Wide-field Infrared Survey Explorer (WISE)

Project Data Management Plan

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1 INTRODUCTION

The Wide-field Infrared Survey Explorer (WISE) is a NASA Medium Class Explorer (MIDEX) mission that is carrying out a sensitive, digital imaging survey of the entire sky in the 3.4, 4.6, 12 and 22 μm mid-infrared bandpasses. WISE will produce and release to the world astronomical and educational communities and general public a digital Image Atlas covering the sky in the four survey bands, and a reliable Source Catalog containing accurate photometry and astrometry for approximately 300 million objects. The WISE Catalog and Atlas will enable a broad variety of research efforts ranging from the search for the closest stars and brown dwarfs to the most luminous galaxies in the Universe. The WISE science data products will serve as an important reference data set for planning observations and interpreting data obtained with future ground and space-borne observatories such as JWST.

WISE conducts its survey using a 40 cm cryogenically-cooled telescope equipped with a camera containing four mid-infrared focal plane array detectors that simultaneously image the same 47'x47' field-of-view (FOC) on the sky. The spacecraft flies in a sun-synchronous 525 km polar orbit and the telescope points near the zenith to scan the sky continuously while a scan mirror temporarily freezes the sky on the focal planes. As the telescope scans, a sequence of independent 8.8 sec exposures are acquired on each point on the sky. The FOV of each successive exposure overlaps the previous one by 10%, and the scan paths of adjacent orbits overlap by approximately 90% of the FOV on the ecliptic due to the WISE orbital precession. The number of independent exposures accumulated on each point on the sky is typically eight or more on the ecliptic equator and increases towards the ecliptic poles as the orbital scan paths converge. WISE is designed to achieve a minimum point source sensitivity on the ecliptic corresponding to a flux signal-to-noise ratio $\geq$5 at flux densities of 0.12, 0.16, 0.85 and 4.00 mJy at 3.4, 4.6, 12 and 22 μm, respectively, with eight exposures on the ecliptic in regions of the sky not confused by Milky Way stars and diffuse emission. The astrometric precision of the WISE Source Catalog and Atlas will be $\leq$0.5" with respect to the 2MASS All-Sky PSC.

WISE was launched on December 14, 2009 from the Western Test Range at Vandenberg Air Force Base. Nominal survey observations were started on January 14, 2010 following a one-month in-orbit checkout (IOC) phase. In this plan the nominal on-orbit data acquisition operations period is assumed to be nine months long with the entire sky being covered once in the first six months. A second survey will be conducted during the final months of cryogen lifetime. On orbit data acquisition will continue as long as WISE has cryogen.

A preliminary Source Catalog and Image Atlas covering 55% of the sky observed during the first survey will be released on April 14, 2011. The final Catalog and Atlas will be released 17 months after the end of on-orbit data acquisition. WISE science data products will be distributed via the on-line and computer-compatible services of the NASA/IPAC Infrared Science Archive (IRSA).

The WISE principal investigator is Dr. Edward Wright (UCLA). Management of the WISE mission, mission systems engineering, mission assurance, and mission operations are performed by the Jet Propulsion Laboratory. The Space Dynamics Lab., Utah State University is responsible for the WISE payload (telescope, optics, detectors, electronics). Ball Aerospace and Technology Corp. is responsible for the WISE spacecraft and system integration. Science data processing, archiving, and distribution is performed by the Infrared Processing and Analysis Center, California Institute of Technology (IPAC). IPAC serves as the WISE Science Data Center (WSDC). Education and Public Outreach for the WISE mission is managed by UC Berkeley. The components of the WISE system and responsible institutions are illustrated in Figure 1.

1.1 Document Scope

This Project Data Management Plan (PDMP) describes project-level policies, schedules and plans for handling, processing, distribution and archiving of the science data for the Wide-field Infrared Survey Explorer.

The scope of this document covers the ground data system as it applies to the mission science data, from downlink to final archiving. This document does not apply to operating the mission or spacecraft, which is managed separately by the WISE project. The PDMP identifies the primary and supplementary science data products of WISE, systems associated with data handling, and the roles and responsibilities, and operational interfaces affecting those systems.

This document duplicates some information found in the WISE MOS/GDS Functional Design Book (JPL D-37573) and the WISE Science Data Center Functional Design Document (WSDC D-D001).

1.2 Applicable Documents

This plan conforms to the specifications in the following project documents:

WISE Project Plan (JPL D-28683)
WISE Level 1 Requirements Document (JPL D-34056)
WISE Level 1.5 Science Requirements Document (JPL D-30563)
WISE MOS Requirements Document (JPL D-30571)
MOS GDS Interface Control Document (JPL D-34372)
MOS GDS Functional Design Book (JPL D-37573)
WSDC Function Requirements Document (WSDC D-R001)
WSDS Functional Design Document (WSDC D-D001)
WSDC Science Data Quality Assurance Plan (WSDC D-M004)
WSDC/IRSA Archive Design Document (WSDC D-D007)
WISE Digital Electronics Box Data Processing Description (SDL/06-070)

2 ROLES AND RESPONSIBILITIES

2.1 IPAC – WISE Science Data Center (WSDC)

The Infrared Processing and Analysis Center (IPAC) at the California Institute of Technology is the WISE Science Data Center and is responsible for science data processing, distribution and archiving. IPAC works with the PI and Science Team to develop algorithms for the data processing pipeline, metrics for science data quality verification, and to develop an effective archive that is accessible to the WISE team and to the scientific user community. IPAC develops a long-term archive plan for the Level 0 science data and the main science data products from the mission. The plan describes the contents of the archives, the size of the archives, and the schedule for delivery. The final archive is to be integrated into the services and policies of the NASA/IPAC Infrared Science Archive (IRSA), NASA's designated archive center for infrared and sub-millimeter astronomy missions.

2.2 JPL - Mission Operations System (MOS)

The WISE MOS is responsible for all flight system scheduling and navigation, commanding, real-time operations and flight system health/safety monitoring, and uplink and downlink processes and coordination with WSDC. The WISE MOS is responsible for managing the data holdings at White Sands Complex (WSC). MOS coordinates with WSC to receive the downlinked telemetry packets. MOS operates a High Rate Data Processor (HRP) that converts raw telemetry from each downlink session into transfer packets and transfers them electronically to the WSDC. An interim archive of raw telemetry will be maintained by the MOS at WSC for retransmission to WSDC in the event of corruption in the original transfer or ingest process at IPAC. MOS element architecture and functional roles are described in detail in the WISE MOS/GDS Functional Design Book (JPL D-37573).

2.2.1 WISE Telemetry Command and Communications Subsystem (WTCCS)

The WTCCS is the core of the MOS real time uplink and downlink system. WTCCS receives high rate science data from the TDRSS terminal and processes them using a WISE-supplied and operated high rate data processor (HRDP) at WSC. WTCCS receives low-rate engineering telemetry from the TDRSS terminal and performs frame synchronization and packet extraction. The packets are channelized for processing and display and the CFDP file data is reconstructed. High rate data science data packets are transmitted electronically to the WISE Science Data Center (IPAC). The engineering telemetry is transferred electronically to the MOS at JPL. A daily frame accountability summary is generated and transmitted to MOS and WSDC.

2.3 TDRSS Terminal at White Sands Complex (Ground tracking station)

The TDRSS terminal at the White Sands Complex (WSC) provides real time interfaces allowing the WISE MOS at JPL to receive both "Low Rate" S-band and "High Rate" Ku-band telemetry data and to send uplink commands to the WISE spacecraft via an S-band uplink. The TDRSS terminal performs convolutional decoding of the S-band and Ku-band telemetry. The decoded low rate telemetry is sent to the WISE MOS at JPL. The Ku-band data is transferred to the WISE HRP at WSC for processing via a 100 Mbit/sec data stream.

2.4 Space Dynamics Laboratory, Utah State University (SDL)

SDL is responsible for design, construction and delivery of the WISE payload. The payload includes the detector instrument package, imaging optics system, telescope and optics and cryostat. SDL is responsible for on-board data processing done within the payload. This processing, which is described in SDL/06-070, is carried out by the payload's Digital Electronics Box (DEB). Four data processing boards within the DEB, one dedicated to each band of focal plane data, perform sample-up-the ramp processing and transmit processed data to the spacecraft. The DEB processing also includes the 2x2 binning of the band 4 (22μm) pixel data. The on-board payload data processing is not described further in this document.

During mission operations, SDL will participate in reviewing and trending WISE payload engineering telemetry that is sent to them from the MOS at JPL.

2.5 Ball Aerospace and Technology Corporation (BATC)

BATC is responsible for design, construction and delivery of the WISE spacecraft, and integration and testing of the flight system. The spacecraft bus includes all power and navigation facilities for the flight system, and all communication equipment. The spacecraft system contains a flash memory system that stores and stages up to three days of WISE science and stored telemetry data. On-board science data and telemetry processing is performed by the spacecraft's Mission Unique Board (MUB). This processing includes applying Rice (lossless) compression to the WISE payload data, packetizing and applying CCSDS encoding. Science and some engineering telemetry data are transmitted to TDRSS via a Ku-band high gain antenna. Command uplink and some telemetry downlink is made via S-band transceiver. The interface between the WISE flight system and ground operations is described in the WISE Flight-Ground ICD. This interface and details of on-board spacecraft data processing are not discussed further in this document.

During mission operations, BATC will participate in reviewing and trending WISE spacecraft engineering telemetry that is sent to them from the MOS at JPL.

2.6 Survey Planning Center at the Univ. of California Los Angeles

The Survey Planning Team at UCLA generates periodic survey plans that are transmitted to the MOS at JPL for translation into command sequences and uplink to the spacecraft for execution. The Survey Planning Team assesses the quality and progress of the ongoing survey using science data QA reports provided by the WSDC.

2.7 Principal Investigator and Science Team

The WISE PI and Science Team work with the WSDC to develop efficient and effective algorithms for data processing, and metrics and tests to assess downlinked science data quality. The PI and Science Team work with IPAC to validate WISE data products during the data processing stage, and in preparation for data product releases. The PI and Team also contribute to the preparation for the mission explanatory documentation.

3 DATA FLOW

In this section, we describe at a high level the flow of WISE science and engineering data from downlink to archiving. WISE end-to-end data flow is illustrated in Figure 2.

Compressed, encoded science data and selected engineering telemetry is transmitted via "High-Rate" Ku-band transmitted from the WISE flight system to TDRS for relay to the TDRSS terminal at White Sands Complex (WSC). Some engineering telemetry is also transmitted to TDRSS terminal via "Low Rate" S-band relay. S-band and Ku-band downlink occurs approximately four times per day, with each contact taking approximately 15 minutes.

The TDRSS terminal performs convolutional decoding of the S-band and Ku-band telemetry. Following each downlink contact, the Ku-band data are transferred to the WISE-provided and operated high rate data processor (HRP) at WSC via a 100 Mbit/sec data stream. The decoded Low Rate S-band telemetry is sent electronically to the MOS at JPL.

The WISE HRP receives the science image data from the TDRSS terminal in the form of a stream of Reed-Solomon encoded AOS transfer frames. The HRP performs Reed-Solomon decoding, packet extraction and stored extracted packet files by virtual channel. The HRP generates a frame accountability report describing the overall quality and continuity of the received data (MOS/GDS Function Design Book). Following the processing of the data from each downlink, the HRP transfers the raw data packets to the WISE Science Data Center at IPAC. (4Mbps data line from WSC to IPAC)

Six months of science data packet files are stored on a RAID file storage system at WSC in the event that a retransmission to IPAC is necessary.

The WTCCS at JPL receives the S-band and Ku-band telemetry frames from the White Sands Data Complex Interface Service Capability (WDISC) and performs frame synchronization and packet extraction. The packets are channelized for processing and display and the CFDP file data is reconstructed. A subset of engineering telemetry along with assorted navigation products are forwarded to the WSDC at IPAC for merging with the

raw science data. The engineering telemetry, navigation and ancillary files provided by the MOS are:

a. Housekeeping telemetry in CSV format files
b. Sp Kernel files that provide spacecraft ephemeris (plus planetary SP Kernels)
c. C Kernels that contain spacecraft pointing information
d. SCLK Kernels that provide flight system clock information
e. Leap Seconds Kernels
f. Ground track file that gives the flight system's position over the Earth
g. Predicted Events File
h. Command mnemonics file (.cmf)
i. Survey Plan (output from Science Planning System)

Processed spacecraft and payload engineering data are also routed to BATC and SDL for health and safety monitoring and flight system trending.

The WSDC at IPAC receives the science data packets transferred by the HRP, validates the contents of each transfer and reports the status of the validation to MOS so that that the data can be released from the WCS interim storage, if necessary. The WSDC receives engineering telemetry files from MOS asynchronously from the science packets. Because of their smaller size, the engineering telemetry and ancillary files from MOS will usually arrive at IPAC before their respective science data packets. However, if the downlink science data is small, then this may not be the case.

Once each electronic transfer from the HRP is complete, the WISE Science Data System (WSDS) Ingest subsystem decompresses the science data packets, and assembles them into raw FITS format images. Ancillary files are processed using NAIF library routines and custom code and along with the engineering telemetry are correlated with the science data using VTC time stamps. Relevant engineering parameters are added to the headers of the raw FITS images to create Level 0 FITS images. The Ingest file system then stages the Level 0 science data for pipeline processing.

Pipeline processing at the WSDC (described in Section 4), removes the instrumental signature from the raw science image frames, detects and characterizes discrete sources on the images, and derives and applies astrometric and photometric calibration to the image and extracted source data. A later stage of processing combines all images covering a region of the sky and detects and characterizes sources from the coadded images. Processed image, extracted source and metadata associated with both are written to the WISE science archive.

During and following data processing, the WISE Science Data Center performs quality assurance that assesses the integrity of flight system data, the completion status of data processing, and the derived characteristics of the science data relative to the WISE mission performance and data product requirements.

At the completion of data processing, the WSDC in collaboration with the WISE PI and Science team generates and validates the WISE Image Atlas and Source Catalog for release.

These products are “delivered” to IRSA. The WISE Image Atlas and Source Catalog are distributed to the astronomical community and general public via the on-line and computer-friendly interfaces of IRSA. IRSA also provides the long-term “living” archive for the final WISE science products to insure their accessibility to the community in perpetuity.

Following the end of WISE mission activities, the WSDC will send a copy of the WISE Level 0 FITS image data to the NSSDC for long-term archiving.

4 SCIENCE DATA PROCESSING

4.1 The WISE Science Data System (WSDS)

Science data processing at the WSDC is carried out by the WISE Science Data System (WSDS). The WSDS is a hardware, software, operations and analysis system that converts raw WISE image data packets and engineering telemetry into the photometrically and astrometrically calibrated Image Atlas and Source Catalog. The requirements for the WSDS are described in the WSDC Functional Requirements Document (WSDC D-R001). The design of the WSDS is described in the WSDC Functional Design Document (WSDC D-D001).

In Figure 3 is shown the functional flow of the WSDS. The WSDS is comprised of seven primary subsystems: INGEST, PIPELINES, QA, EXEC, FPG, ARCHIVE and NEOWISE. The high level function of each subsystem is described below.

4.1.1 INGEST

The WSDS INGEST subsystem receives science data packets from the HRP at WSC and engineering telemetry and navigation data from MOS/WTCSS and assembles from them Level 0 FITS-format files. INGEST also stages Level 0 images and metadata for pipeline processing.

4.1.2 PIPELINES

The WSDS PIPELINES converts Level 0 imaging data into photometrically and astrometrically calibrated images and extracted source lists. The PIPELINES subsystem is comprised of three main components, the Scan/Frame Pipeline, the Multi-Scan Pipeline and the Multiframe Pipeline.

Scan/Frame Pipeline – The Scan/Frame pipeline operates on individual f*ramesets* (images in the four WISE bands corresponding to one exposure) within one *scan* (=1/2 orbit) of WISE data. It performs basic instrumental calibration, detects and characterizes sources from individual images, and derives and applies photometric and astrometric calibration. The Scan/Frame Pipeline also identifies sources detected in the individual frames that are associated with known solar system objects such as asteroids, comets, planets and planetary satellites. The Scan/Frame functional block diagram is shown in Figure 4.

Multi-Scan Pipeline – The Multi-Scan pipeline is an adjunct of the Scan/Frame pipeline. It performs operations such as artifact flagging and photometric calibration that require access to frame data from multiple scans, but whose results are still applied to the individual frameset images and source extractions. The combination of the Scan/Frame and Multiscan pipelines produce Level 1 images, source extractions and metadata.

Multiframe Pipeline – The Multiframe pipeline operates on data from more than one frameset from multiple scans. This pipeline combines images covering the same region on the sky, detects and characterizes sources from those images and performs any updates on the photometric and astrometric calibration that are necessary. The Multiframe pipeline functional diagram is shown in Figure 5. The Multiframe pipeline produces Level 3 images, source extractions and metadata.

4.1.3 QA (Quality Assurance)

The QA subsystem generates concise reports summarizing science data quality using summary outputs from all of the other WSDS subsystems. These reports are in the tabulated in web-based compilations that provide capability to drill-down to detailed image, graphical and tabular data. QA reports are reviewed by quality assurance scientists at the WSDC. Final quality assignments for WISE data are approved by the WISE PI or his designee.

4.1.4 EXEC

The EXEC subsystem of the WSDC provides interface-related services to software wrappers and pipelines. EXEC mediates between external callers and applications, providing a uniform interface, binding execution units (modules) together into a unified pipeline

4.1.5 FPG (Final Product Generation)

The WSDC FPG subsystem constructs the WISE Preliminary and Final Image Atlases and Source Catalogs from the results of the Scan/Frame pipeline. FPG includes a Multiframe pipeline step, along with database and human analysis-intensive operations. The FPG system selects the subset of rows in the source Working Databases that satisfy the WISE Level 1 Requirements for Catalog reliability. For both the Image Atlas and Source Catalog, FPG assembles final formats and generates any new derived header or catalog parameters that are not already in the Level 3 image and source archives. The FPG system includes characterization, validation, and documentation of the WISE release data products.

4.1.6 ARCHIVE

The WSDC Archive subsystem is a multi-tier system that stores raw and processed mission data and metadata. The WISE Archives, described in Section 9, store and serve images, source and metadata to the operational processing system, and to the WISE project team and astronomical community. A component of the ARCHIVE subsystem is integrated into the WSDS processing system and a component is integrated into the IRSA at IPAC.

4.1.7 NEOWISE

The NEOWISE subsystems is an enhancement to the primary WISE mission data processing system that enables the discovery of previously unknown solar system objects, and provides a database for science users to pre-cover objects that are found after the end of the WISE mission. Funded by the NASA Planetary Division, the NEOWISE enhancement consists of the WISE Moving Object Pipeline System (WMOPS) that links non-inertial detections made on the single-exposure WISE images made near the same point on the sky to form candidate moving object "tracklets" that are reported to the Minor Planet Center (MPC). The goal of WMOPS processing is to report candidate tracklets within 10 days of the midpoint of the WISE observations. The MPC is computes initial orbits and posts objects on their websites for follow-up and confirmation by ground-based observers.

The archive component of the NEOWISE enhancements provides for the release of the WISE single-frame images and extracted source databases to the science community in conjunction with the WISE primary mission data releases. These products will be released via the IRSA interfaces. NEOWISE also provides for the development of interface query enhancements to the IRSA service that will enable searching for the image or extracted source information for moving objects by solar system object name or orbital elements.

The NEOWISE subsystem is described under separate cover and is not discussed further in this document.

4.2 Data Processing Steps

4.2.1 Ingest

Ingest processing receives, unpacks and decompresses the science packets sent from the HRDP, and time-stamped engineering data files from MOS/WTCCS. The HRDP packets are assembled into FITS-format images. Engineering data is then matched to the appropriate science images using time coordination, and written into the image FITS headers to produce Level 0 images. Data receipts are validated for content. The Level 0 images are then staged for pipeline processing.

4.2.2 Scan/Frame Processing

4.2.2.1 Instrumental Frame Calibration

Correct Si:As array images for droop. Subtract detector bias structure using the array detector reference pixels. Subtract dark response, linearize, divide by the flat field response image, and subtract sky illumination correction for each image. Mask bad pixels.

4.2.2.2 Source Detection and Characterization

Detect sources on individual frames for the purpose of calibrating band-to-band offsets and basic position reconstruction. Then detect sources on images in four WISE bands simultaneously for optimal extraction. Determine source centroids and measure brightnesses using profile-fit and multi-aperture photometry.

4.2.2.3 Artifact Identification

Identify and flag extracted sources that are associated with the predicted positions of image artifacts produced by bright sources. Artifacts include spurious detections of latent images of stars falling on preceding frames, diffraction spikes, optical and electronic ghosts, etc. Also flag real source detections that may be contaminated due proximity to image artifacts.

4.2.2.4 Position Reconstruction

Derive transformation to convert pixel coordinates to equatorial (J2000) coordinates in four bands. Transformation uses detections in each frame of 2MASS All-Sky PSC sources, which is the WISE astrometric reference, to fit for the field offset and rotation with respect to the commanded pointing. The astrometric solution also uses an a priori band-dependent model for optical distortion and plate scale that was derived from off-line analysis of the measurements of large samples of reference stars. The transformation is applied to both the images (WCS information in the headers) and extracted source position data.

4.2.2.5 Photometric Calibration

Derive transformation to convert brightness of sources measured in instrumental units (DN or digital units) to physical units. Photometric calibration is made relative to measurements of a network of standard stars of known brightness in the four WISE bands that are observed by WISE frequently. Photometric calibration information is applied to the individual images and to the extracted source databases.

4.2.2.6 Known Solar System Object Association

Sources extracted from each image frameset are associated with the positions of *known* solar system objects (at the time of data processing) that are predicted to be within the boundaries of the image at the epoch of the WISE observation. No attempt is made to identify previously unknown solar system objects in this operation (see Section 4.1.7).

4.2.3 Multiple Frame Processing

4.2.3.1 Image Combination/Mosaicking

Some or all image frames that cover a specified area (nominally the footprint of a WISE Image Atlas) are registered, resampled and optimally combined to produce a more sensitive image. Images from all four WISE bands are aligned to the same footprint and pixel scale. Images will be scaled to a common throughput level and will have backgrounds matched within the boundaries of the Atlas Image. Pixel combination includes outlier rejection to suppress transient events such as cosmic ray strikes, unstable or "hot" pixels and fast moving objects. The resulting combined images are Level 3 images.

4.2.3.2 Source Detection and Characterization

Sources are detected on the combined images in the four WISE bands simultaneously. The brightness of each detected source is measured using both profile-fitting and multi-aperture photometry. Brightness upper limits are derived in any band in which a source is not detected.

4.2.3.3 Artifact Identification

Identify and flag extracted sources that are associated with the predicted positions of image artifacts produced by bright sources. Artifacts include spurious detections of latent images of stars falling on "preceding" frames, diffraction spikes, optical and electronic ghosts, etc. Also flag real source detections that may be contaminated by proximity to image artifacts.

4.2.3.4 Calibration Update

If necessary, update the astrometric and photometric calibration using information derived from sources measurements in adjacent, overlapping scan/orbits. Apply this information to the extracted source lists and to the WCS header information in the combined images. At the time of version 2.1 of this document, the calibrations derived from the scan/frame pipeline processing are believed to be sufficient and this step will not be necessary in the Multi-frame pipeline.

4.2.4 Quality Assurance

Perform quality analysis for image and extracted source data. This analysis verifies data integrity, processing completion status, and extracted science data quality. Science data quality is assessed by comparison extracted image and source data properties to metrics that are linked to the WISE Level 1 and 1.5 requirements on sensitivity, photometry and astrometric accuracy, completeness and reliability. QA analyses also examine a limited number of payload parameters that may be monitored using science data, including scan-mirror/spacecraft scan rate synchronization, system throughput and detector noise properties. Concise reports summarizing the science data quality are posted in web-format for review by quality assurance scientists at WSDC, Survey Planning Team at UCLA and MOS for the purpose of tracking mission sky coverage and flight system performance.

During Scan/Frame processing, each frameset is assigned a numerical quality score that combines factors based on several metrics. These scores are used to determine if a frameset will be included in Multiframe processing for the WISE data releases.

The QA activities are described in detail in the WSDC Science Data Quality Assurance Plan (WSDC D-M004).

4.2.5 Archive

Once scan/frame and multi-frame pipeline processing steps are completed, the calibrated images, source extraction tables and assorted metadata are transferred to and loaded into an Image Archive and *Source Working Database* (WDB). These archives are built within the framework of the Infrared Science Archive (IRSA) at IPAC so that the WISE Science and Team and partners can access the data using the extensive image visualization and database query tools already developed by IRSA.

The WISE Image Atlas and Source Catalog are derived from the pipeline-processed data contained in the working archives. After validation and review, these products are served to the astronomical community via the IRSA interfaces.

4.2.6 Final Product Generation

WISE Final Product Generation is a multistep process that is carried out for each WISE data release.

FPG begins by selecting the scan and frameset data that will included in a particular data release. This is driven by the release scope (55% of the sky for the Preliminary Release and 100% of the survey data for the Final Release) and frameset quality as assessed during the scan/frame processing QA evaluation. Multi-frame pipeline processing is then run to construct the Atlas Images for each release, and extract sources from the images to construct the Source WDB.

The Source WDB will contain detections of real astrophyscial sources, as well as spurious detections of faint noise excursions, image artifacts and transient pixel events. The Catalog preparation FPG step selects the subset of reliable detections in the WDB using SNR and other quality flag criteria to comprise the rows in the Source Catalog. Catalog preparation may also include the definition of final Catalog columns and formats, and the generation of new columns as necessary.

The Atlas Image Preparation FPG step entails applying any updates necessary to the headers of the Atlas Images required for the release. This might include the deletion or addition of metadata that would be considered useful for the end users.

Once the provisional Source Catalog and Image Atlas are generated, the next step in FPG is the general validation and characterization of the products. Validation will include analyses that confirm that the Atlas and Catlog satisfy the requirements for release, as specified in the

mission Level 1 and 1.5 requirements documents. Characterization includes analyses that described the general features and limitations of the release products with the intention of enhancing usability of the products for the science community. All validation and characterization steps are to be adequately documented to support the Release Readiness reviews and for inclusion in the WISE Explanatory Supplement for each release.

The final step in FPG is the assembly, editting and review of the Explanatory Supplement for the release. The Supplement is the general user guide for the data release that contains a general description of the WISE mission elements, survey operations, data processing, and data product formats, contents and cautionary notes. It also provides data aceess guides.

4.3 Data Processing Levels

The terminology used to describe WISE image data during the different stages of downlink and processing is summarized in Table 1. There are corresponding extracted source tables, databases or catalogs at Levels 1b, Level 3 and Atlas Image. Level 0, Level 1b and Level 3 images are retained for long-term archiving. Level 2 images are transient products not retained in long-term disk storage.

Table 1 - WISE Data Processing Levels

Name	Description	Source
Telemetry	CCSDS Source Packets	MOS/HRDP
Raw	FITS, integer 2.75" pixels, band+time meta-data	WSDC/Ingest
Level 0	Raw + Floating point pixels, add much meta-data	WSDC/Ingest
Level 1	Level-0 + instrumental, astrometric/photometric calibration	WSDC/Scan-Frame P/L
Level 1a	Level-0 + instrumental calibration applied to pixels	WSDC/Scan-Frame P/L
Level 1b	Level-1a + astrometric/photometric calibration in header	WSDC/Scan-Frame P/L
Level 2	Level-1 + upsampled and undistorted (rubber-sheeted)	WSDC/Scan-Frame P/L
Level 2a	Level-1a + upsampled and undistorted	WSDC/Scan-Frame P/L
Level 2b	Level-1b + upsampled and undistorted	WSDC/Scan-Frame P/L
Level 3	Multiple frame coadds, upsampled, undistorted	WSDC Multiframe P/L
Atlas Image	Selected FPG Level-3 products	WSDC/FPG

4.4 Multi-Stage Data Processing

Science data collected by WISE will be processed in multiple stages depending on the phase of the mission. This multi-stage approach to processing is designed to balance the need to release data as quickly as possible to the community with the need to generate well-vetted products that fully exploit the scientific capabilities of WISE.

4.4.1 Provisional Processing

During IOC and the first several months of survey operations, *provisional processing* of WISE science data is performed to support IOC testing and Quicklook quality assurance assessment to monitor survey performance. This processing stage will use the pre-launch version of the WSDS (v3.0) along with calibration products based on the best available ground test results. Provisional processing will be discontinued once update calibration products and the first post-launch version of WSDS (v3.5) is delivered, and first-pass processing begins.

4.4.2 First-Pass Processing

Following WSDS testing and tuning to actual on-orbit performance during IOC and the first two months of on-orbit operations, the WSDC will initiate first-pass processing of the Level 0 WISE science data. This processing will use preliminary instrumental, photometric and astrometric calibrations that are derived from ground test, IOC and early survey data. During first-pass processing, the WSDS systems may be updated in response to improved understanding of WISE data and processing algorithm characteristics. All of the early survey data run through provisional processing will be rerun during first-pass processing to generate a fairly uniform archive of images and extracted source lists. The WISE Preliminary Release Image Atlas and Source Catalog are generated from this stage of processing.

4.4.3 Second-Pass Processing

Following the end of on-orbit data acquisition, all WISE science data will undergo a complete reprocessing using an updated version of the WSDS (v4) that incorporates the best available calibration and processing parameter and algorithms derived from analysis of payload, spacecraft over the life of the mission, and from analysis of the preliminary processing results. The WISE Final Release Image Atlas and Source Catalog will be derived from the output of the second-pass data processing.

4.4.4 Data Processing Latency

4.4.4.1 Science Data Processing

The WSDC ingests and processes the raw image and engineering data within six days of their arrival from WSC and MOS/WTCCS. Processing is performed during on-orbit mission operations using an automated software pipeline that uses preliminary instrumental, photometric and astrometric calibration parameters, derived during ground test and the in-

orbit validation period. The preliminary Image Atlas and Source Catalog are generated from this first-pass processing.

All science data gathered during on-orbit mission operations undergoes second-pass processing and validation following the end of on-orbit mission operations and the release of the preliminary data products. Second-pass processing incorporates improved parameters derived from analysis of spacecraft, instrument and preliminary processing results over the life of the mission.

The WISE science data processing and archive system at IPAC is sized to be able to keep up with the data acquisition rate. The science data received twice per week from White Sands is processing, validated and loaded into the working archives within one week.

4.4.4.2 Validation

Within 3 days of their arrival at IPAC, IPAC validates the integrity of the raw science data packets sent by the HRP, and compares their contents with the manifest file provided by MOS. If the data are corrupted, contain errors in the read validation, or do not contain the data specified in the manifest report, IPAC requests a resend of the data from WSC.

4.4.4.3 Science Data Transfer

Raw science data are transmitted from the HRDP following each downlink session and processing at WSC. 24 hours of science data take approximately 15 hours to transmit to WSDC. The raw science telemetry are archived for at least 30 days at the White Sands in an interim storage facility so that data can be resent in the event of transfer corruption or failure. Science data are released from the interim archive upon confirmation of their receipt and validation by IPAC.

4.4.4.4 Downlink and Verification

The MOS validates the integrity and content of each downlink at White Sands within 24 hours of the contact. The results of that validation, and the content of the downlink are reported to the WISE Survey Planning Team (UCLA), and the WSDC within 36 hours of the downlink contact. MOS supplies a manifest of data contained in each downlink session.

5 WISE DATA PRODUCTS

The WSDC works with the WISE PI and Science Team to produce two primary data products that will be released to the scientific and educational community to enable the key investigations that embody the WISE mission objectives. The products are an *Image Atlas* and an extracted *Source Catalog*. An Explanatory Supplement that describes the WISE mission and the data products will accompany the release of the Catalog and Atlas. Several ancillary data products will also be generated and released to the user community to enhance to scientific return of the WISE mission. These ancillary products are produced on a best-effort basis.

5.1 Image Atlas

The WISE Image Atlas consists of a set of photometrically and astrometrically calibrated FITS images in four bands that cover the sky. The Atlas will be built on a predefined grid of 18,240 tiles on the sky, with four band-images per tile registered on common astrometric grid. The Atlas Images for each tile will be constructed on an equatorial projection, a pixel scale of 1.375"/pix (two times finer than the native W1/W2/W3 scales), and a size of 4096x4096 pixels (1.564^ox1.564^o). The tiles are distributed in 119 iso-declination bands, with 238 tiles on the equator and six tiles in each of the +/-89.3^o declination bands. The tiles overlap by 180" in right ascension on the equator with the overlap increasing towards the poles.

Each Atlas Image is constructed by coadding multiple L1b images covering each point to improve sensitivity and suppress transient pixel events.. The photometric and astrometric calibration of WISE Atlas Images is tied to the calibration of the extracted source Catalog. The Atlas Image headers will contain all WCS information necessary to describe the conversion of pixel to sky coordinated. Photometric zero points will be included in the headers to enable relative photometric measurements to be performed using the images. However, the pixel values in the Atlas Images are not tied to an absolute scale so cannot be used for direct absolute surface brightness measurements.

5.2 Source Catalog

The WISE Source Catalog contains accurate equatorial (J2000) positions and in-band fluxes (or upper limits) and uncertainties on each measured source in the four survey bands for all reliable sources detected on the Atlas Images. The Catalog will contain a unique identifier for each entry, and a set of flags that encode source detection reliability and measurement quality statistics. The Source Catalog is expected to contain approximately 300 million records.

The requirement for photometric accuracy for entries in the WISE Source Catalog is 7% rms for unsaturated points sources with SNR>100 . Absolute positions of high SNR WISE sources are reconstructed relative to the 2MASS astrometric reference frame, and will be accurate to $\leq$0.5" RMS on each axis with respect to that frame. Lower SNR sources follow the full-width at half-maximum/SNR growth curve.

5.3 Explanatory Supplement

Each WISE data release will be accompanied by an Explanatory Supplement. The Supplement is a web-based document, modeled on the 2MASS and IRAS Explanatory Supplements, that will serve as a user guide to the data relese products. The document will contain descriptions of the WISE mission, payload and spacecraft, WISE mission and operations design, and data processing and calibration algorithms. The Supplement will also provide a detailed description of the WISE product formats and contents, as well as descriptions of the Catalog and Atlas characteristics in relation to the WISE mission

requirements. Users will also be provided a section on caveats and known limitations of the WISE data products.

5.4 Ancillary Data Products

5.4.1 Atlas Image Coverage and Uncertainty Maps

FITS format images will be provided that indicate the depth-of-coverage in each corresponding Atlas Image. Pixel values in the coverage maps are equal to the number of pixels from individual frames that were combined to make the Atlas Image. The coverage maps will take into account fractional pixel coverage due to image reprojection and resampling, and the rejection of masked and outlier pixels. Pixel values in the uncertainty maps will take into account depth-of-coverage, Poisson statistics and detector noise models.

5.4.2 Known Solar System Object Prediction and Association Table

A table will be provided that lists all asteroids, comets, planets and planetary satellites known at the time of data processing that fell within the fields-of-view of the individual WISE exposures. For objects that are positionally associated with WISE detections, the table will also contain the associated WISE source information as well as derived physical parameters such as diameters and albedos.

5.4.3 Single Frame (L1b) Images

L1b images are the photometrically and astrometrically calibrated single-exposure images that are produced during scan/frame pipeline processing. The release of the WISE L1b images as a public data product for WISE is supported as part of the NEOWISE program to enable solar system object related research. The archive of L1b images will contain many different images covering each point on the sky and will be useful for both time-domain studies as well as for validation and analysis of the coadded Atlas Images.

5.4.4 Single Frame Source Working Database

This is the database of detections made on the individual exposure L1b images made during Scan/Frame pipeline processing. This database contains position and brightness measurements and associated uncertainties, along with a selection of flags that indicate the quality of the measurements of that source. This database may contain many apparitions of the same object corresponding to the multiple, independent observations made by WISE during the survey. The single frame extractions are used as input to the NEOWISE Moving Object Pipeline system to identify candidate moving object tracklets. As with the L1b image archive, the release of the Single Frame Source Extraction Working Database as a public product is supported by the NEOWISE program to enable solar system object research.

6 OPERATIONAL DATA PROCESSING CYCLE

The WISE data processing operations cycle is shown in Figure 6.

WISE Science data are transferred from WSC to IPAC up to four times per day following TDRSS contacts. Ingest and Quicklook QA processing is initiated automatically following each transfer. This results in the generation of L0 data and metadata that are stored in the Operations archive.

Scan/Frame processing is run each day following the completion of Ingest and Quicklook QA processing. The resulting Level 1 image, source and metadata products are stored in the Operations archive as well as transferred to and loaded into the IRSA/WISE archive. Transfers to the IRSA archive occur approximately two times per week.

Approximately every two days during the first-pass survey processing, "daily" or more appropriately named "operations" coadds are produced by running the multiframe pipeline processing on two days worth of L1 scan/frame image data. Ops coadds are the same size and pixel scale as Atlas Images, but they are made in an ecliptic coordinate system alignment, and contain only two days worth of L1 image data. The ops coadds and their corresponding source extraction tables are transferred and loaded in the IRSA/WISE archive. WISE ops coadds are used for analysis and testing of the multiframe pipeline in preparation for final product generation. They do not undergo rigorous vetting and are not intended to be a release product.

Final Product Generation processing step is done once before each of the WISE Preliminary and Final Data Releases. Once the Atlas and Catalog products have been generated and validated, they are transferred and loaded into the IRSA/WISE archive for public access.

7 DATA PRODUCT RELEASE PLAN

7.1 Two-stage Data Release Plan

The objective of the WISE mission is to make high quality image and catalog science data products available to the community as rapidly as possible. To facilitate this, data release takes place in two stages. The *Preliminary Data Release* occurs on April 14, 2011. The WISE *Final Data Release* takes place 17 months after the end of on-orbit cryogen data acquisition.

The WISE Preliminary Release consists of an Image Atlas and Source Catalog containing sources with at least SNR>20 in unconfused regions of the sky, along with several Ancillary Products. The Preliminary Release products cover 55% of the sky and are generated using the results of the first-pass processing of data acquired during the first WISE survey of the sky. The Preliminary Release products are intended to introduce science users to WISE data

and enable a broad range of scientific investigations. However, they will not be as extensively vetted and characterized as the final release products.

The WISE Final Data Release consists of the Image Atlas, Source Catalog and Ancillary Products generated using all data taken during cryogenic operations. The Catalog will contain sources as faint as SNR~5 in at least one detected band. The Final Release products will be generated using the results of second-pass data processing made following the end of WISE cryogenic operations. Second-pass processing will utilize the best available calibrations and reduction algorithms that are developed using the full set of survey data. The Final Release products and documentation will be accompanied by more extensive quality analysis, validation and documentation. The Final Release products are intended to be the ultimate deliverables from the WISE mission, and will enable the full range of science investigations planned at the mission's inception.

7.2 Data Release Schedule

The schedule for the WISE Final Data Releases is defined in the project Level 1 Requirements. The schedule is defined relative to the end of on-orbit data acquisition. For the purpose of this document, the end of on-orbit data acquisition is assumed to correspond to the end of cryogenic operations. Shorter or longer cryogenic lifetimes will result in earlier or later final release dates, respectively.

7.2.1 Preliminary Data Release Schedule

Per negotiations with NASA, the WISE Preliminary Data Release will take place on April 14, 2011. This date was designated to allow research using the WISE Preliminary Release data products to be eligible for support under the 2011 NASA ROSES Astrophysics Data Analysis Program (ADAP). To further assist researchers in preparing well-informed proposals to make use of WISE data, the WISE project will post on-line documentation describing the mission, the coverage of the Preliminary Release area, and the anticipated characteristics of the Image Atlas and Catalog by the approximate date of the ADAP call for proposals, which is typically in mid-February.

7.2.2 Final Data Release Schedule

The WISE Final Data Release will take place 17 months following the end of on-orbit data acquisitions, as described in the WISE Level 1 Requirements. For the nominal nine-month survey, the Final Release would take place on March 13, 2012.

7.3 Data Release Readiness Review

A release readiness review will be held approximately one month prior to each scheduled data release date. The reviews will be convened by the WISE PI and IPAC Executive Director. Release readiness will be judged on the characteristics of the WISE Atlas and Catalogs relative to the Level 1 and Level 1.5 specifications, and the appropriateness of the

release user documentation (Explanatory Supplement). Presentations will be made by the WISE Science and Project Team members who have carried out verification analyses on the release products.

8 DATA DISTRIBUTION

8.1 Data Access Policies

Policies governing the access to WISE data prior to the release of formal data products to the community are described in the Science Management section of the WISE Project Plan (JPL D-28683 section 8).

WISE Data Products are released to the astronomical community and general public as rapidly as is technically feasible and scientifically sensible. There is no proprietary period on WISE data, but the mission Data Products are not released to the archive for distribution to the community until they have undergone thorough validation by the PI and Science Team. During first- and second-pass and processing and the data product validation period, the PI and Science Team have unrestricted access to the working archives for the purpose of assisting with the validation of spacecraft, instrument and data processing system performance.

8.2 Data Access

The WISE Atlas and Source Catalog are comparable in size and composition to the 2MASS Image Atlas and Source Catalogs. Thus, plans for Science Team and end-user access to WISE data follow the successful model used to enable access to the data products of 2MASS.

Primary access to the ~10 TB calibrated Image Atlas and ~1 TB Source Catalog is via the on-line services of IRSA at IPAC. Primary WISE access services currently include:

- Catalog Search (GATOR) – a web-based interface that enables complex, efficient queries of massive Catalogs and metadata tables based on any parameter or combination of parameters in the tables.
- Image Service – a web-based interface that enables both interactive and batch requests for all or parts of Atlas Images at a user specified location and size.
- Image Pixel Service – a web-based interface that enables interactive and batch requests of Atlas Images at a user specified location, size, projection and pixel scale. This may combine more than one Atlas Image if the requested footprint intersects boundaries between images.

In addition to the WISE-specific tools, because the WISE data products are integrated into the IRSA infrastructure, WISE data will automatically be visible to a number of IRSA data inventory and cross-mission data discovery services.

WISE science data pipeline processing yields calibrated Images and Source Extractions that are loaded into working databases built within the framework of IRSA at IPAC. The WISE Science Team and project staff will access these working archives using the same on-line IRSA services. Team access to the working archives and preliminary products is restricted using password protection on the IRSA sites.

The WISE Source Catalog may also be distributed via sftp or on DVD or equivalent media, for bulk distribution. Any bulk Catalog distribution will follow the on-line IRSA distribution by several months because of the long production time for commercial DVD vendors.

8.3 Interconnectivity

Because the WISE working archives and release data products are developed with data distribution and archiving in mind, all necessary metadata and other descriptors will be in place to insure compatibility with the existing IRSA tools. This development philosophy that WISE data products are fully interoperable and extensible through the IRSA infrastructure, with related data centers and services that use XML, SOAP, WSDL and UDDI protocols being developed under the NVO initiatives sponsored by NASA and NSF.

9 ARCHIVE PLAN

The WISE Archive has two main components: the Operations archive and IRSA archive.

The Operations archive holds raw and processed data and derived metadata within the processing system. The storage is physically located close to the processing cpu's to minimize latency due to network I/O. The Operations archive serves data to the processing pipelines, QA system and FPG operations through direct file access. The Operations archive design is described in the WISE Science Data System Functional Design Document (WSDC D-D001).

The IRSA archive holds processed data products and derived metadata in the infrastructure of the NASA/IPAC Infrared Science Archive (IRSA). The IRSA archive serves data to the WISE Project Team, the astronomical and educational community, other archive centers and to the general public via on-line interfaces and machine-friendly interfaces. The WISE/IRSA archive is described in the WSDC/IRSA Archive Design document (WSDS D-D007).

9.1 Level 0 Data

Level 0 image data are stored on spinning disk in the Operations archive during the mission period. Three copies of the Level 0 FITS data are written to magnetic tape. Two copies of the Level 0 data tapes are stored at IPAC, and one copy is stored in a commercial off-site secure data storage facility in the Los Angeles area. The commercial facility used is the

same as is being used now by the Spitzer Science Center to archive Spitzer Space Telescope data tapes.

At the completion of WISE project activities after the Final Release, the Operations archive at IPAC will be decommissioned. One copy of the Level 0 data tapes will be sent to the National Space Science Data Center (NSSDC) for long-term, deep archiving. A signed level of service agreement between the IPAC/WSDC and NSSDC describes access capabilities necessary at NSSDC.

9.2 Level 1-3 Data

Level 1 and 3 intermediate images and extracted source databases will be stored in the internal WSDS Operations archive. These will also be delivered to IRSA to provide remote access for the WISE Project Team.

Following the WISE Final Release, all Level 1 and Level 3 data and supporting metadata will have been transferred to IRSA and the Operations archive at IPAC will be decommissioned.

9.3 Final Data Products

WISE Preliminary and Final Release Image Atlas and Source Catalogs will be "delivered" to IRSA. IRSA will provide long-term storage of these data products and the L1 image and source extraction data, and will provide long-term access to them for the astronomical and educational community. At the completion of WISE project activities, IRSA will assume curation of the data products and Explanatory Documentation.

10 ACRONYM LIST

ADAP – NASA ROSES Astrophysics Data Analysis Program
BATC – Ball Aerospace and Technologies Corporation
CPU – Central processing unit
FPG – Final Product Generation
HRDP – High Rate Data Processor
ICD – Interface Control Document
IPAC – Infrared Processing and Analysis Center, California Institute of Technology
IRSA – Infrared Science Archive at IPAC
JPL – Jet Propulsion Laboratory
JWST – James Webb Space Telescope
LAN – Local area network
MOS – Mission Operations System

MSA – Mission Support Area (MOS at JPL)
MTBF – Mean time between failures
MTTR – Mean time to recovery
NASA – National Aeronautics and Space Administration
NSSDC – National Space Science Data Center, NASA/GSFC
QA – Quality assurance
SDL – Space Dynamics Laboratory, Utah State University
TDRSS – Tracking Data Relay Spacecraft System
UCLA – University of California Los Angeles
UTC – Coordinated Universal Time
V&V – Verification and validation
WCS – World Coordinate System
WDISC – White Sands Complex Data Interface Service Capability
WSC – White Sands Complex
WSDC – WISE Science Data Center (IPAC)
WSDS – WISE Science Data System
WTCCS – WISE Telemetry Command and Communications Subsystem
2MASS – Two Micron All-Sky Survey

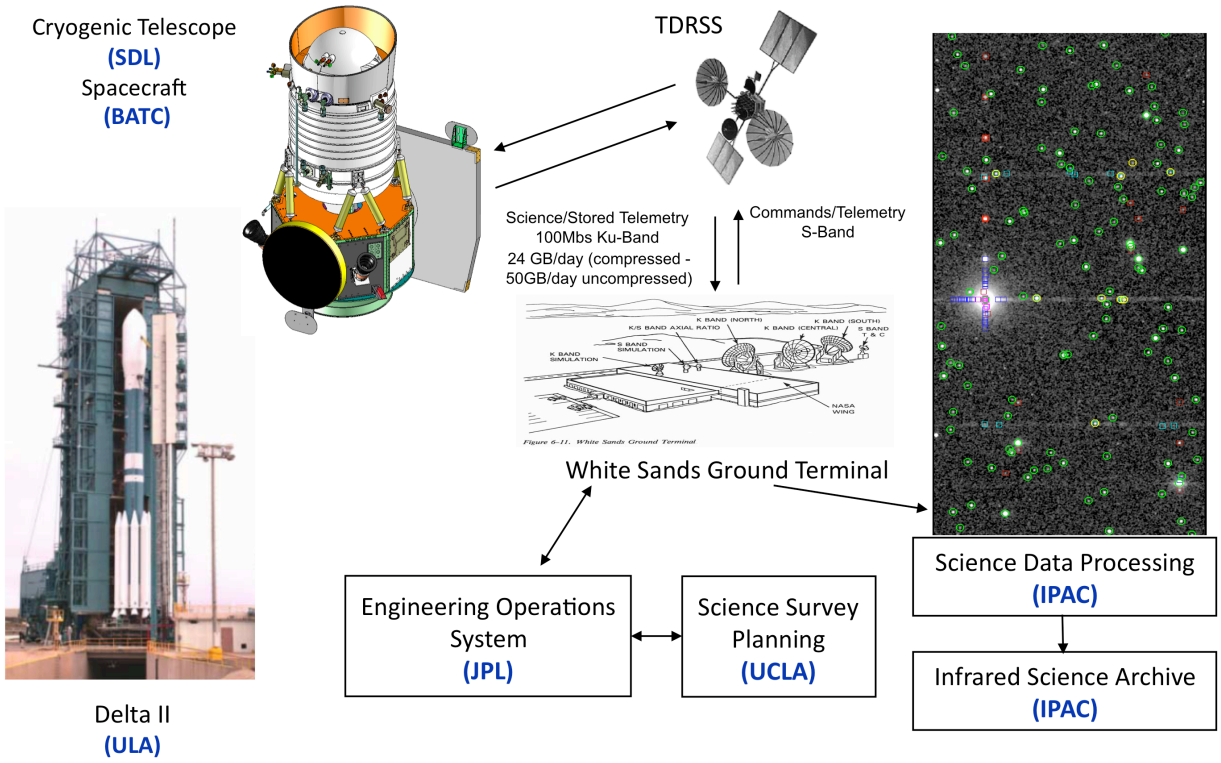

Figure 1 - WISE System Components and Organizations

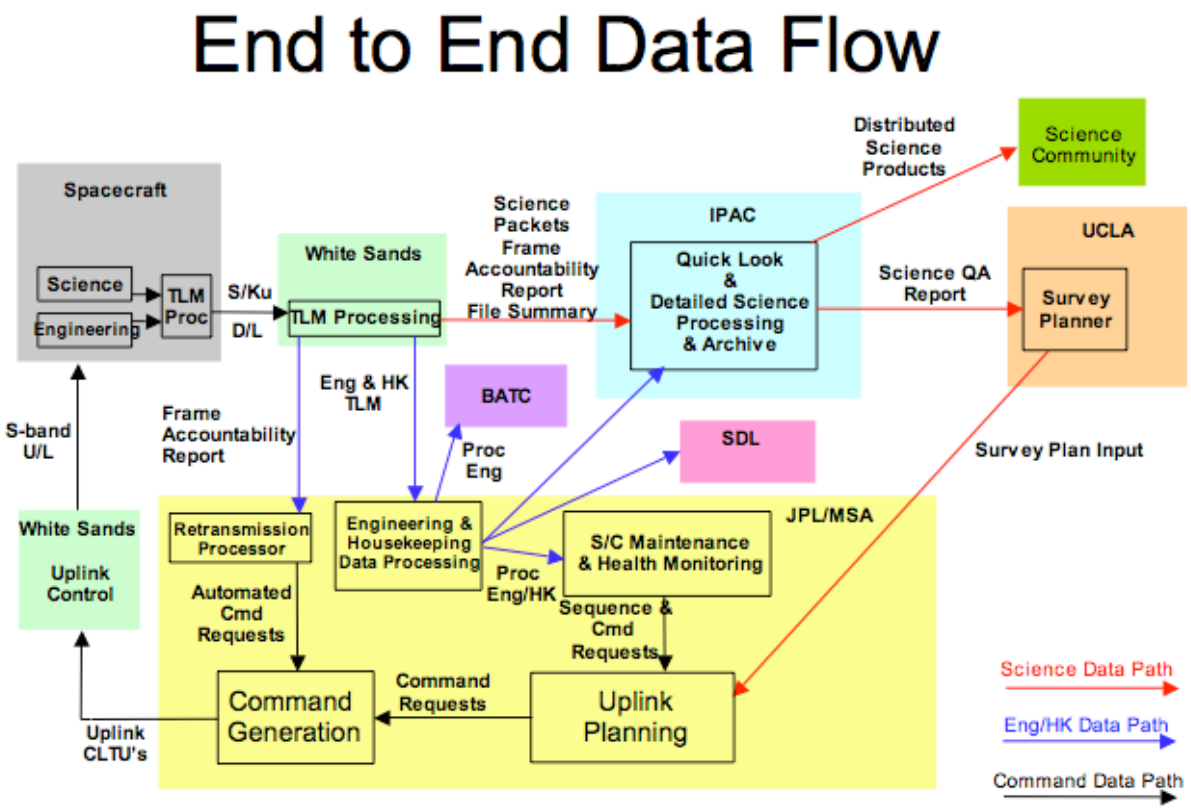

Figure 2 - WISE End-to End Data Flow

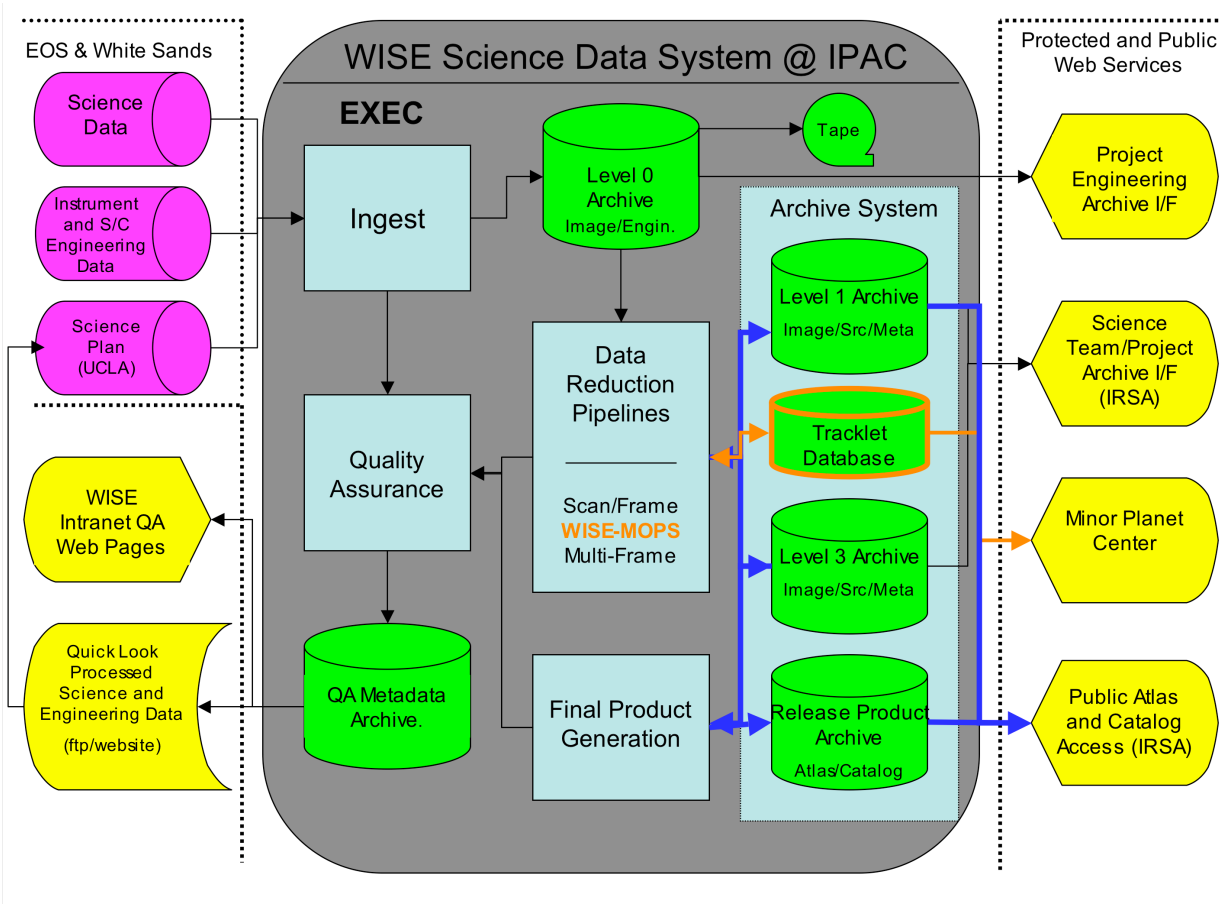

Figure 3 - WISE Science Data System Functional Data Flow

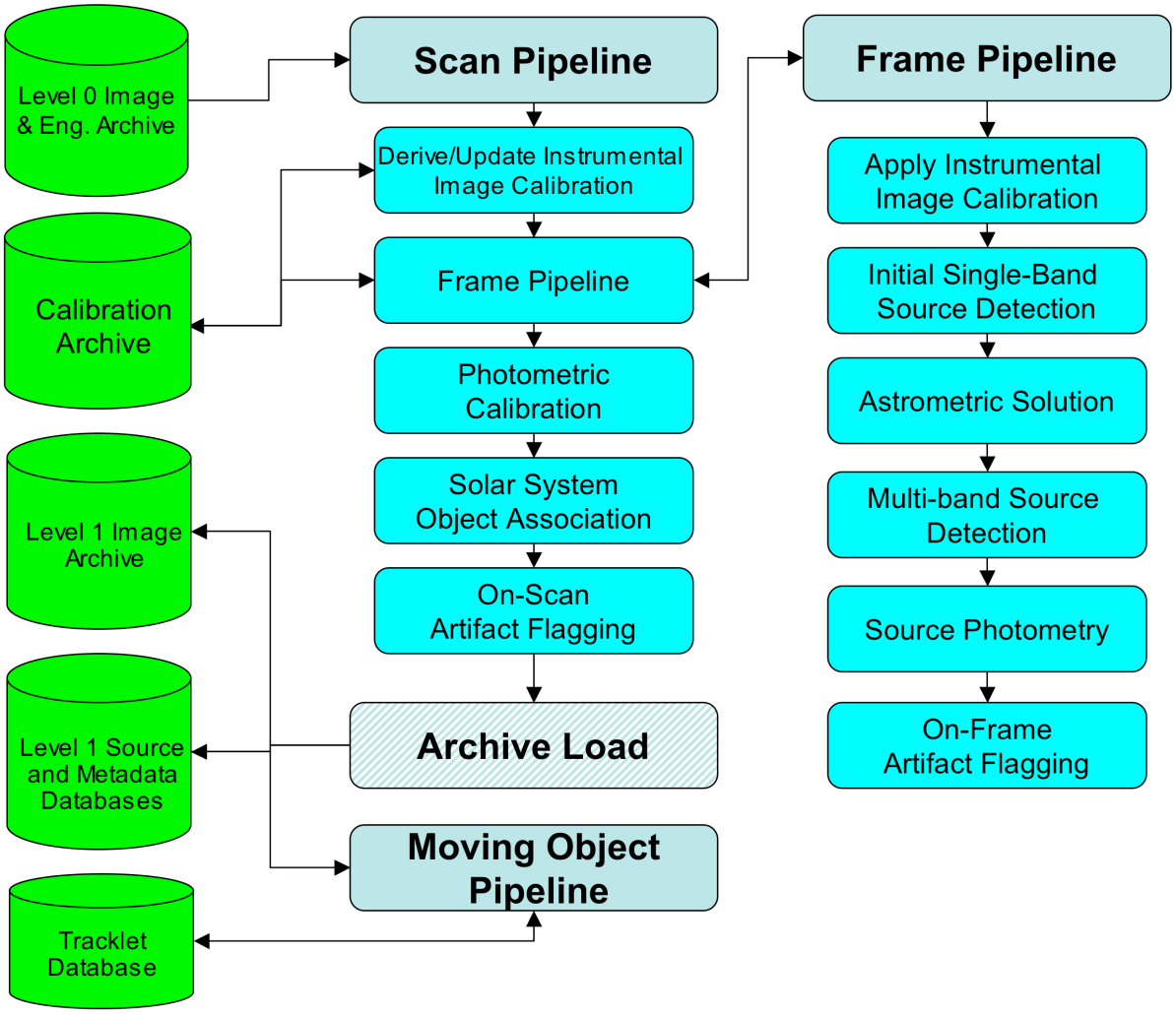

Figure 4 - WISE Science Data System Scan/Frame Pipeline Functional Block Diagram

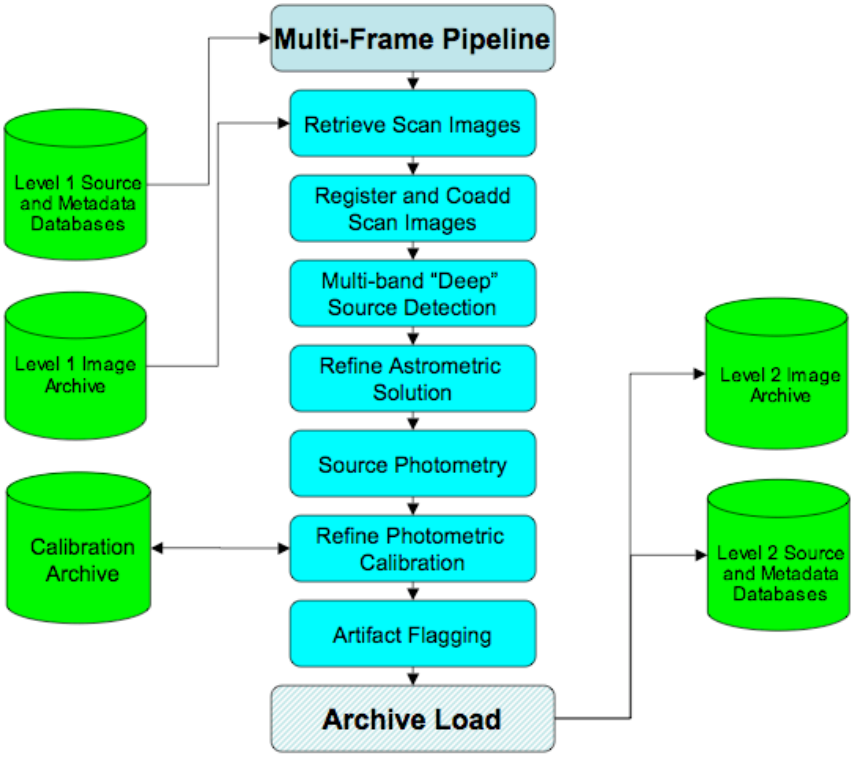

Figure 5 - WISE Science Data System Multiframe Pipeline Functional Block Diagram

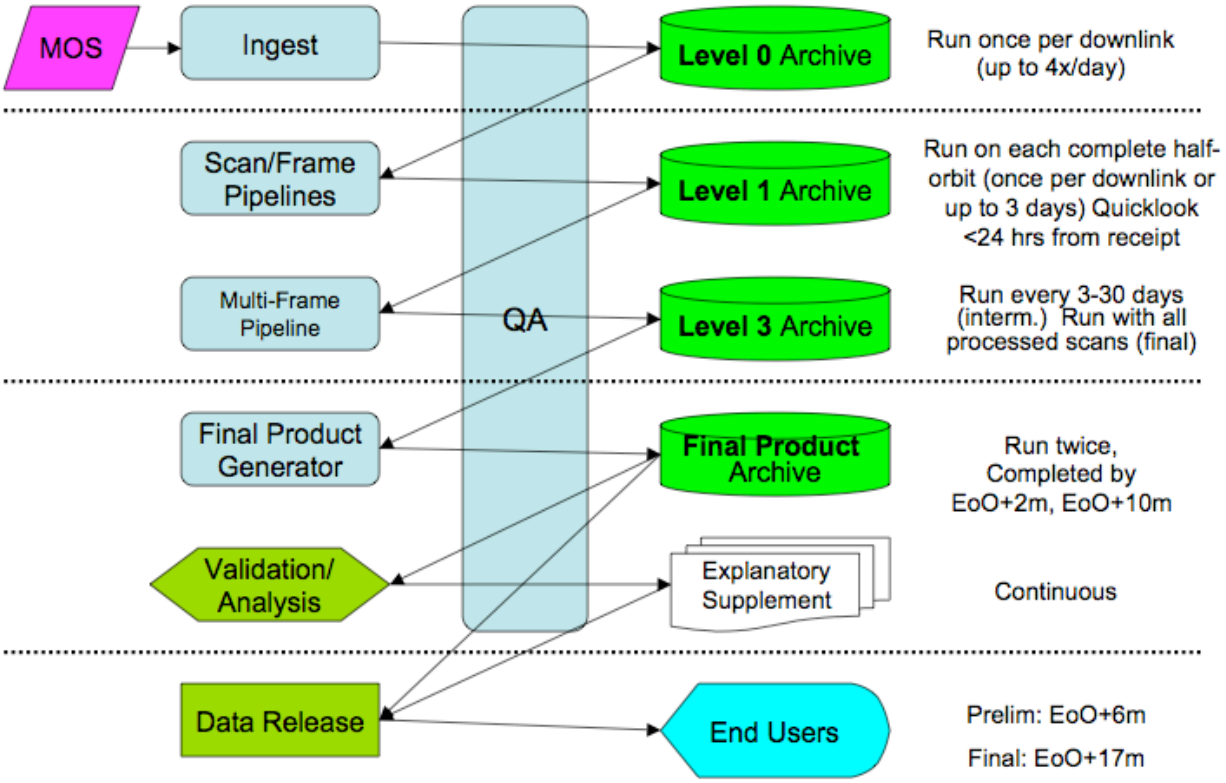

Figure 6 - WISE Science Data Processing Processing Cycle