

Mapping the Thermal Inertia of Phobos using MGS-TES Observations and Thermophysical Modeling N. M. Smith¹, C. S. Edwards¹, M. Mommert¹, D. E. Trilling¹, T. D. Glotch², ¹Department of Physics and Astronomy, Northern Arizona University, Flagstaff, AZ, nms343@nau.edu, ²Department of Geosciences, Stony Brook University, Stony Brook, NY, 11794

Introduction. Phobos represents a unique target for observations: the moons of Mars are the only other moons—beside our own—that orbit a terrestrial planet. They may have an origin as captured carbonaceous asteroids [1], or as accreted or re-accreted ejecta originating from a giant impact [2, 3]. Mars-observing spacecraft have had the opportunity to study Phobos from Mars orbit (e.g. Mars Reconnaissance Orbiter (MRO), 2001 Mars Odyssey, Mars Express (MEx), Viking Orbiters) and as they enter low orbit (e.g. Mars Global Surveyor (MGS)). These missions have produced a long record of observations using the same instruments that were designed to study the surface of the planet below. These observations, however, are generally few and far between [4], and are acquired rarely over each mission.

Close (i.e., resolved) observations of Phobos by spacecraft began in 1971 with the first visible light imaging and two-channel infrared radiometry [5]. Infrared observations continued with the Viking orbiters in 1976 [6], and the Phobos 2 mission in 1989 [7]. MGS's Phobos encounters in 1997 are described below. Since MGS, MRO (beginning 2006), MEx (beginning 2003), and Mars Odyssey (beginning in late 2017) have each recorded spectra of Phobos as they occasionally have opportunities in their orbits. [8,9] These observations have resulted in compositional information of Phobos's surface [10,11].

Using these observations, we can begin to characterize this surface, which is likely blanketed in a layer of fine regolith [5]. The properties of this regolith determine how heat is absorbed, transferred, and re-radiated to space. We use thermophysical modeling to simulate these processes and predict, for a given set of assumptions and parameters, the observed thermal infrared spectra. By comparing models to observations, we can constrain the properties of the regolith, such as thermal inertia (how well heat is retained in the surface over time) and surface roughness. With many observations, we can also begin to understand how these properties vary regionally across the surface. These constraints are key to understanding how Phobos formed and evolved over time, which in turn informs us about the environment and processes that shaped the solar system as a whole.

Thermophysical Model. We have developed a thermophysical model of Phobos adapted from a model

used for unresolved observations of asteroids [12]. Our Phobos model uses the complete 3D shape model [13] to define the facets that make up the modeled surface, improving on prior thermal models which used a tri-axial ellipsoid approximation.

Several significant modifications were made to re-tool our asteroid model for use with Phobos. Unlike sun-orbiting asteroids, Phobos receives significant scattered, reflected, and thermal radiation from the Martian surface. Phobos is also eclipsed by Mars. Another significant change is the linking of the model to resolved observations from Mars-orbiting spacecraft. As the model had previously been used for unresolved observations only, the model had to be restricted to simulate only the facets observed by MGS's Thermal Emission Spectrometer (TES) [14]. By only simulating the region within each TES field of view, the simulated spectra corresponded to the flux integrated across the portion of the Phobos surface where each observation was made.

Thermal Infrared Spacecraft Observations. The mapping of TES field of view footprints to the Phobos surface has not previously been undertaken, and took into account spacecraft orientation, TES pointing mirror angle and the positions of both MGS and Phobos (using SPICE). Over 350 resolved observations of Phobos are available from three orbits (under TES' Orbit Counter Keeper numbering [14], these were OCKs 501, 526, 551). These provide ~50% coverage of the Phobos surface. Each observation was mapped to a set of facets in the Phobos shape model that fell within the field of view of one of TES's six detectors. While far from complete coverage, these data, when combined with the newly adapted thermal model, provide insights into the variations of thermophysical parameters across the surface.

As we are primarily concerned with the thermal properties of the surface, rather than composition, each TES spectrum was converted from radiance to brightness temperature [14].

Comparison of Model and Observations. The geometry of each observation (i.e., the position and orientation of the Sun, Mars, Phobos, and MGS) was extracted using SPICE, and input into the model, along with the facets included in the observation footprint. The model then generated a corresponding scenario and returned the flux received by the simulated detec-

tor at a series of wavelengths. The scenario was remodeled inputting six different assumed thermal inertias (10, 25, 50, 85, 130, and 250 $\text{J m}^{-2} \text{K}^{-1} \text{s}^{-1/2}$). The resulting infrared fluxes were converted to brightness temperatures at the set wavelengths. Fig. 1 shows a comparison between the modeled and observed brightness temperatures.

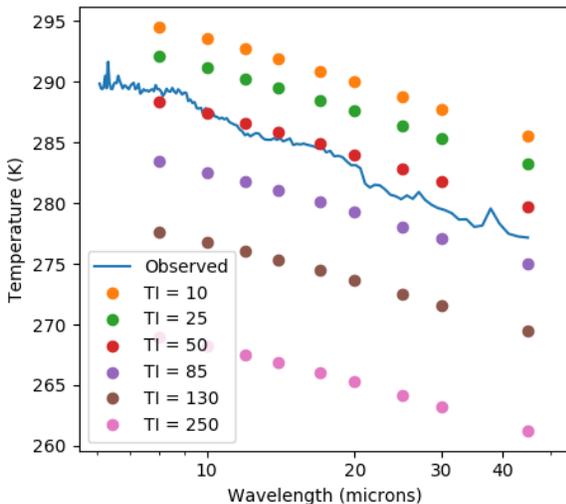


Figure 1. Comparison of brightness temperatures observed by TES (line), and produced by model (points) assuming various thermal inertias, for one observation footprint. Varying surface roughness did not visibly alter these results.

These temperatures were then interpolated to find the thermal inertia corresponding to the observed temperature for that observation. In this way, we derived a thermal inertia for each well-behaved observation.

A subset of observations differed significantly from modeled results, such that no physically sensible thermal inertia could reproduce the observation. Repeating our modeling varying both thermal inertia and surface roughness yielded no significant improvement. While analysis of these poorly-behaved observations is ongoing, we note that they are generally daylight-side or terminator observations, while well-behaved observations were generally collected from the night-side of Phobos. As all three OCKs' observations were made at similar times in Phobos' orbit, this correspondence with illumination also is a regional correlation as well, though this may be spurious.

Discussion. From the observations for which thermal inertias could be successfully derived, we can draw a number of preliminary conclusions. Based on our observations, we find an average thermal inertia of $\sim 70 \text{ J m}^{-2} \text{K}^{-1} \text{s}^{-1/2}$. This is consistent with prior estimates of Phobos' global average thermal inertia, which ranged

from $\sim 40\text{-}70 \text{ J m}^{-2} \text{K}^{-1} \text{s}^{-1/2}$ [6] to $\sim 80\text{-}170 \text{ J m}^{-2} \text{K}^{-1} \text{s}^{-1/2}$ [15].

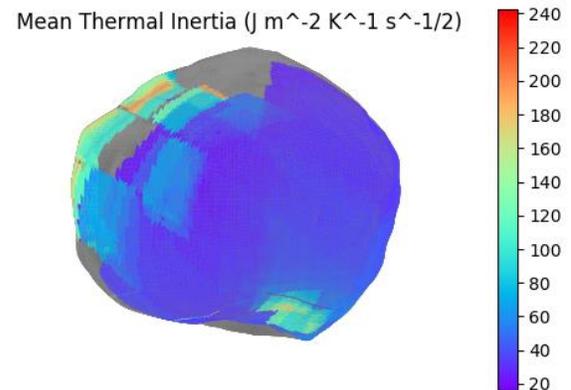


Figure 2. Thermal inertia of Phobos. The trailing hemisphere is in view, and North is oriented up.

As Fig. 2 shows, large regions (in blue) show strong agreement giving a thermal inertia of around $50 \text{ J m}^{-2} \text{K}^{-1} \text{s}^{-1/2}$, while other regions (in green and orange) show less self-consistency, but are consistently, and significantly, higher thermal inertia ($>100 \text{ J m}^{-2} \text{K}^{-1} \text{s}^{-1/2}$). These higher thermal inertia regions could represent a true spatial variation in thermal inertia across the surface, but might also be the result of the same day-side illumination problems which eliminated other observations in the same localities.

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