OSIRIS REx
Science Processing & Operations Center (SPOC) and Science Engineering Peer Review

OSIRIS-REx™
ASTEROID SAMPLE RETURN MISSION

14– Science Processing

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Deputy Principal Investigator

Agenda

- What Science Delivers
- Science Processing Overview
- How we Plan Science Processing
- Tools
- Introduction to Science Team Presentations

What Science Delivers

- Phase C/D
  - Data Product Descriptions
  - Algorithm Descriptions
  - Interface specifications (along with SPOC)
  - Software, test data, and documentation (in 2 builds)
- Phase E
  - Products for testing and training
  - Data products for:
    - Science
    - Navigation and NFT, Flight System Safety
      - Some meet requirements (shape model)
      - Some “boot” processes (rotation state, pole)
      - Some are informational (coordinate system, mass, gravity field)

Science Products (Examples)

- Products for Flight System Safety
  - Natural Satellite and Dust Plume Detection
- Products for Navigation
  - Global Shape Model (Digital Terrain Maps)
- Products for Map Making and Geology
  - Image mosaics
  - Boulder counts
  - Global Shape Model (Digital Terrain Maps)
- Inputs to the Top Maps for Site Selection
  - Temperature and Thermal Inertia
  - Mineralogy Maps
  - Particle size frequency distribution
  - Tilt maps
- Products for Science
  - Yarkovsky Effect
- Complete list on Science Team Wiki at
  - https://sciwik.lpl.arizona.edu/wiki/pages/o6U6F2m7/SPOCScience_MOR_EPR.html

Detailed Survey Science Products (1/2)

Detailed Survey Activities	
Global Deliverability Map (MRD-570b)	1/29/19
SFD Database down to 21-cm for ROI (North) (MRD-121/116)*	1/31/19
SFD Database down to 21-cm for ROI (South) (MRD-121/116)*	2/8/19
Global Image Mosaic (MRD-121)*	2/5/19
Global Stereo Images (MRD-121)*	2/12/19
Global Image Mosaic at 860 nm (x filter)	2/14/19
Global Polycam Photometric Model (MRD-149)	2/15/19
Photometrically Corrected Polycam Imagery	9/12/16
Global temperature maps (MRD-155)	3/14/19
Dust and Plume Search 1 (MRD-142)*	2/6/19
OVIRS Data Selection for Photometric Model	3/13/19
Dust and Plume Search 2 (MRD-142)*	2/26/19
Global Mapcam Panchromatic Photometric Model V1 (MRD-149)*	3/25/19
Photometrically Corrected Mapcam Panchromatic Imagery	9/12/16
Global Mapcam Color Photometric Model V1 (MRD-149)*	4/1/19
Photometrically Corrected Mapcam Color Imagery	9/12/16
Global OVIRS Photometric Model V1 (MRD-149)*	3/25/19
Photometrically Corrected OVIRS Data	9/12/16
SPC Global Regional Shape and Terrain Models SPC_GRS005 and SPC_GRTM005 (MRD-115,121)*	3/19/19
Global Bond Albedo Map (MRD-154)*	4/8/19
Global Thermal Model (FTPM) (MRD-156)	4/15/19
Global Thermal Model (ATPM) (MRD-156)	4/15/19
Asteroid pole, wobble and rotation period (MRD-127,128,129)	3/20/19
Global Crater Map	3/20/19
Global Boulder Map	2/13/19
Global Linear Features Map	3/20/19

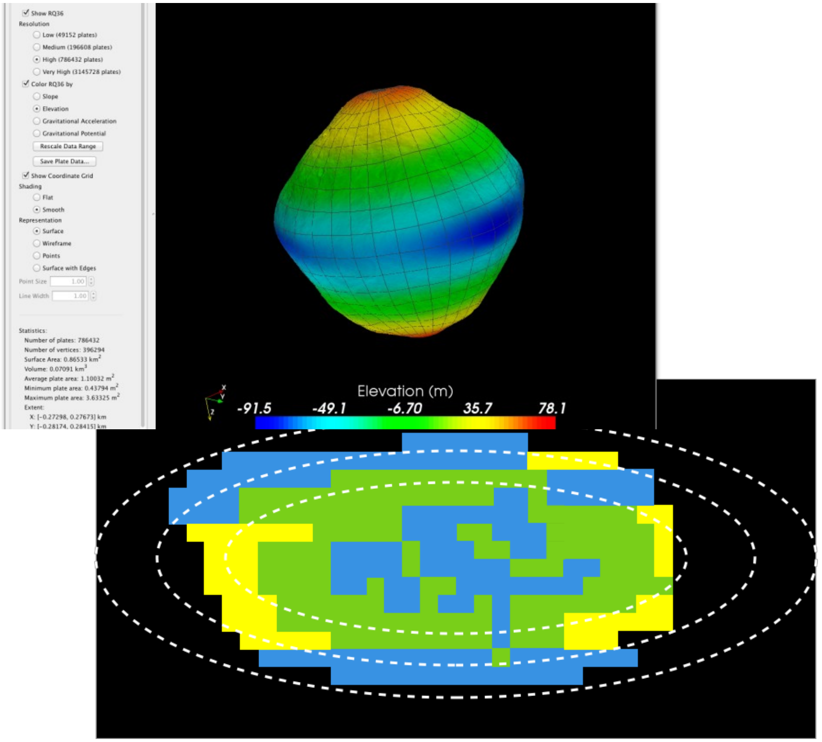
Detailed Survey Science Products (2/2)

Detailed Survey Activities	
Global Temperature Map at Time of TAG or Max Temperature	4/16/19
Global Thermal Inertia map (MRD-155)*	4/22/19
Global Regolith Map	4/23/19
Photometrically Corrected Global Image Mosaic at 860 nm (x filter)	4/3/19
Photometrically Corrected Global Image Mosaic (MRD-121/149)	3/27/19
Photometrically Corrected OVIRS Spectra (MRD-149)	3/26/19
Global Mineral and Chemical, Dust Cover Index Maps (MRD-140)	4/3/19
Global Space Weathering Map	4/4/19
Global Geologic Maps	4/4/19
1064 nm reflectance Map (New)	4/5/19
Global Safety Map (MRD-183a)	4/19/19
Global Sample-ability Map (MRD-183c)*	4/25/19
Global Science Value Map (MRD-183d)	4/26/19
Select Initial 12 sites (MRD-570)	5/1/19
FD Deliverability Maps for 12 sites Complete (MRD-183b)	5/8/19

Other Detailed Survey Science Products	
Global b-v, v-x, and 0.7µ Color Ratio Maps (MRD-141)	3/25/19
OLA Global Shape and Terrain Models OLA_GS075 and OLA_GTM_075 (MRD-122)	3/18/19
Rotationally resolved thermal inertia (MRD-544)	4/11/19
Detailed Survey Gravity Field Model (MRD-130)	3/26/19

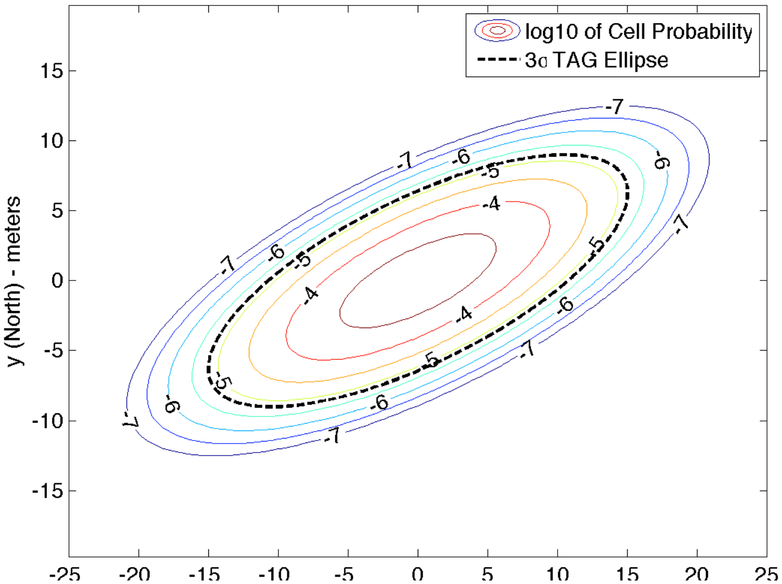
Site Selection Decision — Maps

- Select science products are input to *maps* produced at end of detailed survey, orbital B, and reconnaissance. Maps inform sample site selection.
  - Deliverability
  - Safety
  - Sample-ability
  - Science Value
- SPOC develops software to create safety, sampleability and science value maps based on requirements and algorithms from map teams
  - Map teams delivered draft requirements in late March.
  - Final requirements and algorithms due June 1.
  - Requirements review and sign off July 30 allow SPOC development to proceed

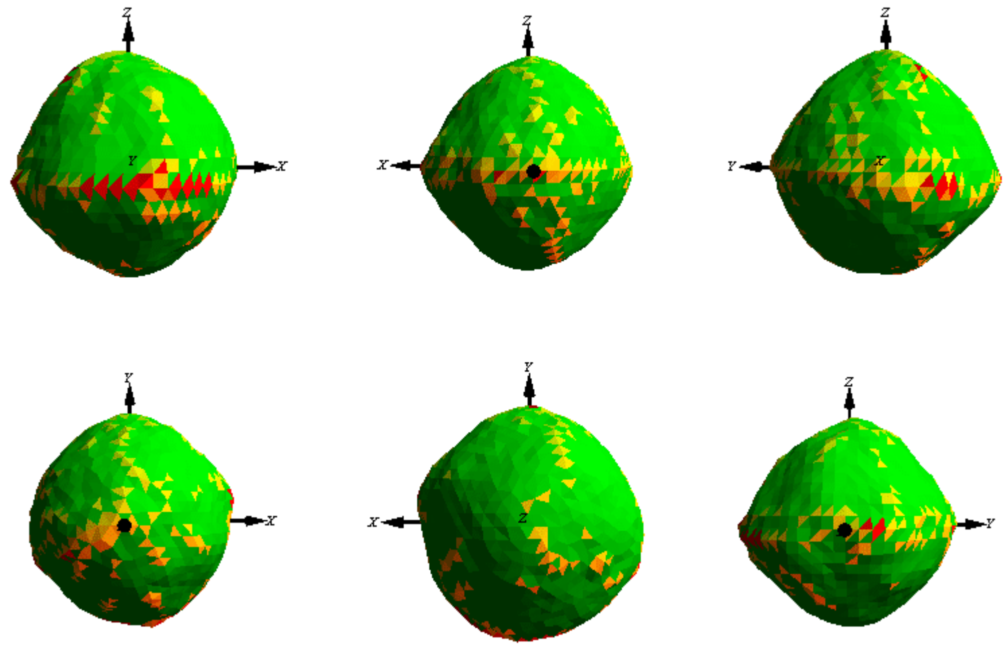


Deliverability Map

The deliverability maps use a Monte Carlo analysis that randomly samples the errors that affect the targeting, and propagates the spacecraft with these errors to determine the targeting error.



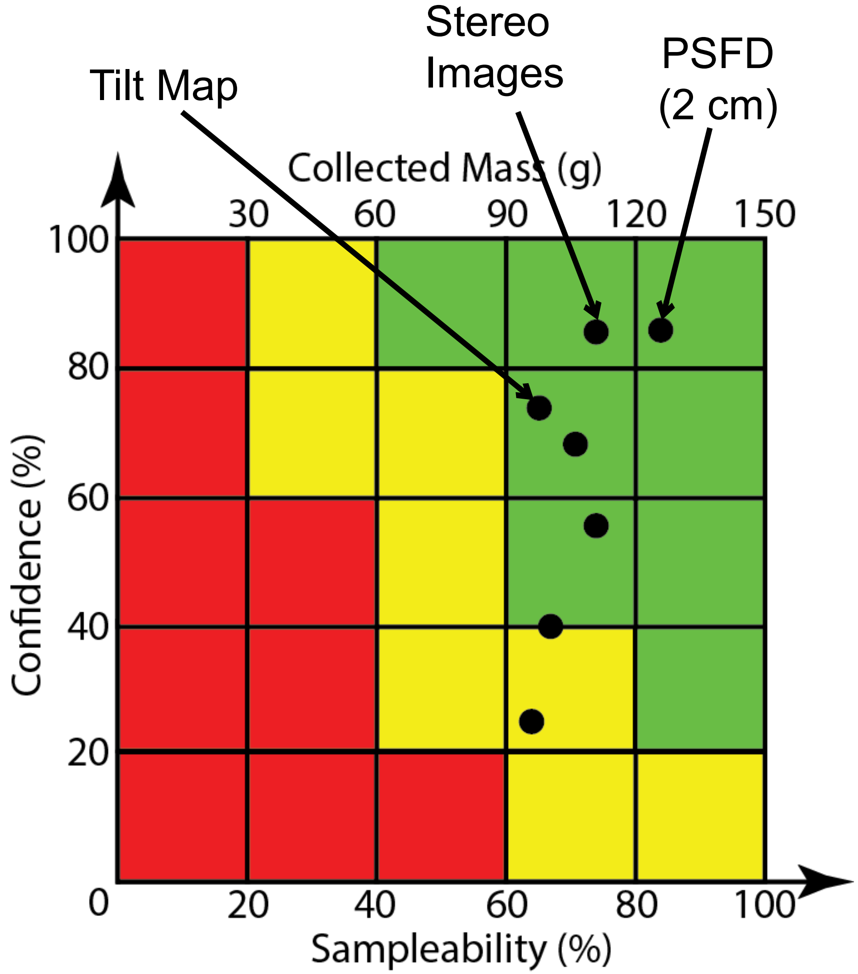
Safety Map



Safety maps are a quantitative integration of factors that affect flight system safety, including surface topography, thermal loads, communications, and guidance system capabilities.

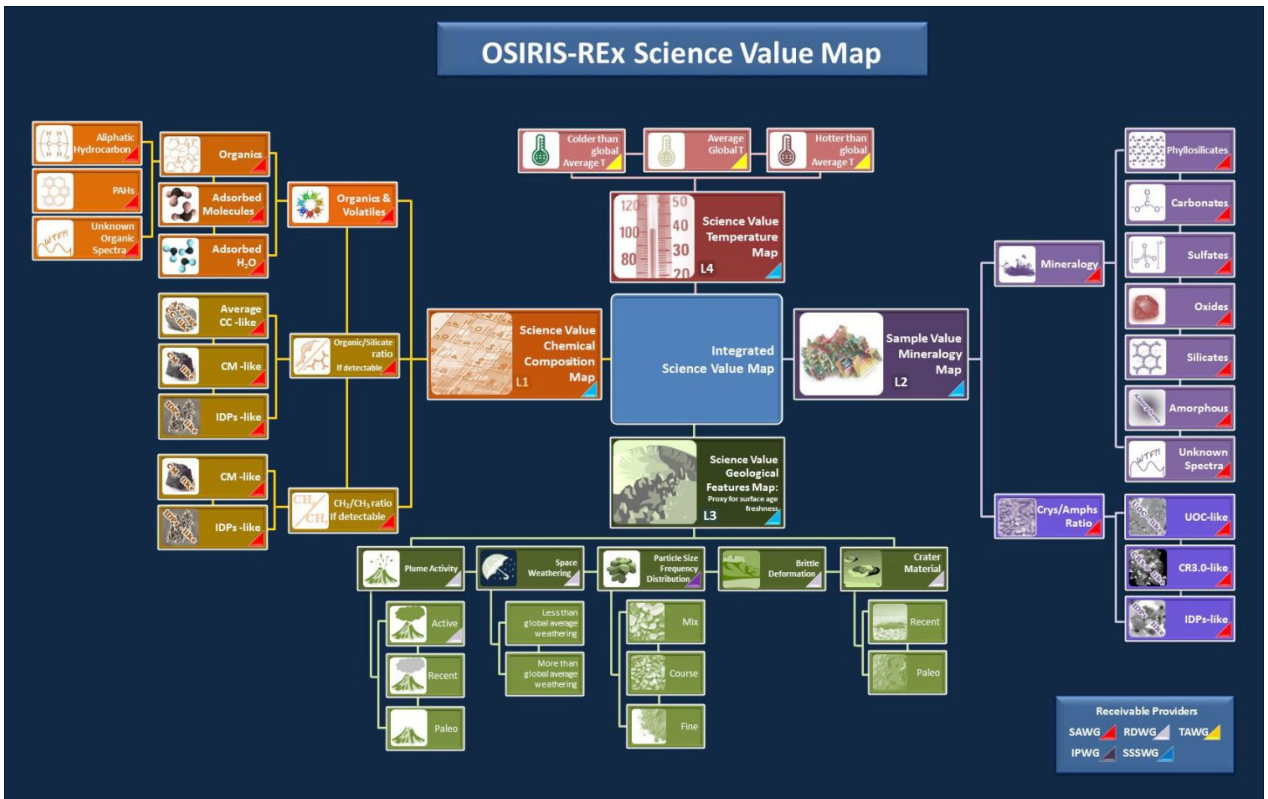
Sampleability Map

Sampleability maps will determine a sampleability and confidence metric for each source data product. Confidence incorporates assessments of accuracy, resolution, model dependency, and correlation with other assessments. Sampleability regions of interest will be convolved with 2-sigma deliverability ellipses.



Science Value Map

The science value map will rank the scientific value of candidate sampling locations. It incorporates weighted inputs from observations of chemical composition, mineralogy, temperature, and geologic features.

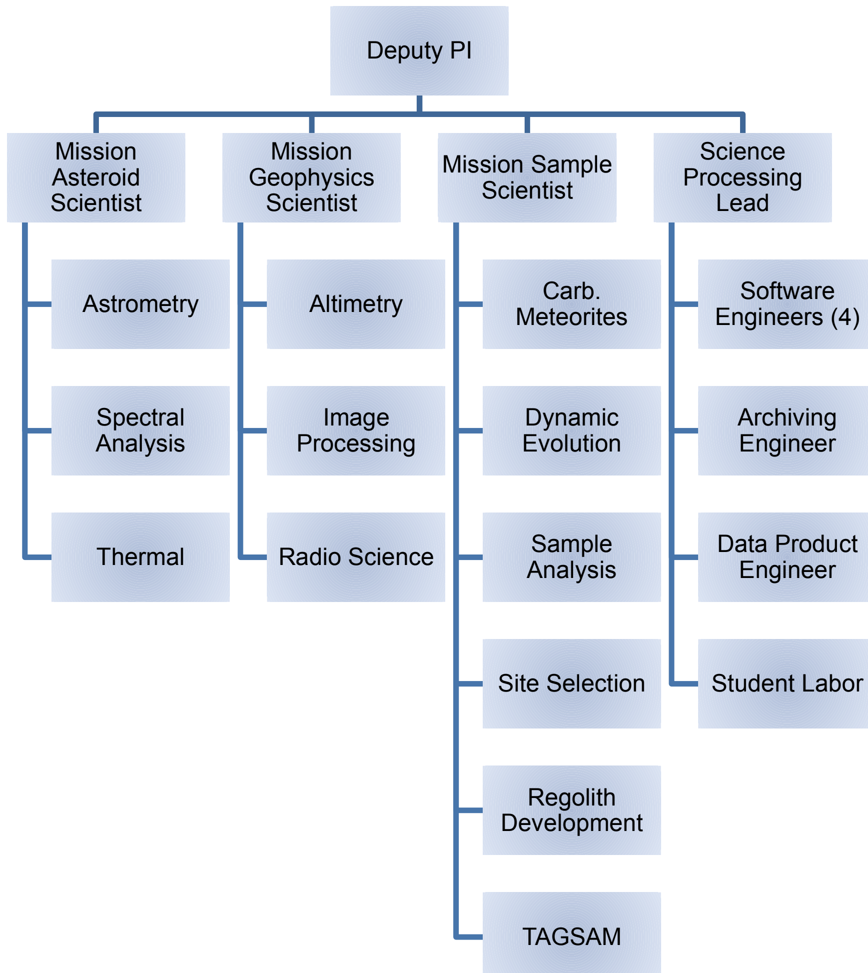


Safety, Sampleability, and Science Value Map Generation During Operations

- Software resides at Science Operations Center in Tucson
  - Uses data from SPOC repository, runs on SPOC machines
- Overseen by map team leads
  - With assistance from Science Operations team members
  - Use J-Asteroid visualization tool to review
  - Requirements and generation process dictated by map teams
  - Product leads for inputs to maps will be available to consult, along with briefing sheets for those products
  - Safety and sampleability maps both require a probabilistic estimate of success require deliverability maps as an input
  - Completion results in a Data Product Completion meeting and briefing sheet
  - Maps completion will trigger formal kickoff of sample site selection process

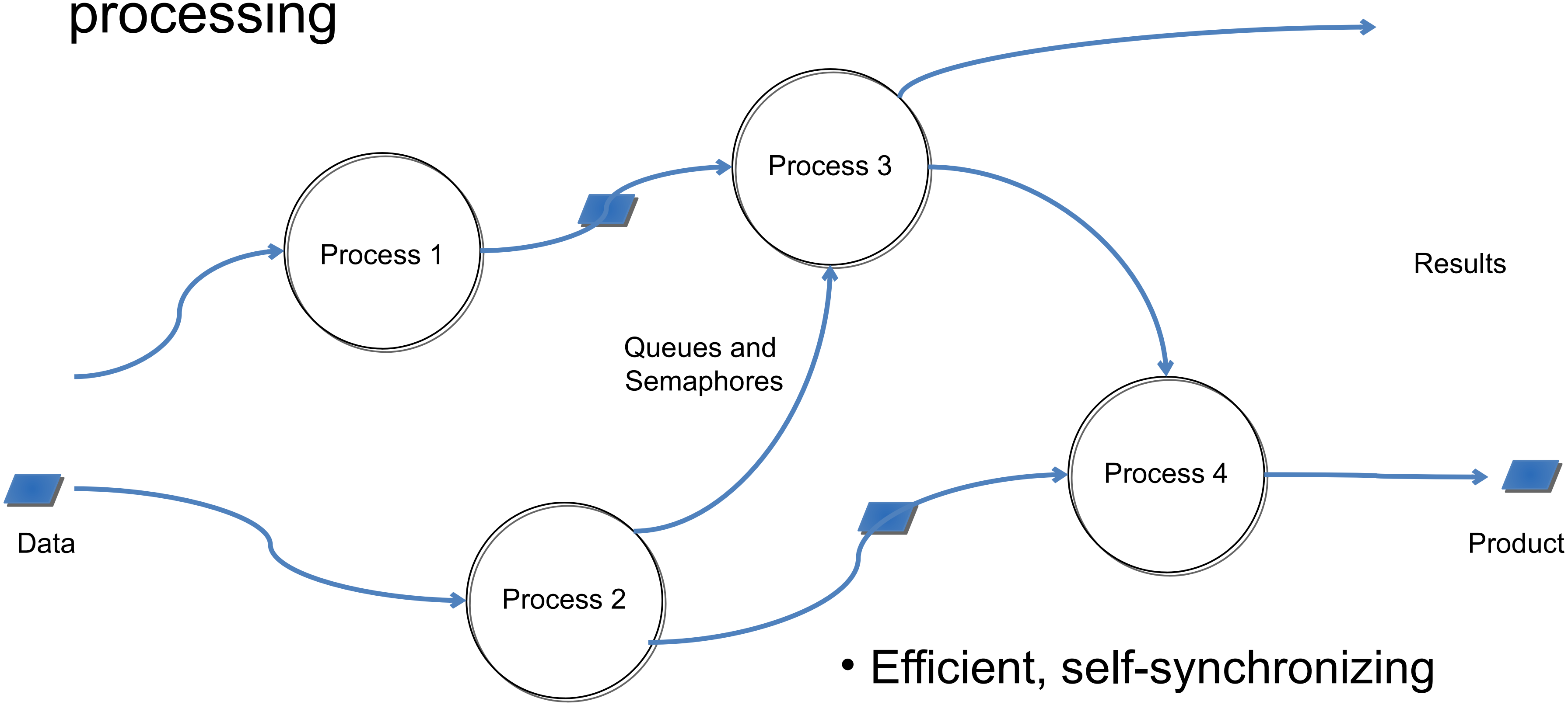
Science Processing Overview

Phase E Science Processing



Data-Driven Parallel Processing

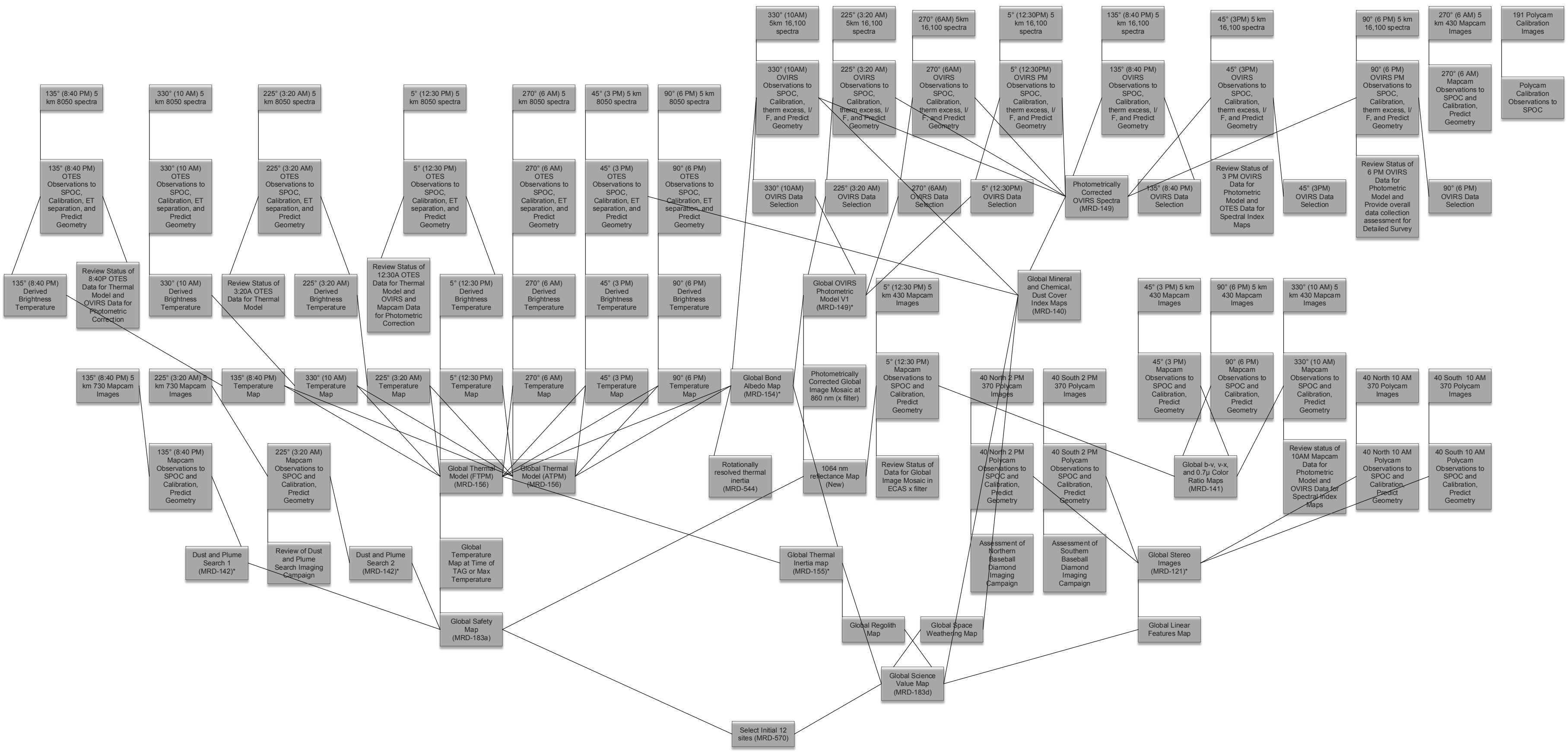
Availability of data initiates processing



- Efficient, self-synchronizing
- Challenge is to eliminate stalls

Science Processing Overview

- Science Processing is a loosely coupled, data-driven, parallel computing architecture



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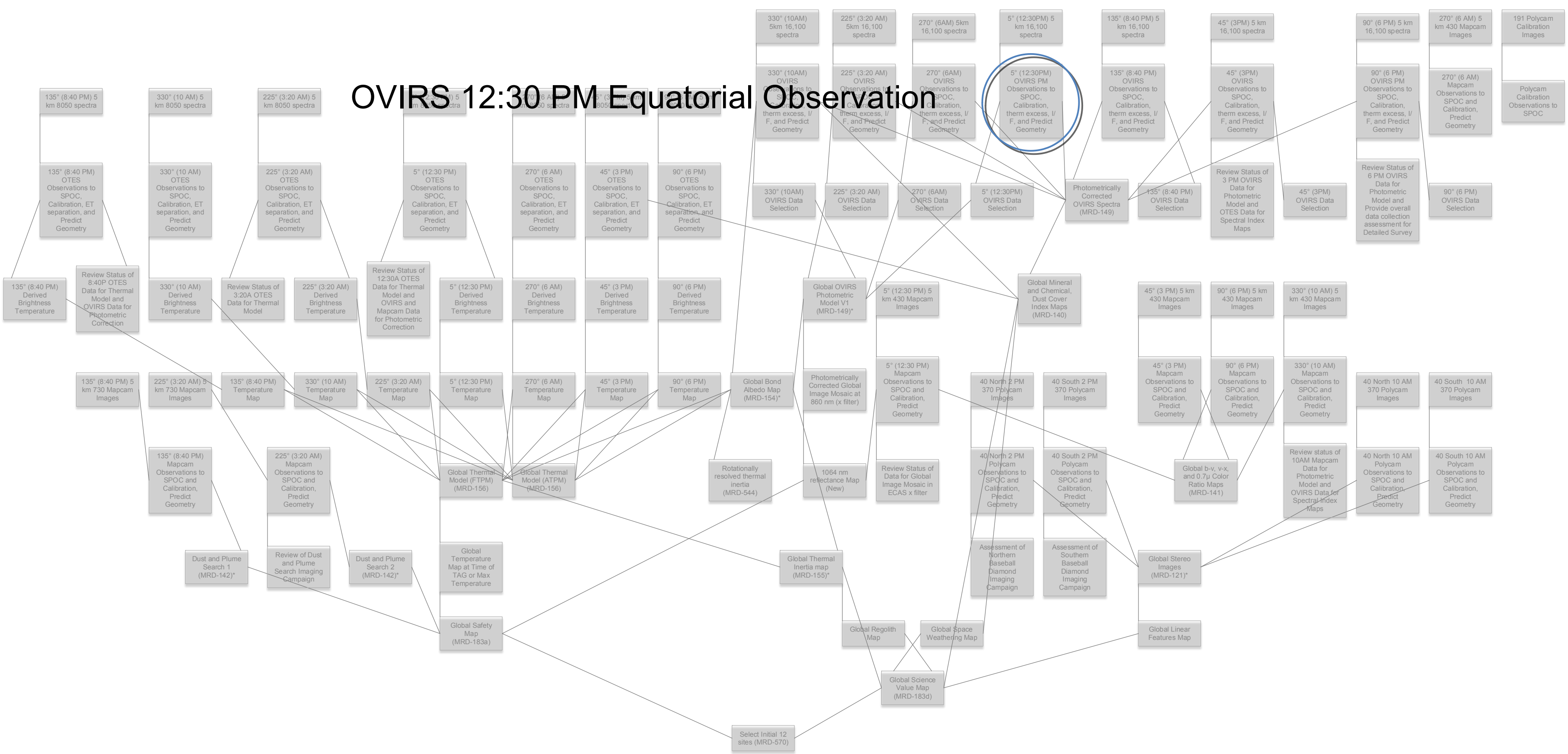

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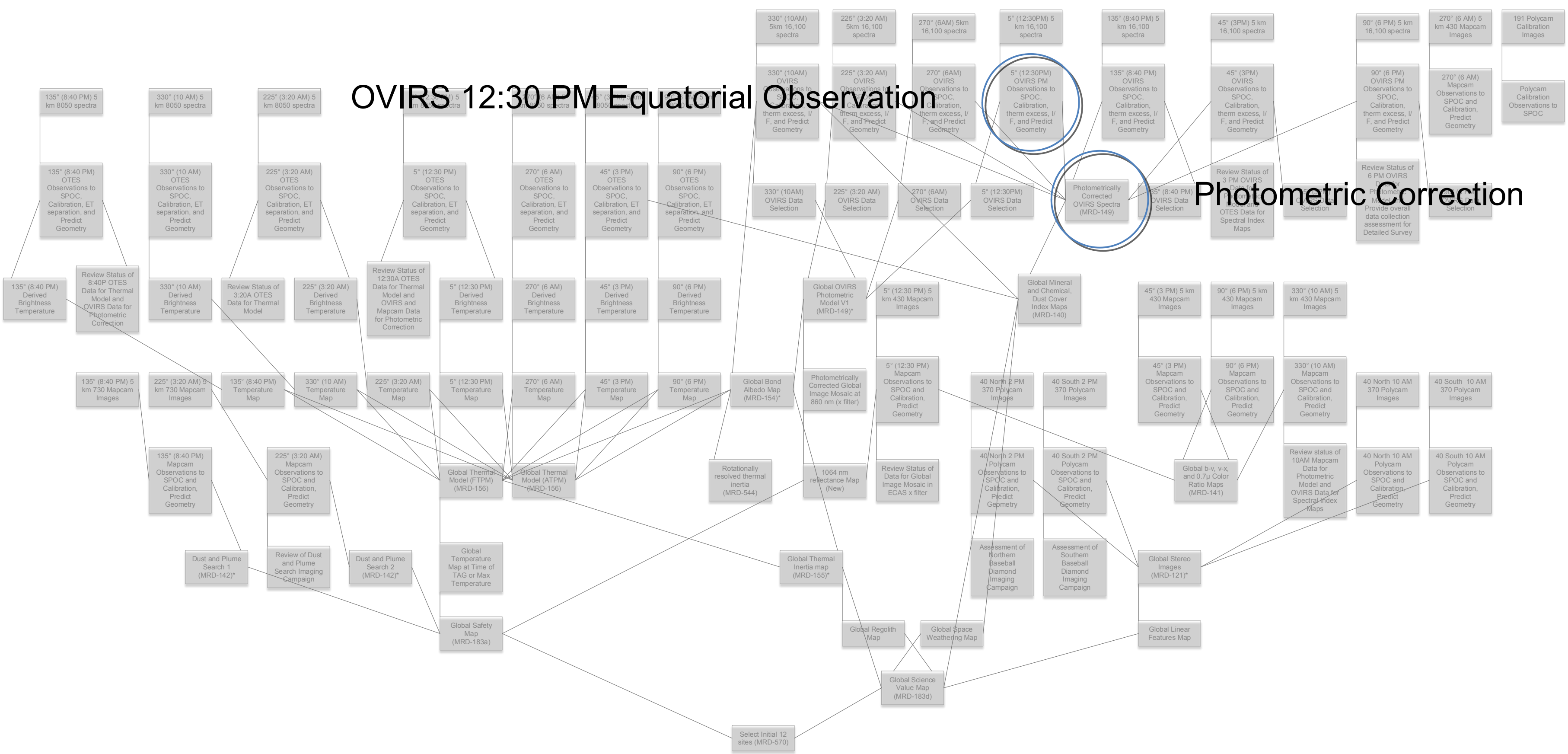

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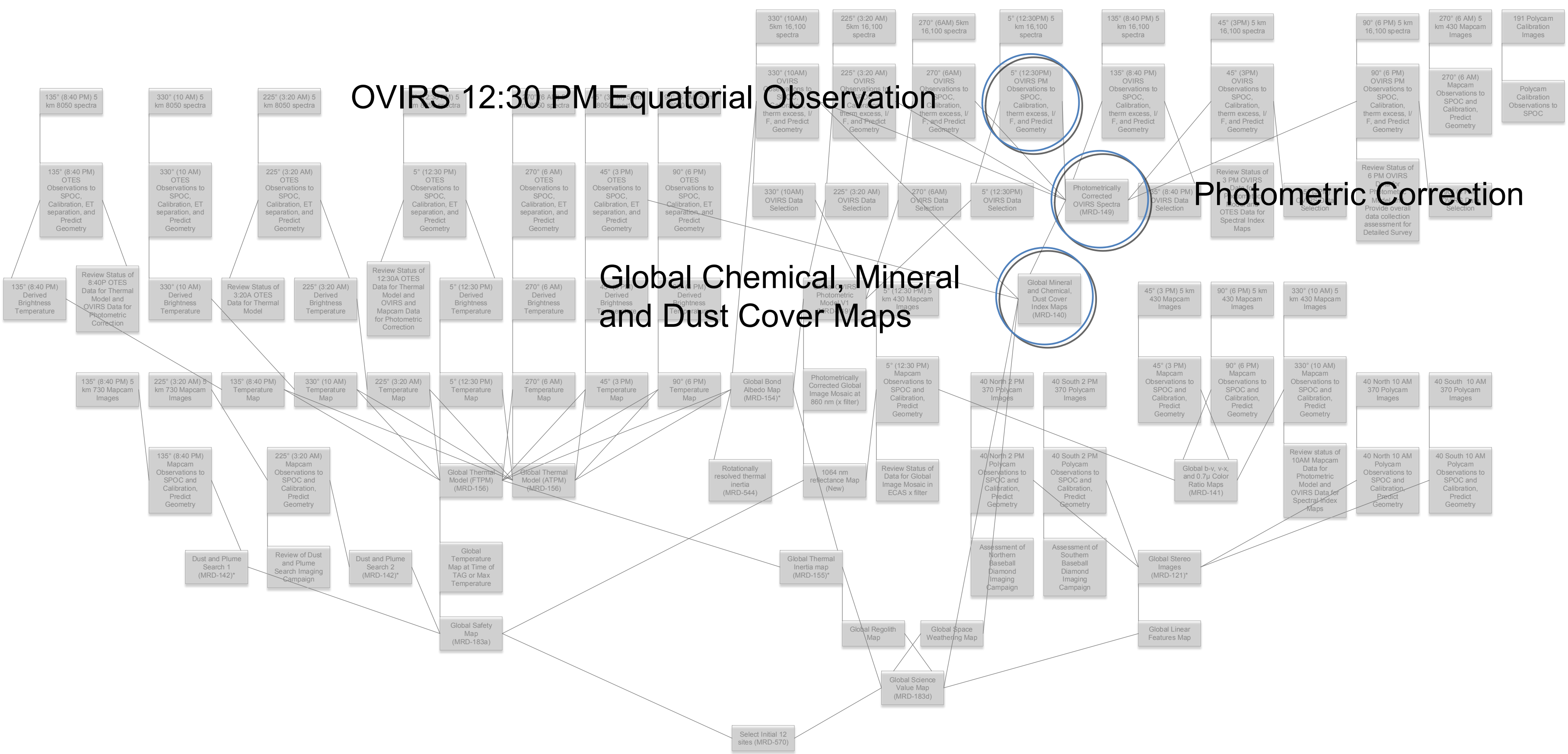

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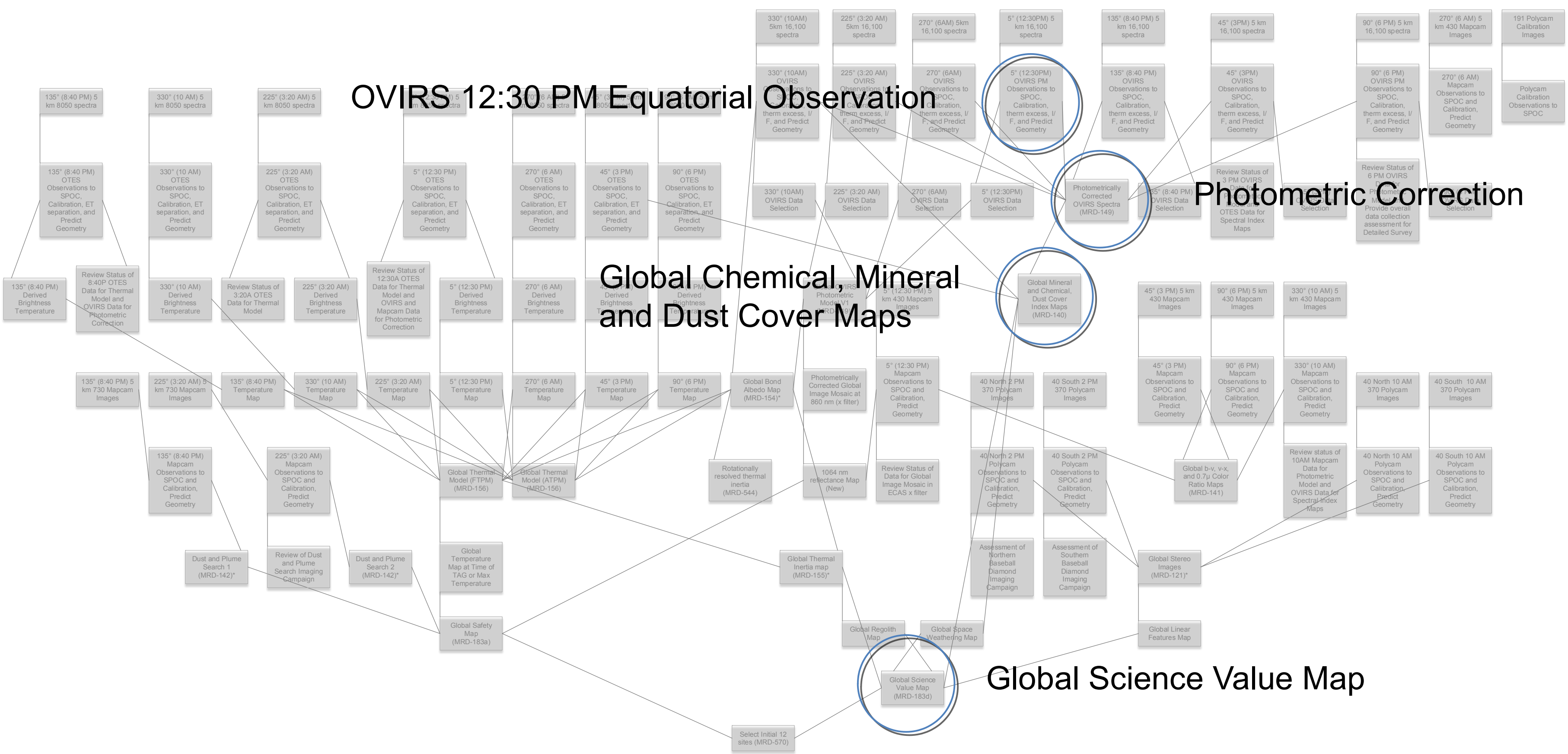

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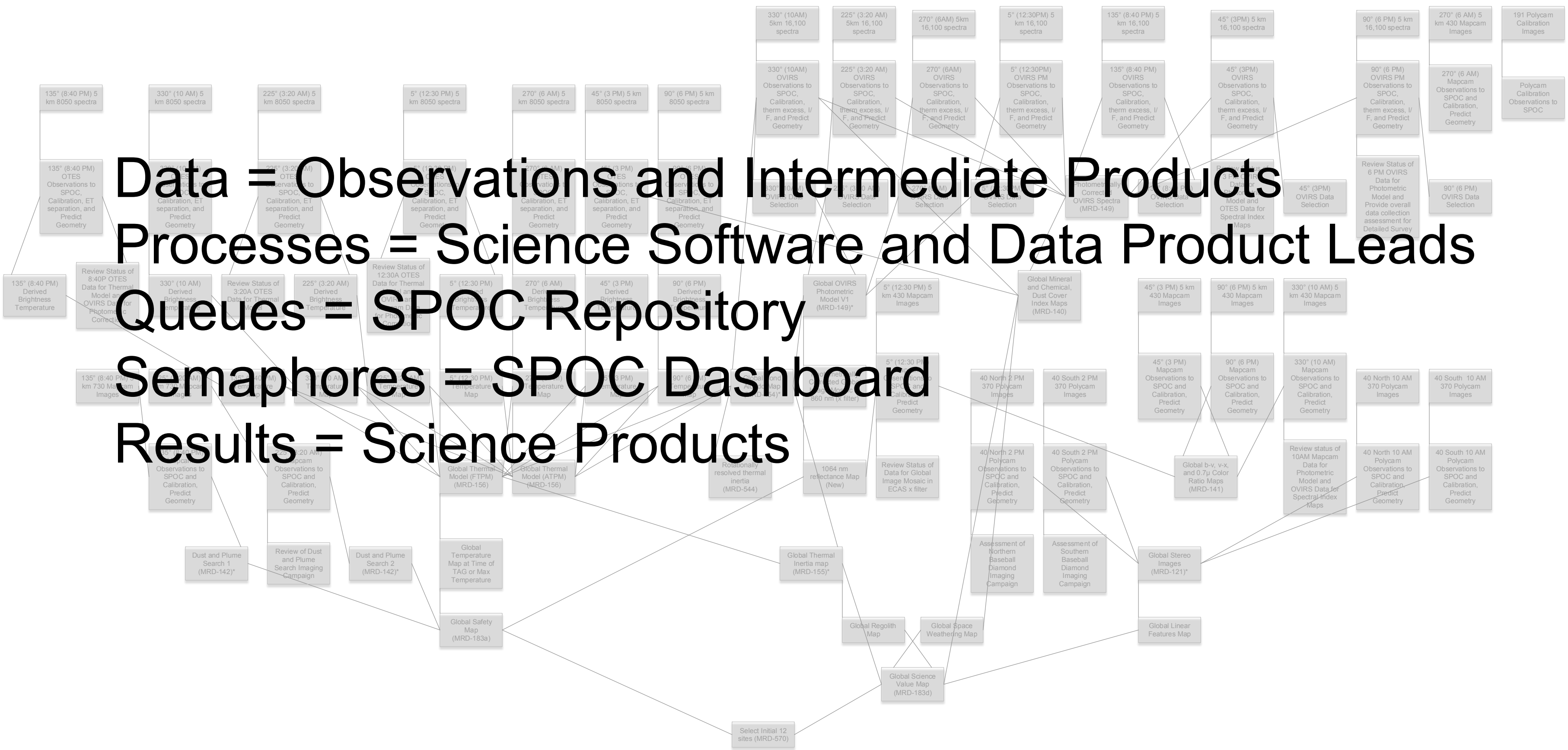


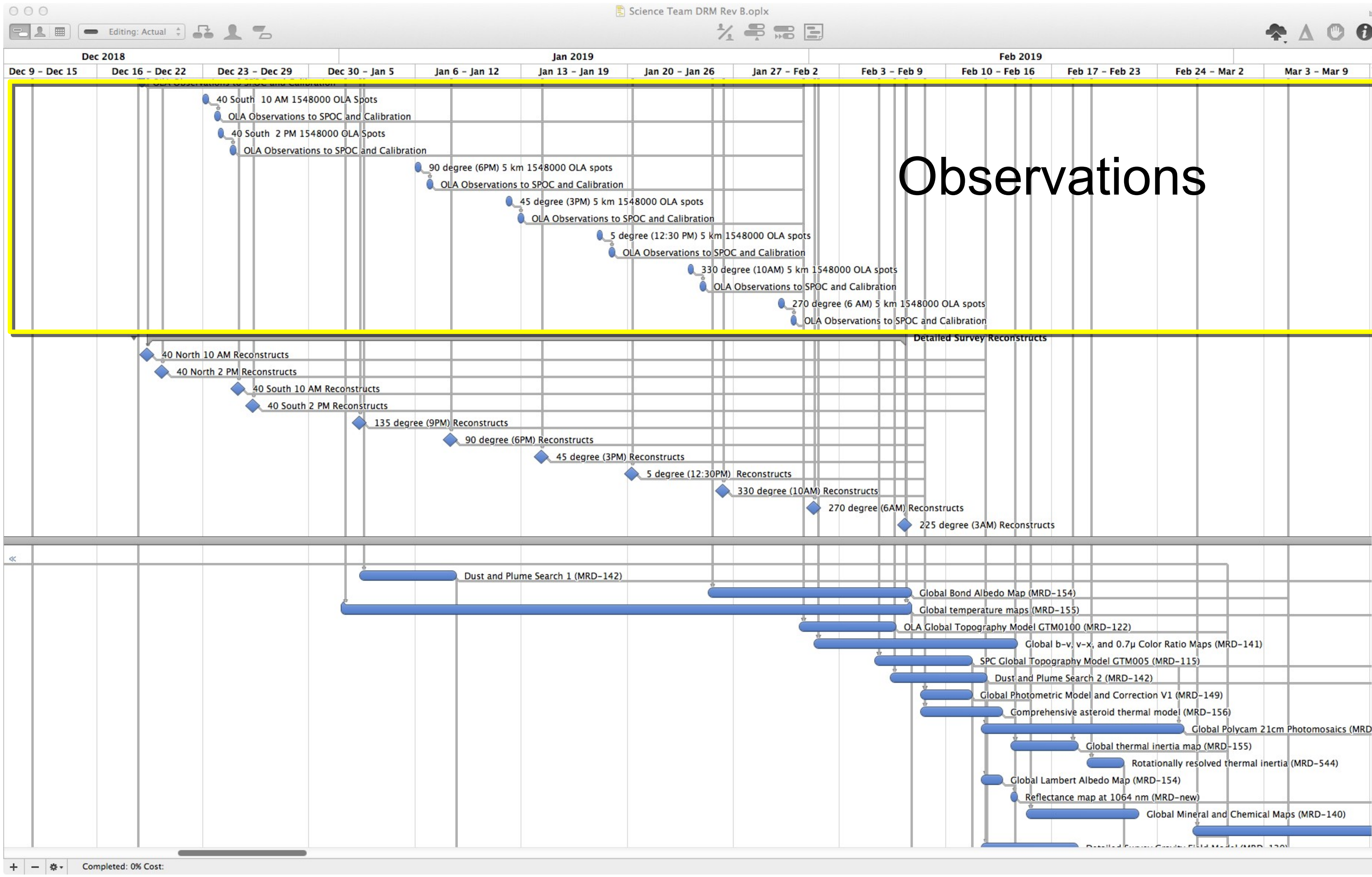
Data = Observations and Intermediate Products
Processes = Science Software and Data Product Leads
Queues = SPOC Repository
Semaphores = SPOC Dashboard
Results = Science Products

Keeping the Science Computing Architecture Efficient — Avoiding Stalls

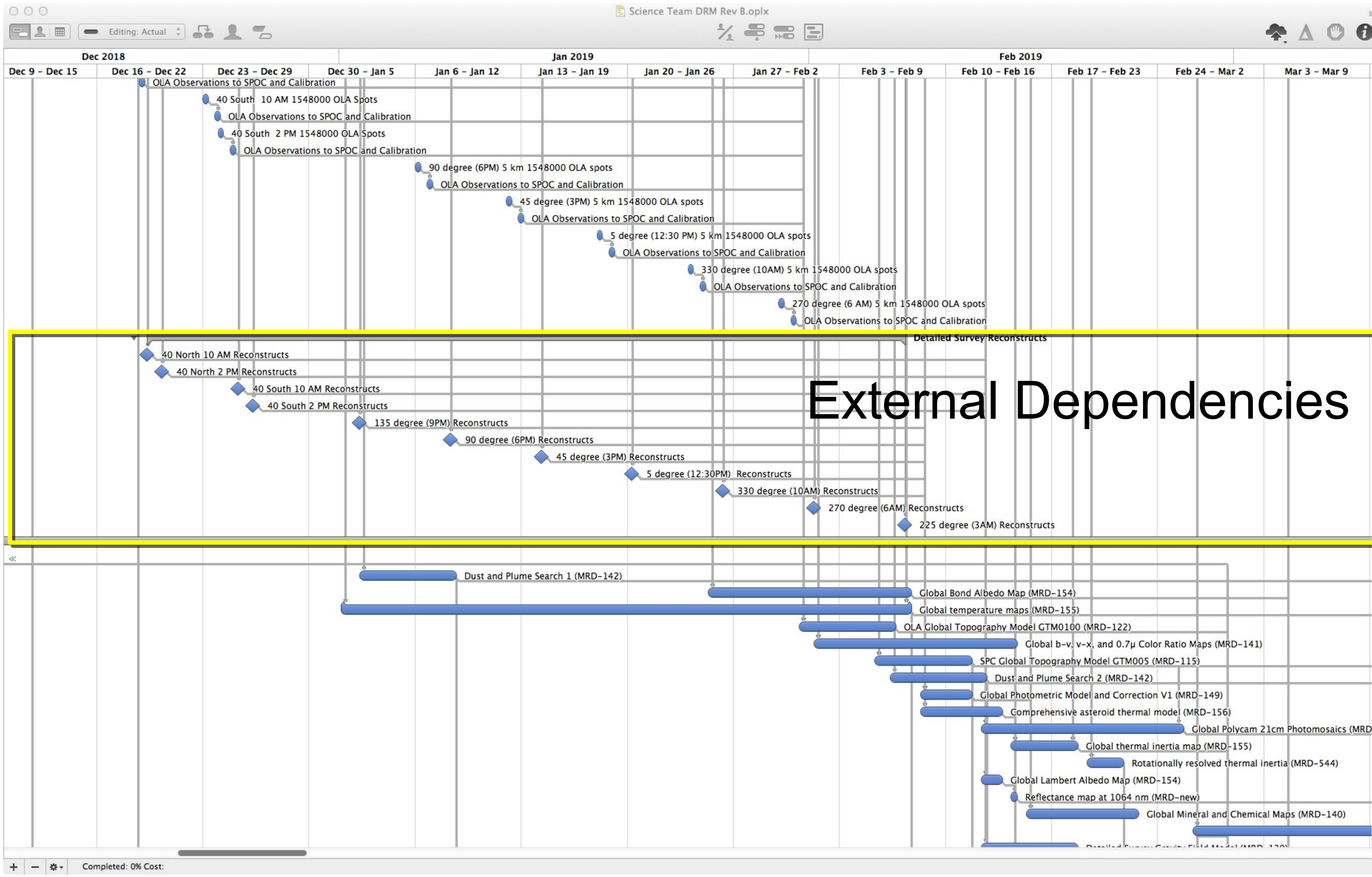
- Understand the data
  - Ensure data conformance to agreed interfaces
- Understand the processes
  - Ensure that processing software conforms to agreed interfaces
  - Ensure WG leads understand and implement planned product production processes
  - Monitor production of products to detect emerging delays
  - Identify alternative products and processes to kickoff their production
- Make sure the content of the repository is correct and is kept that way
  - Well-understood, accurate configuration control and product release process to avoid non-conformant data in repository
- Efficient communication
  - Ensure accurate and prompt communications to WGs about the products in the repository

Science Production Schedule

Science Product Planning Schedule is Fundamental Tool



Science Product Planning Schedule is Fundamental Tool



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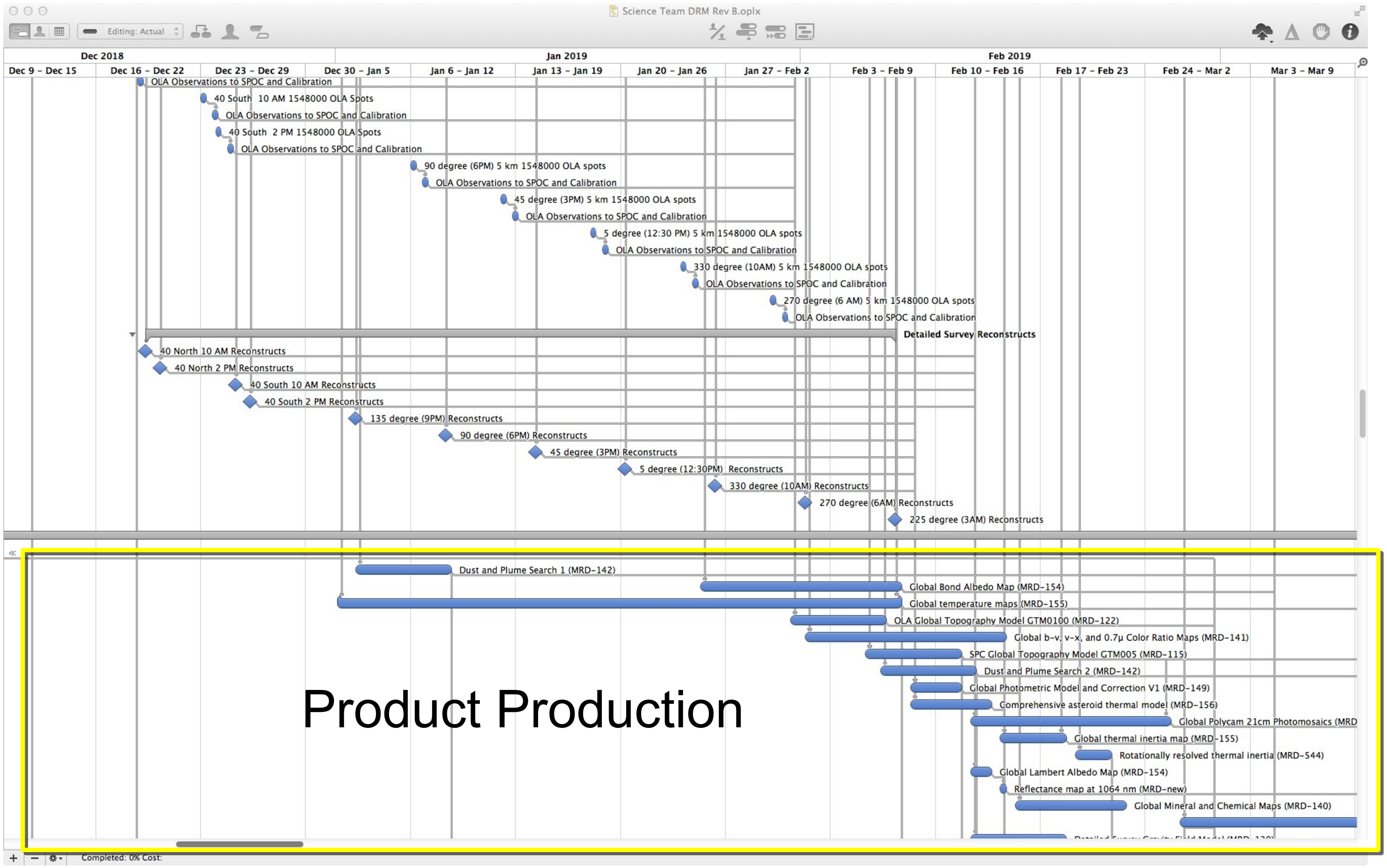


New Since Ground EPR

- Discuss impact of photometric correction and bond albedo updates to initial downselect to 12 sites
- Milestones showing release of map templates
- First milestones showing science decision points
- Data on science team wiki at
  - https://sciwik.lpl.arizona.edu/wiki/pages/o6U6F2m7/SPOCScience_MOR_EPR.html

SPOC Operational Model via COREsim

- SPOC operational activities and data product generation schedule has been captured and simulated via COREsim
  - Employs the science data product schedule to generate a discrete event simulation
    - Every functional block in the SPOC is assigned with completion time
    - Blocks are triggered according to the logical SPOC concept of operation
- SPOC COREsim enables the validation of the science product schedule
  - Confirmation that science data products can be generated when needed
  - Can be used to evaluate the impact of reprocessing
  - Analyzes the impact of missed observations on the data product generation schedule (sensitivity analysis)
  - Enables Monte Carlo simulations of the SPOC concept of operation based on probabilistic evaluation of science data production time

Science Playbooks

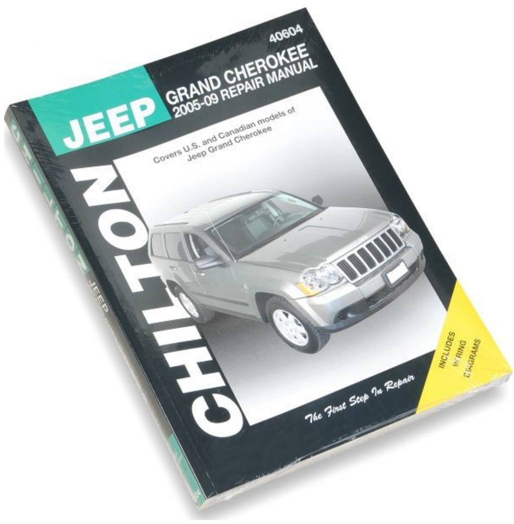
"…a notional range of possible tactics…."

- Playbooks document the nominal plan for the *production* of science products to support spacecraft operations, site selection, and mission science objectives.
  - Product and link to product description on the DPD pages
  - Key inputs and external dependencies
  - Responsible parties
  - Relevant dates (start of production, due date)
  - Requirements satisfied (if applicable)
  - Forward and backward dependencies

Science Playbooks

"…a notional range of possible tactics…."

- Playbooks also provide technical and operational guidance about alternatives and options in the event that schedule, resources, or technical constraints limit proximity operations. This guidance may include
  - Alternative mission profile status
  - Strategies for alternative observations plans
  - Science priorities
  - Relevant decision points or milestones
  - A troubleshooting guide for science processing…



Playbooks Will Exist for Each Product

Approach Dust Plume Survey Playbook

Beshore updated March 6 at 12:23 PM

Back to Science Playbooks Home

Product Description

The asteroid dust plume survey will be conducted during approach and detailed survey equatorial station phases. The approach phase portion, documented here, will look for evidence of dust in vicinity and along the orbit plane of Bennu. Dust could represent a potential hazard to the spacecraft and is a possible source of contamination to instruments.

Nominal Observation Plan and Timing

MapCam and Polycam will perform an initial search for plume activity by examining the point-spread function of Bennu and searching for low light level evidence of ejected dust and gas. Imagery consists of 64 co-added images, dithered via 0.05 - 0.1mrad/sec constant slew during imaging.

Timing of observations: 9/12/18
Instrument: Polycam and Mapcam (no filter)
Data Product Lead: Carl Hergenrother, Backup (TBD)

Timing of Product Availability

Downlinked imagery to get through calibration pipelines by 3AM on 9/13. Analysis of the observations should be complete by the end of day on 9/13. (Estimate for analysis time is 8 hours.)

Dependencies on other Products
The production of this product is not dependent on the availability of previous products.

Products with Dependencies on this Product (with Links to Playbooks)

If no dust cloud is detected, there are no dependencies on this product.

Positive identification of a dust cloud, while currently not constituting a contingency, will result in review by the phase transition team to evaluate a safe path forward. In addition, positive identification of a dust plume will trigger MRD-143 which calls for spectral characterization of the dust cloud during the mission.

Links to algorithm description, data description, other relevant resources

Data Product Description

- Approach dust plume survey
- Description of MRD-142 and -143
- Plume Spectral Characteristics (MRD-143)

Algorithm Description

- Detection of Dust Plume

Priority classification of science product

This product is produced during the approach phase, part of the navigation campaign, and is not affected by changes in the science mission profiles. This is considered a high priority product, as failure to account for a dust plume may

Wiki Supports Multiple Indexing Schemes

Science Playbooks

Beshore updated Today at 10:24 AM

Introduction to the Science Playbooks

Science Mission Profiles

Science Playbooks by Complete Baseline Science Mission Profile

- Approach Products
- Preliminary Survey Products
- Orbital A Products
- Detailed Survey Products
- Orbital B Products
- Reconnaissance Products
- Rehearsal Products
- TAG Products

Science Playbooks Indexed by Various Topics

- Playbooks by Other Science Mission Profiles
  - Science Playbooks by Science Driven Sample Profile
  - Science Playbooks by Sample with Context Profile
  - Science Playbooks by Pristine Sample Profile
  - Science Playbooks by Required Sample Profile
  - Science Playbooks by Minimum Mission Success Profile
- Playbooks by Responsible Party or Working Group
  - Science Playbooks by Data Product Lead
  - Science Playbooks by Backup Data Product Lead
  - Science Playbooks by Working Group
- Science Playbooks by Mission Requirements (MRD)

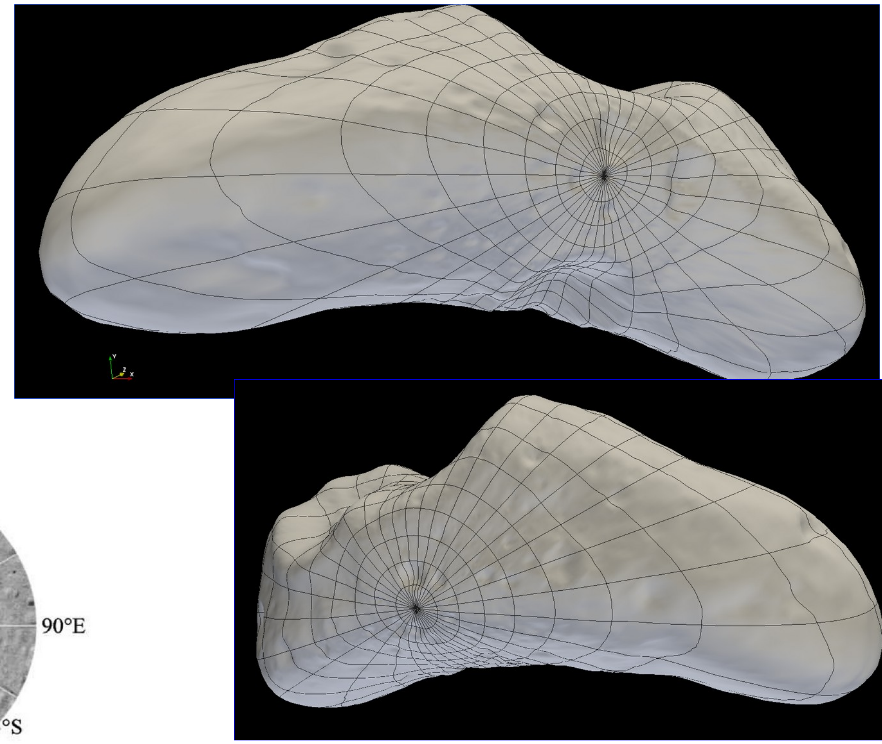
Appendices

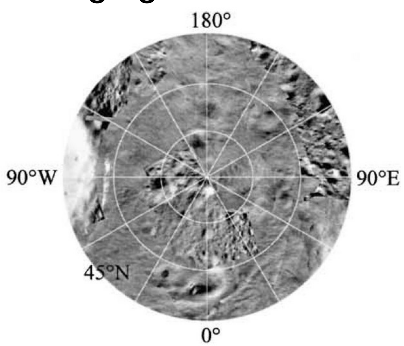
- Science Playbook Template

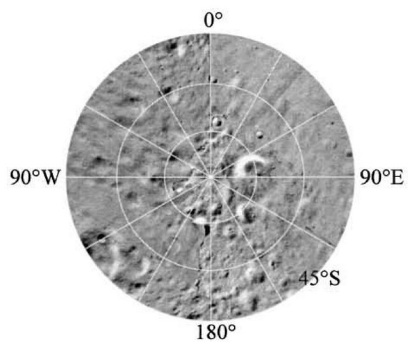
Tools

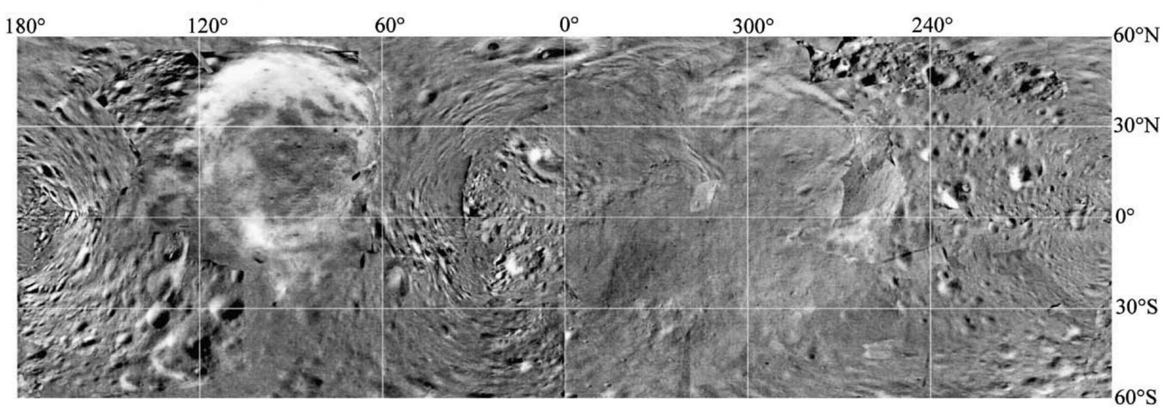
3D Views of Bennu Will Yield Superior Decision Making

Right: Snapshots of the 3D Gaskell Eros shape model as viewed in SMBT. 3D views of an irregular object eliminate distortions created by projecting the surface of the body using standard cartographic map projections. Panning around the 3D model of a planetary body map can provide better geospatial context than a map if the body is irregular, or has significant overhanging terrain.





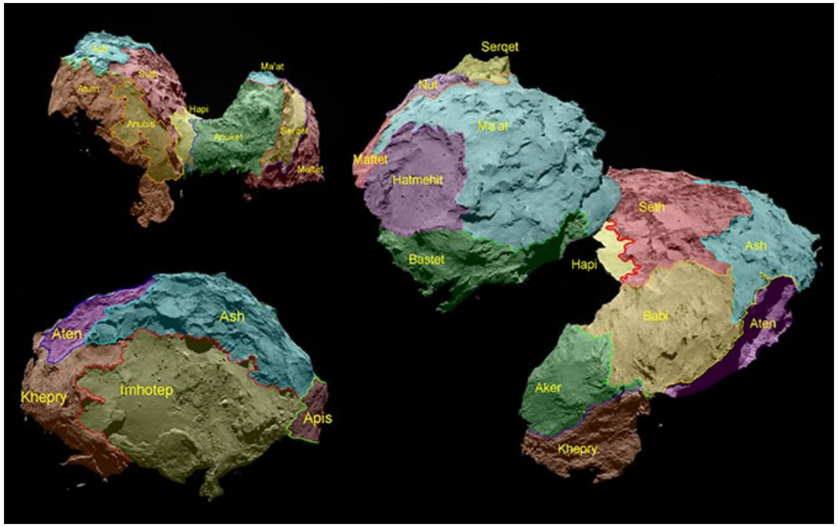




Left: Although 2D maps typically have the advantage of displaying the entire planetary surface in a single product, the distortions present in maps of irregular bodies hinder the ability of these maps to provide appropriate geospatial context. Eros base map created by Bussey et al. (2002).

J-Asteroid (Visualization)

- Based on ASU's Mission-planning and Analysis for Remote Sensing (J-MARS) tool
  - Client-server
  - Data selection
  - Supports spectral and image data
  - Direct support for, and links to, analysis capabilities
  - Strong 2D features
- Changes for OSIRIS-REx
  - Support for instrument formats
  - 3D display via standard format
  - Support for 3D map markup
  - Use of native geometry info (Geogen)
  - Simple layer calculations
  - Arbitrary viewing angles



Viz Tool Status

- ✓ Create set of global- and site-specific site selection visualization scenarios to illustrate our needs (1/30/15)
- ✓ Obtain input from Science team, review and feedback to development team. (1/30/15)
- ✓ Discuss with the science team the standard map formats and how to produce. Provide tools to support the creation of maps. (1/30/15)
- ✓ Close out J-Asteroid Visualization feature set (2/15/15)
- Sneak peak (~7/1/15)
- First release (10/1/15)

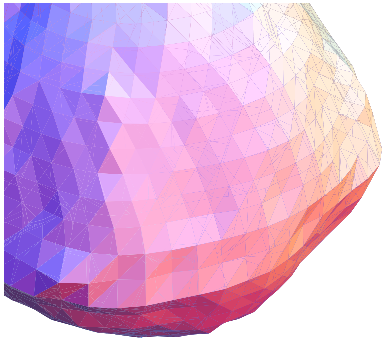
J-Asteroid Exchange Formats

- FITS images
- Images (including mosaics) with geogen files
- OBJ files with ancillary facet values
- Shapefile markups using some standard representations
- Link to SIS available on Science Team Wiki at
  - https://sciwik.lpl.arizona.edu/wiki/pages/o6U6F2m7/SPOCScience_MOR_EPR.html

FITS Images and Mosaics, Spectra and OLA Sports with Geogen

- Geogen adds information to images, OLA, and Spectrometer datasets that includes positional information on the surface of the asteroid, based on available shape models and spacecraft trajectory information
- As new shape models (global and regional), or updated trajectory data (reconstructs) become available, geogen information can be regenerated to provide better fidelity.
- J-Asteroid will be able to use this information to display image data on a shape
  - Multiple pixels will be mapped onto a shape model facet, similar to texture mapping.

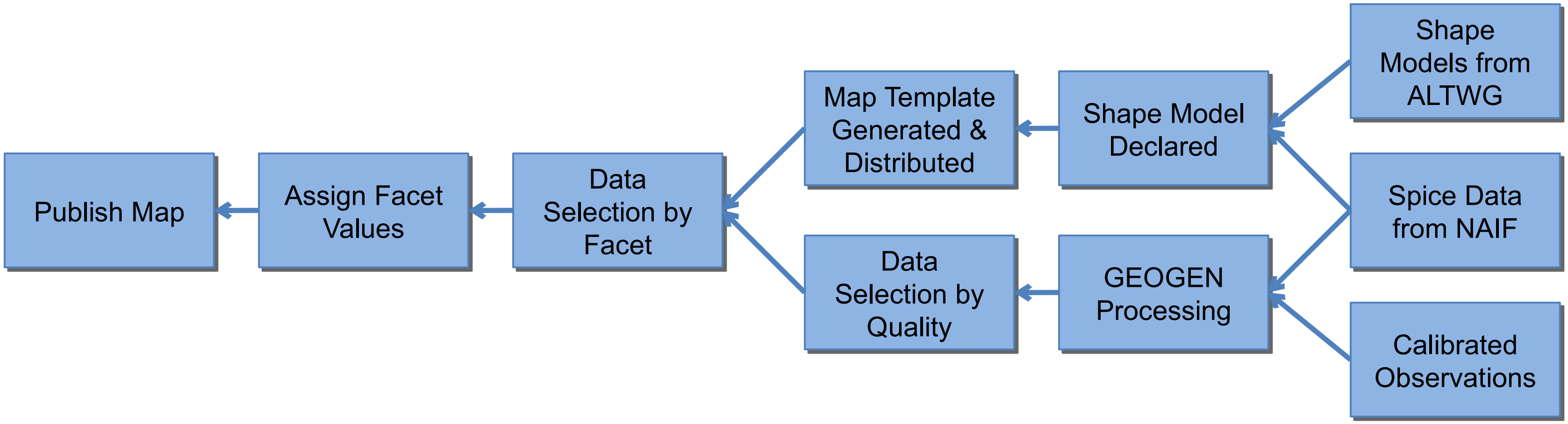
OBJ Files Are the Basis of 3D Maps



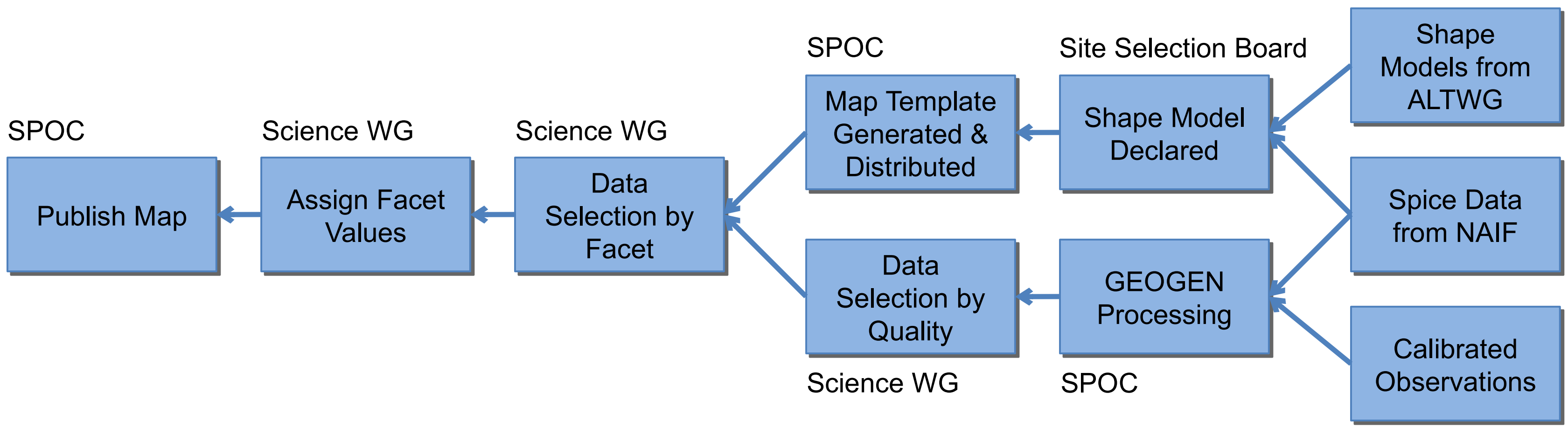
OBJ Files

- OBJ files can be read by the J-Asteroid tool, the Small Body Mapping Tool, IDL, others. OBJ enjoys excellent support.
- J-Asteroid can display multiple superimposed OBJ files as layers. Layers can be moved with respect to one another, and the transparency of each can be adjusted.
- There is a one-to-one correspondence between a DSK (Digital Shape Kernel) and an OBJ file, both are used to represent 3D shapes.
- DSKs are optimized for analyzing the intersection of a spacecraft bore sight vector and the surface of an object as a function of time. They are supported by the NASA NAIF SPICE toolkit, and the basis for J-Asteroid's representation of shape information about Bennu.
- 1-2 weeks before the global maps are due, a DSK upon which they will be based will be selected, and a corresponding OBJ file will be created. This OBJ file will be the framework for all of the global maps.
- We have identified in the product production schedule milestones when these standard maps will be declared.

Map Generation Process

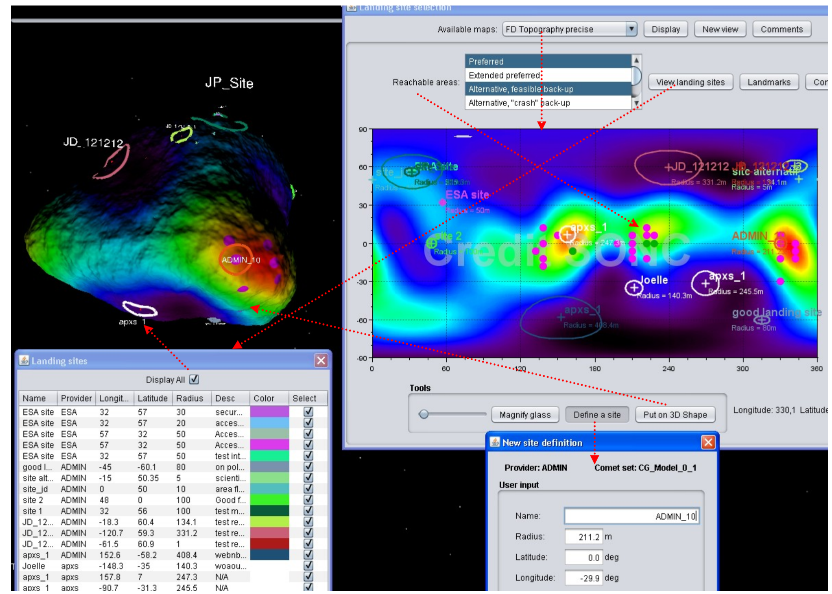


Map Generation Process



Visualization Lessons Learned from Rosetta

- Visited CNES Philae Operations Center in Toulouse, Feb, 2015
- Strong commitment to tools across site selection team
- If resources would have allowed, Rosetta team would have fully adopted the OSIRIS-REx approach to map making
- Site selection products were keyed to periodic releases of “standard” shape models



Comet Models Deliveries

#	Delivery Date	Provider	Shape/kin/albedo (ESA/OSIRIS)	Composition (VIRTIS)	Temp. (VIRTIS)	Temp. (MIRO)	Fluxes (MIRO)	Gas (ESA/LATMOS)	Grav (ESA/RSI)	Dust (ROSINA)	Comet model set	Select
1	2014/06/29 00:00:00	OSIRIS	Shape_1									○
2	2014/06/30 00:00:00	ESA	Shape_1						GRAV_ESA_001		CG_Model_1_1	○
3	2014/07/02 18:27:10	VIRTIS	Shape_1	Comp_1_1								○
4	2014/07/05 18:27:10	LATMOS	Shape_1	Comp_1_1				Gas_1_1			CG_Model_1_2	○
5	2014/07/01 20:27:10	ESA	SHAPE_ESA_001								CG_Model_ESA_001_1	○
6	2014/07/02 18:27:10	VIRTIS	SHAPE_ESA_001	Comp_001_1								○
7	2014/07/03 18:27:10	MIRO	SHAPE_ESA_001	Comp_001_1		Temp_M_001_1						○
8	2014/07/10 16:39:08	MIRO	SHAPE_ESA_001	Comp_001_1	Temp_V_001_1	Temp_M_001_1					CG_Model_ESA_001_2	○
9	2014/07/10 16:39:10	LATMOS	SHAPE_ESA_001					Gas_1_1				○
10	2014/07/10 16:39:11	GRGS	SHAPE_ESA_001					Gas_1_1	Grav_001_1		CG_Model_ESA_001_3	○

Science Product Presentations

Science Presentations

- Product status for some representative key products
  - Go to flight system safety, navigation, or the top maps
    - Natural satellite search
    - Global shape model, rotation state, coordinate systems
    - Global mosaics and size-frequency distributions
    - Temperature maps
    - Site-Specific topographic maps
- Each presenter will discuss
  - Relevant Requirements
  - Inputs and Outputs
  - Schedule
  - Nominal Development Process
  - Status of software development and delivery
  - Effect of the minimum mission scenario
  - Off nominal discussion
  - Work to go

Science Presentations — Top Maps

- Review of the top maps
  - Maps are required to address top four concerns of site selection
  - Teams were asked to conceive using the available products
  - In some cases, new products were approved to service the maps
    - *1064 nm reflectivity*
    - *Overlying dust*
    - <u>*TAG reconstruction*</u>
- Each presenter will discuss
  - Driving MRD requirements
  - Requirements for map processing software
  - Required inputs to map
  - Nominal map development process
  - Operational schedule
  - Status of algorithm development
  - Minimal mission scenario impact
  - Off nominal discussion
  - Work to go

Work to Go

- 2015 season working group meetings
  - Continue refinement of product production schedule, decision points
  - Develop Science Playbooks to document nominal, off-nominal activities
- Continue use of science team splinters to resolve/educate/discuss operational topics and concerns
- Work closely with ASU development team to provide feedback on visualization tool
- Provide support to science team for map making
- Reprocessing
  - Understand role of reconstructs, coordinate systems in developing reprocessing plans. Attempt to minimize need for reprocessing during proximity operations by partitioning products by global, site-specific observations.
- Refine Co-location needs for Science Team Members
  - Science operations provide strong remote capabilities. Need policy statements for co-location tied to science product schedule.
- Science processing management
  - Develop specific job requirements for PI Office/Science Executive Council using science product schedule, operations plans as guidance
- Dealing with conflicting results
  - How does science deal with operational products that conflict?

Backup

Shape Modeling

- Shape models provide a computable representation of topography
- Includes global shape models and regional digital terrain maps
- Fundamental to science investigations
  - Volume leads to density
  - Used by thermal inertia models
  - Geological interpretation
- Foundation for map making
- Needed by NAV and NFT for landmark navigation and on-board feature recognition
- Science has ability to develop shape models via
  - Stereophotoclinometry from imaging
  - OLA LIDAR observations
  - Classical stereophotogrammetry