in the data collection.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.9	The PSPS shall derived for each object associated from the P2 and P4 Σ images for each filter in which it has been observed, the mean magnitude and its variance, the minimum and maximum measured magnitudes, and the number of times the object has been observed in the filter.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.10	The PSPS shall derive, when sufficient measures in the observed filters are available, for each non-stellar object in the Cumulative Sky data collection its photometric redshift and a measure of its uncertainty.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.11	The PSPS shall derive, when sufficient measures are available, for each stellar object an estimate of its proper motion and the uncertainty in this estimate.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.12	The PSPS shall update the derived attributes such that they lag their associated published detection records by no more than the number of job cycles described in Table 3.8.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.2.13	The PSPS shall store in a searchable database the detections with a significance of 5σ and above from P4 Δ frames.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD

Requirement	Description	Specification	Section
3.2.14	The PSPS shall store as blobs on a per frame basis the detections from P4 Δ frames with less than 5σ significance.	IPP-PSPS IRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD
3.3.1	The IPP shall publish data to the PSPS after it has been astronomically validated.	IPP-PSPS IRS	Allocated to IPP SDD
3.3.2	The IPP shall publish data to the PSPS on monthly job cycles.	IPP-PSPS IRS	3.2.2
3.3.3	The IPP shall publish each monthly job as a sequence of "batch" data transfers.	IPP-PSPS IRS	3.2.2
3.3.4	The IPP shall provide with each job cycle a job manifest that identifies the data transfer "batches" that make up the job.	IPP-PSPS IRS	3.2.2, 3.5.2
3.3.5	The IPP job manifest shall provide sufficient information to allow the PSPS to verify that the "batches" transmitted corresponded to what was itemized in the manifest.	IPP-PSPS IRS	3.2.2, 3.5.2
3.3.6	The IPP shall provide with each data transfer a "batch" manifest of the data that was transmitted.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.4, 3.5.1
3.3.7	The IPP "batch" manifest shall provide sufficient information to allow the PSPS to verify that the transfer process did not corrupt the data transfer.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.5.1
3.3.8	The IPP "batch" manifest shall provide sufficient information to allow the PSPS to verify that the data transmitted corresponded to what was itemized in the manifest.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.5.1
3.3.9	The IPP shall push the data transfers to the PSPS.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.4
3.3.10	The IPP shall retransmit data to the PSPS if it has been notified by the latter that the data was corrupted in transmission.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.3.2
3.3.11	If the PSPS finds that transmitted data fails content verification, the IPP shall send the correct data.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.3.5

Requirement	Description	Specification	Section
3.4.1	The PSPS shall verify data transmission from the IPP has not corrupted file contents within TBD seconds of notification of the files arrival from the IPP.	IPP-PSPS IRS	3.2.1, 3.2.2
3.4.2	The PSPS shall acknowledge to the IPP the receipt of a data transfer.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.3.3
3.4.3	The PSPS shall verify data transmitted from the IPP corresponds to the manifest inventory received from the IPP.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.3.1, 3.3.7
3.4.4	The PSPS shall notify the IPP if a data file was corrupted during transmission and request it be retransmitted to the PSPS.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.3.2
3.4.5	The PSPS shall notify IPP if a data file's contents do not correspond to the description in the manifest inventory from the IPP.	IPP-PSPS IRS	3.2.1, 3.2.2, 3.3.5
3.4.6	The PSPS shall inform the IPP when the entire collection of data for a processing cycle has been loaded in the PSPS data stores.	IPP-PSPS IRS	3.2.2, 3.3.11
3.1.21	The IPP shall publish the static sky images to the Pan-STARRS Published Science Products Subsystem (PSPS) at a rate so the full sky is transmitted once per year.	IPP SRS	Not Allocated: PS4 Requirement
3.1.22	The IPP shall publish the detected objects to the Pan-STARRS Published Science Products Subsystem (PSPS) at a rate such that the objects from the full sky are transmitted once per year.	IPP SRS	3.2.2, 3.6.2, 3.6.4, 3.6.5
3.1.23	The IPP shall send the IPP metadata and received OTIS metadata to the Pan-STARRS Published Science Products Subsystem (PSPS) weekly.	IPP SRS	3.2.2, 3.6.2, 3.6.4, 3.6.5
3.4.5.1	The IPP Scheduler shall publish the static sky images to the Pan-STARRS PSPS at a rate so that the full sky is transmitted once per year.	IPP SRS	Not Allocated: PS4 Requirement
3.4.5.4	The IPP Scheduler shall publish the detected objects to the Pan-STARRS PSPS at a rate so that the objects from the full sky are transmitted once per year.	IPP SRS	3.2.2, 3.6.2, 3.6.4, 3.6.5

Requirement	Description	Specification	Section
3.4.5.5	The IPP Scheduler shall publish the IPP and OTIS metadata to the Pan-STARRS PSPS on a time-scale of 1 week.	IPP SRS	3.2.2, 3.6.2, 3.6.4, 3.6.5
3.4.3.1.1	The PS1 ODM shall accept data from the PS1 IPP in accordance with the PS1 IPP - PSPS IRS.	PSPS SRS	3.2.1, 3.2.2
3.4.3.1.2	The PS1 ODM shall accept ingest request notifications from the PS1 IPP in accordance with the PS1 IPP - PSPS IRS.	PSPS SRS	3.2.2
3.4.3.2.1	The PS1 ODM shall transmit notifications of integrity check failures to the PS1 IPP in accordance with the PS1 IPP - PSPS IRS.	PSPS SRS	3.2.1, 3.2.2, 3.3.2
3.4.3.2.2	The PS1 ODM shall transmit notifications of successful completion of an ingest request to the PS1 IPP in accordance with the PS1 IPP - PSPS IRS.	PSPS SRS	3.2.1, 3.2.2, 3.3.11
3.4.3.2.3	The PS1 ODM shall transmit notifications of the failure of an ingest request to the PS1 IPP in accordance with the PS1 IPP - PSPS IRS.	PSPS SRS	3.2.1, 3.2.2, 3.3.10
3.4.3.3.2.1	The PS1 ODM shall ingest data from the PS1 IPP in accordance with the procedures described in the PS1 IPP-PSPS IRS.	PSPS SRS	3.2.1, 3.2.2
3.4.3.3.2.2	The PS1 ODM shall validate the integrity of the data it receives from the PS1 IPP before ingesting the data, based on the integrity information provided by the PS1 IPP.	PSPS SRS	3.2.1, 3.2.2, 3.3.6, 3.3.8
3.4.3.3.2.3	The PS1 ODM shall generate an integrity check failure notification for transmission to the PS1 IPP for an ingest request if any of its data files failed the integrity check.	PSPS SRS	3.2.1, 3.2.2, 3.3.6, 3.3.8
3.4.3.3.2.4	The PS1 ODM shall not process an ingest request whose data failed the integrity check.	PSPS SRS	3.2.1, 3.2.2
3.4.3.3.2.5	The PS1 ODM shall generate a successful completion notification for transmission to the PS1 IPP for an ingest request after it completes ingest and loading successfully.	PSPS SRS	3.2.1, 3.2.2, 3.3.11
3.4.3.3.2.6	The PS1 ODM shall generate an ingest failure notification for transmission to the PS1 IPP for an ingest request that does not complete ingest and loading successfully after it passed the integrity check.	PSPS SRS	3.2.1, 3.2.2, 3.3.10

Requirement	Description	Specification	Section
3.4.3.3.4.1	The PS1 ODM shall derive the ODM attributes listed in Table 3.7 from the correlated detections.	PSPS SRS	Allocated to PSPS ODM Ingest SDD and PSPS ODM DBDD

5 Notes

The following sections provide the reader with a listing of the terminology and notation used in this document.

5.1 Glossary

Batch	A compressed archive file containing the IPP science data products as a set of FITS files and a batch manifest file.
Catalog	Collection of information
Detection	A source identified by the IPP in one of the various Pan-STARRS image data products by the IPP's source detection algorithms. The detection will have a number of attributes including, at a minimum, position, flux, and their associated errors. Other attributes may be present depending upon the signal-to-noise in the source image.
Frame	A frame is defined to contain IPP products describing an area of sky. A frame is equivalent to the IPP products generated on an exposure by the P2, P4Σ, and P4Δ processes, and can be defined by the IPP for cumulative sky products.
Job	The science data published by the IPP corresponding to an observation cycle.
Lag	The interval between two related events.
Latency	The interval between stimulus and response. As used in this specification: the interval between object observation and the availability of the science data resulting from the observation.
Object	A celestial source with at least one detection. Objects will, in general, have multiple detections attributed to the same physical source on the sky.

5.2 Acronyms

AFRL	Air Force Research Laboratory
CAM	One Giga Pixel CCD cameras, a Pan-STARRS subsystem
CCD	Charge Coupled Device
FITS	Flexible Image Transport System
HDU	Header Data Units
ICD	Interface Control Document
IfA	Institute for Astronomy
IPP	Image Processing Pipeline
IRS	Interface Requirements Specification
MOPS	Moving Object Processing Software, a Pan-STARRS subsystem
ODM	Object Data Manager
OTIS	Observatory, Telescope, and Instrument Software control system, a Pan-STARRS subsystem
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
PS1	Pan-STARRS 1, the one telescope operational prototype configuration
PS4	Pan-STARRS 4, the four telescope fully functional system configuration
PSDC	Pan-STARRS Document Control
PSF	Point Spread Function

PSPS	Published Science Product Subsystem
SAIC	Science Applications International Corporation
SCD	System Concept Definition
SGS	Science Goals Statement
SRS	Software Requirements Specification
SSDD	System/Subsystem Design Definition
TEL	An array of four 1.8m telescopes, a Pan-STARRS subsystem
UH	University of Hawaii
XML	eXtensible Markup Language

6 APPENDIX A: FITS KEYWORD GLOSSARY

KEYWORD: AIRMASS
 REFERENCE: NOAO
 HDU: extension
 DATATYPE: real
 UNIT: none
 COMMENT: air mass
 DEFINITION: The value field shall contain a floating point number giving the air mass during the observation by a ground based telescope. The value of the airmass is often approximated by the secant of the elevation angle and has a value of 1.0 at the zenith and increases towards the horizon. This value is assumed to correspond to the start of the observation unless another interpretation is clearly explained in the comment field.

KEYWORD: ANALVER
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: integer
 UNIT: none
 COMMENT: software analysis version index
 DEFINITION: Numerical index corresponding to the analysis version used in the data reduction

KEYWORD: BIASVAL
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: real
 UNIT: ADU
 COMMENT: bias value
 DEFINITION: The mean bias of the CCD on a given exposure.

KEYWORD: BIASVAR
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: real
 UNIT: ADU
 COMMENT: bias variance
 DEFINITION: The variance of the bias level measured for the CCD during a given exposure.

KEYWORD: BITPIX
 REFERENCE: FITS Standard
 STATUS: mandatory
 HDU: any
 VALUE: integer
 RANGE: -64, -32, 8, 16, 32
 COMMENT: bits per data value
 DEFINITION: The value field shall contain an integer. The absolute value is used in computing the sizes of data structures. It shall specify the number of bits that represent a data value.

KEYWORD: CAMERA

REFERENCE: Pan-STARRS
HDU: any
DATATYPE: string
UNIT: none
COMMENT: camera name
DEFINITION: A character string giving the unique camera name, e.g., 'GPC1' for a specific detector system

KEYWORD: CAMERAID
REFERENCE: Pan-STARRS
HDU: any
DATATYPE: integer
UNIT: none
COMMENT: camera id
DEFINITION: This is a numerical code relating to the camera name string.

KEYWORD: CD1_1
REFERENCE: NOAO
HDU: extension
DATATYPE: real
UNIT: CUNIT1/pixel
COMMENT: coordinae scale matrix
DEFINITION: Coordinate scale matrix for image world coordinates. This describes the scales and rotations of the coordinate axes.

KEYWORD: CD1_1
REFERENCE: NOAO
HDU: extension
DATATYPE: real
UNIT: CUNIT1/pixel
COMMENT: coordinae scale matrix
DEFINITION: Coordinate scale matrix for image world coordinates. This describes the scales and rotations of the coordinate axes.

KEYWORD: CD1_2
REFERENCE: NOAO
HDU: extension
DATATYPE: real
UNIT: CUNIT1/pixel
COMMENT: coordinae scale matrix
DEFINITION: Coordinate scale matrix for image world coordinates. This describes the scales and rotations of the coordinate axes.

KEYWORD: CD2_1
REFERENCE: NOAO
HDU: extension
DATATYPE: real
UNIT: CUNIT2/pixel
COMMENT: coordinae scale matrix
DEFINITION: Coordinate scale matrix for image world coordinates. This describes the scales and rotations of the coordinate axes.

KEYWORD: CD2_2
REFERENCE: NOAO
HDU: extension
DATATYPE: real

UNIT: CUNIT2/pixel
COMMENT: oordinae scale matrix
DEFINITION: Coordinate scale matrix for image world coordinates.
This describes the scales and rotations of the coordinate axes.

KEYWORD: CELLVER
REFERENCE: Pan-STARRS
HDU: any
DATATYPE: integer
UNIT: none
COMMENT: sky cell image version
DEFINITION: This defines the combination of Skycell location, filter, version number, and creation/expiration data for the cumulative sky images defined on the skycells.

KEYWORD: CERROR
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: mas
COMMENT: RMS of astrometric solution
DEFINITION: This is a measure of the astrometric precision derived from fitting standard star positions to the measured positions of these objects on the CCD.

KEYWORD: CHECKSUM
REFERENCE: Checksum
HDU: any
DATATYPE: string
COMMENT: checksum for the current HDU
DEFINITION: The value field of the CHECKSUM keyword shall contain a 16 character string, left justified starting in column 12, containing the ASCII encoded complement of the checksum of the FITS HDU (Header and Data Unit). The algorithm shall be the 32-bit 1's complement checksum and the ASCII encoding that are described in the checksum proposal. The checksum is accumulated in FITS datastream order on the same HDU, identical in all respects, except that the value of the CHECKSUM keyword shall be set to the string '0000000000000000' (ASCII 0's, hex 30) before the checksum is computed.

KEYWORD: CLASSID
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: index locating CCD in focal plane
DEFINITION: This index defines the location of a CCD in the focal plane of the camera.

KEYWORD: COMMENT
REFERENCE: FITS Standard
STATUS: reserved
HDU: any
VALUE: none
COMMENT: descriptive comment
DEFINITION: This keyword shall have no associated value; columns 9-80
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may contain any ASCII text. Any number of COMMENT card images may appear in a header.

KEYWORD: CRPIXn
 REFERENCE: FITS Standard
 STATUS: reserved
 HDU: image
 VALUE: real
 COMMENT: coordinate system reference pixel
 DEFINITION: The value field shall contain a floating point number, identifying the location of a reference point along axis n, in units of the axis index. This value is based upon a counter that runs from 1 to NAXISn with an increment of 1 per pixel. The reference point value need not be that for the center of a pixel nor lie within the actual data array. Use comments to indicate the location of the index point relative to the pixel.

KEYWORD: CRVALn
 REFERENCE: FITS Standard
 STATUS: reserved
 HDU: image
 VALUE: real
 COMMENT: coordinate system value at reference pixel
 DEFINITION: The value field shall contain a floating point number, giving the value of the coordinate specified by the CTYPEn keyword at the reference point CRPIXn. Units must follow the prescriptions of section 5.3 of the FITS Standard.

KEYWORD: CTYPEn
 REFERENCE: FITS Standard
 STATUS: reserved
 HDU: image
 VALUE: string
 COMMENT: name of the coordinate axis
 DEFINITION: The value field shall contain a character string, giving the name of the coordinate represented by axis n.

KEYWORD: DATASUM
 REFERENCE: Checksum
 HDU: any
 DATATYPE: string
 COMMENT: checksum of the data records
 DEFINITION: The value field of the DATASUM keyword shall be a character string containing the unsigned integer value of the checksum of the data records of the HDU. For dataless HDU's, this keyword may either be omitted, or the value field shall contain the string value '0', which is preferred. A missing DATASUM keyword asserts no knowledge of the checksum of the data records.

KEYWORD: DATE
 REFERENCE: FITS Standard
 STATUS: reserved
 HDU: any
 VALUE: string
 COMMENT: date of file creation
 DEFINITION: The date on which the HDU was created, in the format specified in the FITS Standard. The old date format was 'yy/mm/dd' and
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may be used only for dates from 1900 through 1999. the new Y2K compliant date format is 'yyyy-mm-dd' or 'yyyy-mm-ddTHH:MM:SS[.sss]'.

KEYWORD: DEC
 REFERENCE: NOAO
 HDU: any
 DATATYPE: real or string
 UNIT: deg
 COMMENT: declination of the observed object
 DEFINITION: The value field gives the declination of the observation. It may be expressed either as a floating point number in units of decimal degrees, or as a character string in 'dd:mm:ss.sss' format where the decimal point and number of fractional digits are optional. The coordinate reference frame is given by the RADECSYS keyword, and the coordinate epoch is given by the EQUINOX keyword. Example: -47.25944 or '-47:15:34.00'.

KEYWORD: DETECTID
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: integer
 UNIT: none
 COMMENT: detector identifier
 DEFINITION: This is a numerical identifier assigned to a specific CCD device.

KEYWORD: DETRENDn
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: character
 UNIT: none
 COMMENT: Name of n-th detrend image
 DEFINITION: The detrend images will include the names of flat field frames, bias frames, sky fringing frames, etc. used in the IPP to remove systematics from the astronomical image.

KEYWORD: END
 REFERENCE: FITS Standard
 STATUS: mandatory
 HDU: any
 VALUE: none
 COMMENT: marks the end of the header keywords
 DEFINITION: This keyword has no associated value. Columns 9-80 shall be filled with ASCII blanks.

KEYWORD: EXPTIME
 REFERENCE: NOAO
 HDU: any
 DATATYPE: real
 UNIT: s
 COMMENT: exposure time
 DEFINITION: The value field shall contain a floating point number giving the exposure time of the observation in units of seconds. The exact definition of 'exposure time' is mission dependent and may, for example, include corrections for shutter open and close duration, detector dead time, vignetting, or other effects. This keyword is synonymous with the
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EXPOSURE keyword.

KEYWORD: EXTEND
REFERENCE: FITS Standard
STATUS: reserved
HDU: primary
VALUE: logical
COMMENT: may the FITS file contain extensions?
DEFINITION: If the FITS file may contain extensions, a card image with the keyword EXTEND and the value field containing the logical value T must appear in the primary header immediately after the last NAXISn card image, or, if NAXIS=0, the NAXIS card image. The presence of this keyword with the value T in the primary header does not require that extensions be present.

KEYWORD: EXTLEVEL
REFERENCE: FITS Standard
STATUS: reserved
HDU: extension
VALUE: integer
RANGE: [1:]
DEFAULT: 1
COMMENT: hierarchical level of the extension
DEFINITION: The value field shall contain an integer, specifying the level in a hierarchy of extension levels of the extension header containing it. The value shall be 1 for the highest level; levels with a higher value of this keyword shall be subordinate to levels with a lower value. If the EXTLEVEL keyword is absent, the file should be treated as if the value were 1. This keyword is used to describe an extension and should not appear in the primary header.

KEYWORD: EXTNAME
REFERENCE: FITS Standard
STATUS: reserved
HDU: extension
VALUE: string
COMMENT: name of the extension
DEFINITION: The value field shall contain a character string, to be used to distinguish among different extensions of the same type, i.e., with the same value of XTENSION, in a FITS file. This keyword is used to describe an extension and should not appear in the primary header.

KEYWORD: EXTVER
REFERENCE: FITS Standard
STATUS: reserved
HDU: extension
VALUE: integer
RANGE: [1:]
DEFAULT: 1
COMMENT: version of the extension
DEFINITION: The value field shall contain an integer, to be used to distinguish among different extensions in a FITS file with the same type and name, i.e., the same values for XTENSION and EXTNAME. The values need not start with 1 for the first extension with a particular value of EXTNAME and need not be in sequence for subsequent values. If the EXTVER keyword is absent, the file should be treated as if the value were 1. This keyword is used to describe an extension and should

not appear in the primary header.

KEYWORD: FILTER
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: character
UNIT: none
COMMENT: filter name
DEFINITION: This is a string defining a specific filter uniquely.

KEYWORD: FILTERID
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: filter holder slot number
DEFINITION: This keyword identifies the opening of the filter slide (and hence filter) through which a given exposure was obtained.

KEYWORD: GCOUNT
REFERENCE: FITS Standard
STATUS: mandatory
HDU: extension
VALUE: integer
COMMENT: group count
DEFINITION: The value field shall contain an integer that shall be used in any way appropriate to define the data structure, consistent with Eq. 5.2 in the FITS Standard. This keyword originated for use in FITS Random Groups where it specifies the number of random groups present. In most other cases this keyword will have the value 1.

KEYWORD: MAGCOMP
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: mag
COMMENT: magnitude of 95% completion of detections
DEFINITION: This is the magnitude at which the IPP determines that the source catalogs are 95% complete.

KEYWORD: MAGSAT
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: mag
COMMENT: saturation magnitude
DEFINITION: This is the magnitude at which sources will saturate on the CCD for a given exposure.

KEYWORD: MJDATE
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: days
COMMENT: Modified Julian Date at start of exposure
DEFINITION: This defines the time of the start of an exposure, expressed as a modified Julian date.

KEYWORD: NAXIS
REFERENCE: FITS Standard
STATUS: mandatory
HDU: any
VALUE: integer
RANGE: [0:999]
COMMENT: number of axes
DEFINITION: The value field shall contain a non-negative integer no greater than 999, representing the number of axes in the associated data array. A value of zero signifies that no data follow the header in the HDU. In the context of FITS 'TABLE' or 'BINTABLE' extensions, the value of NAXIS is always 2.

KEYWORD: NAXISn
REFERENCE: FITS Standard
STATUS: mandatory
HDU: any
VALUE: integer
RANGE: [0:]
COMMENT: size of the axis
DEFINITION: The value field of this indexed keyword shall contain a non-negative integer, representing the number of elements along axis n of a data array. The NAXISn must be present for all values n = 1,...,NAXIS, and for no other values of n. A value of zero for any of the NAXISn signifies that no data follow the header in the HDU. If NAXIS is equal to 0, there should not be any NAXISn keywords.

KEYWORD: NCELLS
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: number of cells in a P4Σ, P4Δ, or image stack data set
DEFINITION:

KEYWORD: NFILES
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: number of files contributing to image
DEFINITION:

KEYWORD: NP2IMGS
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: number of P2 images contributing to image stack
DEFINITION: This keyword shows how many P2 images were combined into the image stack for which the catalog information is being provided to PSPS>

KEYWORD: NX
REFERENCE: Pan-STARRS
HDU: extension

DATATYPE: integer
 UNIT: none
 COMMENT: number of columns in CCD
 DEFINITION:

KEYWORD: NY
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: integer
 UNIT: none
 COMMENT: number of rows in CCD
 DEFINITION:

KEYWORD: OBS_ID
 REFERENCE: HEASARC
 HDU: any
 DATATYPE: string
 COMMENT: unique observation ID
 DEFINITION: The value field shall contain a character string which uniquely identifies the dataset contained in the FITS file. This is typically a sequence number that can contain a mixture of numerical and character values. Example: '10315-01-01-30A'

KEYWORD: PnRECIP
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: integer
 UNIT: none
 COMMENT: Recipe for processing stage n in IPP pipeline
 DEFINITION: Definition of the specific IPP recipe used to process data being run through stage "n" of the pipeline.

KEYWORD: PCALxmYn
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: real
 UNIT: none
 COMMENT: WCS coefficient for higher order polynomial fit
 DEFINITION: This provides the WCS coefficient for the polynomial terms (greater than linear) used in the astrometric solution in the IPP. PCALxmYn is the coefficient of the $X^m * Y^n$ term of the fit for the l-th axis

KEYWORD: PHOT_C
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: real
 UNIT: none
 COMMENT: photometric zero point measured for this run
 DEFINITION:

KEYWORD: PHOT_C0
 REFERENCE: Pan-STARRS
 HDU: extension
 DATATYPE: real
 UNIT: none
 COMMENT: nominal photometric zero point

DEFINITION:

KEYWORD: PHOT_C1
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: character
UNIT: none
COMMENT: name of color #1 in photometry reduction
DEFINITION:

KEYWORD: PHOT_C2
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: character
UNIT: none
COMMENT: name of color #2 in photometry reduction
DEFINITION:

KEYWORD: PHOT_CS
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: mag
COMMENT: scatter in photometric zero points
DEFINITION:

KEYWORD: PHOT_K
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: none
COMMENT: photometric extinction term
DEFINITION:

KEYWORD: PHOT_NM
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: number of images used in photometry calibration
DEFINITION:

KEYWORD: PHOT_NS
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: number of stars used in photometry calibration
DEFINITION:

KEYWORD: PHOT_X
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: none
COMMENT: photometry color term
DEFINITION:

KEYWORD: PHOTCODE
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: character
UNIT: none
COMMENT: photometry code identifier
DEFINITION: A unique string defining the photometry reduction code.

KEYWORD: PHOTCID
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: integer index of photometry code
DEFINITION: Numerical index corresponding to a particular PHOTCODE.

KEYWORD: POLYORD
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: polynomial order of astrometric fit
DEFINITION: The order of the polynomial fit performed in mapping the pixel locations on the CCD to astronomical coordinates.

KEYWORD: PSF_EX1
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT:
COMMENT: PSF extra term #1
DEFINITION: An "extra" psf description parameter.

KEYWORD: PSF_EX2
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT:
COMMENT: PSF extra term #2
DEFINITION: An "extra" psf description parameter.

KEYWORD: PSFFWHM
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: pixels
COMMENT: PSF Full width at half maximum
DEFINITION:

KEYWORD: PSFMODE
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: PSF model identifier

DEFINITION:

KEYWORD: PSFTHETA
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: degrees
COMMENT: PSF orientation angle
DEFINITION:

KEYWORD: PSFWIDX
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: pixels
COMMENT: PSF width in X coordinate
DEFINITION:

KEYWORD: PSFWIDY
REFERENCE: Pan-STARRS
HDU: extgension
DATATYPE: real
UNIT: pixels
COMMENT: PSF width in Y coordinate
DEFINITION:

KEYWORD: QAFLAGS
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: character
UNIT: none
COMMENT: quality assurance flags
DEFINITION: Quality assurance flags provided by the IPP.

KEYWORD: RA
REFERENCE: NOAO
HDU: any
DATATYPE: real or string
UNIT: deg
COMMENT: R.A. of the observation
DEFINITION: The value field gives the Right Ascension of the observation. It may be expressed either as a floating point number in units of decimal degrees, or as a character string in 'HH:MM:SS.sss' format where the decimal point and number of fractional digits are optional. The coordinate reference frame is given by the RADECSYS keyword, and the coordinate epoch is given by the EQUINOX keyword. Example: 180.6904 or '12:02:45.7'.

KEYWORD: SIMPLE
REFERENCE: FITS Standard
STATUS: mandatory
HDU: primary
VALUE: logical
COMMENT: does file conform to the Standard?
DEFINITION: The SIMPLE keyword is required to be the first keyword in the primary header of all FITS files. The value field shall contain a logical constant with the value T if the file conforms to the

standard. This keyword is mandatory for the primary header and is not permitted in extension headers. A value of F signifies that the file does not conform to this standard.

KEYWORD: SKYCELL
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: sky cell index
DEFINITION: A numerical index defining the location of a specific sky cell.

KEYWORD: SKYVAL
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: ADU
COMMENT: sky level
DEFINITION: The median value of the sky level for a particular P2 image frame.

KEYWORD: SKYVAR
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: real
UNIT: ADU
COMMENT: sky level variance
DEFINITION: The variance of the sky level in a particular frame.

KEYWORD: STACKID
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: index for an image stack
DEFINITION: Numerical identifier for an image stack generated by the IPP.

KEYWORD: TBCOLn
REFERENCE: FITS Standard
STATUS: mandatory
HDU: ASCII_table
VALUE: integer
RANGE: [1:]
COMMENT: begining column number
DEFINITION: The value field of this indexed keyword shall contain an integer specifying the column in which field n starts in an ASCII TABLE extension. The first column of a row is numbered 1.

KEYWORD: TELNUM
REFERENCE: Pan-STARRS
HDU: extension
DATATYPE: integer
UNIT: none
COMMENT: telescope number
DEFINITION: Numerical identifier related to a given TELESCOP name.

KEYWORD: TELESCOP
REFERENCE: FITS Standard
STATUS: reserved
HDU: any
VALUE: string
COMMENT: name of telescope
DEFINITION: The value field shall contain a character string identifying the telescope used to acquire the data associated with the header.

KEYWORD: TFIELDS
REFERENCE: FITS Standard
STATUS: mandatory
HDU: table
VALUE: integer
RANGE: [0:999]
COMMENT: number of columns in the table
DEFINITION: The value field shall contain a non-negative integer representing the number of fields in each row of a 'TABLE' or 'BINTABLE' extension. The maximum permissible value is 999.

KEYWORD: TFORMn
REFERENCE: FITS Standard
STATUS: mandatory
HDU: table
VALUE: string
COMMENT: column data format
DEFINITION: The value field of this indexed keyword shall contain a character string describing the format in which field n is encoded in a 'TABLE' or 'BINTABLE' extension.

KEYWORD: TTYPEn
REFERENCE: FITS Standard
STATUS: reserved
HDU: table
VALUE: string
COMMENT: column name
DEFINITION: The value field for this indexed keyword shall contain a character string, giving the name of field n. It is recommended that only letters, digits, and underscore (hexadecimal code 5F, ('_')) be used in the name. String comparisons with the values of TTYPEn keywords should not be case sensitive. The use of identical names for different fields should be avoided.

KEYWORD: TUNITn
REFERENCE: FITS Standard
STATUS: reserved
HDU: table
VALUE: string
COMMENT: column units
DEFINITION: The value field shall contain a character string describing the physical units in which the quantity in field n, after any application of TSCALn and TZEROn, is expressed. The units of all FITS header keyword values, with the exception of measurements of angles, should conform with the recommendations in the IAU Style Manual. For angular measurements given as floating point values and specified with

reserved keywords, degrees are the recommended units (with the units, if specified, given as 'deg').

KEYWORD: XTENSION
REFERENCE: FITS Standard
STATUS: mandatory
HDU: extension
VALUE: string
COMMENT: marks beginning of new HDU
DEFINITION: The value field shall contain a character string giving the name of the extension type. This keyword is mandatory for an extension header and must not appear in the primary header. For an extension that is not a standard extension, the type name must not be the same as that of a standard extension.

REFERENCES

Checksum:
<http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/docs/general/checksum/checksum.html>

FITS Standard:
http://archive.stsci.edu/fits/fits_standard/

HEASARC:
http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/docs/general/ogip_94_001/ogip_94_001.html

NOAO:
<http://iraf.noao.edu/iraf/web/projects/ccdmosaic/imagedef/fitsdic.html>