THERMOPHYSICAL PROPERTIES OF (101955) BENNU FROM OSIRIS-REx OBSERVATIONS. J. P. Emery[1], B. Rozitis[2], P. R. Christensen[3], V. E. Hamilton[4], A. A. Simon[6], D. C. Reuter[6], M. Delbó[5], L. F. Lim[6], C. A. Thomas[7], B. E. Clark[8], A. Ryan[3,5], C. M. Elder[9], M. A. Siegler[10], E. S. Howell[11], M. C. Nolan[11], D. S. Lauretta[11], and the OSIRIS-REx Team. [1]University of Tennessee, Knoxville, TN (jemery2@utk.edu); [2]Open University, Milton Keynes, UK; [3]Arizona State University, Tempe, AZ; [4]Southwest Research Institute, Boulder, CO; [5]Observatoire de la Côte d'Azure, Nice, France; [6]NASA Goddard Space Flight Center; [7]Northern Arizona University, Flagstaff, AZ; [8]Ithaca College, Ithaca, NY; [9]NASA Jet Propulsion Lab, Pasadena, CA; [10]Southern Methodist University, Dallas, TX; [11]University of Arizona, Tucson, AZ.

Introduction: NASA's OSIRIS-REx spacecraft arrived at its target asteroid, (101955) Bennu, in December 2018. The primary objective of the mission is to return a pristine sample from Bennu in order to address some of NASA's (and humanity's) fundamental questions: How did the Solar System form? How did life evolve in the Solar System? Are asteroids harbingers of life or death – or both? [1]

Prior to picking up the sample from the surface, OSIRIS-REx will spend more than a year characterizing the surface with cameras, spectrometers, and the laser altimeter that are onboard the spacecraft [1]. Global and local determination of thermophysical properties inform maps of sampleability, spacecraft safety, and science value of the surface. The primary data set being used for thermophysical analyses consists of thermal spectra from the OSIRIS-REx Thermal Emission Spectrometer (OTES) [2]. The long-wavelength end of spectra obtained by the OSIRIS-REx Visible and InfraRed Spectrometer (OVIRS) [3] is also be dominated by thermal emission.

Full-disk observations during Approach were hemispherically averaged, but rotationally resolved. The Approach observations enable direct comparisons to previous Spitzer space telescope observations of Bennu. Data from Preliminary Survey provided the first disk-resolved thermal data of Bennu. During the Detailed Survey phase, OTES will measure the infrared radiation from the entire surface, enabling us to map temperatures over Bennu at seven different local times of day (3:20am, 6am, 10am, 12:30pm, 3pm, 6pm, and 8:40pm). The diurnal temperature curves will be used to map the thermal inertia of the surface at a ~40-m spatial scale. The Orbital B phase of the mission will enable higher-spatial-resolution thermal observations of up to 12 potential sample sites, and the Reconnaissance phase will enable observations at even higher spatial resolution of the two highest-priority potential sample sites. Thermophysical analysis is being carried out with a custom thermal model that is based on the Advanced Thermophysical Model of Rozitis and Green [4,5,6].

Previous Thermal Analysis of Bennu: The Spitzer Space Telescope obtained disk-integrated thermal observations of Bennu in May 2007. The observations consisted of spectra (5.2 to 38 μm) of opposite hemispheres and photometry at 11 rotational phases at 3.6, 4.5, 5.8, 8.0, 16, and 22 μm. Analysis of these data using the shape model derived from radar observations [7] revealed a thermal inertia of 310 ± 70 J m^{-2} K^{-1} s$^{-1/2}$ and suggested no significant variation in thermal inertia with rotational phase [8].

Approach and Preliminary Survey Observations: Disk-integrated spectra of Bennu were obtained with OVIRS on November 2 and 3, 2018. During each observing sequence, spectra were collected continuously while Bennu completed slightly more than one rotation. The FOV of OVIRS was scanned in a small zig-zag pattern on November 2, and Bennu was entirely in the FOV for all spectra. The zig-zag pattern was larger on November 3, and Bennu was entirely in the FOV for ~5400 of the spectra. Observing parameters are given in Table 1.

Disk-integrated spectra of Bennu with OTES were obtained on November 8 and 9, 2018. Pointing remained relatively fixed while Bennu completed slightly more than one rotation, collecting over 8,000 spectra each day.

The first spatially resolved observations of Bennu with OVIRS and OTES occurred on December 2, the last day of the Approach phase. The two spectrometers also collected spatially resolved spectra as "ride-along" observations during the Preliminary Survey phase in early-to-mid December 2018. OVIRS obtained one set of spectra during the third pass over the north polar region, two sets during the pass over the equator, and one set during the pass over the south polar region. OTES obtained two sets of spectra during the first north pole pass (December 4), three during the third north pole pass (December 8/9), two during the equatorial pass (December 12/13), and three during the south pole pass (December 16/17). The range to the surface and viewing geometry changed throughout each of these passes. The minimum distance during OVIRS and OTES observations was ~7.3 km, and the maximum was ~12.6 km, corresponding to spatial resolutions of ~30 to 50 m for OVIRS and ~60 to 100 m for OTES.

Table 1. Approach Observing Parameters

	r (km)	Δ (AU)	α (°)	Fill	t_{obs} (hr)
OVIRS					
Nov 2	~197	1.041	5.1	~0.37	4.34
Nov 3	~190	1.037	4.5	~0.39	4.37
OTES					
Nov 8	~162	1.021	4.5	~0.14	4.91
Nov 9	~159	1.018	5.7	~0.15	4.91

r = spacecraft-Bennu distance, Δ = Bennu heliocentric distance, α = phase angle, Fill = fraction of FOV filled by Bennu, t_{obs} = total time for the observing sequence

Results: The first analysis we performed was to reanalyze the Spitzer data using a shape model derived from OSIRIS-REx images of Bennu and update spin state information. One of the goals of the Approach phase observations was to provide a link between telescopic observations and spatially resolved observations of Bennu. The purpose of the reanalysis here was to make step-wise progress in that linkage. This analysis resulted in a best-fit thermal inertia that is slightly higher than, but consistent with, the previous determination [8]. The updated analysis is still consistent with no significant thermal inertia variations with rotation. The fits with the updated shape model require a rougher surface than previously.

The thermal analysis of OTES data to date has focused on fitting relative thermal light curves within individual spectral channels for the disk-integrated Approach observations on November 8. These data are consistent with the analysis of the Spitzer data, including requiring a fairly rough surface to fit the light curve.

OVIRS data between 3.5 and 4.0 μm, where the thermal flux from Bennu was 8 to 25 times the reflected flux, were also used for thermophysical analysis. The analysis so far has also focused on the disk-integrated Approach observations (November 2 and 3, in this case). We find that these data are also consistent with a thermal inertia that is slightly higher than, but still within the uncertainties of, the previously published thermal inertia of Bennu [8].

Discussion: Images of the surface of Bennu reveal a surface that has more large boulders than would be expected from standard methods of interpreting regolith particle size from this thermal inertia. Typical approaches [e.g., 9, 10] assume a single particle size for the entire regolith. However, we know that such an assumption is highly unrealistic, so those estimates are, at best, some kind of “thermally characteristic” size. We will discuss several possibilities for resolving the apparent contradiction between the measured thermal inertia and the observed rock and boulder abundance.

We will also discuss initial analysis of the spatially-resolved thermal data measured during the Preliminary Survey observations.

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