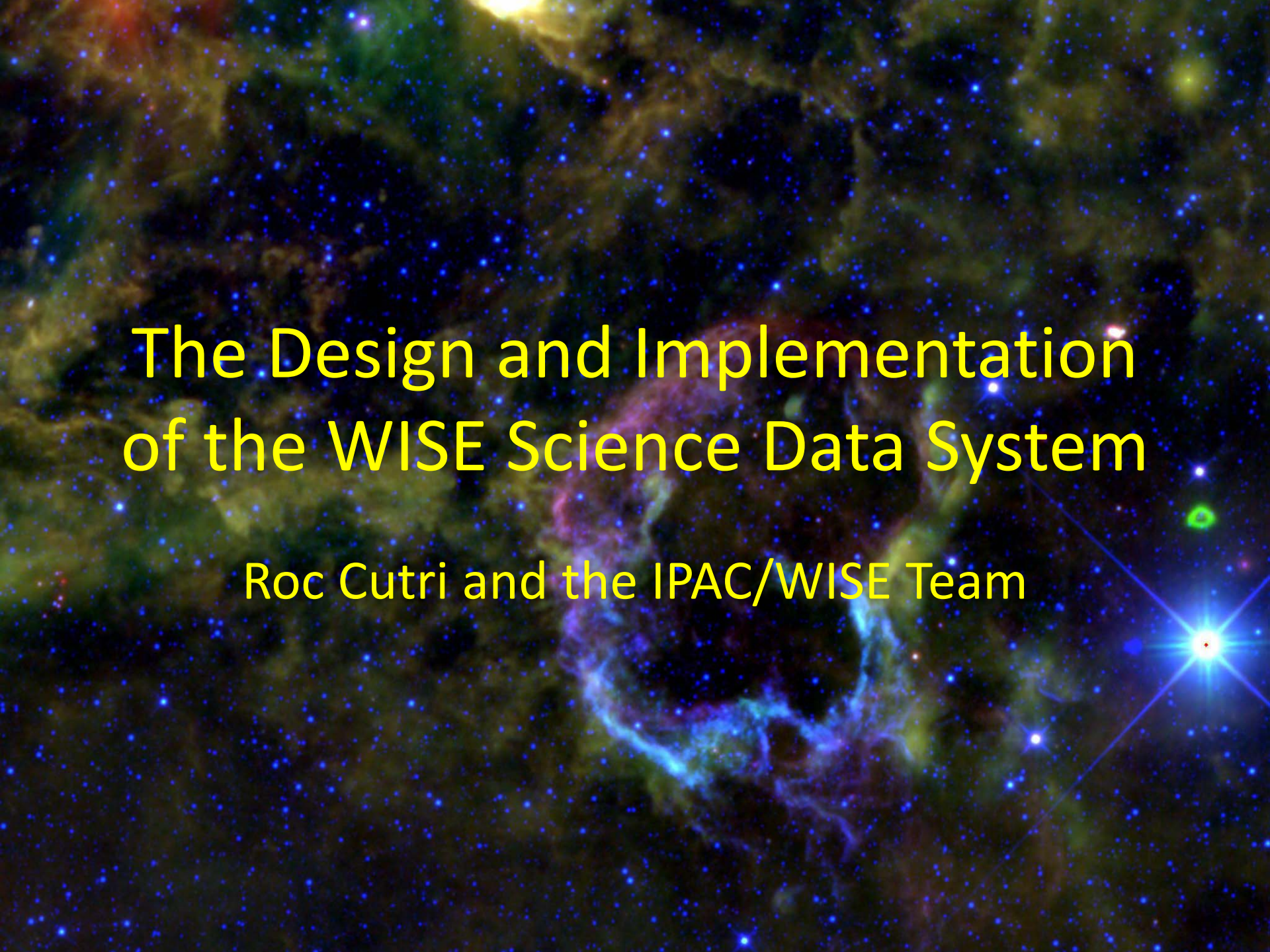


The Design and Implementation of the WISE Science Data System

Roc Cutri and the IPAC/WISE Team

The IPAC WISE/NEOWISE/IRSA Team

Rosemary Alles
James Bauer
Ron Beck
Heidi Brandenburg
Tim Conrow
Roc Cutri
John Dailey
Tracey Evans
Sergio Fajardo-Acosta
Tommy Grav (JHU/PSI)
Chris Gelino
Carl Grillmair
Steve Groom
Jennifer Herstein
Doug Hoffman
Tom Jarrett
Davy Kirkpatrick
Wilson Liu
Ken Marsh
Frank Masci
Howard McCallon
Bruce McCollum
Wei Mi
Serge Monkewitz
Debbie Padgett (GSFC)
Mike Papin
Ramon Rey
Trey Roby
Scott Terek
Dave Tholen (UH)
Chao-Wei Tsai
Stefanie Wachter
Sherry Wheelock
Mary Wittman
Pamela Wyatt
Xiuqin Wu
Lin Yan
Angela Zhang

WISE – A NASA Medium Class Explorer Mission

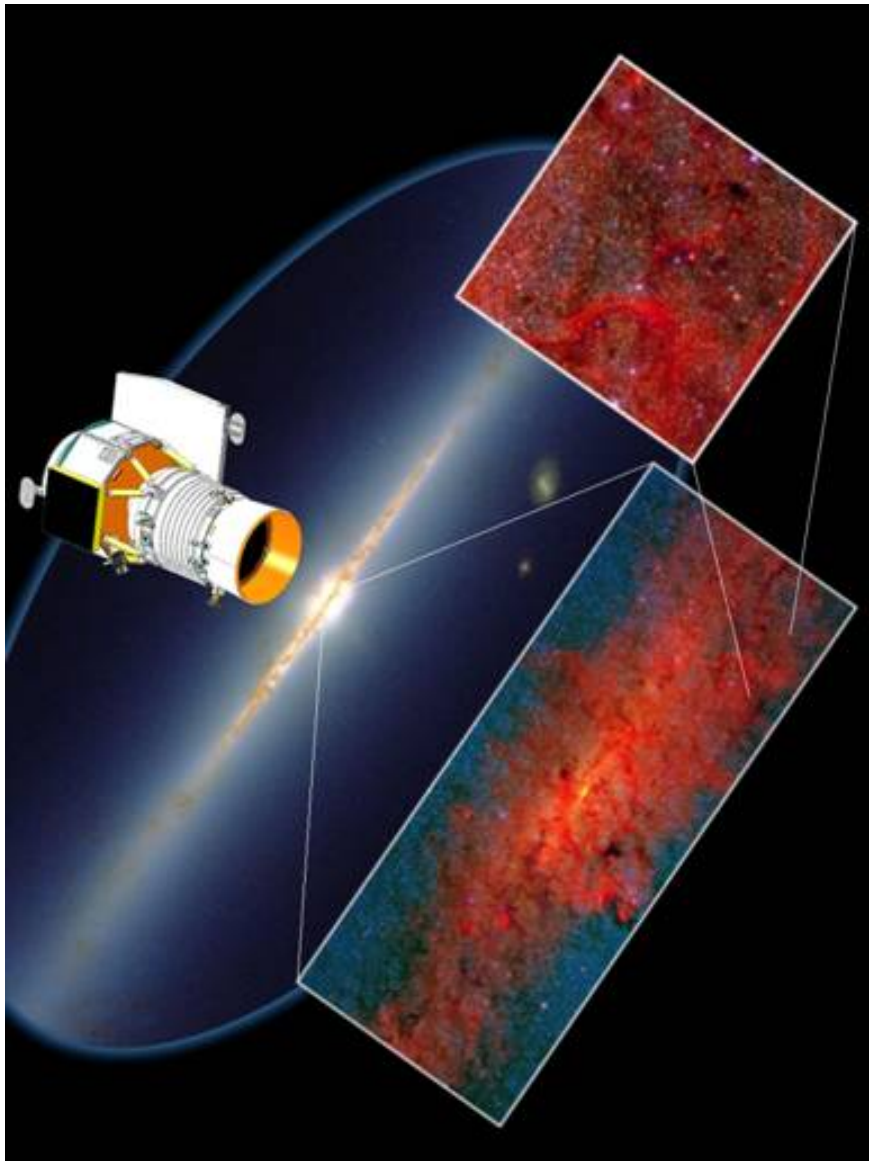
Wide Field Infrared Survey Explorer

Science

- *Sensitive all sky survey with 8X redundancy*
  - *Find the most luminous galaxies in the universe*
  - *Find the closest stars to the sun*
  - *Provide an important catalog for JWST*
  - *Provide lasting research legacy*

Salient Features

- *4 imaging channels covering 3.4, 4.6, 12 and 22 micron wavelengths*
- *40 cm telescope operating at <17K*
- *Two stage solid hydrogen cryostat*
- *Delta launch from WTR: 14 Dec 2009*
- *Sun-synchronous 6am 530km orbit*
- *Scan mirror provides efficient mapping*
- *Expected life: 10 months, actual 7.7-9.5*
- *4 TDRSS tracks per day*

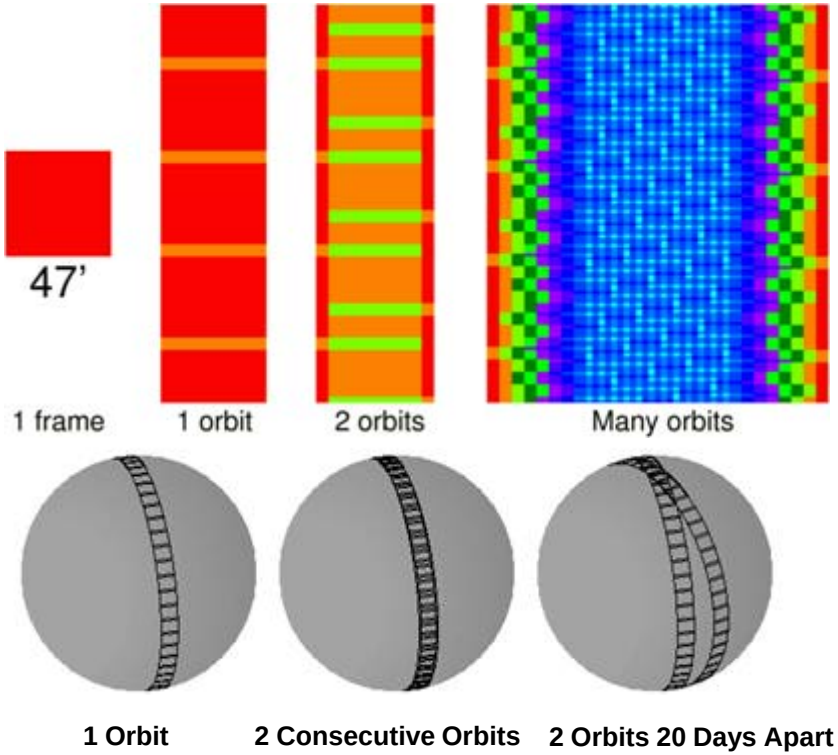


WISE Timeline

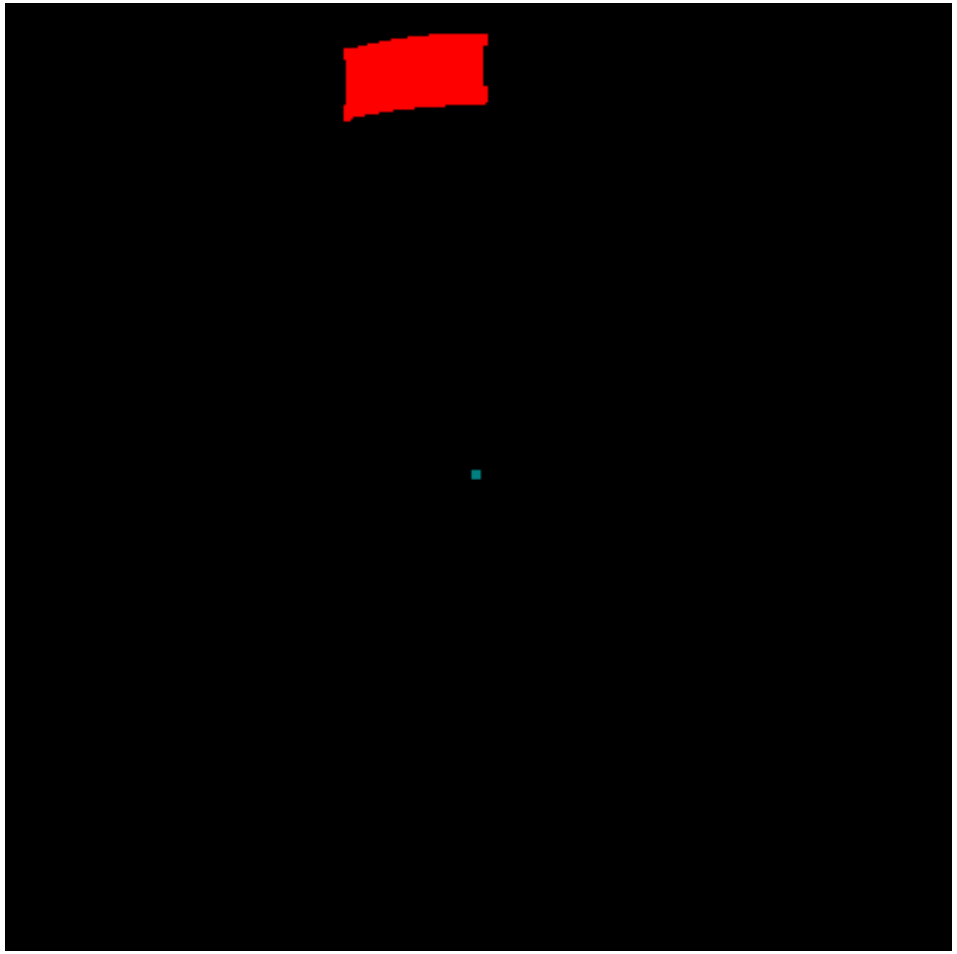
- Launched 2009 Dec. 14
- First Light 2010 Jan. 1
- Survey started 2010 Jan. 14
- First Pass on sky complete 2010 July 17
- Cryogenic survey ended 2010 Sept. 30
- Post-Cryo (3.4/4.6μm) survey ended 2011 Feb. 1
  - Complete Main Belt Asteroids
  - Second pass on sky
- Preliminary Data Release 2011 April 14
- Final Data Release Spring (northern) 2012

WISE Survey Strategy Provides Minimum of 8 Exposures Per Position on the Sky

- Scan mirror enables efficient surveying
  - 8.8-s exposure/11-s duty cycle
- 10% frame to frame overlap
- 90% orbit to orbit overlap
- Sky covered in 6 months observing



- Single observing mode
- Minimum 8, median 14 exposures/position after losses to Moon and SAA

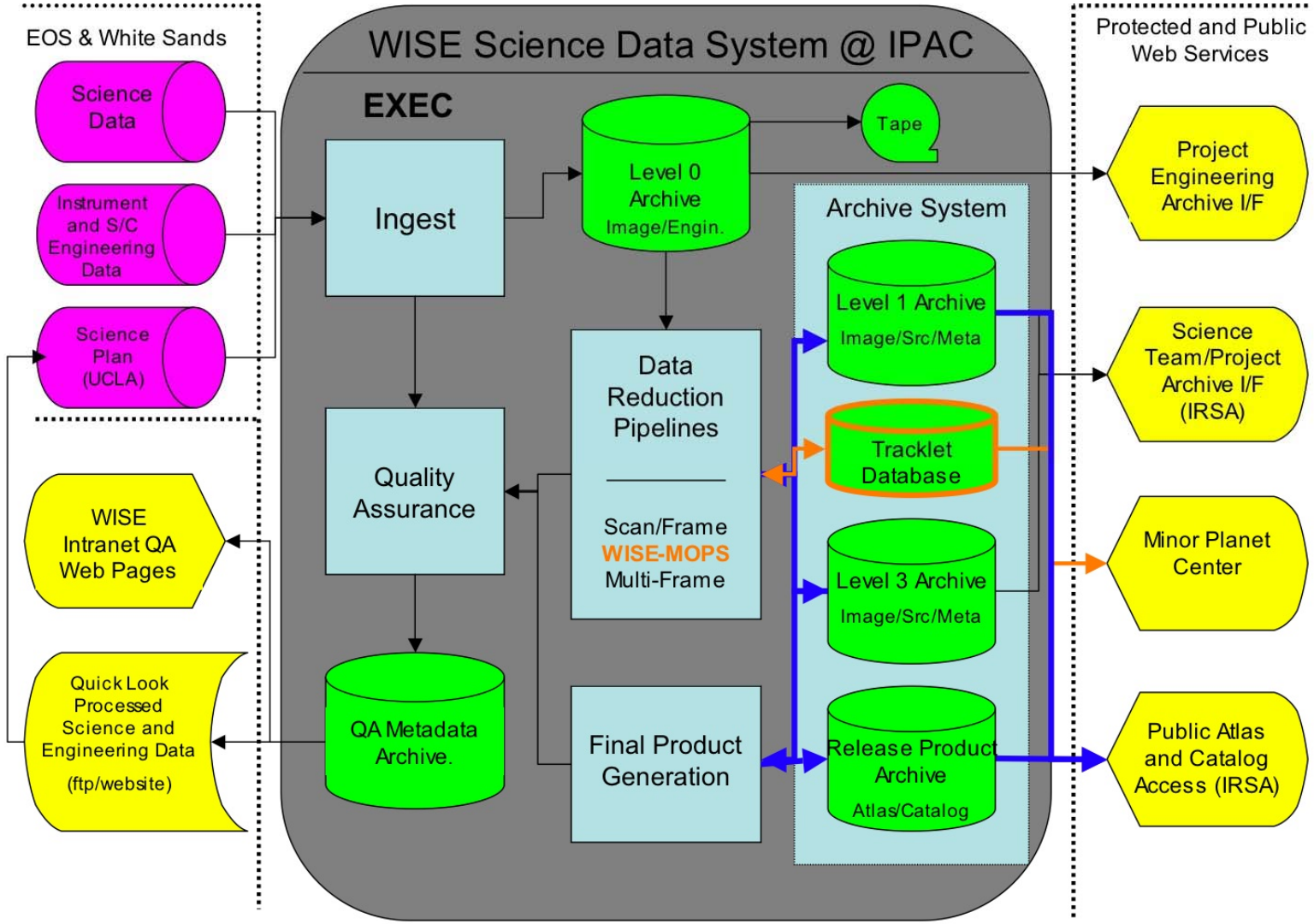


Caltech's Infrared Processing and Analysis Center (IPAC) is the WISE Science Data Center

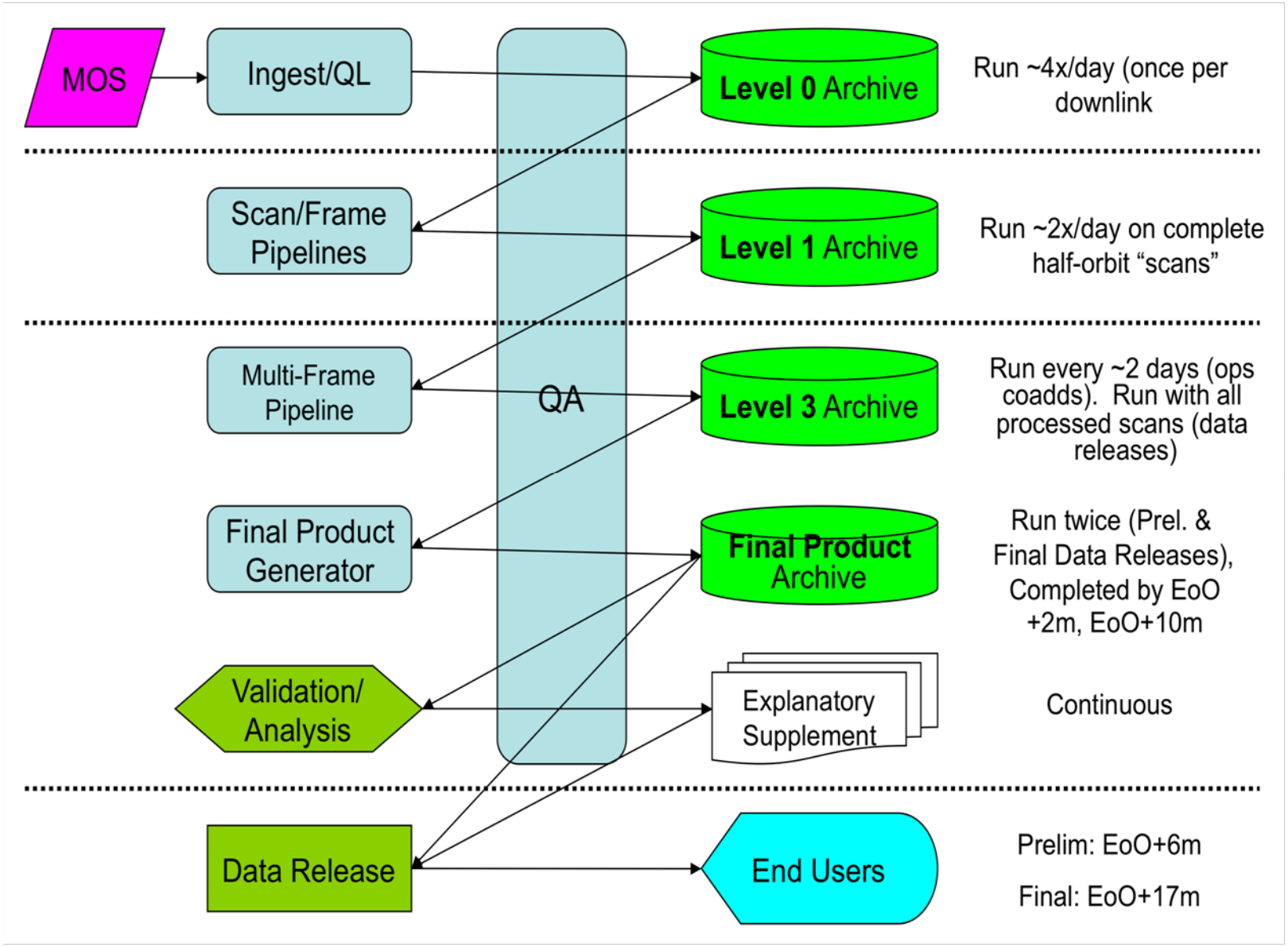
Responsible for:

- Raw science and engineering data ingest from TDRSS ground station
- Pipeline processing to generate science products
- Science data quality assurance
- Data product archiving and distribution

The WISE Science Data System: Operations, Software and Hardware System That Performs the Activities of the WSDC



WSDS Operations Flow



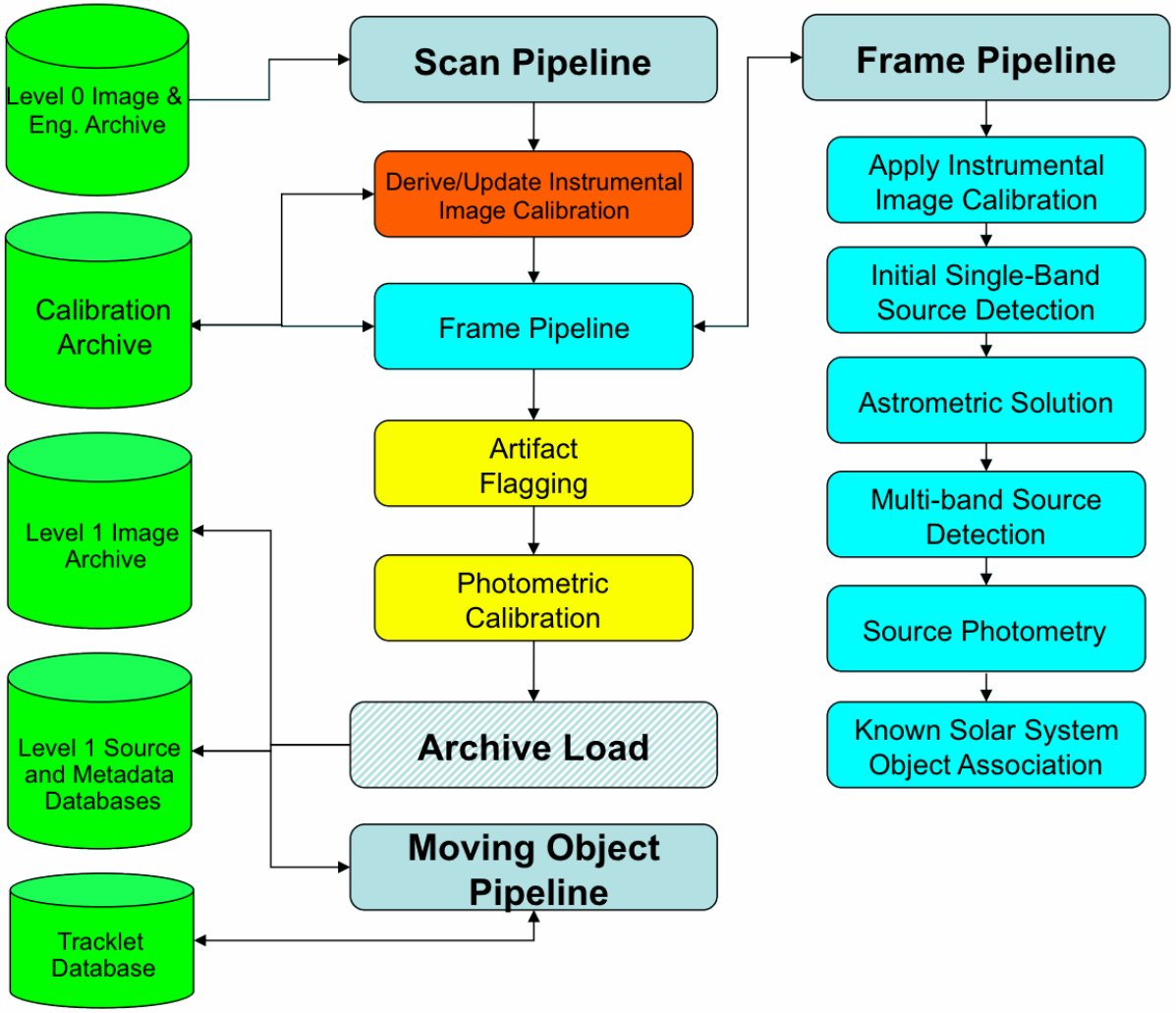
WSDS Design Drivers

- Challenges
  - Highly constrained cost and schedule
  - Ambitious data release schedules (6 & 17 months after on-orbit ops end)
  - Extremely short check-out and verification period to optimize software
  - Limited ground testing representative of on-orbit performance
  - Idiosyncracies of low-Earth orbit (SAA, moon, space junk)
  - High data rate and duty cycle (52GB/day; 24/7 ops)
- Advantages
  - Highly stable platform in space
  - Single highly repetitive observing mode
  - Large FOV, single array detectors
  - 4-band simultaneous imaging
  - Well-defined requirements and schedule
  - Extensive heritage with IR array detectors, large survey data processing, archiving

EXEC: Makes Functions and Data into a Unified System

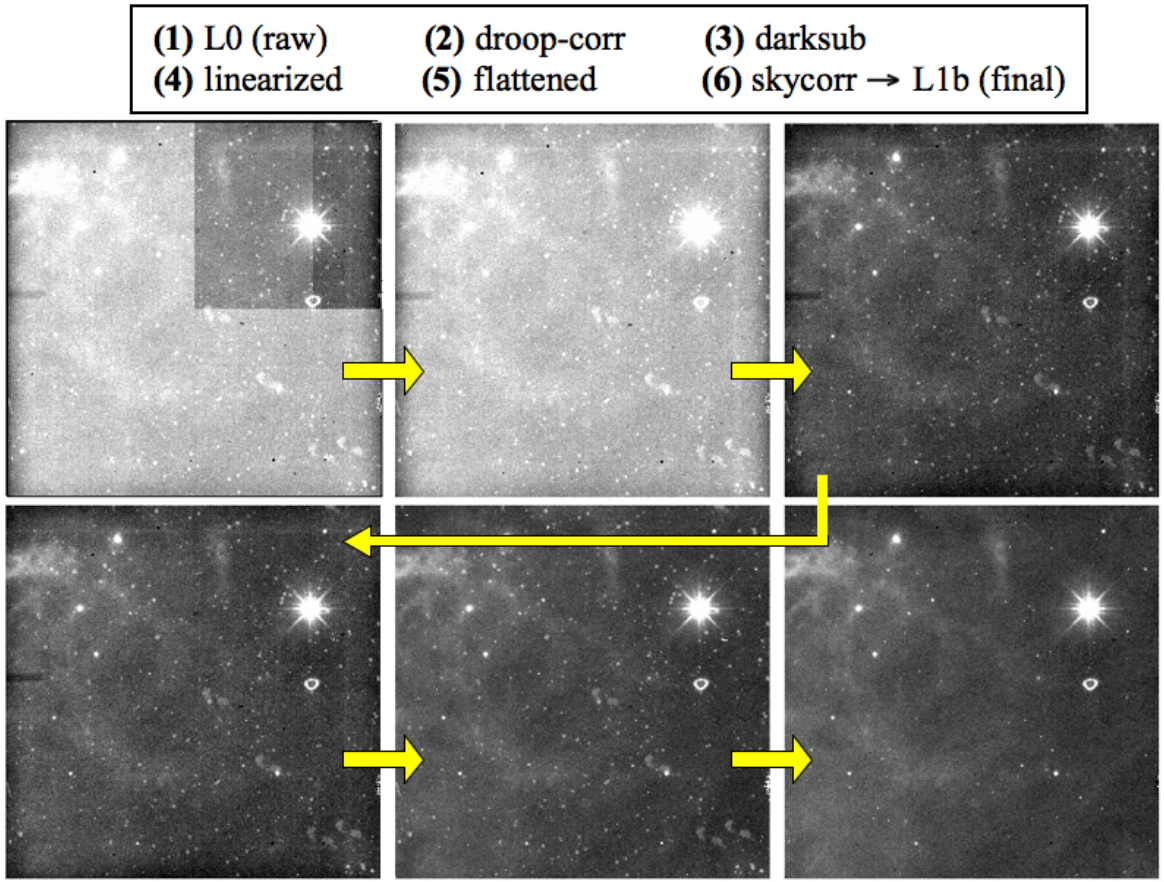
- Provides Interface consistency and services
  - Small number of files providing all necessary data representations
    - Table and meta-data files, FITS pixels, headers, SPICE Kernels, SQLite databases
  - Directory layout
    - Common namespace, load balancing, intent segregation
- Pipelines are strung-together “Wrappers” that encapsulate and enforce organization
  - Hide underlying function call
  - Provide outward-facing parameter interface
  - Transform data as required to/from standard file representation
  - Construct sub-process command lines
  - Monitor/record results
- Wrapper parameter handling provides a common command-line form for all pipeline components

Scan/Frame Pipeline Converts Raw Packets into Calibrated Single-exposure Images and Source Lists



- Image calibration, source extraction, astrometric solutions, artifact identification
- Highly concurrent frame processing
- Output:
  - Calibrated images, uncertainty maps, pixel bit masks
  - Extracted source tables
  - Metadata
- Input for *Moving Objec*t and *Multiframe* Pipelines

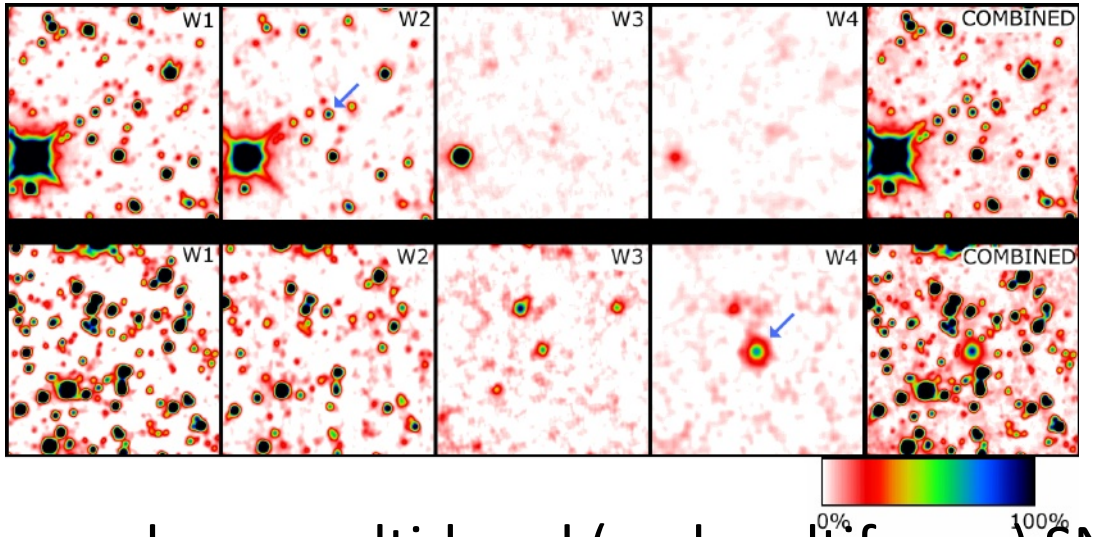
Instrumental Calibration Removes Detector Signatures



- Traditional linearity, static dark and flat corrections
- Dynamically generated flat corrections and sky offset corrections
- Customized features to respond to WISE detector idiosyncracies
  - Banding (HgCdTe)
  - Droop (Si:As)
  - Long-term latent images (Si:As)

Multiband Source Detection and Characterization Exploits Simultaneous 4-band Imaging

(Marsh and Jarrett 2011, PASA, submitted)

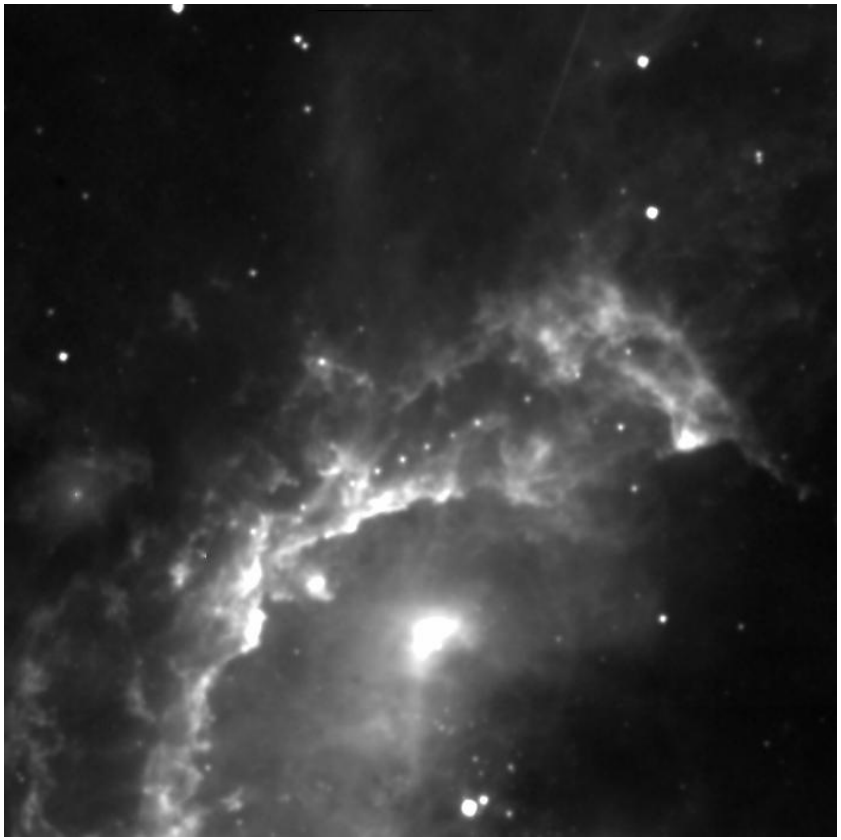


Brown dwarf

ULIRG

- Detection made on multi-band (and multiframe) SNR image
  - Stacking images in spectrally neutral way improves flux sensitivity for given SNR threshold
- Simultaneous multiband parameter estimation via profile-fitting
  - Leverages better resolution at short wavelengths
  - Avoids deblending ambiguity between bands

Moving Object Pipeline System (WMOPS) Exploits WISE Survey Strategy to Identify Previously Unknown Solar System Objects



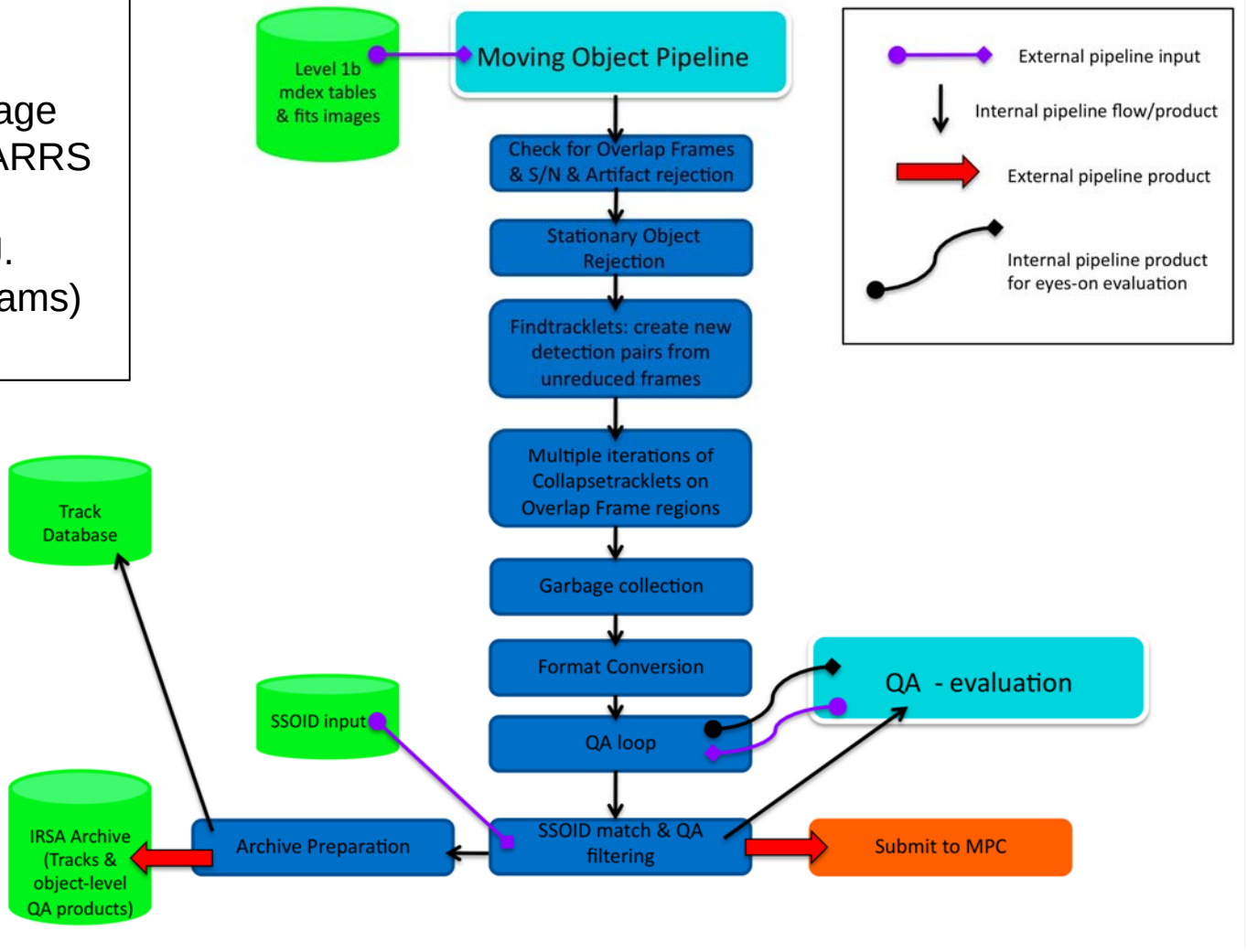
14’x14’ section of a WISE W3 image covering Sh2-236 made from 11 separate exposures showing serendipitous detections of (1719) Jens 1950 DP (coadd made without outlier rejection)

- On ecliptic, WISE typically yields ~10 observations of a particular object over ~30 hours
- Identify moving object candidate detection and form position/time tracklets
- Tracklets are delivered to Minor Planet Center within 10 days of midpoint of WISE observation
- Rely on additional ground-based observations to get long term orbits, although most WISE observations are long enough to receive a designation.

WISE Moving Object Pipeline System (WMOPS) Identifies Moving Object Candidate Tracklets From Single-exposure Source Lists

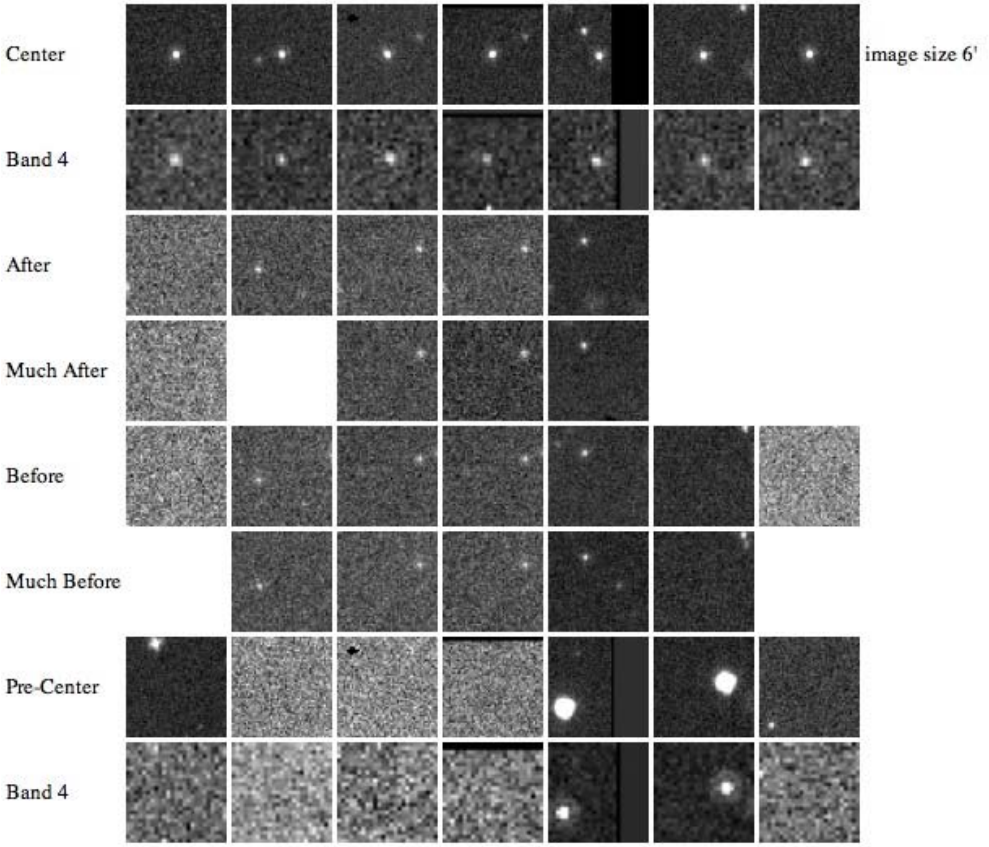
Integrated into the WISE Science Data Procesing System architecture

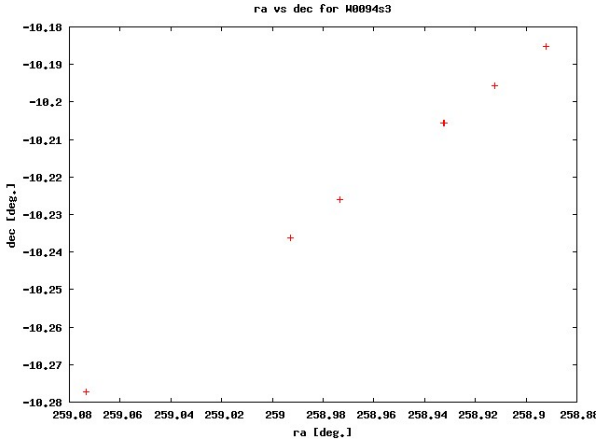
Extensive use of heritage software from PanSTARRS and LSST MOPS (J. Kubica, L. Denneau, J. Myers), MPC (G. Williams) and Auton Lab (CMU)

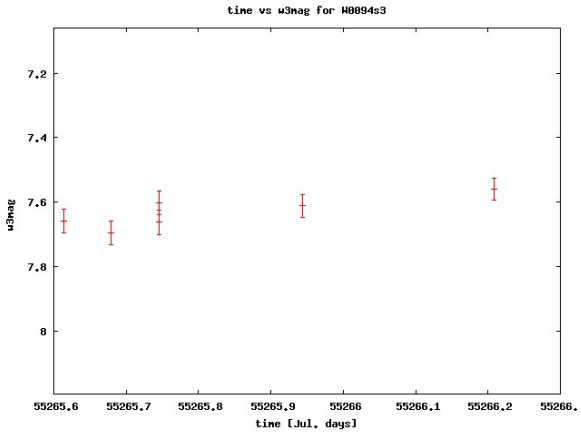


WMOPS Tracklet Validation

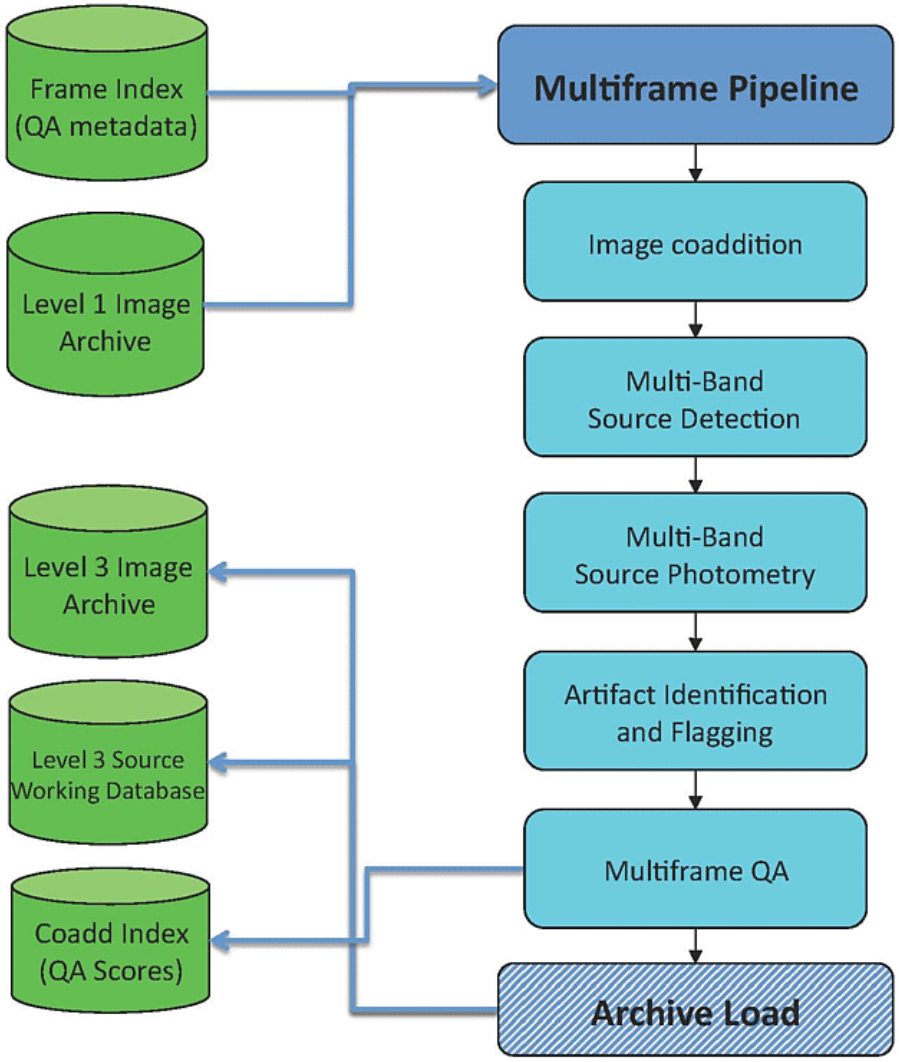
- Use scan/frame pipeline artifact flagging to filter out most spurious extractions
- Require >4 detections to form tracklet
- 50-65% of tracklets are high reliability and automatically validated
- Lower reliability tracklets validated by visual examination, orbit parameters
- ~2 runs/week, 5000-7000 tracklets/run, ~90% approved for reporting







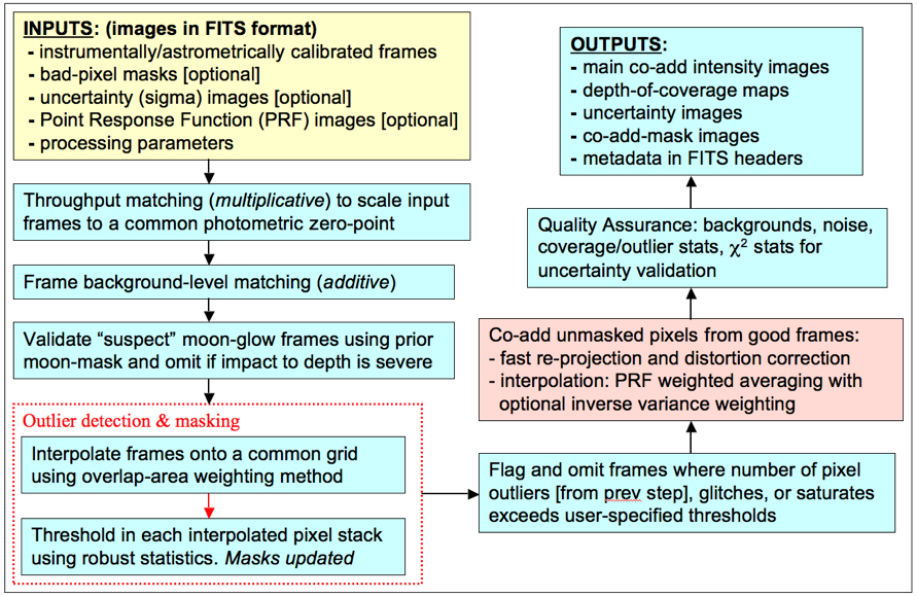
Multiframe Pipeline Combines Single-exposure Images for Deep Source Detection and Characterization



- Output:
  - Atlas Image sets
  - Source Working Database from which Source Catalog is derived
- Run following scan/frame pipeline at different intervals

Image Coadder Registers, Resamples and Combines Single-exposure Images

- Based on AWAIC (Masci - ADASS 2009)
- Atlas Image, coverage and uncertainty maps built on pre-defined grid of 18,240 1.56x1.56 deg "Tiles" that cover the sky
- Temporal pixel outlier rejection specifically designed for WISE (asteroids, satellites, etc)
- Handling of moon contamination specific to WISE according to prior moon mask and probabilistic algorithm coupled to outlier rejection
- Uncertainty propagation, estimation, and internal validation
- Plethora of QA metrics to validate quality of all steps, including uncertainty estimation.

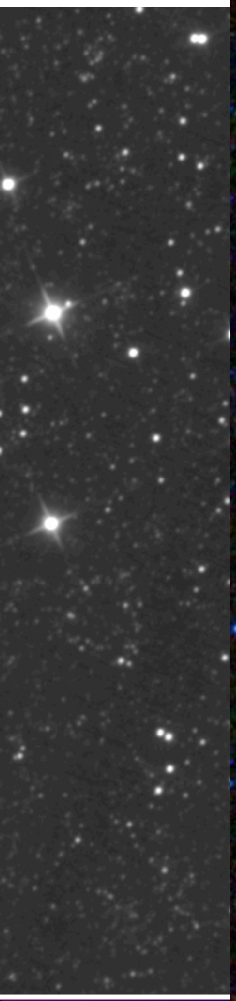


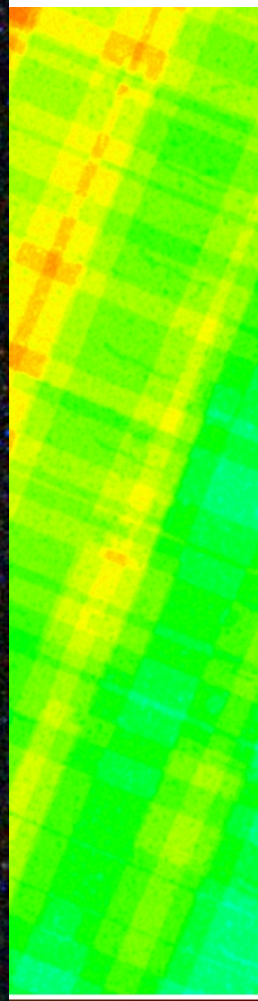
Coadder Example: Tile 0521m334_aa11

0.4x0.4 deg region in Tile 0521m334. (right) single 7.7s exposure W1 image. (left) coadded W1 image. 245 framesets cover full are of this Tile.

WIS

a11

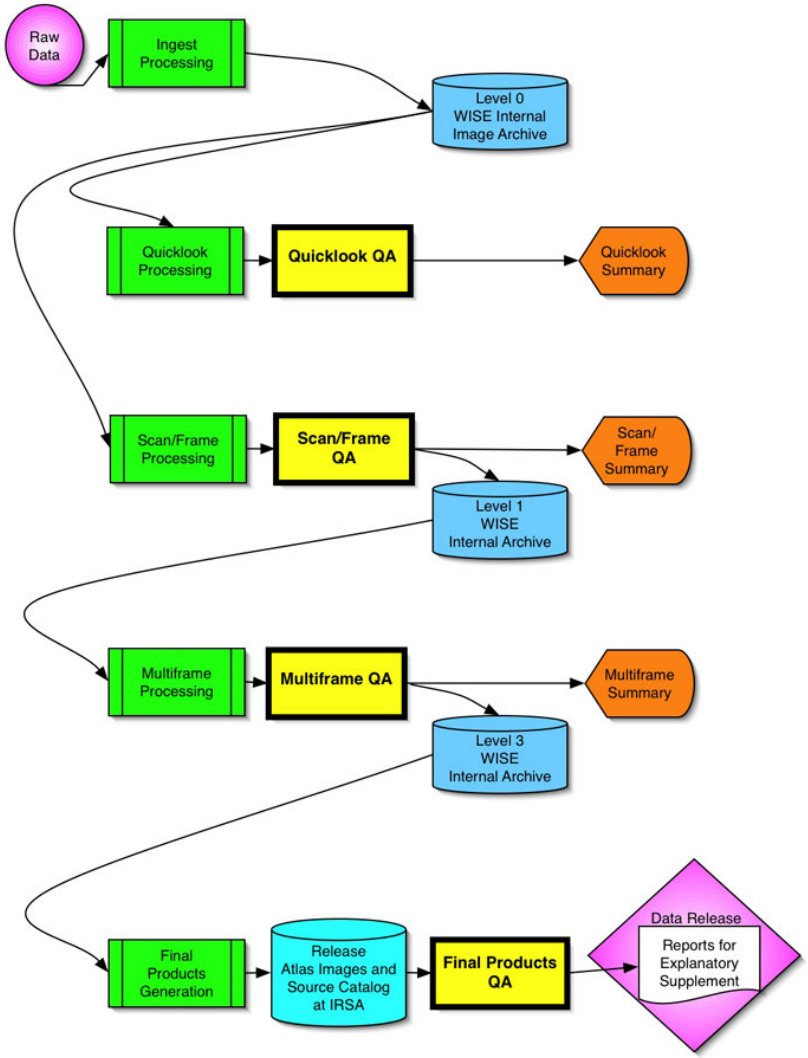




35

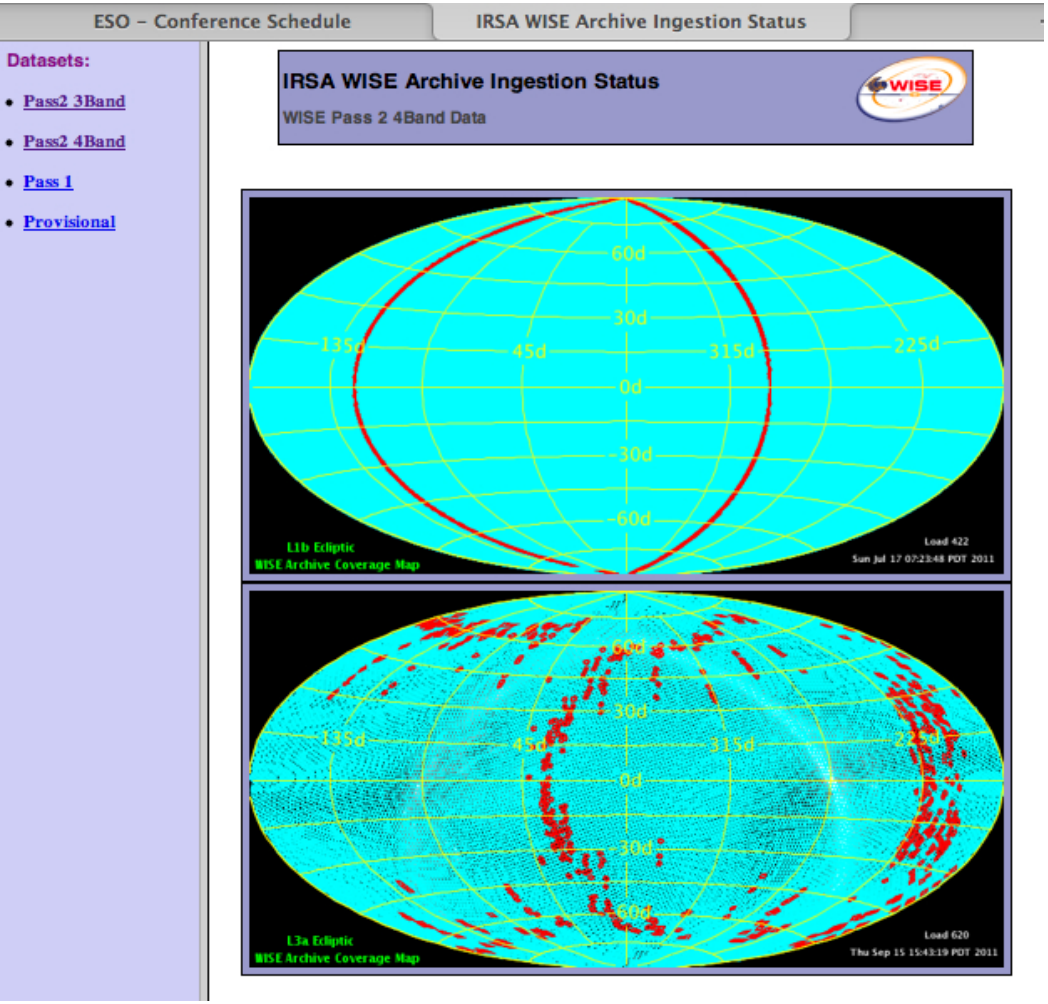
left)

Quality Assurance Subsystem Validates WISE Science Data at each Processing Step



- Approach modeled closely on successful 2MASS QA System
- WSDS subsystems generate QA metadata
- QA software system harvests metadata, compiles into **concise web-based reports**
  - Science-based performance metrics
  - Trending data
  - Drill down capability to investigate anomalies
- QA scientists review high level reports to confirm automated scoring, override if necessary

Archive System Curates and Serves WISE Data Products

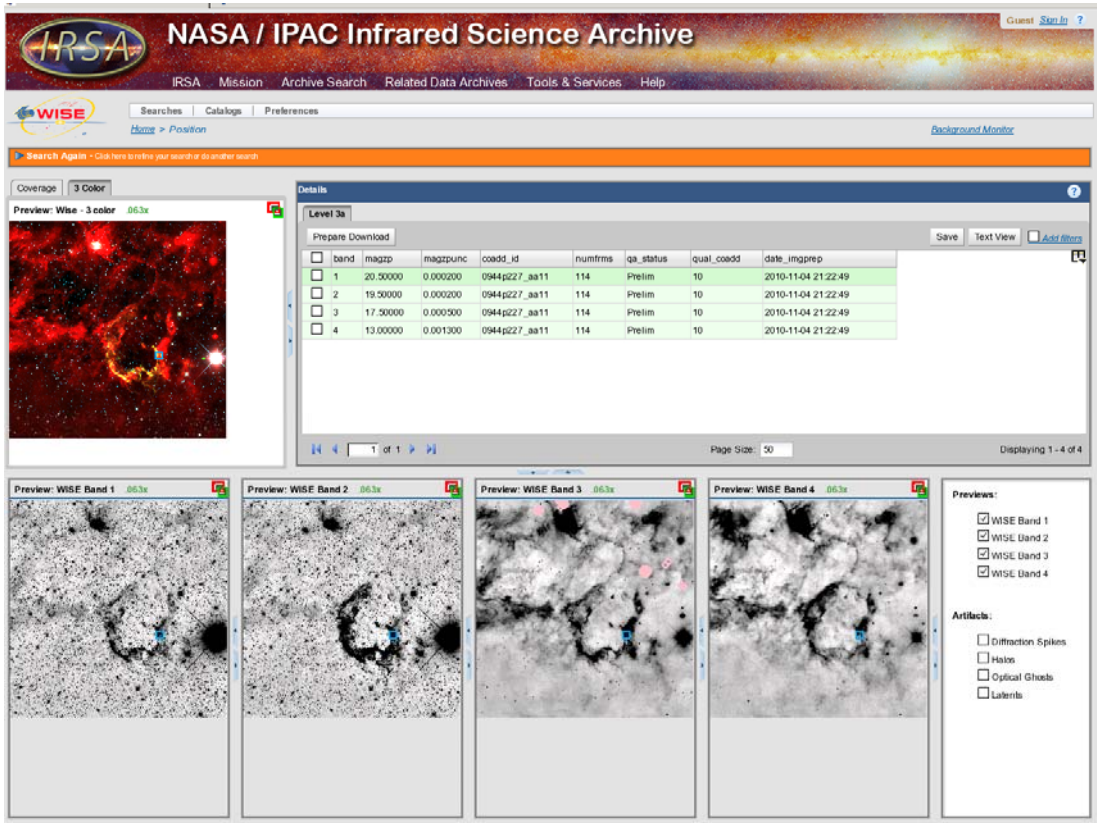


- Developed within infrastructure of the NASA/IPAC Infrared Science Archive (IRSA)
  - Leverages IRSA experience serving similar very large tabular and image data sets for other missions and programs
  - Leverages IRSA interoperability and VO compatibility
- Image and Tabular data produced by WSDS Pipelines and QA are ingested into the IRSA archives within ~1 week of processing

WISE Team and Public Data Access via IRSA On-line and Machine-friendly Interfaces

http://irsa.ipac.caltech.edu

- Source Catalog, L1 Database and metadata table queries via *GATOR* search engine interface
- Image view and download via *WISE Image Server* (based on Spitzer Heritage Archive server architecture)
- Solar system object search capability by name or orbital elements (NEOWISE)

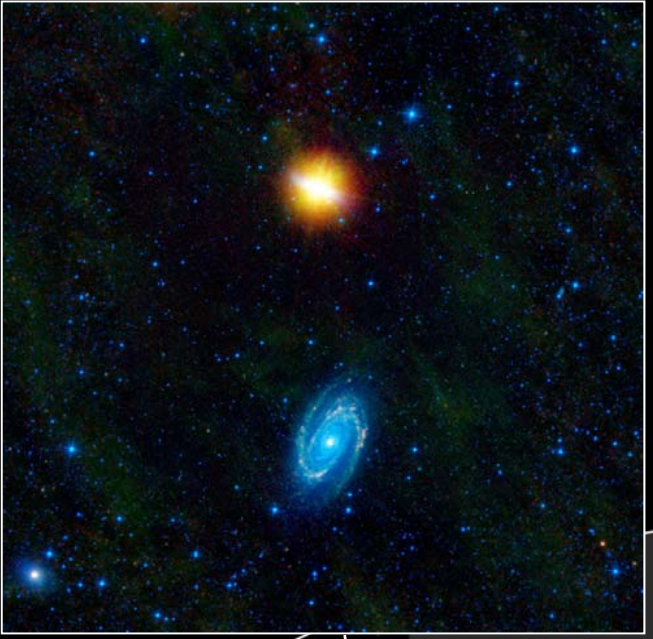


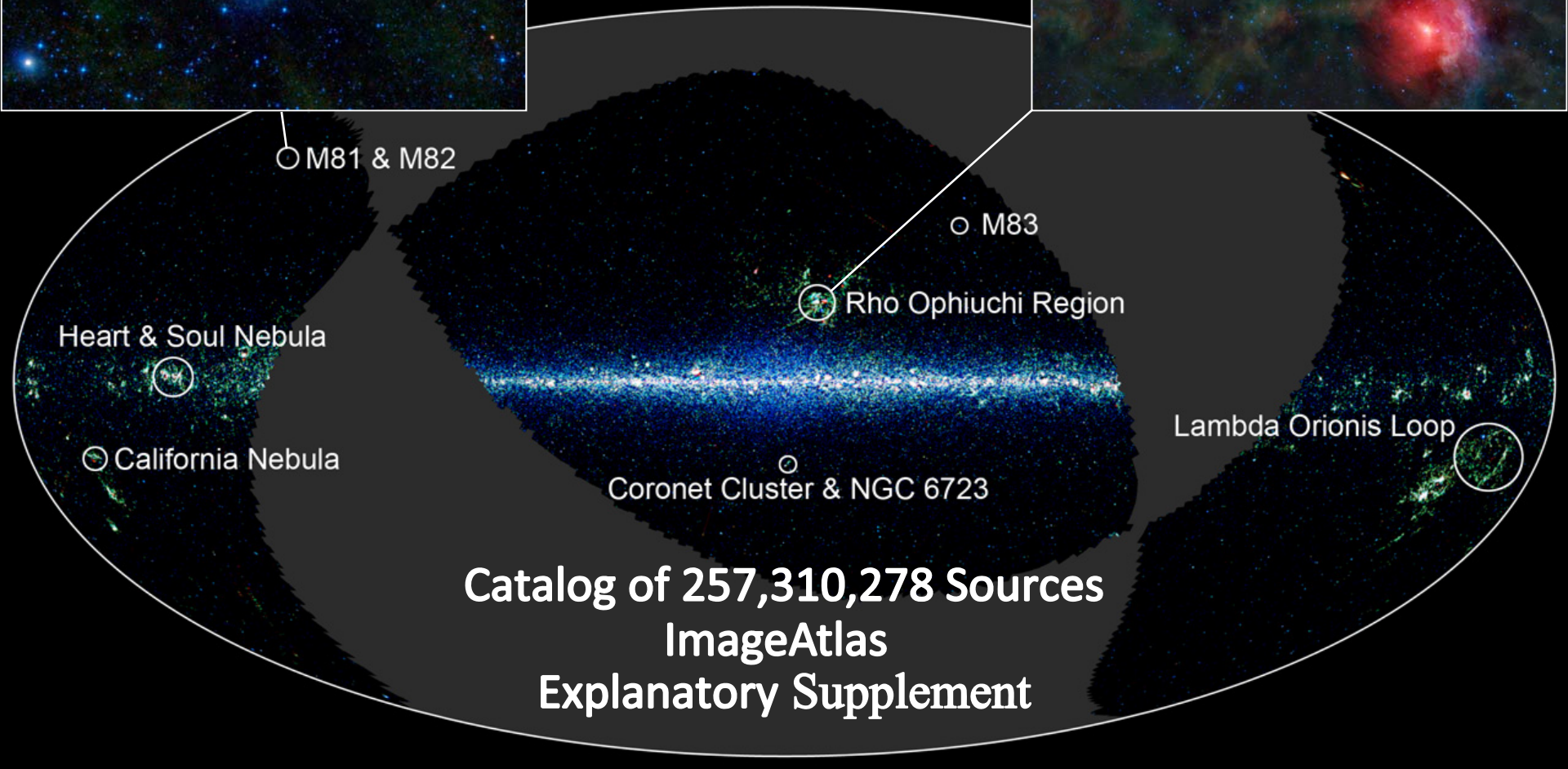
IRSA/WISE Image Server showing result of a query for the WISE Image Atlas containing IC443

WISE Preliminary Data Release

April 14, 2011

First 57% of sky



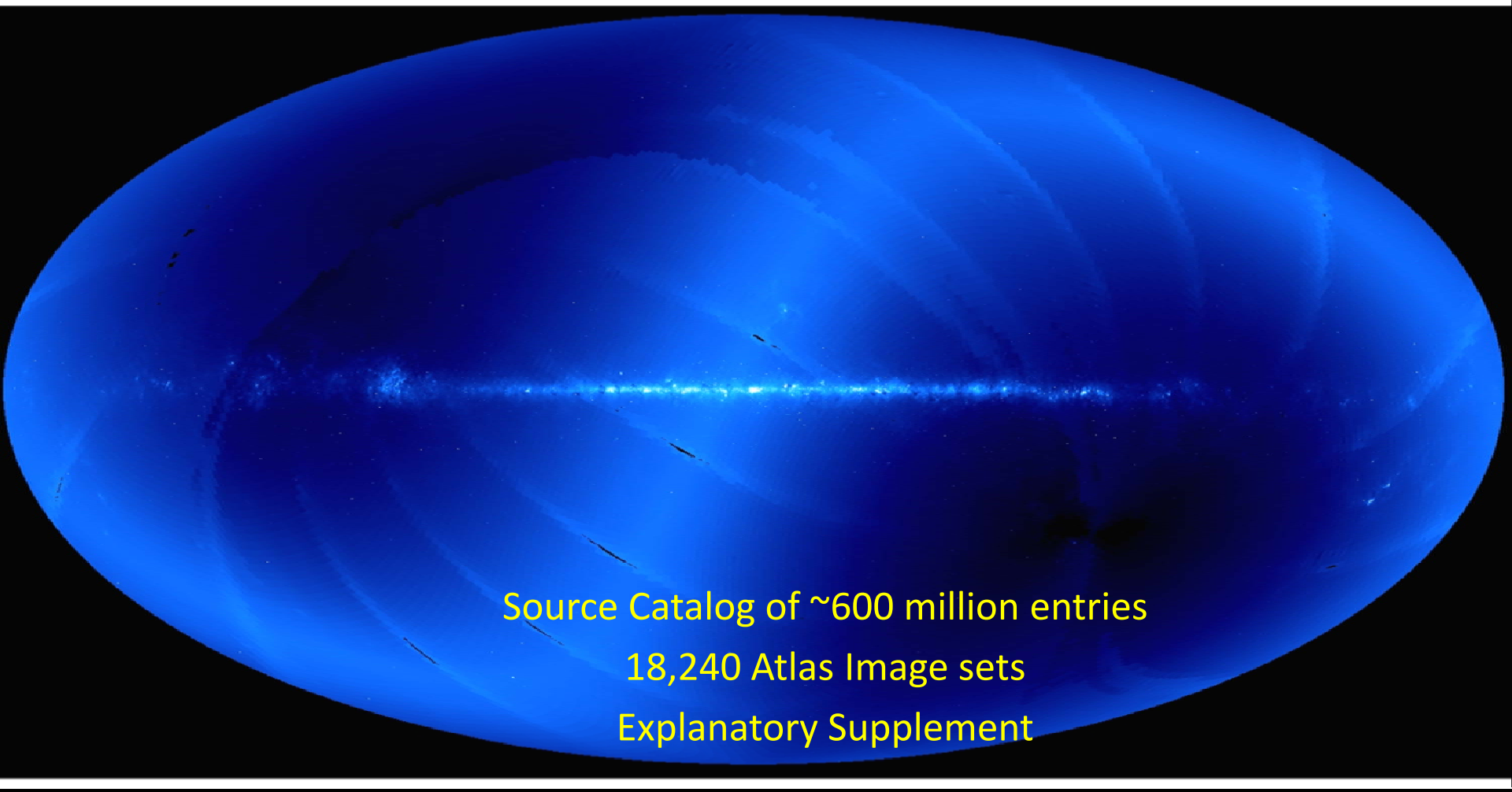


Catalog of 257,310,278 Sources

ImageAtlas

Explanatory Supplement

WISE Final Release – Northern Spring 2012



All-Sky W3 Atlas Image Mosaic (no background matching)

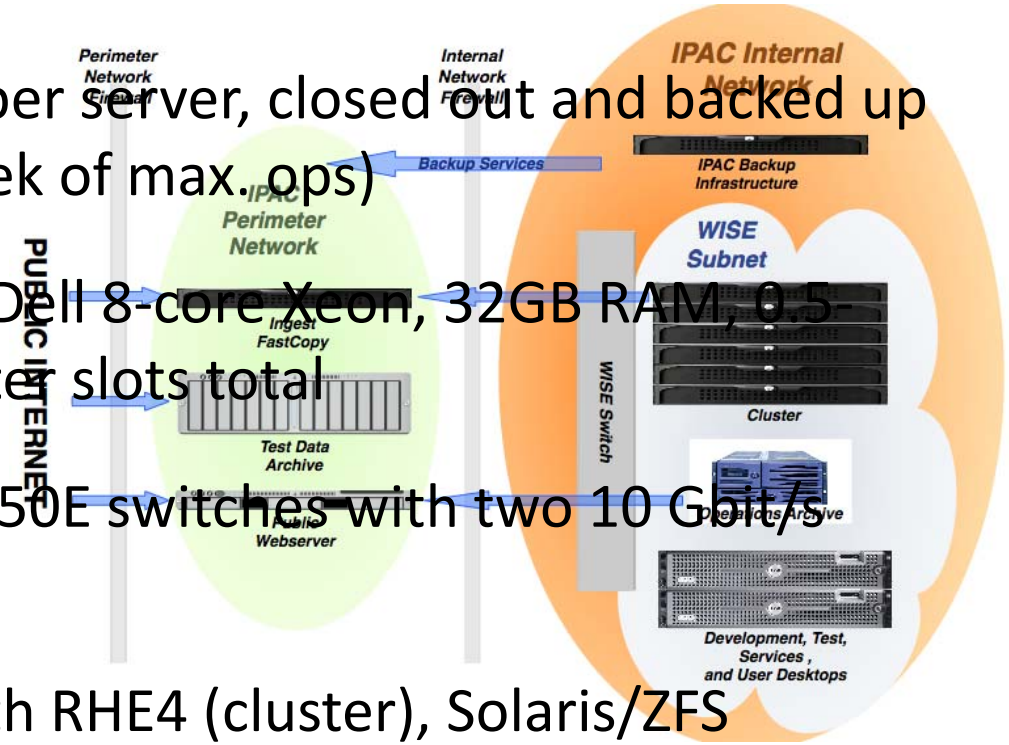
Backup Slides

The WISE Data Products are the Ultimate Mission Deliverables

- Image Atlas
  - **18,240** Calibrated FITS image sets (4 bands/set), 4kx4k pix @1.375”/pix
  - Formed by combining all single exposures covering *Atlas Tile* footprint
  - Pixel depth-of-coverage, uncertainty maps and metadata for each image
- WISE Source Catalog
  - Accurate positions, calibrated 4-band photometry, quality and value-added flags and parameters for **~600 million** objects
- Explanatory Supplement
  - On-line user’s guide describing mission, data product formats and characteristics, cautionary notes and access modes
- Ancillary Products
  - Single exposure images and extracted source database (**10^{13} pix, 2×10^{9} srcs**)
  - Moving object tracklets (**2×10^{6}** measurements of **1.6×10^{5}** bodies)
  - Known solar system object associations (**3×10^{7}** obs of **2×10^{5}** bodies)

Ops Hardware Details

- 5 Sun/Oracle X4270 Storage Servers (4 ops + spare)
- 15 Sun/Oracle J4400 SAS JBOD's, H/W RAID, 3 X 18TB usable per server; 270 TB total
  - Partitions of 3-4 TB ea. per server, closed out and backed up when full (approx. 1 week of max. ops)
- 42 node compute cluster; Dell 8-core Xeon, 32GB RAM, 0.5-1TB internal disk; 320 cluster slots total
- 3 Cisco 48-port Catalyst 3750E switches with two 10 Gbit/s interfaces each
- Resource management with RHE4 (cluster), Solaris/ZFS (servers), NFS3, Condor, Ganglia



Key Implementation Features - 1

- WSDC integrated into WISE planning and design from the beginning
  - WSDC participates in project management activities, decisions, strategic planning
- 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
- Strong intellectual heritage from other IPAC-supported missions/projects
  - WSDS software developed by many of the same engineers and scientists that performed similar tasks on IRAS, 2MASS, Spitzer, GALEX
- Planned two-stage data processing and data release
  - “Can’t get it right the first time”
  - Gets preliminary version of data out to community as rapidly as possibly
  - Allows time to incorporate best knowledge of actual instrument performance, calibration and sky for “final” version

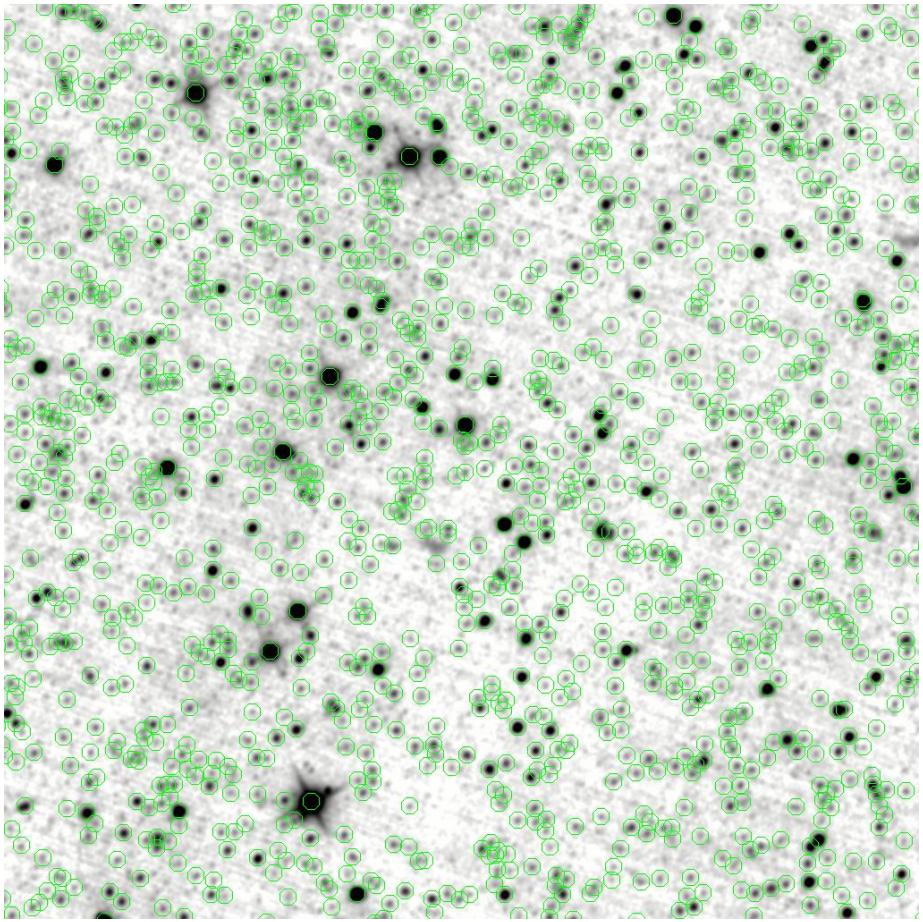
Key Implementation Features - 2

- Design from outset with *end product development and distribution* in-mind
  - Leverage IRSA infrastructure to provide easy access to intermediate and final data products for Science and Project Team
  - Interfaces well-tested prior to public releases
- Thoroughly vetted and characterized data products with detailed on-line user documentation (Explanatory Supplement) describing processing algorithms and products
- On-going interaction with WISE Science Team during all phases of the project
  - Strategic designs based on science motivation
  - Peer reviews to validate pipeline algorithm design/development
  - Science Team participates in data and product validation
- WSDC software developers remain on staff throughout mission
  - Necessary to support IOC, response to actual on-orbit performance, and for two-stage processing strategy - final processing takes place after the end of on-orbit operations
  - Retains personnel with key expertise in WSDC software systems, algorithms and survey data for fast response to issues

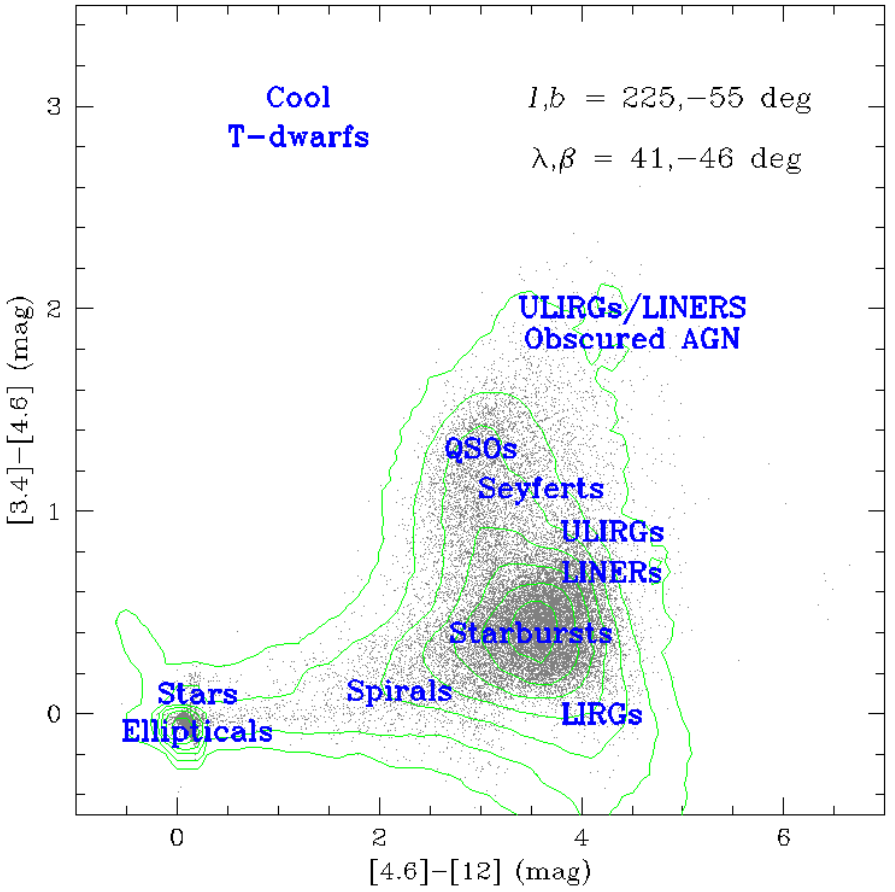
The WISE Team

- UCLA – PI Ned Wright
- JPL – Project Mgmt, Mission Operations
- Space Dynamics Laboratory, Utah State Univ. - Payload
- Ball Aerospace and Technology Corp. – Spacecraft, System I&T
- IPAC/Caltech – Science Data Center
- UC Berkeley – E/PO

Source Catalog Will Contains ~600 Million Entries



0.4x0.4 deg section of W1 Atlas Image at *l,b=225,-55* deg. Green circles denote Catalog entries.



W1-W2-W3 color-color diagram of Catalog sources in 116 deg^2 regions centered on *l,b=225,-55*