# WISE Mission Operations System Preliminary Design Review

# Science Data Center Overview

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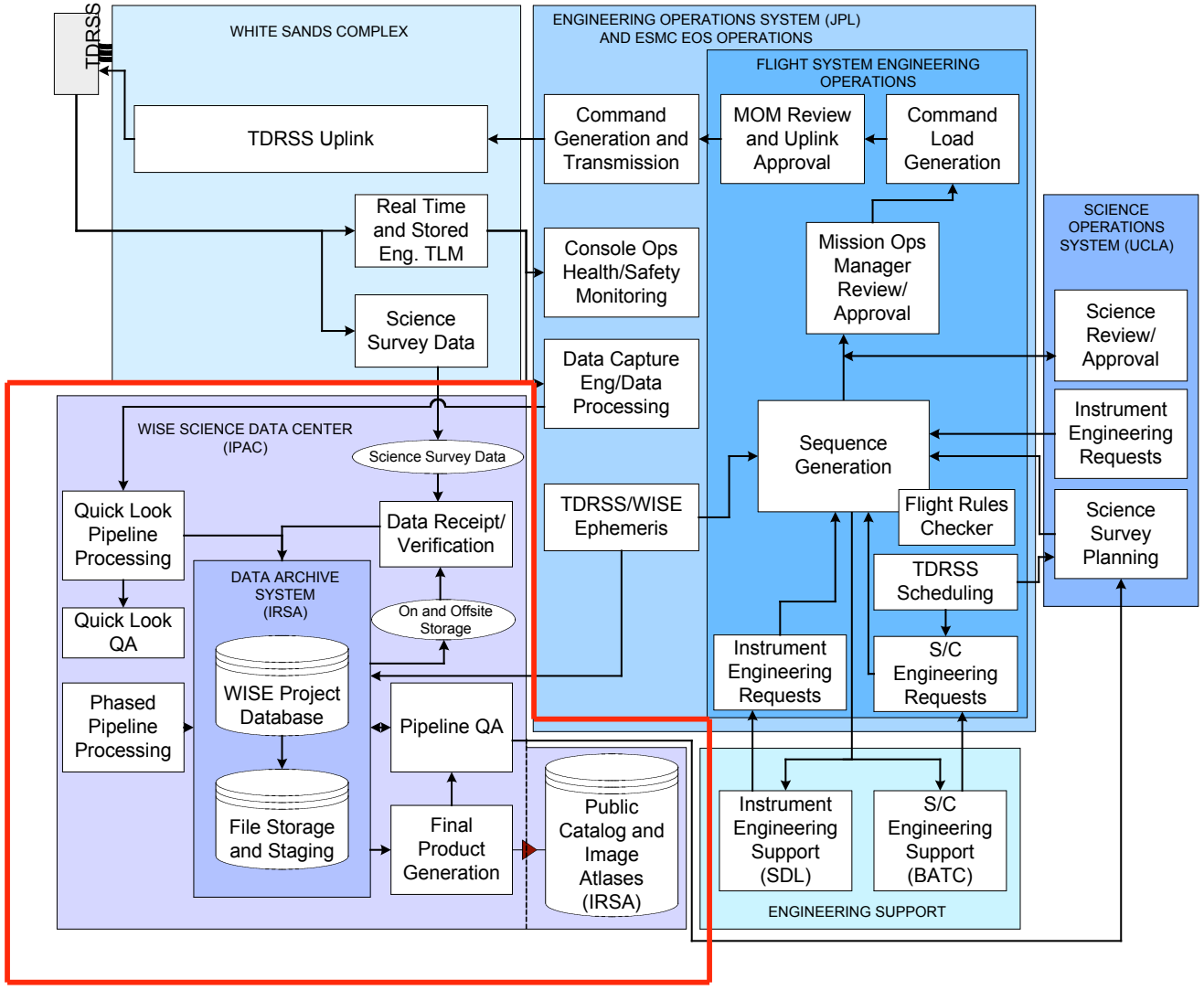
# MOS Functional Block Diagram





# WSDC Responsibilities



- Science Data Processing
  - Convert Level 0 engineering and imaging data into photometrically and astrometrically calibrated Image Atlas and extracted Source Catalog
  - Generate intermediate data products to support mission requirements (*e.g.* depth-of-coverage maps)
- Science Data Quality Assurance
  - Quicklook QA feedback for on-orbit performance (*e.g.* scan mirror synch)
  - Assess overall science data QA for survey planning
- Science Data Archiving and Distribution
  - Archive Level 0 data during mission
  - Provide long-term archive for primary and intermediate WISE data products
  - Serve WISE science data products to project team, astronomical community and general public

# Driving Requirements (*1 of 2*)



| Higher Level Requirement | Level 4 Requirement | Compliance | Verification Method |
|---|---|---|---|
| **L3MOS-366,374 (L1PP-34)** | **Data Release:** The WSDC shall release to the public an image atlas and source catalog covering the full survey area within 17 months after the end of on-orbit data collection. | By design | Demonstration |
| **L3MOS-355, 363 (L1.5SRD-50)** | **Preliminary Data Release:** The WSDC shall release to the public a preliminary image atlas and source catalog covering at least 50% of the surveyed area within 6 months after the end of on-orbit data collection | By design | Demonstration |
| **L3MOS-417 (L1PP-010)** | **Catalog Reliability:** The reliability of sources in the WISE catalog shall be >99.9% for sources in unconfused regions detected in a single band with SNR>20. | By design | Test: Comparison with external "truth tables"; detection confirmation |
| **L3MOS-363, 418 (L1PP-011)** | **Catalog Completeness**: The WISE catalog shall be ≥95% complete for sources in unconfused regions detected in a single band with SNR>20. | By design | Test: Detection repeatability in deep coverage areas (e.g. the ecliptic poles) |
| **L3MOS-376 (L1PP-012)** | **Photometric Accuracy:** The relative photometric accuracy of the WISE catalog shall be better than 7% in each band for unsaturated point sources in unconfused regions with signal to noise ratio greater than 100. | By design | Test: Photometric repeatability; stellar color stability over sky |

# Driving Requirements (*2 of 2*)



| Higher Level Requirement | Level 4 Requirement | Compliance | Verification Method |
|---|---|---|---|
| **L3MOS-370 (L1PP-013)** | **Astrometric Accuracy:** The RMS positional accuracy of sources in the Catalog shall be <0.5" with respect to the 2MASS Point Source Catalog | By design | Test: Comparison with 2MASS PSC and other astrometric catalogs (e.g. UCAC) |
| **L3MOS-420 (L1PP-4)** | **Photometric Sensitivity:** Source measurements in the WISE catalog shall achieve a signal to noise ratio of 5 or more in regions unconfused by Galactic sources, but including the effects of extragalactic source confusion, on point sources with fluxes of 0.12 mJy at 3.3 micrometers, 0.16 mJy at 4.7 micrometers, 0.65 mJy at 12 micrometers, and 2.6 mJy at 23 micrometers. | By design | Test: Photometric repeatability; Colors of normal stars, galaxies |
| **L3MOS-272** | **Quicklook Quality Assurance:** Approximately 3% of the science data from each orbit shall be processed and data quality summary reports posted to the WISE internal web site within 24 hours of receipt at the WSDC. | By design | Demonstration |
| **L3MOS-286** | **Single Orbit Data Processing Latency:** Within 3 days of receipt of a given data set, the WSDC shall process all single orbit data through the first stage of pipeline processing. | By design | Demonstration |
| **L3MOS-381** | **Archive Longevity:** The WSDC shall make the WISE Image Atlas and Source catalog available to the astronomical community in collaboration with the Infrared Science Archive to ensure long term availability and to insure interoperability with other NASA mission archives. | By design | Demonstration |

# Driving Design Factors



- High data rate (51GB/day uncompressed), large data volume (11TB raw, ~80TB processed)

  ⇒ Automated, high-throughput processing system with little opportunity for human intervention; extensive automated QA system

- Ambitious data release schedule (EoO+6m & EoO+17m)

  ⇒ Two-stage release with planned full re-processing

- Strict Catalog reliability and completeness requirements

  => Extensive automated QA system monitor science-based metrics during processing

# Key External Interfaces



- GDS/EOS (receive and acknowledge)
  - Spacecraft H/K data and metadata, spacecraft ephemeris
- GDS/White Sands (receive and acknowledge)
  - High-rate science data
- Science Operations (receive and send)
  - Science observation plan
  - Science data processing QA (Quicklook and standard) to monitor scan mirror synchronization and close loop on survey planning
- Project Team (send)
  - Intermediate processed data products and working databases
- Astronomical Community (send)
  - Primary mission Image Atlas and Source Catalogs and additional products (*e.g.* coverage maps)
  - Data product documentation (on-line Explanatory Supplement)

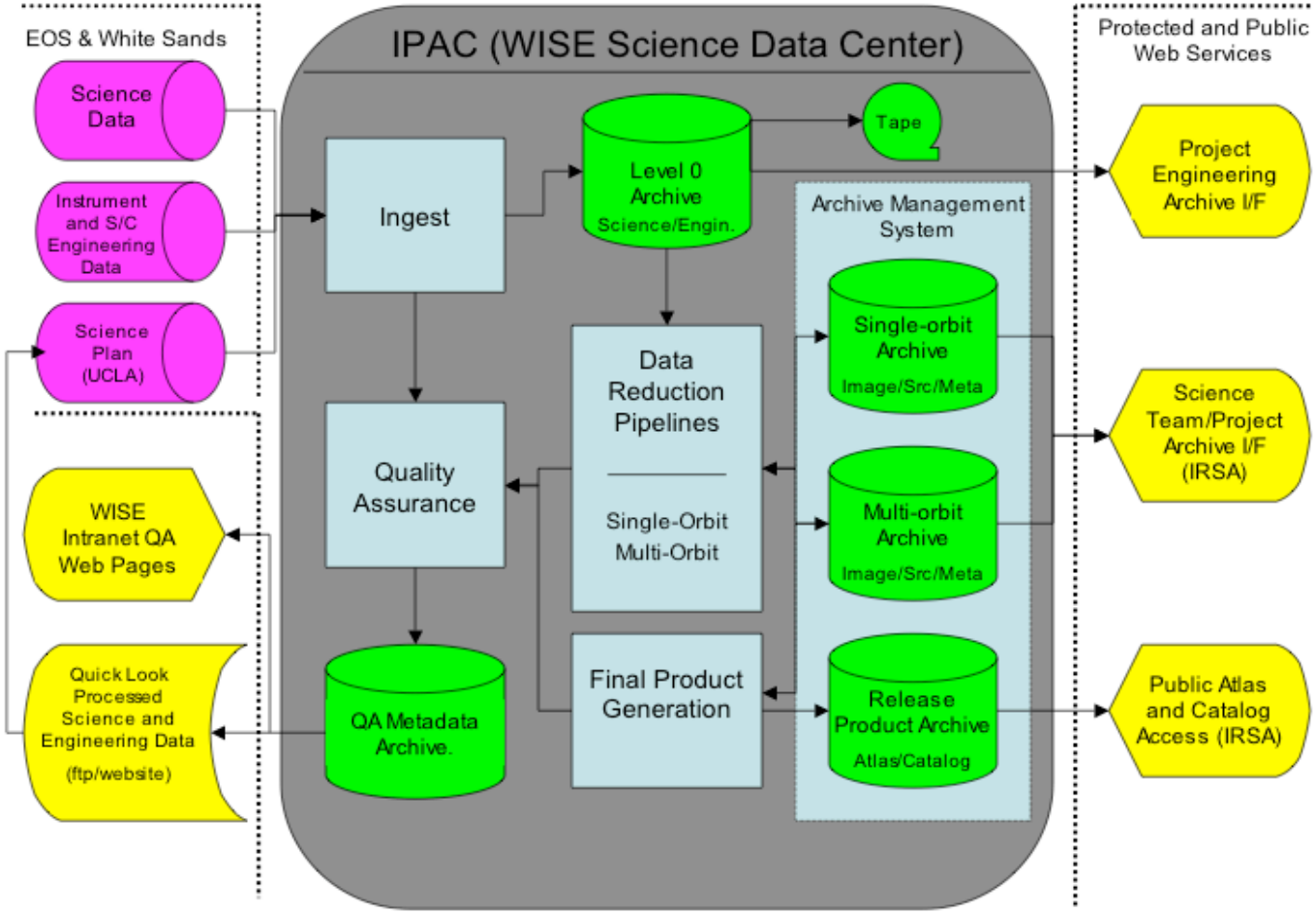
# WSDC *Intellectual Heritage*



- WISE benefits from *intellectual expertise* from IPAC support of other missions (2MASS, IRAS, WIRE, Spitzer, GALEX)
  - All aspects of WISE data processing, archiving and distribution tasks demonstrated on past and current missions
  - <10% actual code re-use, but many of the same engineers will develop subsystems similar to the ones they developed for other missions
  - Five WISE co-I's are IPAC staff members (Cutri, Jarrett, Kirkpatrick, Lonsdale, Padgett) with scientific investment in WISE and will participate in WSDC activities
  - Take advantage of excellent IPAC infrastructure: administrative, systems, network, archives

# Functional Block Diagram





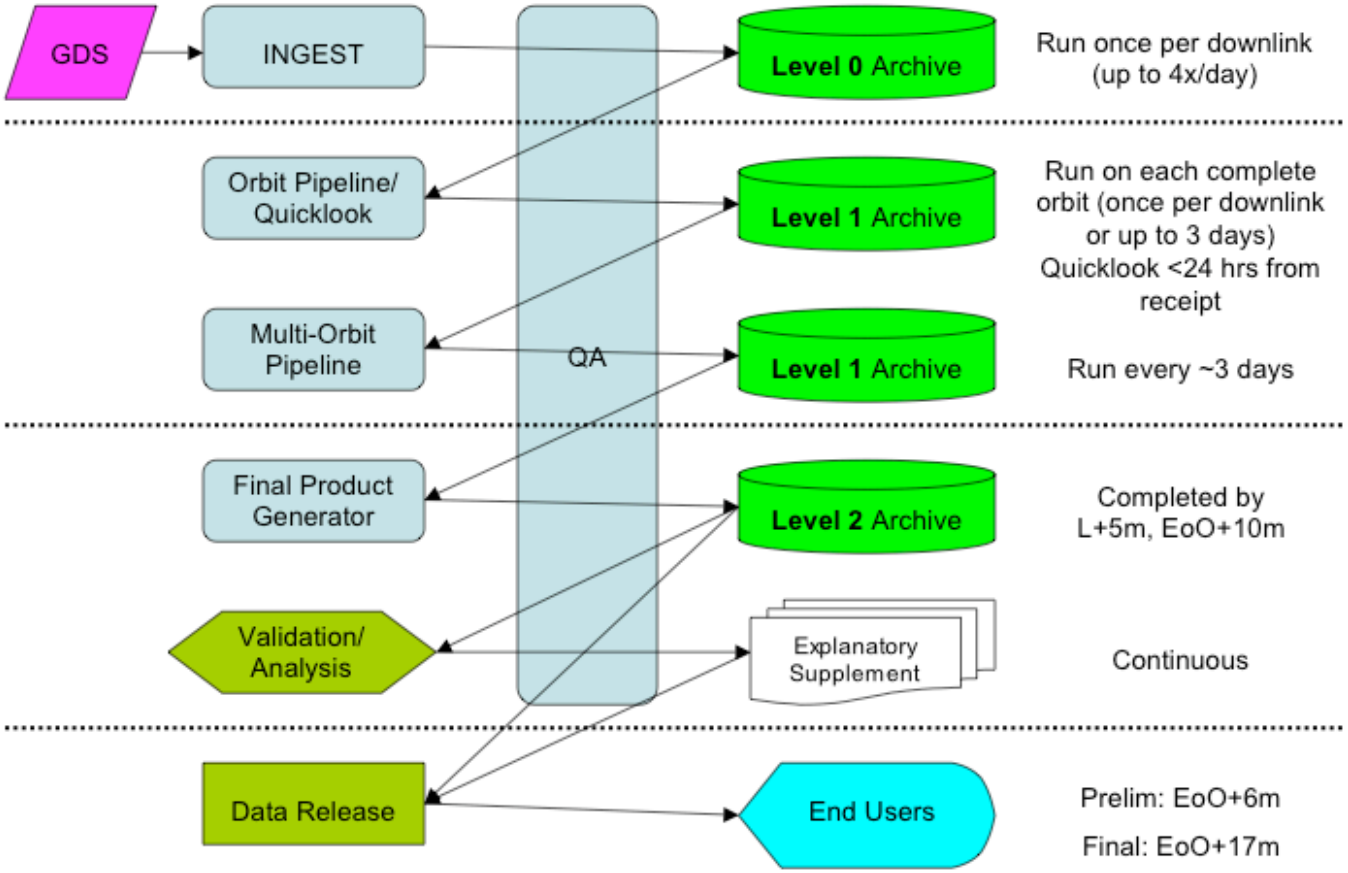
# WSDC Major Subsystems



- Ingest
  - Receive, decompress and combine Level 0 science data from White Sands, H/K and ephemeris data from EOS, Science observation planning from SOC (UCLA)
- Data Reduction Pipelines
  - Convert Level 0 imaging and spacecraft H/K data into *Working Databases* of calibrated images and extracted source lists
- Final Product Generator
  - Construct WISE Image Atlas and Source Catalog from image and extracted source *Working Databases*, validate and document
- Quality Assurance
  - Generate concise reports summarizing science data quality from each subsystem
- Archive/Distribution
  - Archive raw and processed mission data. Serve Image Atlas, Source Catalog and mission metadata to WISE project team and astronomical community.

# Internal Data Flow and Operational Cycle





# Key System Features



- Processing, QA, FPG, archive based closely on systems used for 2MASS
  - Highly automated, "industrial strength" data processing software system designed for high-throughput, reliable operation
  - Extensive use of automated QA reporting
  - Modular system to facilitate parallel development, unit-testing
  - Extensive use of parameter control files to allow "tuning" for actual payload performance
- Planned two-stage data processing and data release
  - "Can't get it right the first time"
  - Allows incorporating best knowledge of actual instrument performance, calibration and sky
  - Gets data out as rapidly as possible, and uses community as "beta-testers"
- Design from outset with product development and distribution in-mind
  - Source and image databases developed within IRSA
  - Enable easy access to intermediate and final data products for Science and Project Team to empower them
- Detailed on-line Explanatory Supplement describing processing algorithms and characterizing data products (*a la* IRAS, 2MASS)

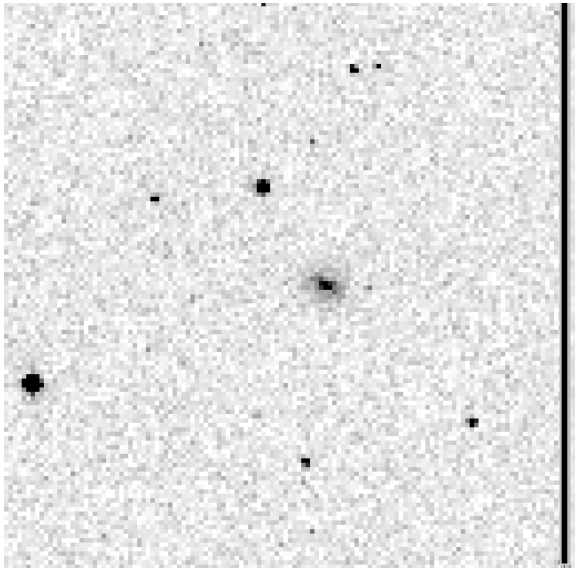
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Wide-field Infrared Survey Explorer (WISE)

# Data Reduction Pipelines
# Image Processing

Science Data Center

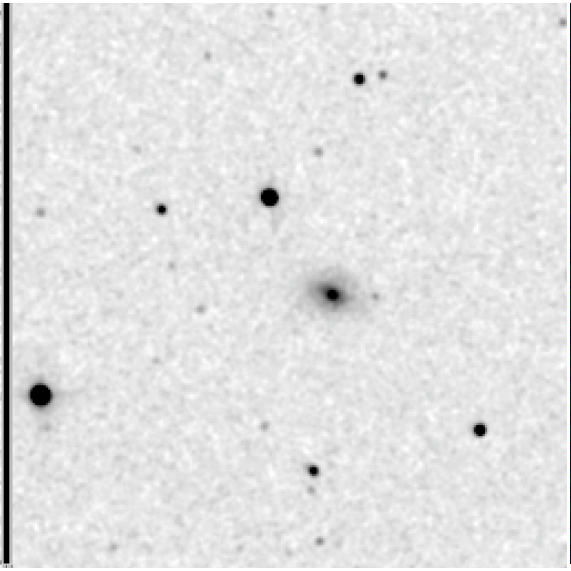
## Single-Orbit Pipeline:
## Operate on each image frame



Single 1.2μm 1.3s frame (2"/pix)

- Instrumental calibration:
  - flat-field, illumination corrections, linearize, etc
- Detect and characterize bright sources
- Photometric and astrometric calibration for orbit

## Multi-Orbit Pipeline:
## Combine images from ≥8 orbits



Combined 7.8s 1.2μm Atlas Image (1"/pix)

- Shift and register frames using
- Smooth and resample each image
- Scale and combine ≥8 samples for each pixel, reject cosmic rays, asteroids and other transients.

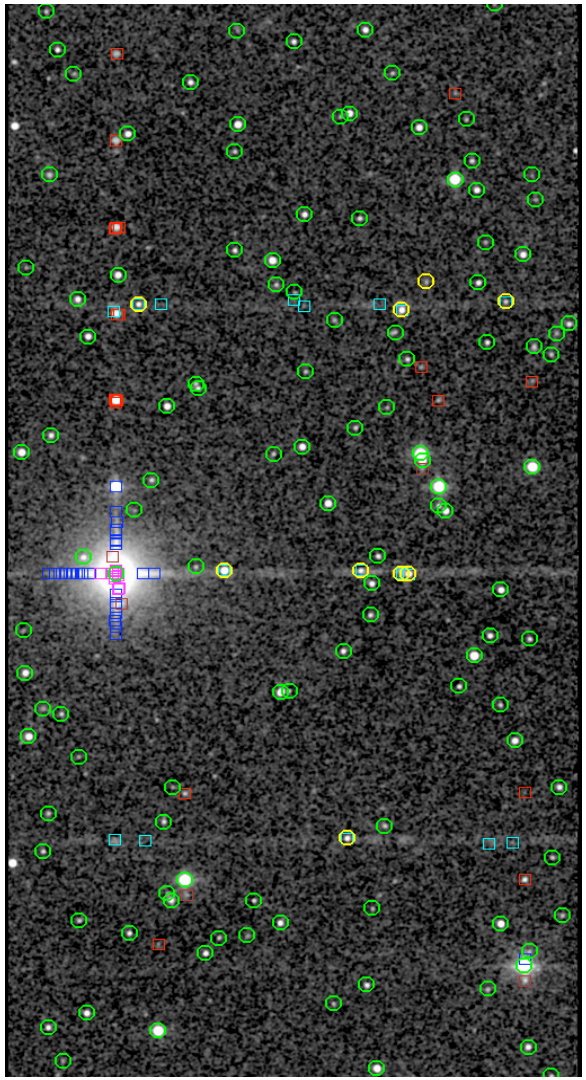
3-color composite (1.2+1.6+2.2μm) Atlas Image

- 4 bands resampled on common spatial grid for color studies
- Detect and characterize sources on combined images

# Data Reduction Pipelines
# Source Characterization



- Brighter sources detected on individual image frames
  - Confirmation statistics for source reliability
  - Known asteroid identification
- Final source detection on combined images
  - Maximum sensitivity
- Measure and calibrate:
  - **Aperture Photometry** with respect to standard star network located near celestial poles
  - **Astrometry** with respect to 2MASS PSC objects
- Artifact detections identified in source lists
  - Image artifacts produced by bright stars
  - Transients suppressed by image combination



Artifact Identification on 2MASS Atlas Image:

**Green** - True sources

**Yellow** -True sources contaminated by artifacts

**Red** - Residual images

**Blue** - Diffraction spikes

**Magenta** - Dichroic glints

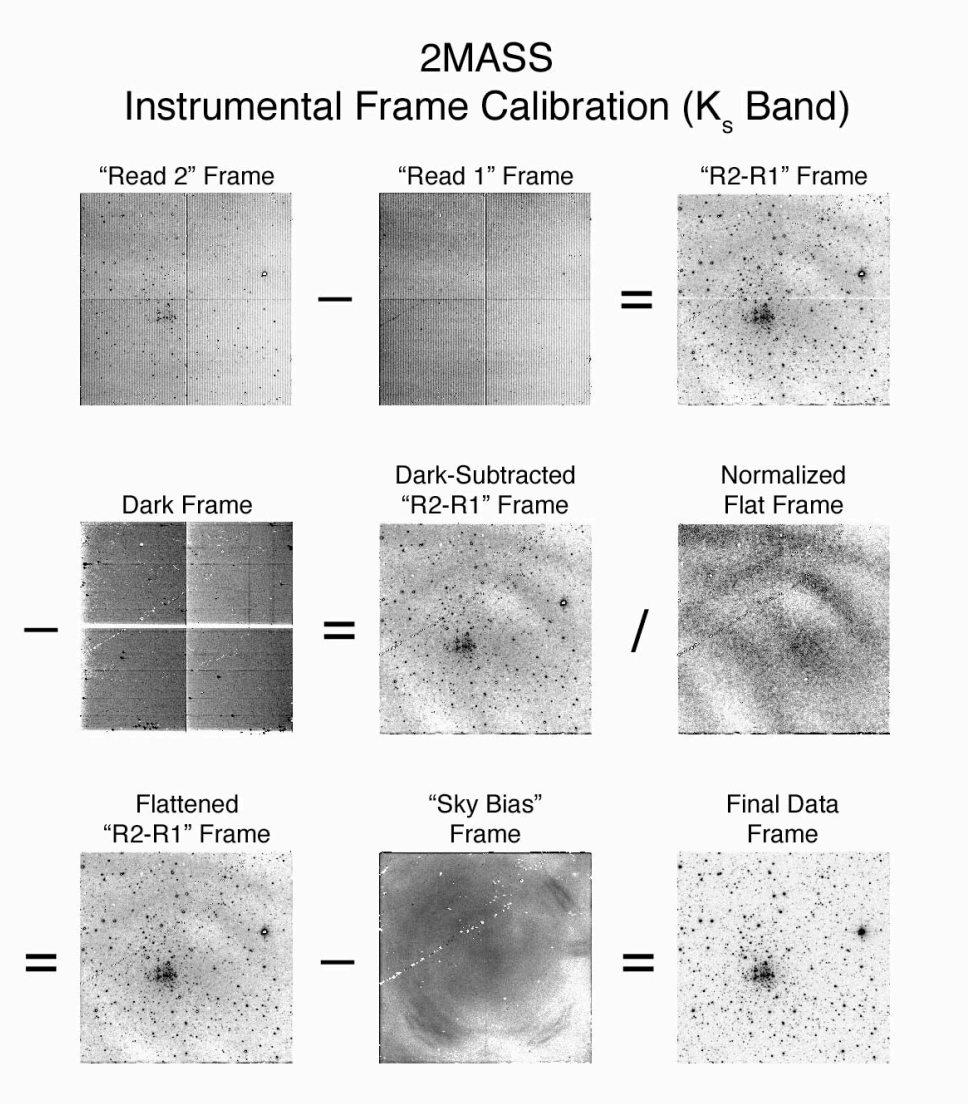
**Cyan** -Electronic stripes

*Not shown:* low SNR noise extractions

# Data Reduction Pipelines Calibration - 1



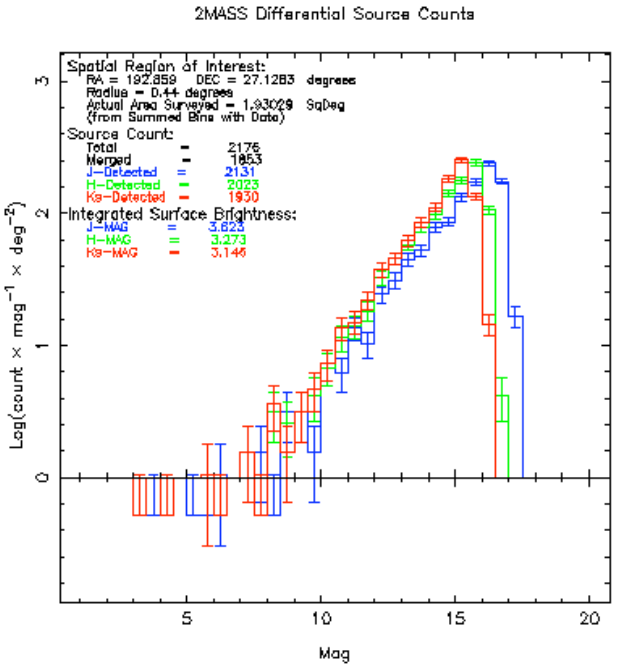
- Instrumental - remove signature of detector/optics from raw images
  - Responsivity (flat-field), sky illumination, linearity, bad pixel masks, etc.
  - Derive corrections using combination of measurements
    - ground-calibration - QE and high-noise/low response pixel maps, linearity, pixel-pixel gain
    - IOC - cover-on flat-fields (3.3 and 4.7 μm only), stimulator flashes
    - on-orbit - dark and bright sky flat-fields (zodiacal BG gradient), sky illumination, point source residual mapping
  - QA using point source residuals derived from orbit-orbit overlap regions



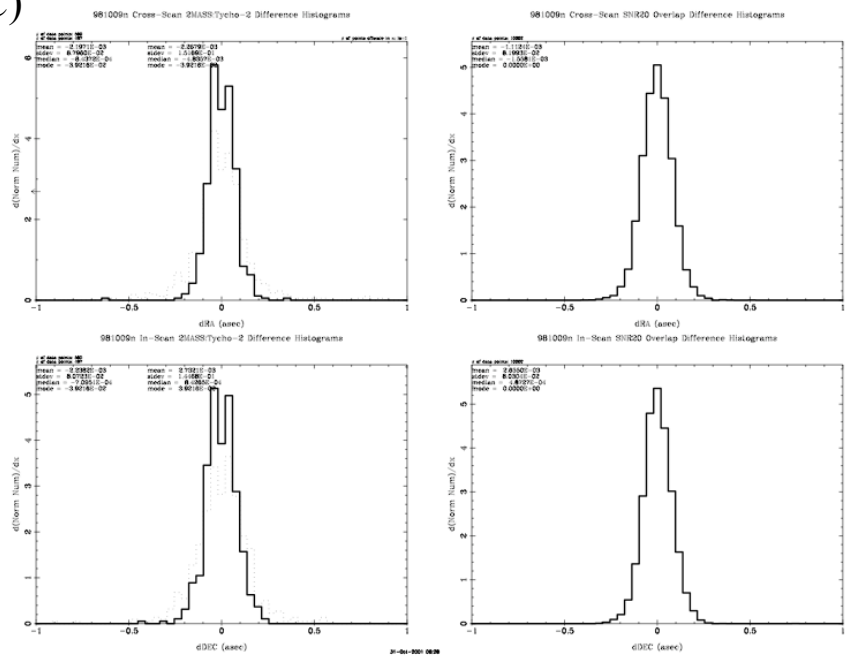
# Data Reduction Pipelines Calibration - 2



- Astrometric - convert instrument coordinate system to J2000
  - (x,y) => (α,δ) transformation derived using measurements of 2MASS PSC sources in each WISE image frame (≥70 high SNR 2MASS sources per frame detected by WISE at >SNR=20)
  - Leverage up to 4 independent band detections of sources to improve accuracy
  - Reconstructed WCS information placed in image headers, source positions reconstructed in 2MASS reference frame
  - QA using reconstructed position residual with respect to 2MASS PSC and independent all-sky astrometric reference (e.g. Tycho 2, UCAC)




2MASS PSC source counts in 0.44 deg$^2$ at the NGP



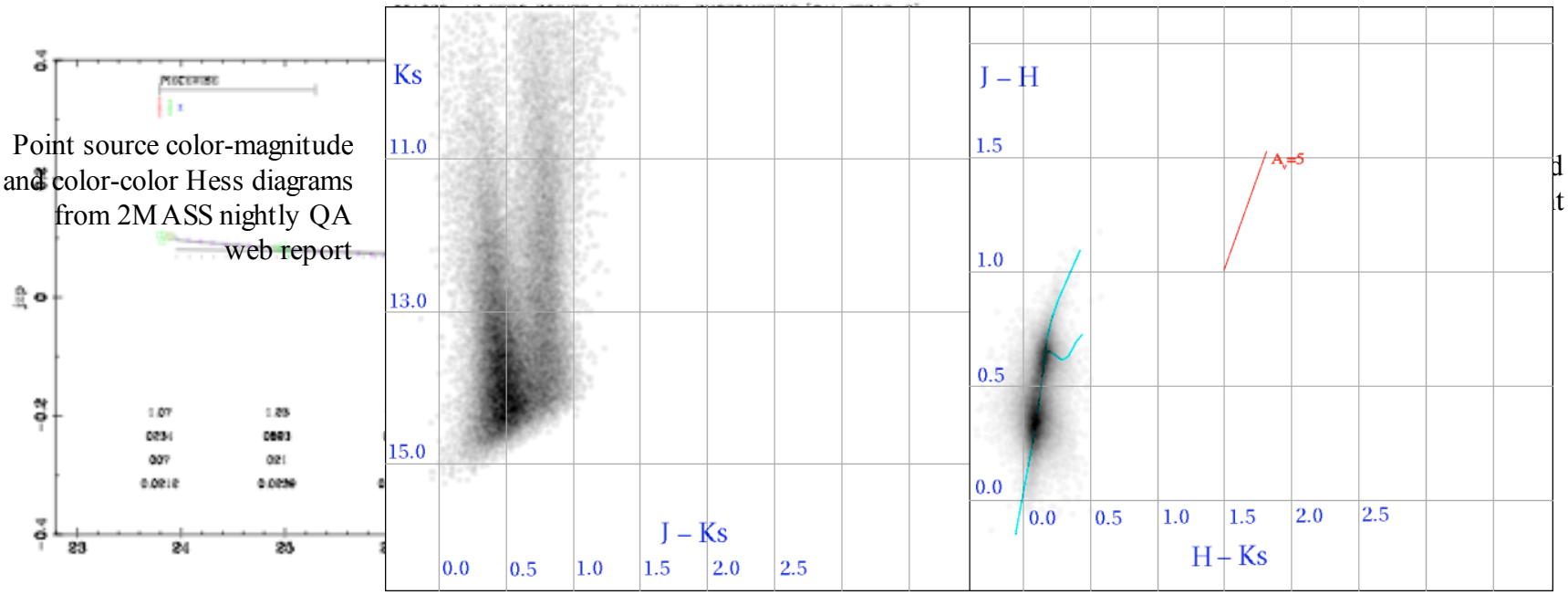
Astrometric residual plots from 2MASS QA (Tycho 2 and scan-scan)

# Data Reduction Pipelines Calibration - 3



- Photometric - convert measured instrumental intensities to flux units
  - (dn) => (flux density) transformation derived using measurements of a network of photometric calibration standard stars surrounding ecliptic poles
  - Photometric zero point offset $\langle S_{true}(\lambda)/S_{inst}(\lambda) \rangle$ measured twice per orbit, modulo downlinks and annealing which are done at poles
  - Zero points interpolated/monitored using in-scan and cross-orbit frame-to-frame overlaps
  - Band-to-band calibration monitored using source color distributions

Point source color-magnitude and color-color Hess diagrams from 2MASS nightly QA web report



# Data Reduction Pipelines Calibration - 4



- Pre-flight calibration receivables
  - Ground detector and payload ground test results (SDL). WSDC staff will be present for integrated payload testing at SDL and assist in analysis
  - Transmission/reflection curves for all optical elements, QE curves for detectors (SDL). To be used for absolute calibration, color-term calibration.
  - Standard star network (Science Team/Calibration WG)
  - WISE Calibration Plan document (Calibration WG to work in close, on-going collaboration with WSDC - Cutri is member of Calibration WG).
- Update using analysis of on-orbit measurements
  - Responsivity corrections using zodiacal BG gradient, dark sky medians, point source residuals
  - Illumination corrections using dark sky medians
  - Focal plane distortion using comparisons with astrometric reference stars on every frame
  - Internal uniformity of standard star network using repeated photometric solutions from every orbit
- Calibration plan, algorithms will be iterated, tested and validated in on-going collaboration with Science Team and Calibration WG

# Quality Assurance Operations Overview - 1



- Ingest QA
  - Verify integrity and contents of science and engineering data sent from from White Sands and MOS/EOS, science observation plan from SOC/UCLA
  - Run after each transfer
  - Report successful transfer or anomalies to MOS/EOS, SOC/UCLA
- Science Data Quicklook QA
  - Scaled-down single-orbit pipeline processing of ~5% of science data from each downlink
  - Completed within 24 hours of end of data transfer to WSDC
  - Web-based Quicklook QA Report summarizes critical performance parameters against pre-established metrics - *e.g.* scan mirror synchronization
  - SOC/UCLA responsible for reviewing web-based report, initiating requests for modifications
- Science Data Processing QA
  - Examine output of data processing pipelines, compares performance to science-based metrics
  - Run after completion of each single-orbit and multi-orbit pipeline run
  - Assign quality score to each data frame or collection of frames to be used in FPG
  - PI or designee responsible for signing-off on final quality assessment

# Quality Assurance Operations Overview - 2



- Archive QA
  - Validates accuracy of source and metadata database loading and verifies integrity of database tables
  - Checksum and RTB queries run after each database load and periodically on static tables
- Final Product QA
  - Assess and document achieved sensitivity, photometric and astrometric accuracy, completeness and reliability of preliminary and final release Atlas Images and Source Catalogs to Level 1 and 1.5 requirements
  - Run on Atlas and Catalogs after FPG process prior to release
  - Conducted by Science Team and WSDC scientists/analysts
  - Final approval for release is responsibility of PI

# Science Data Processing Quality Assurance Process



- Automated Quality Assurance system gathers QA reports generated by each run of single-orbit and multi-orbit data reduction pipelines and generates concise web-based report
  - Summarizes achieved performance against science-based metrics
  - Assigns each frame/pointing/orbit a provisional quality score based on quality required for mission science requirements
  - Links to enable drilling-down to detailed levels
- QA scientists at WSDC review web reports daily and prepare written summary reports
  - Drill down into data as necessary, use stand-alone analysis tools to investigate any failures
  - Issue Incident/Surprise/Anomaly (ISA) report if serious anomaly is found
  - Confirm/override provisional scores assigned to frame/pointing/orbit
- PI or designee (external to WSDC) reviews summary report, accepts scores or suggest modifications
  - Iterated with WSDC lead QA scientist until convergence
  - PI has ultimate responsibility for sign-off
- Once science data quality score is confirmed, WSDC loads processed image and source data into survey Working Databases