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

April 21 - 23, 2015

OSIRIS-REx™
ASTEROID SAMPLE RETURN MISSION

22 – Predicted Temperature Maps

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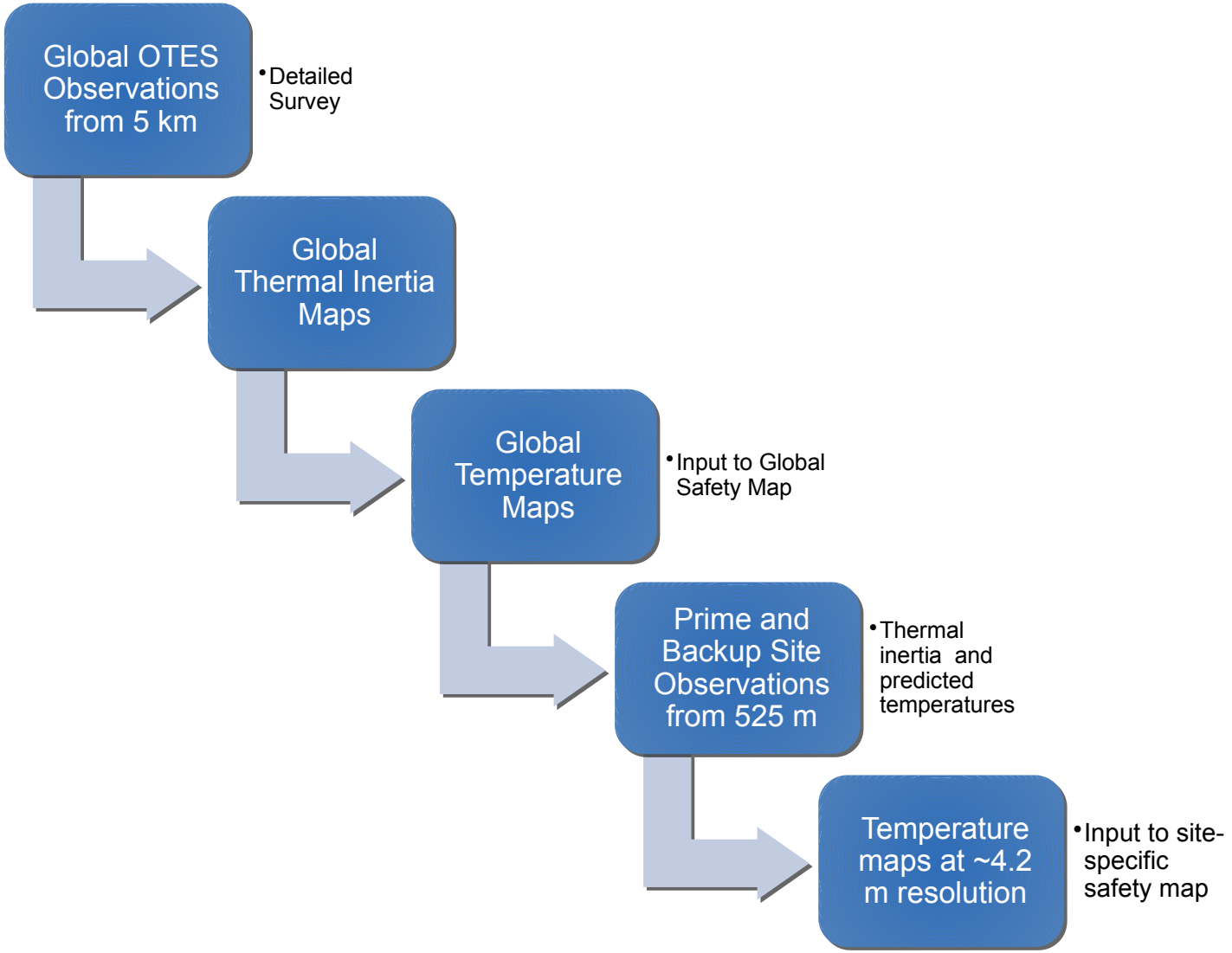
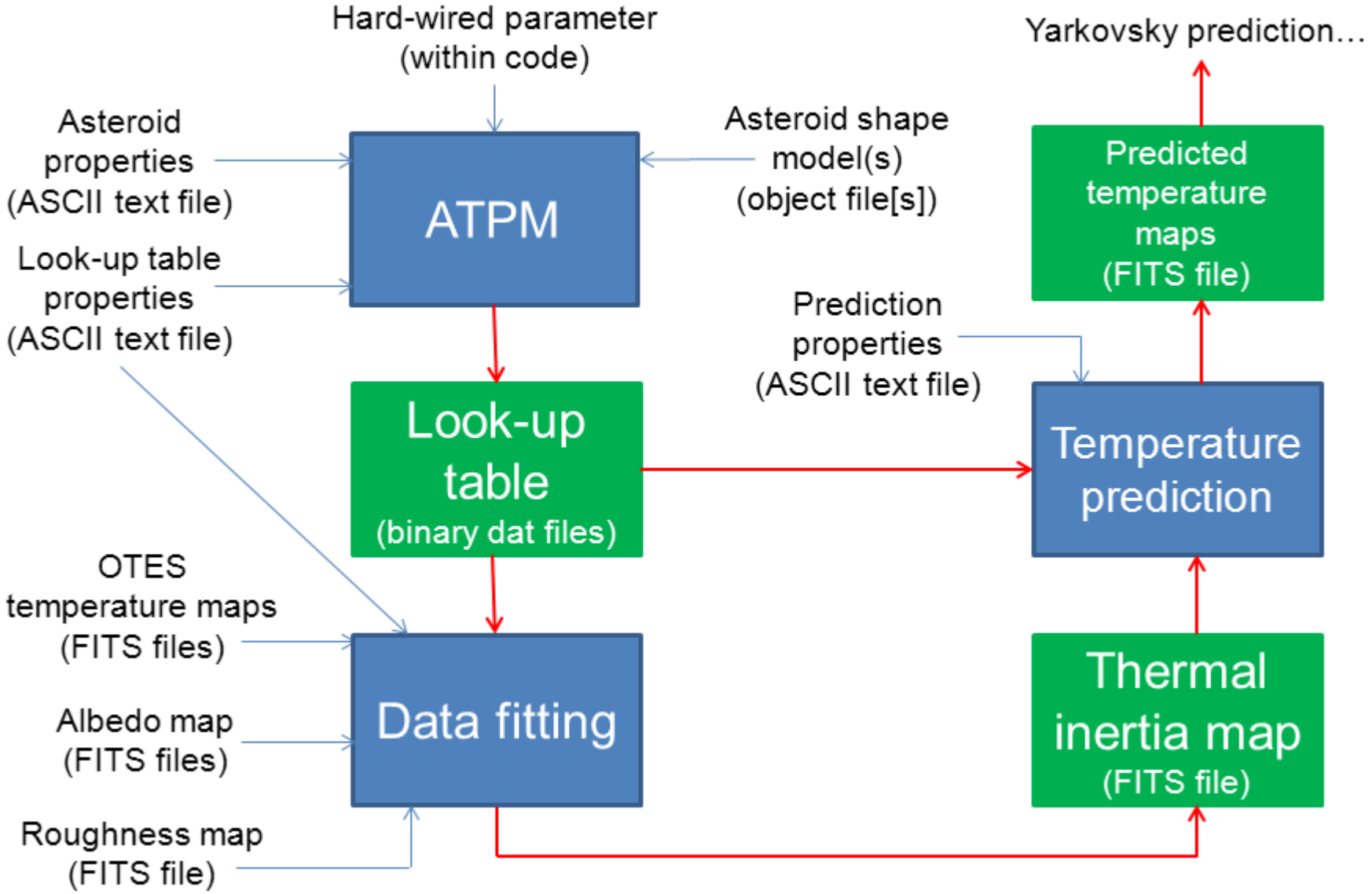
Relevant Requirements

- Driving Requirement
  - MRD-411 — Produce, within 7 days of final downlink of applicable data, a predicted temperature map of each candidate sampling ellipse for the estimated dates and Bennu times of day for TAG with ≤ 5m spatial resolution and accurate to ±10 K
- Related Requirements
  - MRD-540 – For . . . up to 12 candidate sampling sites, . . . derive and map thermal inertia at a spatial resolution of ≤ 8m
  - MRD-155 – For ≥ 80% of the asteroid surface . . . temperature at 7 different local solar times plus the derived thermal inertia at a spatial resolution of ≤ 50m
  - MRD-156 – Produce a thermal model of the asteroid to determine the radiation imbalance in the regolith and test the theory of Yarkovsky acceleration

Nominal Product Development



Nominal Product Development Process



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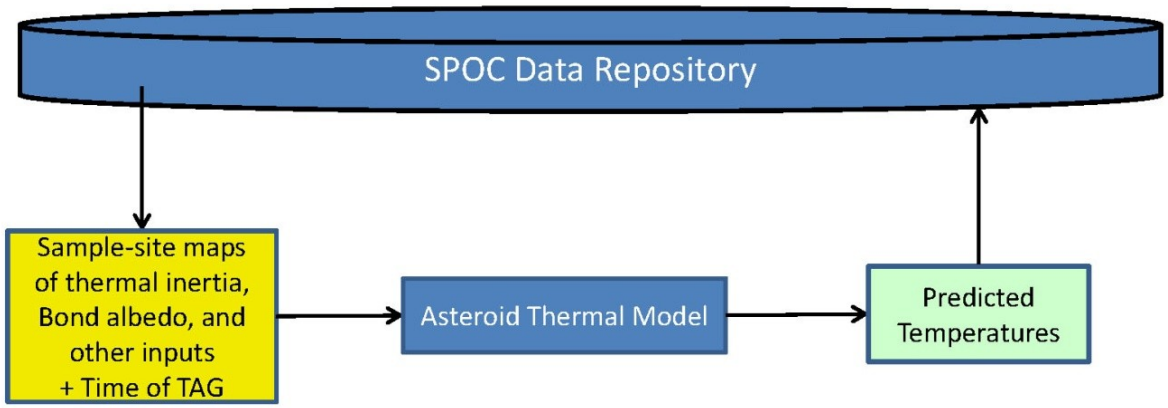
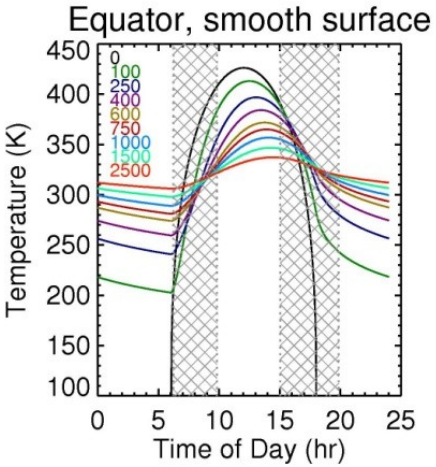
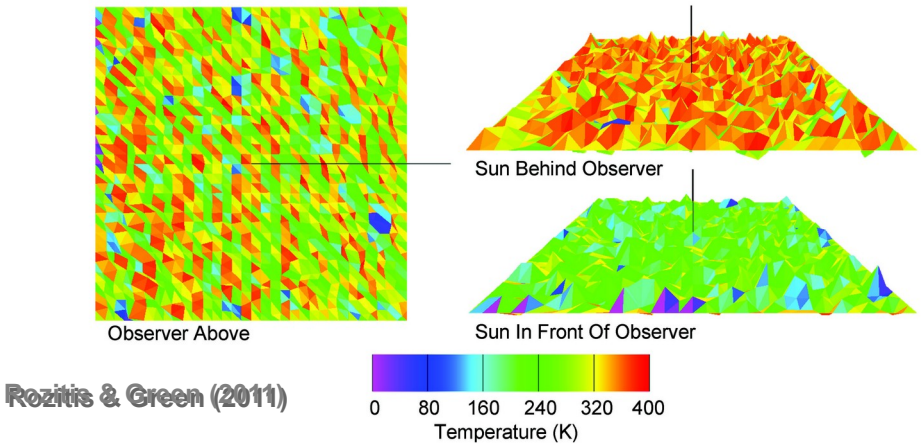


- Software
  - OSIRIS-REx thermal model (MRD-156)
  - Finite difference code to pre-compute temperature look-up table
    - LUT already computed. Will update as appropriate during mission
  - Software to interpolate multi-dimensional look-up table
- Inputs
  - Thermal inertia (TI) map of sample site
    - Determined by varying TI in thermal model to match measured temp
  - Time/position of sampling, shape, spin-state, albedo, roughness



Nominal Product Development Process

- Procedure
  - Inputs are provided to model
  - Asteroid thermal model computes temperatures on each facet of the sample-site map
- Product
  - 3D table of thermal inertias and uncertainties
    - function of x, y, and depth
  - Provided as input to site-specific safety map



Rozitis & Green (2011)

Relevant Schedule and Inputs

- Observations for product begin:
  - 1/28/19 (Global Observations)
  - 7/21/19 (Prime and Backup)
- All observations for product in to SPOC:
  - 3/12/19 (Global Observations)
  - 8/4/19 (Prime and Backup)
- Primary Products (thermal inertia and derived temperatures) available:
  - 4/17/19 (Global thermal inertia map)
  - 7/22/19 (Site 1, Prime)
  - 8/5/19 (Site 2, Backup)
- Processing begins on
  - Global: 1/31/19
  - Prime and Backup: 7/22/19
- Data product lead : Josh Emery
- Backup data product lead: Ben Rozitis

Status of Software Development

- Custom thermal model
  - Based on the Advanced Thermophysical Model (Rozitis & Green 2011)
  - Developed in C++
  - Makes use of Graphics Processing Units (GPUs) for speed
- Delivered Build 1 on time (November 2014)
  - SPOC was able to install. Minor updates based on their feedback
- Delivered Build 2 on time (April 2015)
  - Includes documentation for installation and running
- Testing
  - SPOC engineers able to install and reproduce test data
  - Tested against previous ATPM and model from Emery et al. (2014)
- No work remaining to meet requirements for Temp prediction
  - Will continue to look at efficiency and perhaps add a some extra options for science analysis

Minimal Mission Scenario

- Temperature of sample site
  - Thermal inertia estimate is required for temperature predictions. The MMS has several levels of backup for these estimates (see below)
  - Temperatures will be *measured* at 10 am and 2 pm from the "baseball diamond" at 50m spatial resolution. In the (unlikely) absence of any reliable thermal inertia estimate, we can use these temperature measurements to extrapolate sample site temperatures at the time of TAG
- Thermal inertia of sample site
  - OTES observations of sample site in Orbital B and Recon become best effort. If OTES observes, we can proceed as described previously.
  - If no OTES data on Orbital B or Recon, we will use thermal inertias determined from previous phases.
  - In Detailed Survey, still observe baseball diamond. These positions are not ideal for thermal inertia, but we will make best effort
  - At the very least, we will have rotationally resolved thermal inertias from Approach Phase.

Off Nominal Strategies

- Lost instrument – OTES
  - Recover temperature information from the long wavelength (λ > 3 μm) portion of OVIRS
  - Dawn and Rosetta provide good examples
- Lost thermal observations
  - Mission plan provides observations at slowly increasing resolution
    - Can generally recover data from previous/later phases
  - Detailed Survey
    - Nominal plan is to observe full asteroid at 7 times of day
    - We can still provide global thermal inertias if some stations are lost
  - Sample site thermal inertia
    - Nominally get applicable data from both Orbital B and Recon
    - If data from one phase is lost, can use data from the other
    - If both Orbital B and Recon are lost, can use the coarser-resolution global thermal inertia map from Detailed Survey
  - Observations of opportunity
    - Orbit-A, Preliminary Survey, Orbit-B nighttime

Off-Nominal Discussion

- Other missing data
  - Topography
    - Topography for temperature predictions comes from early mission phases, and is a critical mission product, so it is unlikely that we will not have good topography
    - If topography is missing, thermal model is fast enough that we can run predictions for a suite of topographies and produce probabilistic temperature predictions
  - Albedo
    - Can use quantitative albedo maps from previous phases
    - Check imaging for any albedo variability
- Schedule
  - The thermal model only requires a few minutes (seconds, really) to compute temperatures.

Work to go

- The thermal model, as delivered, is able to meet all requirements
  - No additional development is required
- SPOC is providing computers with appropriate graphics cards to run the code
  - SPOC has already verified that model runs on current hardware
- Input/output formats
  - The code is set up to be flexible with input and output formats
  - As instruments start producing data, we will test the model and tweak those scripts as necessary

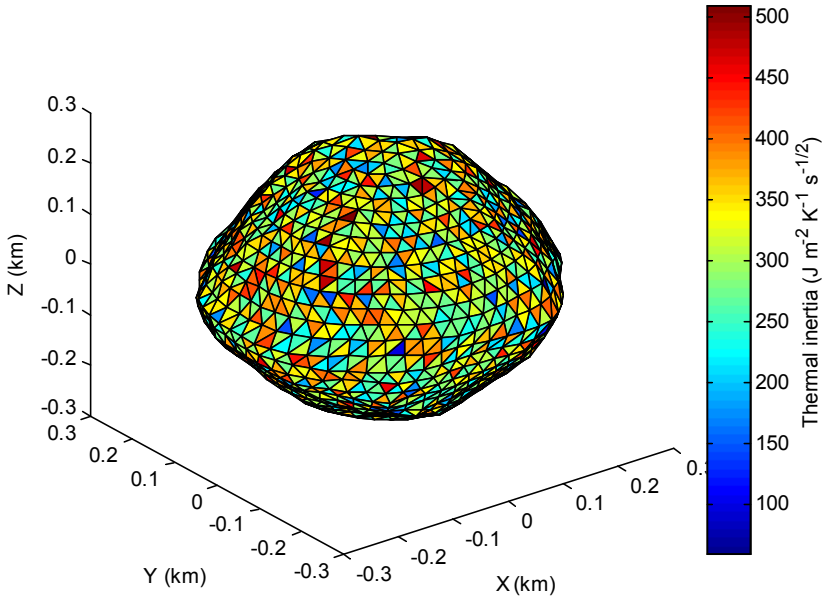
Next Topic (This slide will be done for you)

#	Start Time	Topic	Presenter
	7:45 AM	Coffee/Refreshments	
1	8:00 AM	Welcome	E. Beshore
2	8:10 AM	OSIRIS-REx Mission Overview and Priorities	D. Lauretta
3	9:10 AM	DRM Science Collection Overview	B. Boynton/J. Kidd
	9:55 AM	Break	
4	10:10 AM	Ground System Overview	J. Gal-Edd
5	11:10 AM	SPOC Overview	C. Shinohara
	11:55 AM	Lunch	
6	12:55 PM	Operations Overview	S. Barnes
7	1:40 PM	SPOC/Science Planning Process	B. Boynton/C. Hergenrother
	2:40 PM	Break	
8	2:55 PM	SPOC Implementation Process	S. Barnes
9	4:25 PM	SPOC Downlink Process	S. Balram
	4:55 PM	Board Caucus	Board

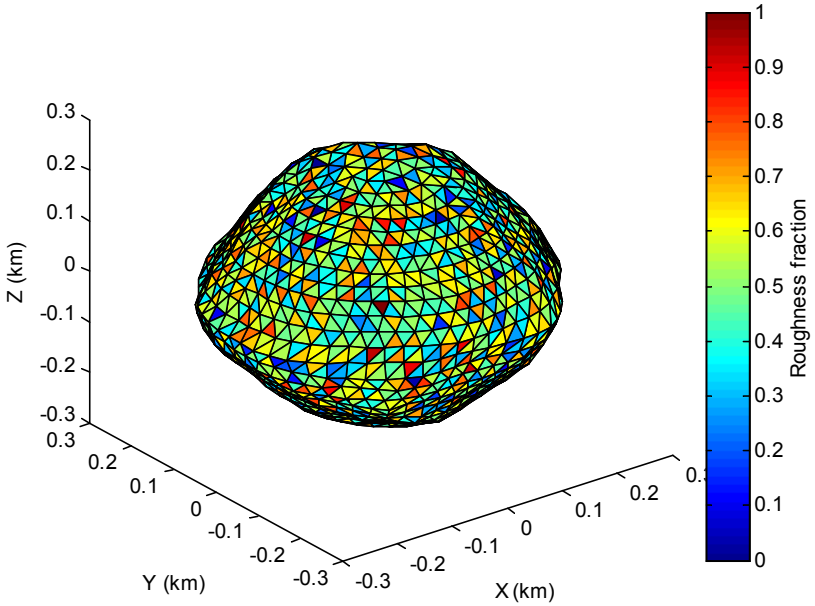
Backup

Test Asteroid

- Randomly generated maps

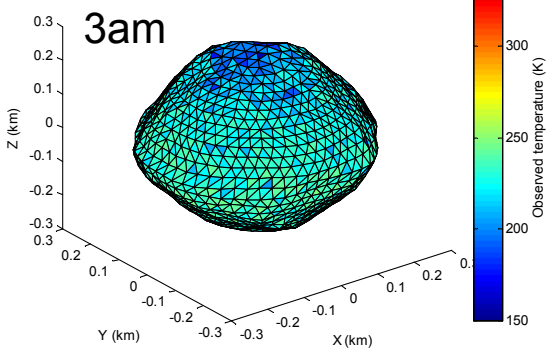


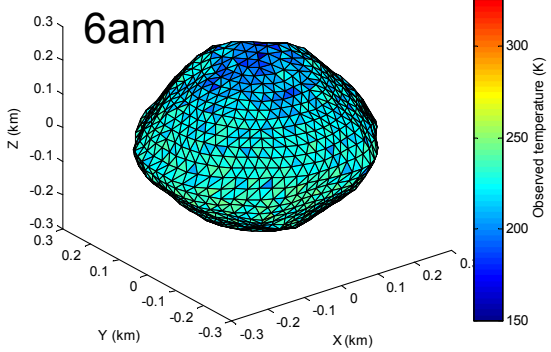
Thermal inertia map generated from 310 ± 70 J m^{-2} K^{-1} s$^{-1/2}$

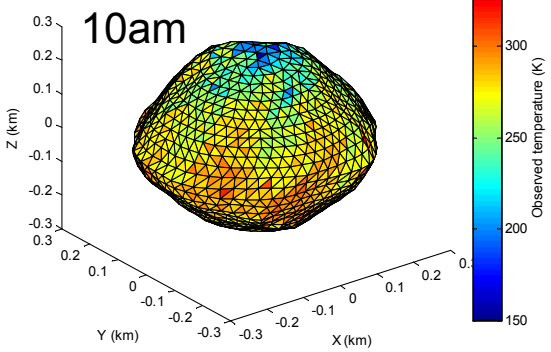


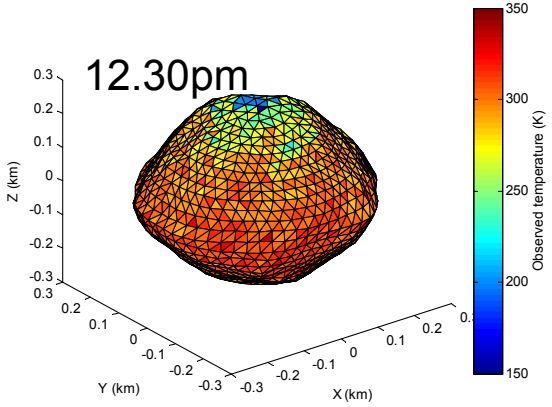
Roughness fraction map generated from 0.50 ± 0.16

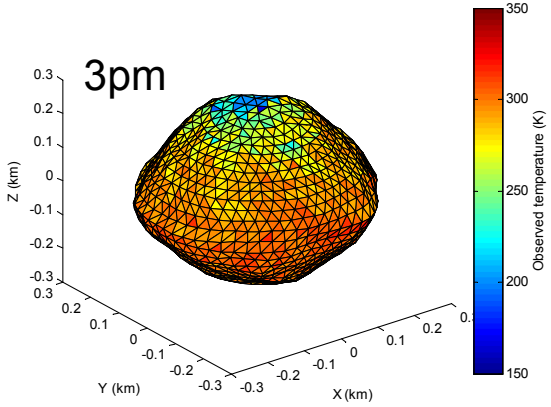
Test Data

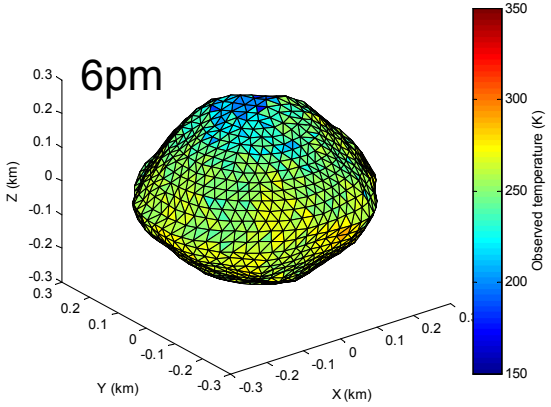


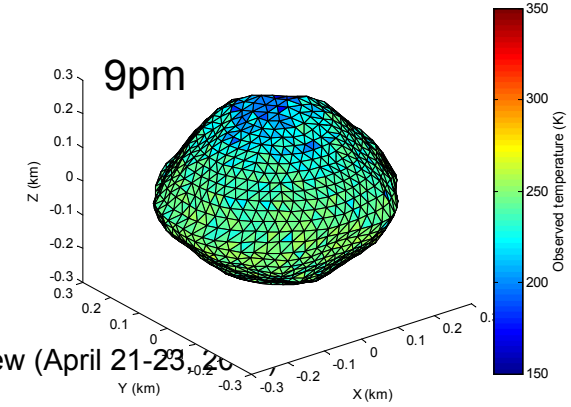










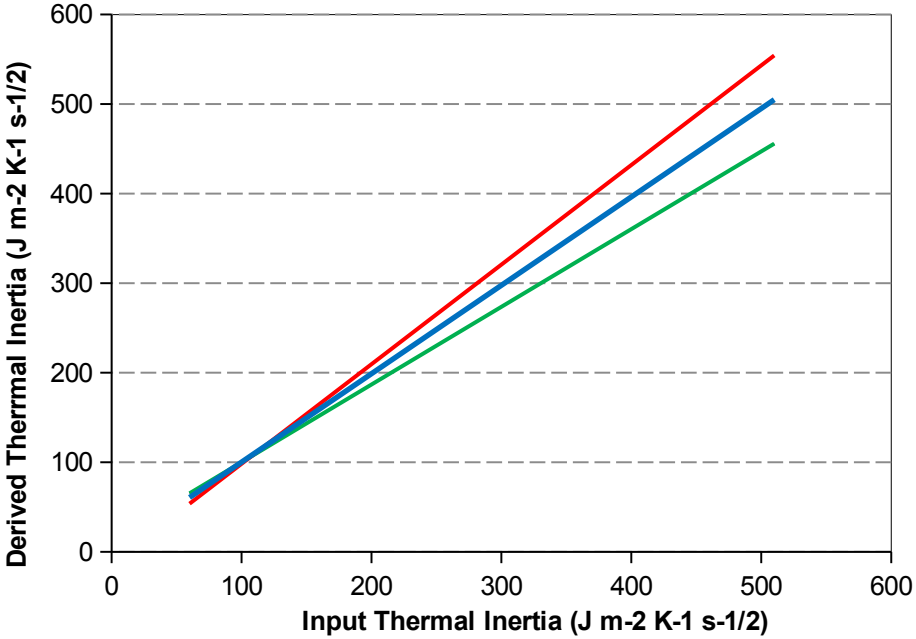


Simulated 11 μm brightness temperature maps at the 7 different observing stations

Includes 1 K of Gaussian random noise to simulate OTES instrument uncertainties

Test Comparison

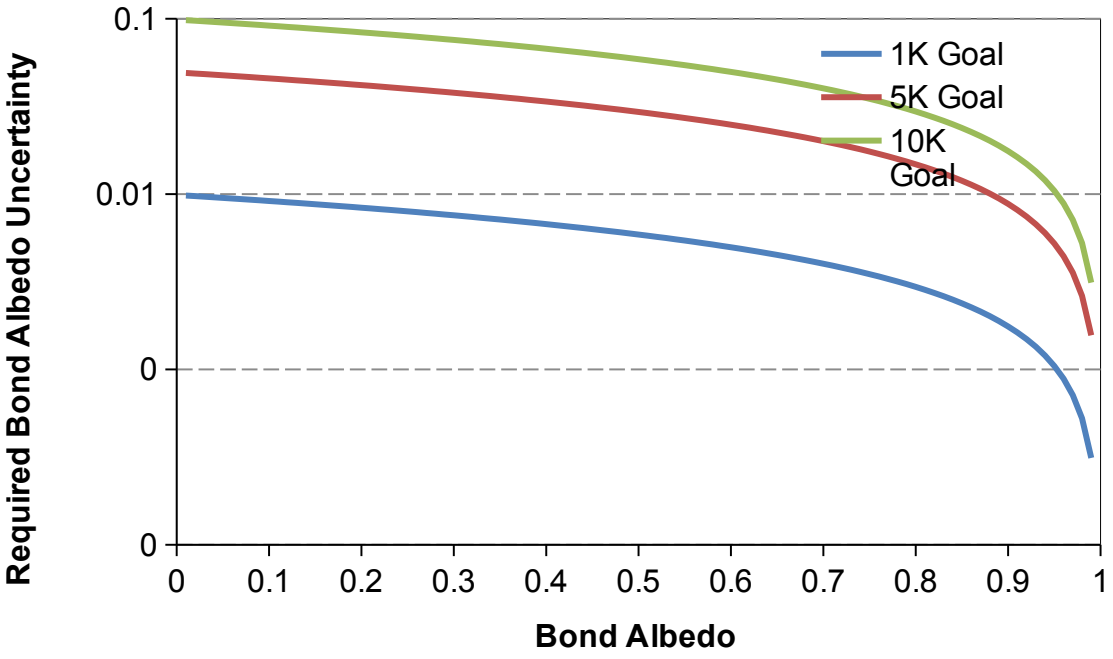
- Nominal albedo of 0.1
- Underestimated albedo (0.0):
  - Overestimates temperatures
  - Overestimates thermal inertia
- Overestimated albedo (0.2):
  - Underestimates temperatures
  - Underestimates thermal inertia
- Derived thermal inertia is still accurate to 2-sigma



Effect on Temperature Predictions

- Consider instantaneous equilibrium between absorbed sunlight and emitted thermal radiation

$$(1 - A)\frac{F_{SUN}}{r^2} = \varepsilon\sigma T^4$$



- For 0 to 0.2 Bond albedo:
  - ± 1 K temperature uncertainty requires ± 0.01 Bond albedo uncertainty
  - Easily achieved with 0.017 ± 0.002
- Better precision required for higher Bond albedo

Summary and Conclusions

- Sensitive to Bond albedo if it is ~0.1 instead of ~0.017
- Thermal inertia still derived to 2-sigma accuracy if 100% wrong!
- Best effort determination is good enough
- Temperature predictions require Bond albedo with ± 0.01 accuracy
- Bright albedo spots might cause problems but these will be readily visible anyway